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ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Natural Gas Research and Development Program

Proposed Program Plan and Funding Request for Fiscal Year 2018-2019

Edmund G. Brown Jr., Governor

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ABSTRACT

Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) authorizes the California Public Utilities Commission (CPUC) to impose a surcharge on all natural gas consumed in California. These monies fund energy efficiency programs and public interest research and development projects benefitting natural gas ratepayers. In 2004, the CPUC issued Decision 04-08-010, designating the California Energy Commission as the administrator for the research funds. The Energy Commission manages the Natural Gas Research and Development program, using competitive solicitations aligned with California's climate, energy and safety policies to support energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. To help ensure a high return on ratepayer investments, administrative costs are limited to 10 percent, funds are rewarded through a competitive process, technical advisory committees inform technology development and deployment for each project, and these results are made public. The Energy Commission submits an annual proposed program plan and funding request to the CPUC for review and approval.

This *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2018-19,* describes the Energy Commission's proposed natural gas research initiatives in energy efficiency, renewable energy, and energy infrastructure, including natural gas safety and integrity. The proposed research funding for fiscal year 2018-19 is $24 million, and the budget plan covers July 1, 2018 through June 30, 2019. The report proposes research to improve measuring emissions measurements and advance developing and deploying natural gas in heavy-duty trucks to help improve air quality in the state's severely polluted air basins. The recommendations are based on input from California stakeholders, research institutions, equipment manufacturers, and governmental partners, with several initiatives in this budget plan to benefit disadvantaged communities. These initiatives were carefully chosen while considering ongoing public outreach seeking research initiatives from California researchers.

Keywords: California Energy Commission, California Public Utilities Commission, California Air Resources Board, natural gas research, PIER, energy research, R&D, energy efficiency, renewable energy, smart energy infrastructure, public safety, disadvantaged communities, transportation

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EXECUTIVE SUMMARY

Natural gas plays an important role in California's energy system: it is used in homes and businesses mainly for space and water heating, drying and cooking, and it is used in the industrial and transportation sectors for process heating, combined cooling, heating and power, and vehicle operation. In 2016, Californians consumed about 2.1 trillion cubic feet of natural gas, with the power generation and industrial sectors accounting for more than half of consumption at 32 percent and 37 percent respectively. According to the *2017 Natural Gas Outlook*, these numbers are expected to grow slightly, with estimates showing an average demand increase of about 0.55 percent per year from 2018 to 2028.

Nearly 90 percent of California's natural gas supply comes from outside California from Canada, Mexico and the Rocky Mountain regions. This reliance on imported gas leaves the state vulnerable to price shocks, supply disruptions, and issues associated with pipeline safety and storage integrity. With California consuming roughly 5.8 billion cubic feet per day on average, and 11.157 billion cubic feet at peak times, ensuring the safety, reliability, and efficient operation of natural gas infrastructure and systems is critical in maintaining California's economic vitality and in reaching its greenhouse gas emission reduction goals.

As California continues to pursue its ambitious emission reduction and renewable energy targets to tackle climate change issues and improve public health and safety, the role of natural gas in the energy system is expected to change. For California to achieve its climate and energy goals, it is imperative to continue impartial public research and development investments in natural gas innovations and technologies. Recognizing that some applications of natural gas will switch to other fuels going forward, research is still needed to drive innovation in targeted industries and technology applications that move away from diesel or continue to rely on natural gas.

The California Energy Commission's Energy Research and Development Division administers the Natural Gas Research and Development Program (Natural Gas R&D) with oversight by the California Public Utilities Commission (CPUC) and to date, has funded 237 research agreements totaling more than $216.6 million.

The Energy Commission Research and Development Division staff develops natural gas research initiatives guided by state energy policies, legislative mandates, and stakeholder input. Some of these key policies and mandates include CPUC Decision 04-08-010, the *Integrated Energy Policy Reports; Energy Action Plan; the California Energy Efficiency Strategic Plan*; Assembly Bill 32, the Global Warming Solutions Act (Núñez, Chapter 488, Statutes of 2006); and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016).

Research Vision and Goals

The *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2018-19* (FY 2018-19 Natural Gas R&D Budget Plan) identifies and addresses emerging natural gas-related trends that are important to California's energy future. These trends include opportunities to reduce statewide natural gas consumption through energy efficiency and to increase and optimize the use of natural gas in various sectors such as the transportation sector, where state-of-the-art natural gas engines being introduced into the market are showing near-zero emissions for oxides of nitrogen (NO_x). Identifying market trends helps the program focus attention on the market barriers and information gaps that can be effectively addressed by future research.

Furthermore, the program coordinates with the CPUC to respond to critical research issues, such as developing technologies that increase natural gas pipeline integrity and safety and improving resilience of the natural gas system.

The Natural Gas R&D Program uses a competitive solicitation process that supports research to:

- **Assure** safe, reliable natural gas services by conducting research that focuses on the integrity and safety of the natural gas infrastructure.
- **Stimulate** California's economic growth by attracting and developing businesses and creating and supporting jobs.
- **Achieve** long-term benefits to natural gas ratepayers by developing technologies and products that provide clean, diverse, and environmentally sound energy systems.

Research Approach and Stakeholder Participation

On January 25, 2018, California Energy Commission staff held a public workshop to present the proposed natural gas research initiatives and received comments from stakeholders supporting the proposed initiatives. Recommendations from the workshop were considered and used to refine the FY 2018-19 Natural Gas R&D Budget Plan. The staff presentation given and a summary of questions and answers from the workshop are referenced in Appendices A and B of this budget plan report. The Energy Commission staff benefits from and appreciates the thoughtful comments of engaged stakeholders.

Senate Bill 350 (De León, Chapter 547, Statutes of 2015) prioritizes maximizing benefits to low-income customers and those in disadvantaged communities. Several initiatives in this budget plan are either targeted directly to or have components that benefit disadvantaged communities and include:

- Reducing natural gas use for greenhouse gas (GHG) emission-intensive industries: This initiative can include process heating efficiency improvements

that reduce operating costs and air emissions from the burning of natural gas in facilities in disadvantaged communities. Since a large percentage of industrial plants are in disadvantaged communities, reductions in air emissions will improve the air quality in these communities. By reducing operating costs, building and industry owners can have more discretionary funding available to invest in their properties and businesses and be more competitive in the global marketplace.

- Converting Central Valley agricultural waste resources to energy: This initiative has the potential to reduce criteria air pollutant emissions from small dairy and farm operations in the San Joaquin Valley. The San Joaquin Valley is a nonattainment region for ozone and particulate matter that includes several disadvantaged communities, and the local air district projects increases in open pile burning of agricultural waste. Nonattaiment areas are areas considered to have air quality worse than the California Ambient Air Quality Standards. Ozone and particulate matter are linked to asthma and other respiratory illnesses, and disproportionately affect the young, sick, and elderly. Targeting emission reductions in the Central Valley's largest sector will contribute to improving air quality.
- Developing high-efficiency, low-emission, production-ready natural gas engines for long haul applications: Heavy-duty long-haul vehicle applications are a significant source of emissions. Communities around freight corridors are often disadvantaged communities partly because of the higher exposure to criteria emissions. Research supported under this initiative aims to reduce criteria emissions by improving efficiency in long-haul applications operating through heavy-traffic freight corridors.

Natural Gas Research Budget Plan for Fiscal Year 2018-19

The FY 2018-19 Natural Gas R&D Budget Plan divides the project funding among primary research initiatives into four main program areas (Table ES-1). The program also allocates about 10 percent of the total natural gas research budget for program administrative expenses.

Table ES-1: Natural Gas R&D Budget Plan Summary FY 2018-19

Research Areas	Proposed Budget
Energy Efficiency	**$6,000,000**
Renewable Energy and Advanced Generation	**$3,000,000**
Energy Infrastructure	
• Natural Gas Infrastructure Safety and Integrity	**$5,600,000**
• Energy-Related Environmental Research	**$3,000,000**
Natural Gas-Related Transportation	**$4,000,000**
Program Administration	**$2,400,000**
TOTAL	**$24,000,000**

Source: California Energy Commission

CHAPTER 1:
Introduction and Program Overview

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 impose 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 as the administrator for the Natural Gas Research & Development (Natural Gas R&D) program. The CPUC allocates $24 million per year 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, but not limited to, job creation, improved air quality and economic stimulation.
- Consider opportunities for collaboration and cofunding with other entities, such as federal and local agencies.

Research Guides State Energy Policies

California energy legislation and policies guide and respond to California's complex and evolving energy system. The Energy Commission's natural gas R&D Program responds to and informs these policies through research, addressing directives detailed in CPUC resolutions.

Directed primarily by Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006), the Energy Commission's natural gas research is also driven by energy policies identified in the *Integrated Energy Policy Reports (IEPR), 2017 Climate Change Scoping Plan,*[2]

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

[2] *California's 2017 Climate Change Scoping Plan*. November 2017. https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf?_ga=2.214355988.2032521246.1515442068-1515312640.1439561798.

Sustainable Freight Initiative,[3] and *California's Energy Efficiency Strategic Plan*.[4] To achieve the policy goals of Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006) and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016), the Energy Commission and the California Air Resources Board (CARB) work together to identify and develop technologies and strategies that can help reduce greenhouse gas emissions.

Multiple policies drive the Energy Commission's research into natural gas infrastructure safety and integrity. Based on past accidents in San Bruno and Aliso Canyon, Senate Bill 1371 (Leno, Chapter 525, Statutes of 2014) and Senate Bill 887 (Pavley, Chapter 673, Statutes of 2016) addresses the safety and integrity of natural gas pipelines and storage facilities, respectively. Research also supports multiple CPUC policies, including the CPUC's General Order No. 112-F, which addresses the rules for utilities to design, construct, test, operate and maintain piping systems, beyond those required by federal regulations; CPUC Resolution G-3519, which directs the Energy Commission to support research studies stemming from the Aliso Canyon leak; and CPUC's Gas Safety Plan, which will improve the CPUC's safety and enforcement programs.

Recently adopted policies provide additional guidance on the future role natural gas will play in an increasingly renewable and low-emission energy system. The short-lived climate pollutant strategy (Senate Bill 1383, Lara, Chapter 395, Statues of 2016) includes ambitious goals to reduce methane emissions, among other short-lived climate pollutants, by 40 percent below 2013 emissions by 2030. In this budget plan, several initiatives focus on increased efforts to reduce methane emissions in industries such as the dairy industry, where renewable natural gas (RNG) can be sourced through methane recovery.

In accordance with Senate Bill 350 (De León, Chapter 547, Statutes of 2015), which aims to increase clean energy funding directed to low-income and disadvantaged communities, this budget plan includes research initiatives that will support projects that benefit these communities.

Reducing emissions associated with natural gas use will be an ongoing priority as natural gas is considered a primary energy source for several industries, primarily electricity generation. The *2017 Climate Change Scoping Plan Update* continues to emphasize that the need for innovative technologies that improve efficiency, increase

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[3] *California Sustainable Freight Action Plan*. July 2016. http://casustainablefreight.org/documents/PlanElements/Main%20Document_FINAL_07272016.pdf.

[4] California's Long-Term Energy Efficiency Strategic Plan, (September 2008), http://www.californiaenergyefficiency.com/docs/EEStrategicPlan.pdf.

the production of renewable natural gas, and reduce leakage from natural gas infrastructure will be pivotal in meeting future climate change targets.[5]

Additional policies specific to the natural gas research areas are described below in Table 1.

Table 1: Summary of Policy Drivers for Natural Gas Research and Development Activities

Research Area	Policy Drivers
Energy Commission's Primary Natural Gas Policy Drivers	• Energy Action Plan[6] • Integrated Energy Policy Report (IEPR)[7] • Assembly Bill 32 (Núñez, Chapter 488 Statutes of 2006)[8] — California Global Warming Solutions Act of 2006 • Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006)[9] • Senate Bill 32 requires California to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030. • Public Utilities Code Section 895 provides statutory authority for the Energy Commission to administer the natural gas funds using the PIER statutes.[10]

[5] https://www.arb.ca.gov/cc/scopingplan/2030sp_pp_final.pdf.

[6] http://www.energy.ca.gov/energy_action_plan.

[7] http://www.energy.ca.gov/2017_energypolicy.

[8] http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.html.

[9] http://www.leginfo.ca.gov/pub/05-06/bill/sen/sb_1201-1250/sb_1250_bill_20060927_chaptered.pdf.

[10] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=puc&group=00001-01000&file=890-900.

Research Area	Policy Drivers
An Energy-Efficient California: Initiatives focused on buildings energy end use: efficiency; industrial, agriculture, and water efficiency; and energy efficiency-related environmental research.	• Energy Efficiency Buildings Standards (Title 24, Part 6) — goals for 2019 Standards[11] • Increase building energy efficiency cost effectively. • Make progress toward ZNE within the confines of net energy metering and life cycle costing rules. • Contribute to the State's GHG reduction goals. • Ensure real benefits for building occupants with positive benefit to cost ratios. • Appliance Energy Efficiency Standards (Title 20, Division 2, Chapter *4, Article 4, Sections 1601-1608: Appliance Efficiency Regulations*) • Assembly Bill 758 (Skinner, Chapter 470, Statutes of 2009) achieves greater energy savings in existing residential and nonresidential buildings. • Assembly Bill 531 (Saldaña, Chapter 323, Statutes of 2009) discloses commercial building electric and natural gas use. • Senate Bill 350 (De León, Chapter 547, Statutes of 2015) establishes annual targets for statewide energy efficiency savings and demand reduction that will achieve a cumulative doubling of statewide energy efficiency savings for retail customers by January 1, 2030. • California Energy Efficiency Strategic Plan[12] establishes the following goals: • Zero-net-energy (ZNE) buildings: all new residential construction by 2020 and 100 percent new commercial buildings by 2030. • Transformation of the heating, ventilation, and air-conditioning (HVAC) industry to ensure that the performance of HVAC equipment is optimized for California's climate zones. • Significant increases in the efficiency of natural gas use and on-site renewable energy use in the agriculture sector.

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

[12] http://www.energy.ca.gov/ab758/documents/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

Research Area	Policy Drivers
A Renewable Future: Renewable research initiatives target combined heat and power (CHP) and renewable energy-related environmental research and are driven by renewable energy generation and greenhouse gas reduction goals.	• Senate Bill X1-2 — Renewables Portfolio Standard[13](Simitian, Chapter 1, Statutes of 2011) The Renewables Portfolio Standard sets goals for 20 percent of retail sales from renewable energy resources by end of 2013, 25 percent by end of 2016, and 33 percent by end of 2020. • Assembly Bill 1613, the Waste Heat and Carbon Emissions Reduction Act (Blakeslee, Chapter 713, Statutes of 2007)[14] — The Waste Heat and Carbon Emissions Reduction Act requires an electrical corporation to purchase excess electricity from combined-heat-and-power systems that comply with sizing, energy efficiency, and air pollution control requirements. • Senate Bill 350, Clean Energy and Pollution Reduction Act of 2015 (De León, Chapter 547, Statutes of 2015)[15] Increases the electricity generated and sold to retail customers per year from eligible renewable energy resources to 50% by December 31, 2030. • Governor Brown's *Clean Energy Jobs Plan*[16] – Provides that California should develop 12,000 megawatts (MW) of localized energy by 2020, establishes a timeline to make new homes and commercial buildings in California "zero net energy," and provides incentives for the increased use of cogeneration by 6,500 MW by 2030. • *Bioenergy Action Plan*[17] to implement Executive Order S-06-06, which set goals for the production and use of electricity and fuels made from biomass. • CARB's Short-Lived Climate Pollutant Reduction Strategy – recommends actions to reduce emissions of short-lived climate pollutants (SLCPs), which include black carbon (soot), methane (CH4), and fluorinated gases (F-gases, including hydrofluorocarbons, or HFCs), including those from dairies, organics disposal, and wastewater.

[13] http://www.energy.ca.gov/portfolio.

[14] http://www.leginfo.ca.gov/pub/11-12/bill/asm/ab_1601-1650/ab_1613_bill_20120208_introduced.pdf.

[15] http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_0301-0350/sb_350_bill_20151007_chaptered.pdf.

[16] http://gov.ca.gov/docs/Clean_Energy_Plan.pdf.

Research Area	Policy Drivers
A Reliable, Secure, and Smart Energy Infrastructure: Initiatives target natural gas infrastructure research associated with natural gas pipeline integrity and environmental research.	• Public Resources Code 25620[18]—For the state to undertake public interest energy research, development, and demonstration projects that are not adequately provided for by competitive and regulated energy markets and to advance energy science or technologies of value to California ratepayers through investments in advanced transportation technologies that reduce air pollution and greenhouse gas emissions beyond applicable standards, and benefit electricity and natural gas ratepayers. • High Energy Efficiency, Low Emissions Combustion, and Control Technology Development Program[19]—Addresses the goal to improve environmental quality while meeting the wide-ranging demand for energy per the 2003 *Integrated Energy Policy Report*. • Assembly Bill 1496 (Thurmond, Chapter 604, Statutes of 2015), Methane Emissions. Requires the State to monitor methane hotspots.[20] • CARB's Short-Lived Climate Pollutant Reduction Strategy – recommends actions to reduce emissions of short-lived climate pollutants (SLCPs), which include black carbon (soot), methane (CH4), and fluorinated gases (F-gases, including hydrofluorocarbons, or HFCs), including those from dairies, organics disposal, and wastewater.[21]

[17] http://www.energy.ca.gov/bioenergy_action_plan.

[18] http://www.energy.ca.gov/renewables/documents/sb_1250_bill_20060927_chaptered.pdf.

[19] http://www.arb.ca.gov/planning/sip/sip.htm.

[20] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1496.

[21] http://www.calrecycle.ca.gov/climate/slcp/.

Research Area	Policy Drivers
A Reliable, Secure, and Smart Energy Infrastructure: Initiatives that evaluate and resolve environmental effects of energy production, delivery, and use in California; explore how new energy applications and products can solve or reduce environmental problems.	• Executive Order B-29-15—Established actions to save water, increase enforcement to prevent wasteful water use, streamline the state's drought response, and invest in new technologies that will make California more drought-resilient. • Executive Order B-30-15—Set greenhouse gas reduction target of 40 percent below 1990 levels by 2030. • January 6, 2016, proclamation to declare an emergency and detail the administration's ongoing efforts to protect public health and safety and ensure accountability of gas storage facilities. • SB 1371 (Leno, Chapter 525, Statutes of 2014. Natural Gas: leakage abatement)[22]—with priority given to safety, reliability, and affordability of service, the CPUC must determine whether existing practices are effective at reducing methane leaks and promoting public safety and whether alternative practices may be more effective. • I1702002 – CPC Order Instituting Investigation under Senate Bill 380 (Pavley, Chapter 14, 2016) to determine the feasibility of minimizing or eliminating the use of the Aliso Canyon natural gas storage facility in the Los Angeles County while maintaining energy and electric reliability for the region.

[22] http://www.leginfo.ca.gov/pub/13-14/bill/sen/sb_1351-1400/sb_1371_bill_20140921_chaptered.pdf.

Research Area	Policy Drivers
A Cleaner Transportation System: Initiatives support vehicle and component technology advancements and improvements in advanced renewable gas production systems	• Executive Order B-32-15[23] – Directed the development of the Sustainable Freight Action Plan,[24], which establishes the following targets: 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, ensure the strategies for achieving these targets, and consider impacts on future economic growth and competitiveness. • *California's 2017 Climate Change Scoping Plan*[25] – The transportation sector directly accounts for 39 percent of the state's GHG emissions. A 27-32 percent reduction in GHG emissions from the transportation sector is required to meet the state's 2030 GHG reduction goals. • *2016 Mobile Source Strategy*[26] – Reduce 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. Off-road equipment must reflect this same type of transformation to a mix of zero-emission and near-zero-emission technologies operating on renewable fuels. • Low Carbon Fuels Standard (LCFS)[27] – Reduce the full fuel-cycle carbon intensity of transportation fuels pool used in California by encouraging the transition to cleaner/less-polluting fuels that have a lower carbon footprint.

[23] https://www.gov.ca.gov/news.php?id=19046.

[24]http://www.casustainablefreight.org/documents/PlanElements/Main%20Document_FINAL_07272016.pdf.

[25] https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf.

[26] https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf

[27] https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

Importance of Natural Gas Research

More than 90 percent of California's natural gas supply comes from outside the state through an integrated North American natural gas market. These primary supplies are imported from regions including the Southwest, Canada and the Rocky Mountains.[28] By 2025, Energy Commission staff estimates that in-state production will account for only about 2 percent.[29] California has 375.5 billion cubic feet of maximum storage capacity, owned by both gas utilities and independent storage operators. Gas storage provides seasonal and daily balancing of supply and demand. This balancing allows utilities to meet higher peak demand than pipeline infrastructure is able to meet alone. Typically storage levels fluctuate throughout the year based on demand, with gas being withdrawn in the winter to meet the higher demand for heating needs, and more gas being injected during the spring and summer when demand and gas prices are typically lower. With the reliance on imported gas and with an expected growth in demand, California is susceptible to price shocks, supply disruptions, and issues associated with pipeline safety and storage integrity, particularly in peak months when demand is higher.

Demand for natural gas is expected to grow slowly at roughly 0.55 percent per year through 2028, according to the California Energy Commission's *California Energy Demand 2018-2028 Preliminary Forecast*. This forecast is based on a mid-demand case scenario and represents a "business-as-usual" environment and with consideration to current policy mandates such as the Renewables Portfolio Standard, SB 350, and efficiency mandates.[30] In 2016 California consumed about 2.1 trillion cubic feet (tcf), or about 5.8 billion cubic feet (bcf) per day, in homes, businesses, vehicles, factories, and power plants for electric generation.

Electricity generation and the industrial sector account for most of the natural gas use in California. About 32 percent of the natural gas is used in electricity generation, which translates to 50 percent of the gigawatt-hours (GWh) produced in California in 2016. The state's natural gas power plants have actually been able to generate 27 percent more energy using 2 percent less natural gas than 15 years ago because of effective

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[28] Brathwaite, Leon D, Jason Orta, Peter Puglia, Anthony Dixon, and Robert Gulliksen. 2017. *2017 Draft Natural Gas Market Trends and Outlook*. California Energy Commission. Publication Number: CEC-200-2017-009-SD.

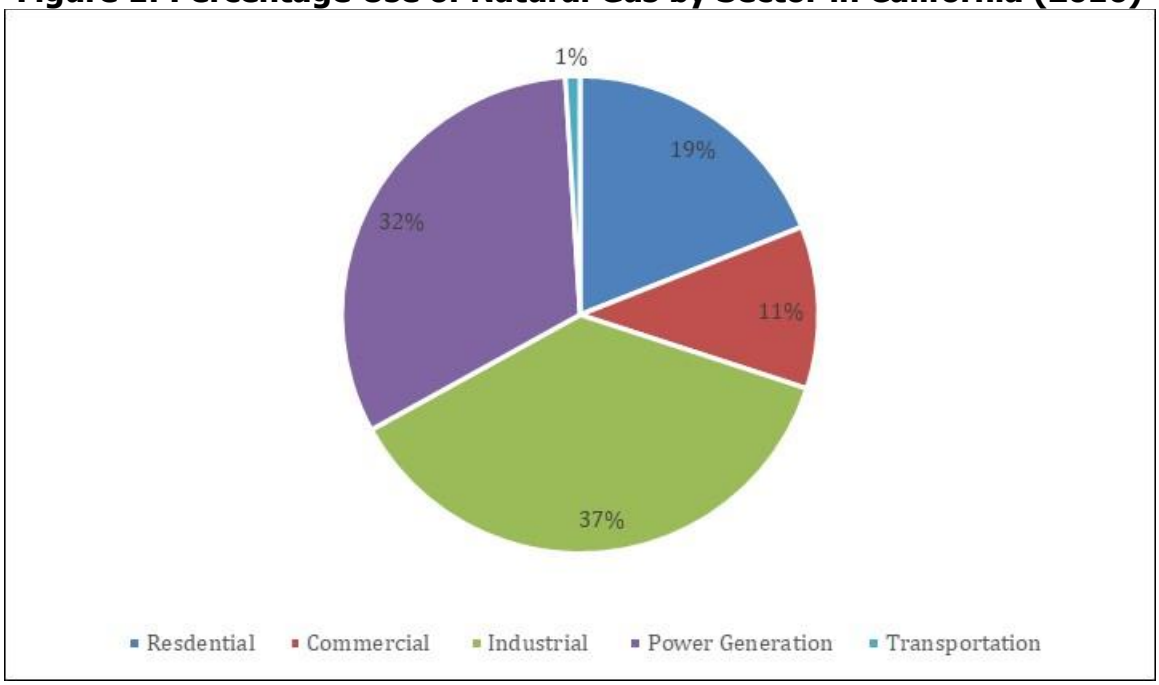
[29] Ibid.

[30] Brathwaite, Leon D, Jason Orta, Peter Puglia, Anthony Dixon, and Robert Gulliksen. 2017. *2017 Draft Natural Gas Market Trends and Outlook*. California Energy Commission. Publication Number: CEC-200-2017-009-SD, Page 1.

thermal efficiency improvements.[31] Demand from the industrial sector has also grown since 2010 by 1,173 bcf, or 15 percent. Some of this growth can be attributed to the growth in combined-heat-and-power installations, particularly in the 1990s, and to lower natural gas prices.[32]

Figure 1 provides a breakdown of natural gas use per sector in 2016.

Figure 1: Percentage Use of Natural Gas by Sector in California (2016)



Source: U.S. Energy Information Administration

While average natural gas demand is expected to grow, forecasts show variability in demand projections by sector. Forecasts indicate that gas-fired generation will decrease at an annualized rate of about 1.5 percent between 2017 and 2028 however, the residential commercial and industrial sectors show average growth rates that vary between 0.37 percent and 0.90 percent for the same time frame.[33] While the role of natural gas in electric generation may change, it will continue to play an important role

[31] California Energy Commission staff. 2017. 2017 Integrated Energy Policy Report. California Energy Commission. Publication Number: CEC-100-2017-001-CMF.

[32] Brathwaite, Leon D, Jason Orta, Peter Puglia, Anthony Dixon, and Robert Gulliksen. 2017. *2017 Draft Natural Gas Market Trends and Outlook*. California Energy Commission. Publication Number: CEC-200-2017-009-SD, Page 11.

[33] Brathwaite, Leon D, Jason Orta, Peter Puglia, Anthony Dixon, and Robert Gulliksen. 2017. *2017 Natural Gas Market Trends and Outlook*. California Energy Commission. Publication Number: CEC-200-2017-009-SF.

in the ability of natural gas facilities to provide ramping capacity for the load changes when renewable generation is not available and can serve as a replacement during extreme events like wildfires when transmissions lines may be de-energized.[34]As natural gas consumption decreases or remains level in most industries over the next decade, it is expected to increase in the transportation sector. While transportation accounts for only about 1.8 percent of natural gas consumption in California, this number is expected to increase significantly due to the growing number of natural gas trucks in the heavy-duty vehicles sector. Consumption of natural gas in California's transportation sector has grown from fewer than 1 million gasoline gallon equivalent (GGE) in 1991 to almost 180 million GGE in 2014.[35] Used primarily to fuel large vehicles such as urban transit buses, refuse trucks, public fleets and utility trucks, natural gas demand will have the greatest growth potential in heavy-duty trucks with high annual mileage. Growth of natural gas demand for refuse trucks and transit buses is limited since the current share of natural gas-powered vehicles is already high.[36]

Overall, these increases are regarded as modest considering that California's population has grown 31 percent since 1990. These results are due to successfully implementing aggressive energy efficiency standards for buildings, appliances, and utilities, reflecting the strides California has made in improving the overall performance of its complex energy system.[37]

Natural gas is a critical source of energy; 32 percent of the natural gas burned in California was used for electricity generation with the remainder consumed in the residential (19 percent), commercial (11 percent), industrial (37 percent), and transportation (1 percent) sectors.[38] Natural gas has also contributed significantly to California's ability to integrate renewable energy sources into the energy system, acting as a source of back-up generation to address intermittency issues associated with renewable integration into the grid. While natural gas generation is relatively clean compared to other fossil fuels like coal, California will not meet its long-term

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[34] California Energy Commission staff. 2017. 2017 *Integrated Energy Policy Report*. California Energy Commission. Publication Number: CEC-100-2017-001-CMF. Page 246.

[35] Bahreinian, Aniss, Eva Borges, Jesse Gage, Bob McBride, Gordon Schremp, Ysbrand van der Werf and Gary Yowell. 2015. Staff Draft Report, Transportation Energy Demand Forecast, 2016-2026. California Energy Commission. Publication Number: CEC-200-2015-008-SD.

[36] Ibid. page 71.

[37] State of California, Department of Finance "California Population Estimates, with Components of Change and Crude Rates, July 1, 1900-2016." December 2016, http://www.dof.ca.gov/Forecasting/Demographics/Estimates/E-7/.

[38] http://www.energy.ca.gov/almanac/naturalgas_data/overview.html.

greenhouse gas reduction goals or air quality mandates without significant improvements in natural gas efficiency and technology breakthroughs that will optimize the use of natural gas in sectors that will experience difficulties in electrifying.

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 greenhouse gas emissions, and improve the safety of pipeline infrastructure. For instance, current research on natural gas inspection technologies used throughout the world is helping identify the most appropriate technologies for inspecting and monitoring pipelines in California. A catalog of the most promising technologies will guide utilities and pipeline operators in selecting the best and most cost-effective tools, increasing safety and reliability of natural gas pipelines for all Californians. Additional examples of research activities are found in Appendix A of this budget plan report.

The *Natural Gas Research and Development 2017 Annual Report* provides a full review of program achievements to the CPUC annually and describes the natural gas research activities in fiscal year 2017-18.[39]

Research Vision and Goals

The Energy Commission's Natural Gas R&D program focuses on identifying and addressing research of emerging natural gas-related trends important to California's energy future. These trends include reducing statewide natural gas consumption through energy efficiency; using natural gas efficiently through combined heat and power or cogeneration; exploring opportunities for nontraditional natural gas alternatives such as biogas and other renewable gas replacements; avoiding natural gas losses and increasing safety by improving pipeline integrity; and using natural gas to diversify California's transportation fuel mix and reduce petroleum consumption.

[39] http://www.energy.ca.gov/2017publications/CEC-500-2017-036/CEC-500-2017-036.pdf.

CHAPTER 2:
Natural Gas Research Budget Plan for Fiscal Year 2018-2019

Developing Research Initiatives

Stakeholder Participation and Strategic Partnerships

The Energy Commission engages with stakeholders to develop a research portfolio responding to challenges in the natural gas sector. Stakeholders provide invaluable input in developing research initiatives, and in some cases, they become partners on research projects with mutual benefits. For example, the current National Ambient Air Quality Standards (NAAQS) requirements for ozone attainment cannot be achieved in California's worst air basins without significant reductions in oxides of nitrogen (NO_x) emissions from heavy-duty vehicle fleets. The Energy Commission cofunded research with the South Coast Air Quality Management District (SCAQMD) and Southern California Gas Company (SoCalGas) to develop an engine technology that reduces NO_x emission rates to 90 percent below the 2010 standard.[40] The research projects will include a production readiness plan to help accelerate natural gas engine technologies on the path to commercialization.

The Energy Commission also collaborates with other 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 outreach improves accountability, transparency, communication, and responsiveness. The Energy Commission 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 provides benefits to the state's natural gas ratepayers.

Commitment to Diversity

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

In April 2015, the Energy Commission 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 LGBT-

[40] Observed rates below 0.02 grams per brake horsepower hour.

owned business enterprises; and economically disadvantaged and underserved communities to participate in and benefit from, Energy Commission programs.

Assembly Bill 865 (Alejo, Chapter 583, Statutes of 2015) provided additional guidance, requiring the Energy Commission to develop and implement a comprehensive outreach plan to broaden and diversify the applicant pool to Energy Commission programs and track progress toward those objectives.

Senate Bill 350 (De León, Chapter 547, Statutes of 2015) also took steps to ensure California's clean energy transformation includes a strong focus on equity to ensure all Californians, especially those in the most vulnerable communities, realize benefits.

The Energy Commission established a Diversity Task Force, under AB 865, to consider and make recommendations about diversity in the energy industry, including diversity of corporate governing boards and procurement from diverse businesses, and addressing and promoting local and targeted hiring. The Energy Commission also created a Disadvantaged Communities Advisory Group, as outlined in SB 350, to advise the Energy Commission 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 Energy Commission recommended that the Energy Commission and CPUC should direct research, development, demonstration, and market facilitation programs to include targeted benefits for low-income customers and disadvantaged communities.[41]

Energy Commission staff has continued to conduct activities to meet these important commitments. Some of these efforts include:

- Continuing and advancing an outreach plan to ensure women, minorities, LGBT 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 Energy Commission'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

[41] http://docketpublic.energy.ca.gov/PublicDocuments/16-OIR-02/TN214830_20161215T184655_SB_350_LowIncome_Barriers_Study_Part_A__Commission_Final_Report.pdf.

for the recipients of R&D awards using the same definitions used by the investor owned utilities via CPUC General Order 156.[42]

The Energy Commission has undertaken several activities in 2017 to demonstrate its commitment to ensure a diverse range of applicants have the opportunity to participate in R&D projects by implementing activities supporting these goals.

Activities included:

- Enhancing the Energy Commission's website to reflect the agency's commitment to diversity.
- 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.
- Distributing R&D informational materials at conferences, meetings, and public events such as:
    - Small Business Workshop & Business Exchange, presented by the Sacramento Hispanic Chamber of Commerce, Sacramento Black Chamber of Commerce, and the Sacramento Rainbow Chamber of Commerce (January 18).
    - VerdeXchange 2017 Conference (January 29-30).
    - Food Processing Expo 2017, presented by the California League of Food Processors (February 7-8).
    - Transformative Climate Communities Stakeholder Summit, presented by the California Strategic Growth Council (February 10).
    - World Agricultural Expo, presented by the International Agri-Center (February 16).
    - CSUS College of Engineering and Computer Science 2017 Career Day, presented by CSU, Sacramento (February 17).
    - Informational Open House on Military, presented by the Governor's Office of Planning and Research and the Governor's Military Council and Navy Region Southwest (February 28).
    - Webinar on Emerging Technologies: Getting to Zero Net Energy Buildings: Present and Future (March 9).

[42] http://docs.cpuc.ca.gov/publisheddocs/published/g000/m152/k827/152827372.pdf.

- Diversity Career Fair, presented by the California Energy Commission (March 30).
- Customers of State Climate Science Research, presented by the California Energy Commission and the California Public Utilities Commission (April 11).
- Emerging Technologies Summit, presented by the Emerging Technology Coordinating Council (April 19-21).
- Exploring Dimensions of Community Engaged Scholarship, presented by the University of California, Davis (May 5).
- State Scientist Day, presented by the California Association of Professional Scientists (May 10).
- Merced Safeguarding California Workshop, presented by the California Natural Resources Agency (May 16).
- Bay Area Safeguarding California Workshop, presented by the California Natural Resources Agency (May 22).
- Los Angeles Safeguarding California Workshop, presented by the California Natural Resources Agency (May 31).
- LA Energy Cluster Meeting and Regional Energy Innovation Cluster (REIC) Launch, presented by the Los Angeles Cleantech Incubator (May 31).
- Sierra Nevada Safeguarding California Workshop, presented by the California Natural Resource Agency (June 14).
- IEPR – Joint Agency Workshop on Renewable Gas, presented by the California Energy Commission, the California Public Utilities Commission, and the California Air Resources Board (June 27).
- IEPR Joint Agency Workshop on Application of Distributed Energy Resources on the California Grid presented by the California Energy Commission, California Public Utilities Commission, and the California Independent System Operator (June 29).
- Microgrid Roadmap Scoping Workshop presented by the California Energy Commission, California Public Utilities Commission, and the California Independent System Operator (July 26).
- Joint Agency Workshop on SB 350 Low-Income Barriers Study Implementation, presented by the California Energy Commission, and the California Public Utilities Commission (August 1).
- IEPR Workshop on Barriers to Demand Response, presented by the California Energy Commission (August 8).
- Webinar on Emerging Technologies: Phase Change Materials, presented by the California Energy Commission (August 16).

- Technical Symposium on Avian-Solar Interactions, presented by the Multiagency Avian-Solar Collaborative Working Group and the Avian Solar Working Group (August 16).
- Combined Heat and Power (CHP) Technical and Market Assessment Workshop, presented by ICF (August 21).
- DGS Boiler Plant Tour, presented by the California Women in Energy (August 25).
- IEPR Workshop on Climate Adaptation and Resilience for the Energy System, presented by the California Energy Commission, and the California Public Utilities Commission (August 29).
- Fourth Assessment Quarterly Meeting, presented by the California Energy Commission, the California Natural Resources Agency, and the Department of Water Resources (September 11).
- Cal-Adapt User Needs Assessment Workshop, presented by the UC Berkeley Geospatial Innovation Facility (September 12)
- Civic Spark 2017 Orientation, presented by the Local Government Council (September 13).
- Secrets to Successful Proposals in California, presented by Pacific Gas and Electric (September 18).
- ETCC Quarterly Meeting: The Changing Energy Landscape for Industrial Customers, presented by the Emerging Technologies Coordinating Council (September 20).
- SBIR Workshop, presented by the Small Business in Research Program (September 25).
- Activate 2017, presented by Activation Energy and Cyclotron Road (September 28).

More information about these and other Energy Commission diversity commitment activities is available at http://www.energy.ca.gov/commission/diversity/.

Collaborative Roadmaps and Technology Assessments

Roadmaps and technology assessments are planning mechanisms and communication tools that establish a clear link between research and key California energy policy goals. Research roadmaps define the topic area, significant issues and barriers, data gaps, information needs, research priorities, and potential partnerships. Energy Commission staff and a wide range of energy researchers and consumers participate in "road mapping" in many program areas.[43] Participants can identify natural gas research needs

[43] Various roadmaps can be found at http://www.energy.ca.gov/publications/searchReports.php?title=roadmap.

by program area and where they overlap. 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, documents the process for better transparency, and yields outcomes more likely to address challenges that involve both areas. An example of a completed roadmap is the *2015 Natural Gas Vehicle Research Roadmap*[44], which provides research recommendations on natural gas vehicle range and storage, engine performance and availability, emissions and environmental performance, and analysis and information sharing.

A technology assessment of the chemical and allied products industry was the focus of a grant funding opportunity (GFO) in 2017. The project identifies technologies and approaches to reduce natural gas use in the chemical and allied products industry. This industry is the fourth largest consumer of natural gas among California industries, using nearly 370 million therms annually.[45] The assessment is anticipated to be completed in 2019.

ICF, a global consulting services company, is developing a comprehensive assessment of small and microscale CHP technical and market potential in California, focusing on residential, commercial, and light industrial markets that have a peak electrical demand less than 5 megawatts. The assessment will consider conventional, renewable gas-fueled and hybrid CHP technologies, applications and their potential. Preliminary results have shown about 10 GW of total technical potential led by commercial office buildings, restaurants, and retail stores. When considering present-day rates and incentives, the total technical potential is about 1 GW of expected market adoption over the next 20 years, mostly in PG&E territory. The assessment is anticipated to be completed by fall 2018.

To identify emerging research trends and gaps, the Energy Commission solicits direct feedback and recommendations from utilities, other state agencies, academic experts, industry associations, and technology developers. Meetings, workshops, and working groups provide a vehicle for California stakeholders to understand past, present, and future research and to provide guidance, recommendations, and improvements for the current program.

Public Meetings in 2017

The Energy Commission's Natural Gas R&D program staff held the following public meetings in the 2017-2018 Fiscal Year:

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[44] Chen, Peter. 2015 *Natural Gas Vehicle Research Roadmap*. CEC-500-2015-091. http://www.energy.ca.gov/2015publications/CEC-500-2015-091/CEC-500-2015-091-CMF.pdf.

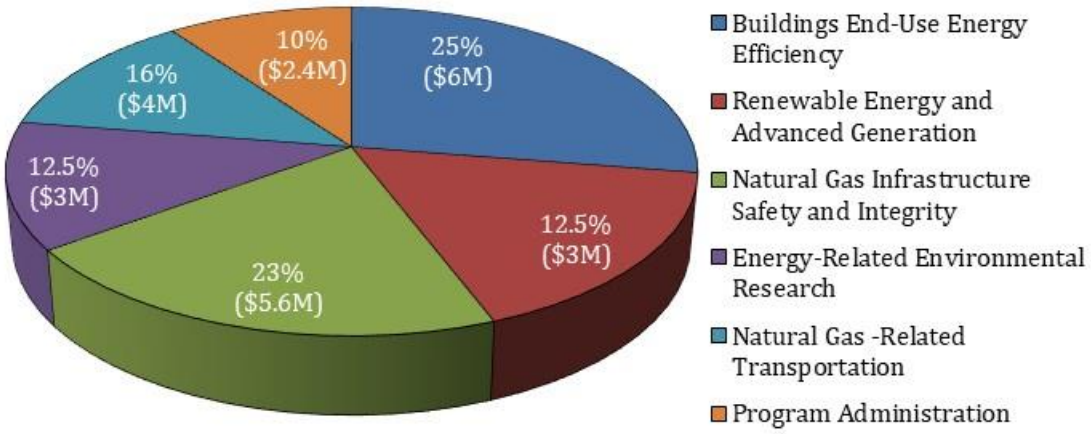
[45] 2015 estimates.

- **December 21, 2017** - Staff Workshop to Discuss Heating, Ventilation and Air Conditioning (HVAC) Research and Development
- **August 16, 2017** - Webinar - Emerging Technologies: Phase Change Materials
- **July 7, 2017** - Staff Workshop on Natural Gas Infrastructure Safety and Integrity Research Program
- **April 11, 2017** - Lead Commissioner Workshop: Customers of Climate Science Research
- **March 9, 2017** - Webinar - Getting to Zero Net Energy Buildings: Present and Future

Proposed Budget

The Energy Commission's *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2018-19* for $24 million is guided by the state policies identified in Table 2 in Chapter 1. The breakdown of the use of those funds is illustrated in Figure 1.

Figure 1: Proposed Natural Gas Research Initiatives Budget Percentages for FY 2018-2019



Source: California Energy Commission

Update to Potential Increase in Natural Gas R&D Funding

In the *Natural Gas Research and Development Program 2017 Annual Report*[46], staff discussed the need to better understand the changing role of natural gas in the state's

[46] *Natural Gas Research and Development Program 2017 Annual Report*. http://www.energy.ca.gov/2017publications/CEC-500-2017-036/CEC-500-2017-036.pdf.

energy system. Since the inception of the program in 2004, research has focused on using natural gas as cleanly and efficiently as possible, fostering the role of natural gas as a low-emission transportation fuel, cultivating technologies that produce and use biogas, improving natural gas and biogas-fueled distributed generation and combined-heat-and-power systems, understanding the effects and interactions of the natural gas system on the environment, and supporting technologies and strategies to reduce leakages and improve the safety of the natural gas system. Since this time, the California energy system has also rapidly transitioned away from dirtier fossil fuels such as oil in favor of natural gas due to the significant reduction in criteria pollutant and carbon emissions. Increased natural gas use in the energy system has already significantly contributed to achieving California's short-term greenhouse gas (GHG) reduction goals.

However, the energy landscape is constantly changing. Visionary mandates and goals to reduce GHG emissions in California, such as reducing GHG emissions by 2050 to 80 percent below 1990 levels, will require significant and long-term changes to the California energy system. Even with a lower carbon content compared to other fossil fuels, these goals suggest that natural gas consumption in California must decline and pathways toward decarbonization must be explored. There is an immediate need to research how natural gas use must change to meet California's GHG emission goals. In addition to these goals, critical incidents such as the San Bruno pipeline explosion (2010) and Aliso Canyon gas storage facility leak (2015) have added to the need to research and improve the safety and integrity of the natural gas system. Finally, environmental events such as the prolonged drought, extensive tree mortality, climate change-related subsidence and seawater rise have broadened the research topics into new areas.

The Energy Commission has explored these priority topics by shifting funds toward increased research in water-energy efficiency, biogas, methane emissions, and natural gas system safety. It has become apparent, however, that the current funding level limits the ability of the program to sufficiently address these time critical issues. Despite these expanding research needs, program funding has not increased since 2009.

To address this limitation, the Energy Commission anticipates submitting a formal request to the CPUC in summer 2018. In response to the request, staff anticipates the CPUC will conduct a proceeding to explore possible expansion of the Natural Gas Research and Development Program. This request will include the proposed funding levels for the expanded program, the program schedule, and a summary of planned research initiatives. Before submitting this request the Energy Commission will solicit input from natural gas utilities, research organizations, and other interested stakeholders through public workshops, written comments, and other feedback methods.

The proposal for the expanded research program is under development and is expected to consider modifications to broaden the program scope including re-establishing a

small grant program to fund early stage technologies, market facilitation to move promising technologies to market, and cost-share programs to leverage federal, state, and local government-funded research programs. Finally, staff anticipates the proposal for the expanded program will be structured to build in-state capabilities for research in areas that lack resources to expand and advance technologies in their respective sectors – namely pipeline safety.

Staff anticipates the proposal will also ask the CPUC to allow changing the submission of research plans from every year (annual plans) to every three years (triennial plans). The Energy Commission has submitted the *Natural Gas Research and Development Program Budget Plan* annually to the CPUC for approval since 2005. However, this can result in research initiatives that have a short-term perspective on future research. In administering the Electric Program Investment Charge (EPIC) program, the Energy Commission has noted several advantages for planning research and development activities over a longer period. These advantages include the ability to aggregate, or combine, funding across fiscal years to create fewer but larger and more effective funding opportunities, an increased applicant pool due to the larger funding opportunities, positive feedback from researchers because of additional preparation time for upcoming funding opportunities, and a longer horizon which allows the potential to transition some technologies from development to pre-commercial demonstration in one three year investment plan cycle. All program details are subject to change based on feedback from CPUC, stakeholders, and further development from Energy Commission staff and leadership.

Ultimately, staff plans to propose that the expanded natural gas research program aims to fund research that will more effectively contribute to the state's statutory energy goals. The Energy Commission plans to include in its application to the CPUC an evaluation of the Natural Gas Research and Development Program.

Stakeholder Support to Increase Natural Gas R&D Funding

During the public staff workshop held on January 25, 2018, staff presented initiatives as a part of the proposed program expansion. Stakeholders generally supported the expansion and provided feedback on the proposed funding areas.

The Energy Commission appreciates the thoughtful comments of several stakeholders and plans to file a formal request to the CPUC requesting consideration of a funding increase. At that time, the Energy Commission will respond fully to the questions posed in the CPUC Resolution G-3519 to inform CPUC review of the overall funding levels of the program.

Proposed Research Initiatives

This proposed $24 million Fiscal Year 2018-19 (FY 2018-19) Natural Gas R&D Budget Plan includes research funding for energy efficiency, renewable energy and advanced generation, energy infrastructure (including pipeline safety and energy- related

environmental research), natural gas-related transportation, and program administration (Table 2). A research initiative consists of one or more research projects, each of which is designed to resolve issues associated with a technology or area of science. The Energy Commission's Natural Gas R&D budget allocates funding to CPUC-approved initiatives that are later acted upon by developing specific projects selected through competitive solicitations.

Table 2: FY 2018-19 Proposed Natural Gas Research Budget Plan Summary

Research Areas	Proposed Budget
Energy Efficiency	$6,000,000
Renewable Energy and Advanced Generation	$3,000,000
Energy Infrastructure	$8,600,000
Natural Gas-Related Transportation	$4,000,000
Program Administration	$2,400,000
TOTAL	$24,000,000

Source: California Energy Commission

Response to CPUC Resolution G-3484

As requested by the CPUC, the Energy Commission has reviewed the unspent funds in the Public Interest Research Development and Demonstration Natural Gas Subaccount to identify the funds no longer available for expenditure under future grants or contracts. The Energy Commission has budget authority for a six-year fund life, including two years to encumber funding and an additional four years to liquidate. 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 Research and Development Program has been successful 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, work on a project is stopped by the Energy Commission before the term end date for various reasons, including challenges with finding replacement host sites for projects and unsatisfactory interim results on projects. The Energy Commission has identified $1.96 million in unspent funds as of fiscal year 2016-2017. Because the unspent funds would amount to one to two projects, the Energy Commission will not request the $1.96 million as a supplement to the FY 2018-19 proposed budget and will instead make a request in a future budget cycle when a more substantive amount of unspent funds has accumulated.

Energy Efficiency Research

Energy efficiency continues to be important in reducing energy demand and greenhouse gas emissions in buildings and the industrial sectors. Energy efficiency is the strategy of first choice since it is the least expensive, most reliable, and most

environmentally sensitive means for minimizing society's contribution to climate change.[47] Sustained development, enhancement, deployment, and operation of better energy efficiency-related technology for existing and planned buildings, and industrial plants and processes, are essential to meet the state's energy efficiency and greenhouse gas reduction goals. California's pursuit of a low-carbon future will hit a critical milestone in 2030. To reach the targets for energy efficiency and greenhouse gas (GHG) emission reductions required by Senate Bill 350 and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016), the pace of technological progress must increase exponentially, especially for industries and facilities that are high emitters of GHG emissions. In 2015, the industrial sector emitted roughly 23 percent of total GHG emissions in California and the building sector emitted less than half of this amount or about 11 percent.[48]

Past energy efficiency research has supported, tested and demonstrated precommercial technologies, strategies, and tools to reduce energy use in buildings and the industrial sectors.

For the building sector, the focus has been on envelope tightening, water, heating efficiency, evaluating and testing solar thermal applications, heat recovery for hot water systems, gas-fired heat pumps and high-efficiency natural gas food service appliances. A solar thermal heat pump that combined a solar thermal energy collector and an absorption heat pump to produce hot and chilled water simultaneously was tested at large hotel in Southern California. The goal was to reduce natural gas use to produce domestic hot water for showers, laundry and kitchen and chilled water for the absorption chiller. The system reduced natural gas use by 30 percent to 50 percent for heating water. Another research project demonstrated natural gas saving retrofits associated with the food service industry (for example restaurants and cafeterias). The project replaced cookline equipment with high efficiency griddles, pots, ovens, steam kettles, conveyor broilers and fryers. Retrofits are saving restaurants between $3,000 and $13,000 in energy costs annually, and contribute to reducing the impact of the Aliso Canyon natural gas storage facility by alleviating natural gas demands.

For the industrial sector, this research has included developing and testing advanced burner designs that can achieve high energy efficiency while lowering NO_x emissions, testing heat recovery methods that allow for secondary uses such as water heating or chilling, testing advanced drying processes coupled with sensors to prevent over drying and excess natural gas use and use of solar thermal for hot water production. For example, a project that focused on an innovative system that extracts waste heat from

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[47] *California Energy Efficiency Strategic Plan, 2011 Update:* http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf.

[48] https://www.arb.ca.gov/cc/inventory/data/data.htm.

biogas to electricity generators and then uses the waste heat for water heating and chilling in cheese making reduced both natural gas (7 percent reduction) and electricity use (65 percent reduction). This technology is being demonstrated at Gallo Cattle Company in the Central Valley town of Atwater. Another project is demonstrating an indirect gas-fired dryer for bulk foods processing. This technology is being demonstrated at Inland Empire Foods in Riverside and has the potential to improve the efficiency of bulk foods dryer by more than 75 percent and reduce natural gas consumption by at least 60 percent.

Some of these technologies, especially those associated with food service, show great promise with a high potential for commercial adoption. But others, especially in the industrial sector need further testing, demonstrations and/or other strategies to bring down equipment costs, ensure performance reliability and product acceptability, and to reduce technical and economic risk.

Due to the greenhouse gas reduction and energy efficiency targets for 2030 and beyond, the primary focus of the FY 2018-19 budget plan for energy efficiency research is on the industrial sector with a secondary focus on the building sector that could benefit from similar technology advancements.

The proposed research budget for energy efficiency is $6 million (Table 3). Research will be coordinated with other program areas, as appropriate.

Table 3: FY 2018-19 Proposed Natural Gas Research Budget Plan Summary – Energy Efficiency

Program Area – Energy Efficiency	Proposed Budget
Proposed Research Initiatives: • Reduce Natural Gas Use for GHG Emission Intensive Industries/Facilities	$6,000,000

Source: California Energy Commission

Energy Efficiency Program Goals

- Conduct research, development, and demonstration to increase energy efficiency while reducing 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 the industry's competitiveness in the global market
- Commercialize technologies with broad market penetration

Project 1: Reduce Natural Gas Use for GHG Emission Intensive Industries/Facilities

The Issue

This initiative focuses on industries/facilities in California that have high natural gas consumption and are very GHG emission-intensive. This sector includes many facilities that are required to report on annual facility level GHG emissions to the California Air Resources Board because they emit more than 10,000 metric tons of GHG emissions annually. Those that emit more than 25,000 metric tons are known as "capped facilities" are subject to California's GHG Cap and Trade Program and must reduce emissions or purchase allowances in quarterly auctions. The cap on how much GHG emissions can be emitted annually will shrink 3 percent annually from 2015 to 2020 and is expected to shrink more quickly each year from 2020 to 2030 to move California toward the goal of reducing GHG emissions to 40 percent below the 1990 level by 2030. To help achieve these emission reduction goals, research is necessary to develop and demonstrate technologies that could significantly reduce natural gas and GHG emissions and generate cost savings. In addition, the focus is on technologies with the potential for broad market penetration to multiple types of industries and facilities in the mid to long-term time frame. The most affected sectors include petroleum refining, oil and gas extraction, glass and cement, food production, paper, chemicals and allied products, metals and dairies.[4950] Furthermore, these industries are risk-averse and want verified performance, economic and reliability data before deciding to invest in major equipment and systems.

The Research

This initiative focuses on industrial and other facilities that emit more than 10,000 metric tons of greenhouse gas emissions annually. Research focuses on developing and demonstrating technologies that could reduce natural gas, GHG and other air pollutants (such as NOx) cost effectively. Potential research could include the following or integrate multiple approaches:

- Test advanced non-thermal water removal technologies
- Test alternatives to steam for sterilization and process applications
- Test or demonstrate highly efficient combustion systems and fuel-flexible industrial combustion systems
- Develop innovative, cost-effective systems to recover waste heat
- Develop advanced sensors, controls and models that reduce energy intensity
- Develop and test advanced materials and catalysis for high-temperature and harsh environmental conditions

[49] https://www.arb.ca.gov/cc/capandtrade/allowanceallocation/v2017allocation.pdf.

[50] https://www.arb.ca.gov/cc/capandtrade/allowanceallocation/v2016allocation.pdf.

- Develop technologies that reduce natural gas use with potential for zero or near-zero NO_x emissions compared to current equipment.
- Assess and deploy best available emission reduction technologies that also result in reductions in natural gas use and greenhouse gas emissions

The Benefits

- **Technology Potential.** The industrial sector uses roughly 37 percent of natural gas consumed in California and contributes 23 percent of greenhouse gas emissions. As a result, successful demonstrations can help reduce technology risk by providing information on performance and benefits and can increase the likelihood of implementation, especially if it increases the potential for global competitiveness.
- **Market Connection**. In California, there are approximately 394 industrial facilities that emit more than 10,000 metric tons of carbon dioxide annually with 358 industrial facilities that emit more than 25,000 metric tons. As these industries must reduce greenhouse gas emissions, identifying cost effective solutions will help maintain the competitiveness of these industries and reduce GHG leakage potential. Leakage is defined by the California Air Resources Board as industries/companies that reduce GHG emissions within California but is offset by an increase in GHG emissions outside of California due to relocation.[51]
- **Energy and Cost Savings.** The amount will depend on the industry, current energy use and equipment to be replaced, but funded technologies are expected to reduce natural gas use and cost by at least 10 percent.
- **Environmental Benefits.** The amount will depend on the industry and the amount of natural gas savings, but funded technologies are expected to reduce natural gas use and GHG emission by at least 10 percent, with the potential of reducing oxides of nitrogen emissions and other air contaminants.
- Responds to the CPUC resolutions G-3519 and G-3527 which instructed the Energy Commission to focus on research solutions to help the emissions intensive industries/facilities:
    - *G-3519:* "…plan to leverage existing research to target industries and facilities that could benefit from research advancements, including entities covered under the Air Resources Board (ARB)'s Cap-and-Trade program, as well as industries that are emissions intensive and trade exposed (EITE), identified in ARB's past and ongoing leakage studies. The

[51] Leakage is a reduction in emissions of GHG within California that is offset by an increase in emissions of GHG outside of California. (https://www.arb.ca.gov/cc/capandtrade/meetings/073012/emissionsleakage.pdf)

intent within the previous resolution was consistent with state goals under AB 32. We continue to press the CEC to do so in the current resolution."

- *G-3527:* "...call upon the CEC to identify and target specific research needs and address R&D challenges of high-, medium-, and low-leakage risk industries. Within energy efficiency, this may require a closer examination of the operating environments within heavy industry and manufacturing that present opportunities for creating higher overall system efficiencies."

Renewable Energy and Advanced Generation

The Renewable Energy and Advanced Generation research area conducts research addressing cost and other barriers to increasing market penetration of renewable energy, including renewable gas, distributed generation (DG), and combined-heat-and-power (CHP) systems. Technologies of focus include hybrid, fuel-flexible, high-efficiency, and low-emission DG and CHP systems for use with natural gas or renewable gas fuel. Technologies such as thermally driven cooling and thermal energy storage are also supported which allow CHP systems to operate flexibly and reduce peak loads. Finally, this research area includes technology advancements for the conversion, cleanup, and upgrading of biomass resources (that is, forest wood waste, landfill gas, or anaerobic digester gas) to renewable natural gas.

Renewable energy resources are essential for reducing greenhouse gas emissions and achieving state statutory energy goals. Solar, wind, hydroelectric, and geothermal are abundant and well-known renewable resources that constitute nearly 90 percent of the renewable electricity in California. The remaining 10 percent of renewable electricity is produced from biomass resources, which along with being renewable have the added benefits of diverting waste from landfills and reducing methane emissions, a powerful short-lived climate pollutant. Reducing short-lived climate pollutants, in particular, has been identified as an opportunity for immediate, significant reductions in GHG emissions in California.

The Energy Commission has funded research related to biomass use in the Natural Gas and EPIC research programs. This research has examined producing biogas from various biomass resources (forest and agricultural wood wastes, dairy waste, food waste), using biogas to produce renewable electricity, and developing the technologies that clean and upgrade biogas to renewable natural gas for pipeline injection and vehicle fuel applications. Most of this research, however, has focused on using biogas at commercial-scale facilities such as landfills and large dairies. Similar programs, such as the California Department of Food and Agriculture's Dairy Digester Research and Development Program, have also focused funding on large facilities. There is a need to research technologies that can benefit small dairies, livestock, and other small farms which would allow them to convert their biomass resources into renewable energy for electricity generation and transportation fuel where economical.

Advanced distributed generation systems are also considered a key distributed energy resource that could contribute to achieving state statutory energy goals. Distributed generation systems have been employed around the state to produce reliable, on-site power for customers in all sectors for many years. However, just because these systems are mature does not mean there isn't room for improvement. The Energy Commission has funded research related to making distributed generators cleaner, more efficient, and fuel-flexible. Other research has focused on combined-heat-and-power configurations to recover waste heat and reduce greenhouse gas emissions. As energy systems become smarter, there is a need to adapt these systems to match the functionality of modern distributed energy resources. The addition of advanced features such as remote controls, automation, flexibility, and islanding/black-start[52] capability would allow distributed generators to function as an integrated component of a modern energy system. There is an opportunity to introduce these functionalities to maximize efficiency, cost-effectiveness, and greenhouse gas emission reductions. These opportunities are targeted in the research initiatives described below.

The proposed research budget for renewable energy and advanced generation is $3 million (Table 4).

Table 4: FY 2018-19 Proposed Natural Gas Research Budget Plan Summary – Renewable Energy and Advanced Generation

Program Area – Renewable Energy and Advanced Generation	Proposed Budget
Proposed Research Initiatives: • Central Valley Agricultural Waste Resources to Energy • Improved Functionality and Readiness of Advanced Distributed Generators for Fire Risk Regions and Critical Facilities	$3,000,000

Source: California Energy Commission

Renewable Energy and Advanced Generation Program Goals

Reduce barriers and increase the amount of renewable energy by:

- Advancing the development and market availability of clean and efficient DG and CHP technologies.

[52] Islanding is isolating the power source and black start is restoring an electric power station or part of the grid to operation with relying on the external electric power transmission network.

- Developing cost-effective hybrid generation, fuel-flexible, energy-efficient, and low-emission gas DG technologies for alternative fuels, including renewable gas and natural gas.
- Developing and demonstrating diversified applications of advanced generation technologies that use renewable gas.

Proposed Research Initiatives

Project 1: Central Valley Agricultural Waste Resources to Energy

The Issue

SB 1383, signed into law in 2016, calls for dramatic reductions in short-lived climate pollutants (SLCP) compared to 2013 levels by 2030. Specifically, California must reduce emissions by 50 percent for anthropogenic black carbon, 40 percent for methane, and 40 percent for fluorinated gasses. SLCP refers to a subset of greenhouse gases which have both high global warming potential and relatively low atmospheric lifetime SLCP emission reductions can make an immediate beneficial impact on climate change. Central Valley farms produce such a high volume of agricultural residues that the handling and disposal of these residues are problematic. These farm residues include orchard and vineyard pruning's and tree and vine removals; nut shells and hulls; and residues from field, cover crops, and vegetables crops. Disposal through open pile burning contributes significant particulate emissions to an already pollution-burdened region with many disadvantaged communities. Projections indicate that emissions from open burning will continue to rise without a cost-effective alternative. Disposal and management of such residues in the Central Valley are further impacted by issues such as reductions in the availability of biomass power plants and limitations in agricultural burning. While the San Joaquin Valley Air Pollution Control District (SJVAPCD) has the toughest rules in place on agricultural burning, it is considering a rollback of the rules that limit agricultural burning because of the glut of biomass resulting from the aforementioned events. In the meantime, the SJVAPCD increased the fine for agricultural burning to $750 per acre; unfortunately, some farmers are opting to pay the heavy fine. A recent SJVAPCD summit focused on the urgent need to find cost-effective alternatives to openpile burning, including bioenergy.

In addition to agricultural residues, livestock manure, primarily from cattle, is the largest source of methane emissions in California, responsible for roughly 25 percent of annual methane emissions. The California Air Resources Board *Short-Lived Climate Pollutant Reduction Strategy* identifies dairy manure management as an opportunity for significantly reducing methane emissions.[53] There exists significant potential to capture

[53] California Air Resources Board. *Revised Proposed Short-Lived Climate Pollutant Reduction Strategy*. 2016. https://www.arb.ca.gov/cc/shortlived/meetings/11282016/revisedproposedslcp.pdf.

and economically convert this methane into on-site generation and transportation fuel, thereby reducing dependence on fossil fuel.

The primary method for capturing and converting methane to energy is via anaerobic digestion. Anaerobic digestion is a complex biochemical process in which organic materials are placed in an oxygen-free environment to decompose into biogas, water, and solids. The biogas (primarily carbon dioxide and methane) can be used to create renewable heat, renewable electricity, or renewable natural gas or a combination of the three. Anaerobic digester technology has been demonstrated at several large dairy farms in California. However, economic payback of these technologies has a large scale-dependency – in other words, these systems are far less economical at small dairy and livestock farms, a number of which are found in the Central Valley. As a result, recent grant programs have focused on large dairy farms. There is a need to develop and demonstrate systems that can operate economically at smaller scale to capture organic waste from smaller farms such as livestock facilities with fewer than 1,000 heads and convert it to biogas or renewable natural gas.

Agricultural residues discussed above could be used to produce renewable natural gas that could be made available for onsite generation or transportation applications where economical. Converting these residues to energy through a controlled process would also reduce pollutant emissions, such as black carbon, compared to open pile burning with positive implications on the overall health and well-being of Central Valley communities.

The Research

This initiative proposes R&D that will support precommercial technologies and strategies to enable effective and economic energy conversion of agricultural residues in the Central Valley as an alternative to open pile burning and flaring. In particular, R&D will emphasize conversion of agricultural organic wastes to biogas and biomethane or RNG production focusing on development strategies that will make such bioenergy conversion economic for smaller farms. CPUC Decision G-3527 recognized that "advancement of biomethane research could not only mitigate short-lived climate pollutants, but also create new energy pathways for underserved communities in the San Joaquin Valley."

Possible technologies and strategies include, but are not limited to, the following:

- Preprocessing steps that improve handling and conversion efficiency of agricultural biomass matched with improvements in conversion technology.
- Development, demonstration and overall improvement to thermochemical conversion approaches for non-manure agricultural residues to renewable natural gas cost-effectively.
- Preengineered systems capable of low-cost deployment at a range of scales in Central Valley farms.

- Innovative strategies such as collecting waste from several small farms to transfer to a central bioenergy plant to improve cost-effectiveness.
- Pretreatment steps (that is solids separation, hydrolysis) before anaerobic digestion; improvements to the anaerobic digestion process (such as mixing or pumping) that increases biogas quality; codigestion of organic wastes; and possibly alternative processes such as thermal hydrolysis.
- Combined heat-and-power systems optimized for biogas operation.

Projects must demonstrate a "whole system approach" from feedstock to end use. End uses must prioritize energy production for the most economical use, potentially including renewable electricity, renewable natural gas for pipeline injection, or renewable natural gas for vehicle fuel, depending on the location of the feedstock. Technologies should focus on improving efficiency, reducing costs, and reducing environmental impact compared to conventional systems and should be demonstrated at a farm in the Central Valley of California.

The Benefits

- **Energy Sector***.* The technologies developed and demonstrated in this initiative are intended for use at small dairy and livestock farms in California. These technologies would allow these farms to produce biogas for on-site heat and power production, offsetting natural gas and electricity demand from utilities. The biogas can also be upgraded to renewable natural gas for generation or transportation applications, if economically feasible at that location.
- **Technology Potential.** According to U.S. Department of Agriculture census data, half of all dairy farms in California have herd size of fewer than 1,000 cows.[54] These farms account for roughly 350,000 of California's 1.8 million dairy cows (approximately 20 percent). Assuming 200 kilowatts (kW) of electricity per 1000 cows, these small farms represents about 70 MW of renewable energy potential in California. This number does not include renewable energy potential from small beef cattle, hog, sheep, poultry, and other small farms.
- **Market Connection***.* According to the U.S. Environmental Protection Agency AgSTAR database, there are 16 operational dairy digester projects in California. Of these, only three are located at farms with fewer than 1,000 cows.[55] Improving biogas generation technologies would help increase these numbers to realize the potential benefits.

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[54] *2012 Census of Agriculture.* United States Department of Agriculture. 2014. https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/California/.

[55] *Livestock Anaerobic Digester Database.* AgSTAR. 2016. https://www.epa.gov/agstar/livestock-anaerobic-digester-database.

- **Energy and Cost Savings.** Increased biogas use at small dairy and livestock farms could significantly offset the fossil fuels that normally provide the heat, electricity, and vehicle fuel used. Specifically, biogas used on-site would offset the typically natural gas-fueled electricity, propane-fueled heating, and diesel vehicle fuel, with the latter two presenting even higher cost savings. Furthermore, these energy and cost savings have the potential to significantly impact small farms where costs are higher per pound of product produced.
- **Environmental Benefits.** As stated above, nearly 20 percent of the dairy cows in California are located at small farms with herd sizes of fewer than 1,000 cows. This number accounts for about 4 percent of statewide methane emissions, or one-tenth of the required reduction to meet the goals set by the Super Pollutant Reduction Act. In addition, reductions in open pile burning will result in criteria air pollutant reductions of NO_x and black carbon (particulate matter), improving air quality in the most pollution burdened air basin in California.

Project 2: Improved Functionality and Readiness of Advanced Distributed Generators for Fire Risk Regions and Critical Facilities

The Issue

Assembly Bill 32 and the Governor's Clean Energy Jobs Plan set aggressive goals for advanced generation technologies, including clean distributed generation (DG), combined heating and power (CHP) and combined cooling, heating and power (CCHP) for California. Despite these drivers, DG, CHP, and CCHP systems have seen minimal growth in recent years. For example only 3,086 MW of CHP capacity has been procured by IOUs since 2010 versus a goal of 6,500 MW by 2030 as outlined in the Governor's Clean Energy Jobs Plan.[56]

In addition, the recent passage of Senate Bill 350 calls for a significant increase in renewable energy generation in California – specifically 50 percent of retail electricity in California by 2030. To achieve these goals, large amounts of intermittent renewable energy (such as solar PV and wind) will be added to California's electricity mix. In recent years, increased penetration of solar PV has caused large diurnal swings in energy load. To manage this load at the utility-scale, smarter grid management practices and advanced technologies such as large-scale energy storage and fast ramping power plants (peaker plants) have been employed.

Recent extreme weather events, such as wildfires or drought, have also impacted power generation and distribution and, in many cases, resulted in wide-scale power interruptions that impacted critical facilities (for example hospitals and fire and police stations). As renewable energy penetration grows to meet California's clean energy

[56] *Tracking Progress – Combined Heat and Power*. California Energy Commission. 2017. http://www.energy.ca.gov/renewables/tracking_progress/documents/combined_heat_and_power.pdf.

goals and as the rate of extreme weather events increase, resilience needs to be built in to demand energy response deployment and operation.

Similar to the utility-scale systems, distribution-scale systems are increasingly integrating renewable generation (e.g. solar PV) with energy storage and traditional DG systems (such as smartgrids and microgrids). Grid system operators and microgrid operators need DG systems that can operate flexibly and resiliently in extreme events such as wildfires.

The Research

This initiative funds precommercial technologies and strategies that address the technical and economic barriers related to deploying clean and efficient DG, CHP, and CCHP systems as a key power enabler in high-fire-risk regions and at critical facilities, and as a key component of an integrated modern energy system. At minimum these systems should be capable of black start and grid islanding. This means the systems can start without the need of grid power and continue to operate in order to restore power to a critical facility. In addition to these capabilities, precommercial technologies should include other enhancing features.

Possible precommercial technologies and strategies include, but are not limited to, the following:

- Systems that are capable of fast ramping (respond to external signals and rapidly adjust electrical output) and other functionalities needed to respond and provide needed power during fire and other catastrophic events. These may include clean and efficient DG and CHP systems, including biogas-fueled systems which maintain high efficiency over a large operating range (high turndown ratio)
- Advanced DG and CHP systems built specifically for integration with renewable energy, energy storage, and microgrid controllers particularly in critical facilities located in high fire hazard severity zones
- CHP systems with multiple operating modes based on external stimuli (such as a CCHP system that switches between heating or cooling, or a CHP system that switches between generator-driven heating and electric heating, based on building loads or in response to extreme events)
- Advanced DG (including biogas-fueled DG and CHP) system controls that allow increased amount of renewable generation, while improving reliability in high fire risk regions and critical facilities

Projects funded by this initiative are expected to demonstrate a "whole system approach." For example if the goal of the project is to combine DG and battery energy storage into an integrated system, actual generation of electricity and storage in batteries must be demonstrated, at least at the bench scale. Technologies should focus on improving efficiency, reducing costs, reducing environmental impact, and improving reliability compared to conventional systems.

The Benefits

- **Energy Sector.** Increased deployment of DG, CHP, and CCHP systems has the potential to reduce statewide consumption of natural gas and provide increased reliability, flexibility, and power quality, reduce transmission and distribution losses, and reduce transmission congestion on the local electric grid.
- **Technology Potential.** There exists a large potential market for DG, CHP, and CCHP systems in the commercial, light industrial, institutional, and multifamily residential sectors. A report produced for the Energy Commission by ICF International identified CHP generation potential for existing facilities in the above-listed sectors of 2,766 megawatts (MW), with an additional 531 MW growth expected by 2030.[57]
- **Market Connection.** Small-scale DG, CHP, and CCHP systems allow facility owners to affordably meet their on-site electric and thermal needs while providing energy security and reliability. Possible customers for small DG, CHP, and CCHP systems include:
    - Hospitals.
    - Hotels.
    - Schools.
    - Multifamily dwellings.
    - Commercial buildings.
    - Light industrial facilities.
- **Energy and Cost Savings.** A report produced for the Energy Commission by BEW Engineering and Lawrence Livermore National Laboratory estimates the potential energy and cost savings of the 448 MW of small CHP identified to nearly 155 million therms per year and valued at $105 million, based on 82 percent penetration in the stated megawatt range. This estimate assumes a 90 percent capacity factor and a commercial cost for natural gas of $0.68/therm.[58]
- **Environmental Benefits.** There could be improved air and environmental quality and reduced climate change impacts through reduced natural gas consumption, greenhouse gas emissions reductions, and water savings.

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[57] *Combined Heat and Power: Policy Analysis and 2011-2030 Market Assessment*. ICF International for the California Energy Commission. 2012. CEC-200-2012-002 http://www.energy.ca.gov/2012publications/CEC-200-2012-002/CEC-200-2012-002-REV.pdf.

[58] BEW Engineering and Lawrence Livermore National Laboratory for the California Energy Commission. 2011. *Geographic Information System-Enabled Renewable Energy Analysis Capability Project Final Report*. CEC-500-2011-026 http://www.energy.ca.gov/2011publications/CEC-500-2011-026/CEC-500-2011-026.pdf.

Energy Infrastructure

The infrastructure providing natural gas to customers is vast and covers most of the state. It includes producing wells, treatment facilities, transmission lines, compressor stations, distribution lines, meters, and small pipes inside homes and buildings. Natural gas is a highly combustible gas, contains toxic compounds and has a very potent greenhouse gas, methane, as one of its main components. California's natural gas wells and pipelines face risks that could cause potential damage or catastrophic events. The massive natural gas leak at Aliso Canyon shined a light on California's aging natural gas infrastructure. Furthermore, five years of extreme drought also exacted a toll on transmission pipelines, prompting the Energy Commission to begin research on drought-induced subsidence impacts on natural gas pipelines. Events such as San Bruno and Aliso Canyon are reminders of the importance that public safety, public health, and greenhouse gas emissions considerations must have in any research portfolio covering natural gas. Further, climate change would exacerbate existing risks such as exposing natural gas infrastructure directly or indirectly to wildfires, landslides, coastal and inland flooding, and ground subsidence due to over drafting of groundwater. Finally, the natural gas system must evolve substantially by lowering the carbon or greenhouse gas footprint if it is going to be part of the solution to comply with the 40 percent GHG reduction mandate by 2030 and the 80 percent reduction goal by 2050.

The Energy Commission has 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 to prevent public safety issues or catastrophic failures. The Energy Commission has also funded research on:

- Methane leaks from wells to final consumption (e.g., emissions from homes).
- The identification of super emitters, indoor air quality implications on using natural gas for cooking and other applications.
- Safety associated with the combustion of different blends or types of natural gas (e.g., using blends with biomethane).
- Potential safety issues related to ground subsidence in the San Joaquin Valley.
- Potential impacts and adaptation options to climate change.
- Strategies to decarbonize the natural gas system.

Projects are still ongoing, and results are shared with state agencies such as the California Air Resources Board to inform greenhouse gas inventory and other policy goals. The Energy Commission's work on safety and environmental issues is a continuum of projects informing each other. For example, preventing catastrophic failures would also help reduce the methane leaks and identifying leaks can be used to identify potential failure modes. However, from a climate perspective most of the important leaks are not associated with potential infrastructure risks.

This year in the safety area, the Energy Commission proposes to enhance prior work to have an improved inventory and characterization of existing natural pipeline infrastructure by developing and using advanced low-cost sensor technologies to gather, store, and analyze pipeline and storage characteristics (for example materials, age, and manufacturer). This characterization would help prioritize the deployment of expensive safety evaluation technology options developed in past research projects. Another area that will receive attention this year is the modeling the potential for mechanical failures. This modeling will enhance prior and ongoing work on risk assessment modeling. Finally, the Energy Commission proposes to support the development of automated shutoff equipment for natural gas infrastructure to prevent dangerous situations. The ongoing risk assessment would identify where this shutoff equipment should be located.

In the environmental area, the Energy Commission proposes continuation the evaluation of climate risks to support creating the California Climate Partnership with energy utilities as recommended in the *2017 Integrated Energy Policy Report (IEPR)*. In the area of emissions and renewable natural gas via biomethane, for the first time, the Energy Commission is suggesting measurement of methane emissions before and after energy facilities are in place because prior and ongoing work supported by the Energy Commission suggests that the climate benefits of these energy projects may be underestimated. Actual emissions of uncontrolled landfills, dairies, and manure management may be much higher than what is reported in official GHG inventories.[59]

In the long term, it is important to consider energy modeling performed for California, which suggests that to meet the GHG emission targets by 2030 and 2050, natural gas consumption must go down substantially and be a very small fraction of what is consumed today. Therefore, the entire transmission and distribution system may be pressurized to meet a much lower demand in the future. Alternatively, it may be that only parts of the system are necessary to provide service to sectors that still rely on natural gas. Another option to lower the GHG footprint of natural gas is the blending of hydrogen produced using renewable electricity and sustainable bio-methane. This blending would bring other RD&D challenges for safety and environmental concerns. While considering the required transformation of the natural gas system to comply with GHG emission targets, other impacts on the natural gas system such as earthquakes and fires, should also be addressed in future environmental and infrastructure safety research.

The energy infrastructure area includes research associated with infrastructure safety pipeline integrity management, and energy-related environmental and climate issues.

[59] Duren, Riley. Personal communication. NASA.

The proposed research budget for energy infrastructure is $8.6 million (Table 5), with $5.6 million allocated for natural gas infrastructure safety and integrity research and $3 million allocated for energy-related environmental research.

Table 5: FY 2018-19 Proposed Natural Gas Research Budget Plan Summary – Energy Infrastructure

Program Area – Energy Infrastructure	Proposed Budget
Natural Gas Infrastructure Safety and Integrity **Proposed Research Initiatives:** • Technologies for Natural Gas Infrastructure Damage and Failure Prevention • Modeling Mechanical Failure Potential • Decreasing Failure Consequences -Developing Automated Shutoff Equipment for Natural Gas Infrastructure	$5,600,000
Energy-Related Environmental Research **Proposed Research Initiatives:** • Measuring the Emissions Benefits of Renewable Natural Gas • Fostering Natural Gas Sector Resilience	$3,000,000

Source: California Energy Commission

Natural Gas Infrastructure Safety and Integrity

Natural Gas Infrastructure Safety and Integrity Program Goals

- Provide research that results in increased safety and enhanced transmission and distribution capabilities of the natural gas system.

Proposed Research Initiatives:

Project 1: Technologies for Natural Gas Infrastructure Damage and Failure Prevention

The Issue

Safely operating natural gas infrastructure remains a substantial challenge, and damage or failure continues to affect natural gas availability, public safety, and greenhouse gas releases. In November 2017, the California Energy Commission, California Public Utilities Commission (CPUC), California Independent System Operator, and the Los Angeles Department of Water and Power released their fourth energy assessment for

Southern California and expressed concern about existing pipeline outages. Recent incidents of pipeline damage on two Southern California Gas Co. (SoCalGas) transmission pipelines have significantly decreased natural gas import capacity to Southern California and exacerbated the potential for shortages. In addition, with the forecasted increase in demand through 2028 and requests for closure of the Aliso Canyon storage facility, safely operating natural gas infrastructure including storage and pipelines will continue to play an integral role in California's energy system. Ensuring current and future infrastructure meets safety requirements will continue to be a priority moving forward.

Properly managing the infrastructure and identifying the greatest risk areas are complicated by the complexity of the system and lack of available data. The system consists of components of varying materials, ages, locations, depths, manufacturers, and operational characteristics, which are threatened by corrosion, natural forces (for example from seismic or climate change impacts), excavation damage, and incorrect operation.[60] It is essential to develop and demonstrate inexpensive technologies for pipelines and storage infrastructure to gather relevant field data to help prevent damage and inform emergency response. Deploying these technologies on existing or new infrastructure will allow utilities to better monitor system risks.

Advanced sensors and controls have the greatest potential to transform the aging natural gas system to smart energy infrastructure. Energy Commission started investing in sensor technologies to reduce incidents of excavation damage and the amount of time required to locate assets for engineering, operations, and one-call activities. This includes a Global Positioning System Excavation Encroachment Notification System (GPS EENS) to increase situational awareness of operating excavators and a real-time active pipeline integrity detection (RAPID+) system to detect pipeline degradation. Initial evaluation of the advanced sensors indicates most of the technologies are at a relatively low technology readiness level (TRL), which requires additional research and demonstration before transitioning to deployment and commercialization.

The Research

Building on existing research and advancements in sensors, mobile technology (for example smartphones and tablets), geospatial systems (such as geographic information systems [GIS] and global positioning systems (GPS), and computing infrastructure (for example the "cloud" and Web), this research will focus on developing and using advanced sensor technologies to gather pipeline and storage characteristics to assist utilities in preventing damage or other failure, improve public safety and system integrity, increasing operational efficiencies, and reducing GHG emissions. Possible research includes, but is not limited to:

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[60] PHMSA. 2014. "Significant Pipeline Incidents by Cause." http://opsweb.phmsa.dot.gov/primis_pdm/significant_inc_trend.asp.

- Developing and using technologies for automating data capture with advanced sensors to allow utilities to collect field data (such as materials of construction, horizontal and vertical location, pressure, manufacturer, serial numbers, dates manufactured/repaired, and certifications) so utilities are better able to use this information in the future to predict potential failures based on knowledge of equivalent system degradation or manufacturer warnings.
- Proposed research that must address the barriers for the full deployment of these technologies by the utilities. Research should focus on evaluating and demonstrating the technologies under various operating conditions typically found in the field. This requires coordinating with entities that can commercialize these products, demonstrating the technologies at utility sites, and conducting cost-benefit analysis for large-scale deployment of the technology to satisfy program objectives.

The Benefits

- **Energy Sector.** The technologies developed and demonstrated in this project are intended to improve safety, reliability, and integrity of natural gas infrastructure.
- **Technology Potential.** Recent advances in advanced sensors, mobile technology, geospatial systems, and computing infrastructure have provided the tools to support next generation technologies for pipeline and storage damage prevention. Deploying these technologies broadly will provide a robust use case to other utility companies and will help prove the value and cohesiveness of integrated technologies.
- **Market Connection.** Despite technological advancements, natural gas operators have diverse approaches to gather data on infrastructure, including paper-based methods to collect and document asset properties and environmental conditions. Utilities could use the proposed and past technologies to automate data capture and allow the data to be accessed in near real-time, including for emergency response.
- **Energy and Cost Savings.** The technologies will result in the ratepayer benefit of improved public safety. Moreover, the technologies will decrease the probability of an incident through real-time data collection and the consequence of an incident through situational awareness during emergency response. A secondary ratepayer benefit of lower cost operations will also be achieved.
- **Environmental Benefits.** Natural gas is an important tool in the suite of GHG emissions reduction options. Reducing the probability of unprecedented pipeline and storage outages by applying advanced sensor technologies will increase usage of natural gas, and will help reduce direct and indirect GHG emissions.

Project 2: Modeling Mechanical Failure Potential

The Issue

Material, weld, and equipment failures account for 53 percent of the total pipeline incidents. The slow progression of mechanical failures such as corrosion, and stress cracking is always challenging to predict because of the variety of conditions that can result in these failures. While some work has begun to develop risk assessment models, more needs to be done to take full advantage of material science and the growing amount of data on system components. This research will build on existing work to develop risk assessment methods by integrating more diverse sources of knowledge and information, including the understanding of failure processes, and by applying data collected from real-time sensors and monitoring devices, either already deployed or to be deployed, to develop more accurate failure predictions. This predictive tool and modeling can be used for pipelines and storage.

The Research

The slow progression of mechanical failures is challenging to predict. With greater availability of material and site data, predictive models can be used to predict these failures systemwide. As the data collected on their systems increase, IOUs could use a predictive tool to better assess potential failures and take actions before a catastrophic failure. Possible projects in this initiative may include:

- Developing and deploying a predictive model/tool by accounting for possible threats to:
    - Evaluate the probability of failure of the nature gas network, including storage systems.
    - Determine the highest threat of failure.
    - Develop the most appropriate mitigation strategy by conducting cost/benefit analyses.
    - Find optimal preventive maintenance and replacement decisions.

The project will involve partnering with major natural gas companies in California to validate the predictive tool for assessing corrosion and mechanical failure threats due to potential threats identified by the Pipeline and Hazardous Materials Safety Administration (PHMSA). The predictive models must be based on the time-dependent failure characteristics of natural gas transmission and distribution pipelines and storage systems. The research should focus on developing more accurate models and customizing and validating the method for California pipelines. Furthermore, it will help integrate information and data generated from this project, such as material types, pipe sizes, operating pressures, age, and so on.

The Benefits

- **Energy Sector.** Recent pipeline failures and storage leakage incidents in California have resulted in injury, fatalities, and environmental damage. The technology principle benefit is to prevent safety hazards. Additionally California

natural gas users and utilities benefit through avoidance of gas delivery disruptions and safety related consequences.

- **Technology Potential***.* Utilities could use the proposed predictive model to predict future pipeline and storage failures, determine the highest threat of failure on each segment, and take mitigation actions before a catastrophic failure.
- **Energy and Cost Savings.** Pipeline failures and storage leakage incidents can result in shut downs and increased energy costs. Therefore, a failure prediction method that can assist natural gas companies in anticipating threats and taking timely corrective actions will benefit ratepayers both by increasing their safety and ensuring reliable supply.
- **Environmental Benefits.** Early prevention and detection of failure will minimize methane leaks and hence reduce GHG emissions.

Project 3: Improving Automated Shutoff for Natural Gas Infrastructure

The Issue

Natural disasters, mechanical failures, operational errors, and external impacts can damage gas infrastructure, resulting in small to catastrophic natural gas leaks. Automatic shut-off devices, such as excess flow valves, provide critical safeguards to limit releases. An important aspect of pipeline safety includes greater use of condition monitoring. Monitoring technology with remotely operated valves would provide more rapid response from a central control location. Existing valves could be equipped with a control device that automatically triggers the actuator and shuts off the flow of natural gas in the event of a large pressure drop. Furthermore, many of these valves can provide routine pressure control to safeguard against exceeding the maximum pressure of the pipeline.

While many of these technologies are well developed for transmission pipelines, much research can be done to explore innovations that are applicable to the distribution system. Upgrading or retrofitting valves on the distribution system with remote-control and automatic shutoff valve technology may provide gas control operators with greater flexibility and shorter response times if it becomes necessary to close a valve or valves quickly in the event of an emergency, such as an earthquake or fire.

The Research

This research proposes to develop, test, and demonstrate automatic shut off technologies to limit the consequences from breaks or ruptures caused by impacts, high pressures, or other causes. Possible projects include developing fast-actuating shutoff valves, regulator equipment, monitoring and automated control of shutoff valves, or other innovative technologies for both pipelines and storage.

The Benefits

- **Energy Sector***.* The technologies developed and demonstrated in this initiative are intended for use on natural gas pipelines and the natural gas storage facilities.
- **Technology Potential.** California has a large gas transport infrastructure that is close to urban areas where protection is needed.
- **Environmental Benefits**. Catastrophic natural gas explosions and fires can be a large source of carbon emissions in California. Large methane leaks are also a source of GHG. If adopted, these technologies could help reduce the chances of catastrophic fires, therefore reducing black carbon emissions and the release of large amounts of methane.

Energy-Related Environmental Research

Energy-Related Environmental Research Program Goals

- 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 Initiatives:

Project 1: Measuring the Emissions Benefits of Renewable Natural Gas

The Issue

Renewable natural gas (biomethane) could become a zero-emission or very-low-emission greenhouse gas (GHG) emission fuel in California and substantially help reduce GHG emissions from major sources of methane such as dairies (manure management), landfills, and wastewater treatment plants. An additional opportunity exists for switching existing combined heat-and-power facilities to producing renewable natural gas (RNG) due to air quality regulations in wastewater treatment plants. The gas could be used on-site to generate heat or electricity or both, to be injected into natural gas pipelines, and be used for mobile applications. The climate benefits of GHG reductions are calculated using standard methods that have been developed by extrapolating from relatively few measurements of actual emissions. The processes involved in the generation and final release of methane and nitrous oxide to the atmosphere are highly complex. Field and modeling studies can produce estimates of GHG emissions that are widely different from what is estimated using accepted regulatory methods. In addition, the air quality implications are still not well understood. For all of these reasons, the actual climate and air quality benefits of RNG projects are not certain.

In addition, many of the RNG projects are located in disadvantaged communities, where air quality and public health are of primary concern. Evidence shows reduction of odor complaints after energy projects are implemented when they operate properly and reduce methane emissions.[61] Actual emissions reductions can be confirmed and quantified by emissions measurements in the field.

The Research

The research will involve measuring methane and other air pollutant emissions at site(s) before and after energy projects are implemented to generate RNG at those sites. Another possibility is measuring sites that are very similar to one with RNG project already implemented. In this case, the sites should be similar in feedstocks, RNG generation capacities and other characteristics. However, there will be a preference for conducting measurements at the same site, before and after project implementation. The target emissions include methane, nitrous oxide, and volatile organic compounds (VOCs) and other criteria pollutants. The measurements should be made multiple times both before and after to estimate annual emissions instead of one-time measurements, because emissions can be temporarily variable.

The Benefits

- **Technology Potential.** The measurement methods could inform the development of standard approaches to track the GHG benefits of renewable natural gas projects and improve emissions estimates for these types of projects.
- **Environmental Benefits.** This research will help the Energy Commission and other agencies pursuing energy recovery projects at dairies or landfills better estimate greenhouse gas and air quality impacts of the projects. Research will also provide baseline emissions from RNG projects, which currently have not been established.

Project 2: Fostering Natural Gas Sector Resilience

The Issue

California's climate leadership includes integrating climate adaptation into planning and investment decision-making, "ensuring that people, communities, and natural systems are able to withstand the impacts of climate disruption."[62] To support adaptation efforts, the California Energy Commission has been a leader in funding research that develops regionally specific climate scenarios with high spatial and temporal resolution for several parameters for the energy system. These scenarios have been adopted as a basis for adaptation planning by the state[63] and made publicly available through Cal-

[61] Duren, Riley. Personal communication. NASA.

[62] http://resources.ca.gov/climate/safeguarding/.

[63] *Planning and Investing for a Resilient California: A Guidebook for State Agencies* (2017). Prepared by the Governor's Office of Planning and Research with the guidance and input of the Technical Advisory

Adapt (cal-adapt.org), an interactive website tailored to conveying climate-related risks in a manner that supports energy sector resilience.

For several years, the state of California has been working to foster energy sector resilience through such efforts as including a climate adaptation chapter in *the Integrated Energy Policy Report* (IEPR), establishing an Energy Sector Adaptation Working Group headed by Commissioner Liane Randolph of the CPUC and Chair Robert B. Weisenmiller of the Energy Commission, and initiating outreach efforts associated with Cal-Adapt.

More recently, the *2017 IEPR* recommended to "explore establishing a California Partnership for Energy Sector Climate Resilience." This partnership, as articulated by SoCalGas, would recognize that "every region of California must be considered and engaged" for the state's resilience efforts to be successful and cost-effective. The *2017 IEPR* also recommended consideration of climate resilience metrics to help track California's resilience action and successes.

Another outcome of multiple Energy Commission workshops held in 2017 was repeated indication by investor-owned utilities (IOUs) that they must be involved in identifying and designing research efforts to provide resilience strategies for their energy systems. This level of involvement requires collaboration before the release of requests for proposals.

The Research

Energy sector resilience is a young and rapidly evolving field, and little is known regarding best practices for designing, implementing, or tracking the success of natural gas resilience strategies. The overarching goal of this research is to provide a scientifically sound basis for designing, implementing, and tracking natural gas resilience strategies. Moreover, this research will ideally provide a test case of close collaboration with IOUs to develop research and actions. California's natural gas IOUs are invited to collaborate in developing a call for proposals, to ensure the funded research is responsive to their needs and concerns. The research would provide crucial support to the California Partnership for Energy Sector Climate Resilience.

Based on input from IOUs voiced in public Energy Commission workshops in 2017, specific research goals might include some or all of the following:

- Developing metrics to assess and track progress in natural gas system resilience.
- Identifying what scenarios, including but not limited to extreme events that are most important for stress-testing the natural gas system, with attention to

Group formed under direction of Executive Order B-30-15. http://opr.ca.gov/planning/icarp/resilient-ca.html.

infrastructure as well as operational considerations and interconnectedness with other critical systems.

- Developing methods for integrating resilience investments into cost-benefit analyses.
- Conducting potential case studies to pilot test methods.

The Benefits

- **Energy Sector.** This research will benefit natural gas IOUs and other natural gas sector representatives by providing, in response to their input, determining extreme events relevant to the natural gas sector as well as system hot spots in the context of climate-related risks. This information may be used to guide adaptation planning in the natural gas sector.

Natural Gas-Related Transportation

California's transportation sector is vital to the state's economy; the freight transportation system is responsible for one-third of the state's economic product and jobs.[64] However, transportation is also responsible for the majority of the state's environmental concerns. The transportation sector accounts directly for 39 percent of GHG emissions and 80 percent of NOx 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 deployment of low-emission technologies is necessary to meet current and future clean air standards. It is paramount to develop and deploy commercially viable technologies that meet the state's sustainability goals while increasing freight transportation efficiency and competitiveness.

When used as an alternative transportation fuel to diesel, natural gas can reduce petroleum dependency, greenhouse gas emissions, local air pollution, and operating costs for businesses and consumers. Because of the characteristics of natural gas fuel, natural gas vehicles face unique market barriers. The *2015 Natural Gas Vehicle Research Roadmap*[65] identifies these barriers, which include but are not limited to, vehicle and engine performance and availability, emissions and environmental performance, storage and infrastructure limitations, and data analysis and information sharing.

The Energy Commission funds natural gas-related transportation research to address these market barriers and continuously advance the science in natural gas vehicle

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[64] *California Sustainable Freight Action Plan*. July 2016. http://www.casustainablefreight.org/documents/PlanElements/Main%20Document_FINAL_07272016.pdf.

[65] 2015 Natural Gas Vehicle Research Roadmap. Schroeder, Alex. October 2016. http://www.energy.ca.gov/2015publications/CEC-500-2015-091/CEC-500-2015-091-CMF.pdf.

technology to reduce emissions beyond applicable standards. Previous work includes developing near-zero NO_x engines, which subsequently led to the successful commercialization of several engines certified at CARB's optional low-NOx standards. The Energy Commission has funded research on a variety of technologies to increase 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 Energy Commission has also funded research on natural gas off-road vehicles to expand the air quality benefits of natural gas to another highly polluting mobile sector. Future research proposed this year includes engine development to fill gaps in availability and engine research to meet long-term efficiency and emissions goals.

The Energy Commission's transportation research area contains a vast portfolio of projects that continuously builds on knowledge gained from previous efforts. For example, hybridization was initially sought for efficiency benefits, but emission tradeoffs were less understood. As a result, research focusing on systems optimization was pursued to better understand the benefits of holistic hybrid design with a shared focus on efficiency and emission improvements. The continuous advancement of natural gas vehicles is a promising approach to help address California's clean transportation goals.

The proposed budged for Natural Gas-Related Transportation is $4 million (Table 6).

Table 6: FY 2018-19 Proposed Natural Gas Research Budget Plan Summary – Natural Gas Related – Transportation

Program Area – Natural Gas Related-Transportation	Proposed Budget
Proposed Research Initiatives: • Develop High Efficiency, Low Emission, Production-Ready Heavy-Duty Natural Gas Engines for Long Haul Applications • Research Natural Gas Compression Ignition to Achieve Comparable Performance to Diesel	$4,000,000

Source: California Energy Commission

Natural Gas-Related Transportation 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 to improve air quality.
- 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 gas vehicles.

Proposed Research Initiatives: Natural Gas-Related Transportation

Project 1: Develop High Efficiency, Low Emission, Production-Ready Heavy-Duty Natural Gas Engines for Long Haul Applications

The Issue

SB 1383 identifies short-lived climate pollutant (SLCP) reduction targets, including a 40 percent reduction of methane by 2030.[66] *The 2017 Integrated Energy Policy Report (IEPR)* identifies renewable natural gas use in medium- and heavy-duty vehicles as an important and cost-effective strategy for improving air quality and reducing methane emissions.[67] The further growth of natural gas vehicles (NGVs) is a critical economic downstream driver for collecting and distributing California's available biomethane resources. When combining the benefits of renewable natural gas with ultra-low nitrogen oxide (NO_x) engines, NGVs represent a sustainable long-term solution to achieving both greenhouse gas and criteria pollutant emission reductions. Replacing diesel trucks with low NOx NGVs can improve air quality in California's high-volume freight corridors and the surrounding disadvantaged communities.

The largest newly certified and commercially available on-road natural gas engine in the North American market is the Cummins Westport ISX12N. However, the 12-liter engine is available only up to 400 horsepower (hp) with a peak torque of 1450 lb-ft, potentially limiting the applications of the engines. In the past, engine development for 15-liter natural gas engines was placed on hold due to the uncertainty of long-haul market acceptance at the time.[68] The *2015 Natural Gas Vehicle Research Roadmap* identifies

[66] California Air Resources Board. March 2017. *Short-Lived Climate Pollutant Reduction Strategy*. https://www.arb.ca.gov/cc/shortlived/meetings/03142017/final_slcp_report.pdf.

[67] California Energy Commission. October 2017. *Draft 2017 Integrated Energy Policy Report*. http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-01/TN221520_20171016T153945_Draft_2017_Integrated_Energy_Policy_Report.pdf.

[68] Berg, Tom. Work 'Paused' on Cummins Natural Gas Engine. January 2014. http://www.truckinginfo.com/channel/fuel-smarts/news/story/2014/01/work-paused-on-isx15-gas-due-to-market-timing-uncertainty-cummins-says.aspx.

the gap in availability for engines larger than 12-liters because of these paused efforts.[69]

Natural gas fueling infrastructure continues to expand steadily with a 50 percent national increase in the number of compressed natural gas (CNG) stations between 2012 and 2016.[70] The release of the near-zero-NO_x 12-liter engine is expected to further catalyze infrastructure development and market maturity. In addition, the *2017 IEPR Transportation Energy Demand Forecast* projects more than 300 percent growth in natural gas truck stock by 2030.[71] With the expectation of NGV market growth in parallel with the growing availability of renewable natural gas, larger natural gas engines must be developed to encourage adoption of the fuel by the long haul trucking market.

The Research

This research integrates applicable high TRL technologies with heavy-duty on-road natural gas engines to fill the gap in availability for engines larger than 12 liters. The research will build on previous transportation research on engine efficiency improvements to develop production-ready prototype engines that exhibit high-efficiency, near-zero emissions, and manufacturability. Projects will coordinate technology providers with engine manufacturers to ensure a robust supply chain for the delivery of commercial products. As with previous Energy Commission-funded engine development projects, there is potential for the Alternative and Renewable Fuels and Vehicle Technology Program (ARFVTP) and other programs to collaboratively fund vehicle demonstration and deployment of engines developed through this research.

The Benefits

- **Energy Sector.** As of 2016, the total natural gas demand for California's transportation sector is roughly 170 million gasoline gallon equivalents (GGEs) annually. In a mid-case scenario, the *2017 IEPR* estimates a steady increase of natural gas demand for transportation to 200 million GGEs by 2020 and 340 million GGEs by 2030 with significant adoption of the fuel for heavy-duty trucks.[72] Large-scale adoption in the long-haul trucking sector can further

[69] Schroeder, Alex. 2015 Natural Gas Vehicle Research Roadmap. October 2016. http://www.energy.ca.gov/2015publications/CEC-500-2015-091/CEC-500-2015-091-CMF.pdf.

[70] Stations. NGVAmerica.org. Natural Gas Vehicles for America. http://www.ngvamerica.org/stations/.

[71] California Energy Commission. Transportation Energy Demand Forecast, 2018-2030. December 2017. http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-05/TN221893_20171204T085928_Transportation_Energy_Demand_Forecast_20182030.pdf.

[72] Ibid.

displace diesel fuel consumption and encourage the use of domestic renewable natural gas.

- **Technology Potential.** This research focuses on the integration of high-TRL engine efficiency and low-emission technologies with natural gas engines suitable for long-haul trucks. This research is critical to bridging innovative technology providers with engine original equipment manufacturers (OEMs) to deliver production-ready engines.
- **Market Connection.** Although this initiative targets mainly the long haul trucking market other vehicle applications that require additional power and torque may also be targeted by this initiative. Engine development programs typically require around three years of engine prototyping, optimization, and vehicle demonstration to produce a commercial product.
- **Energy and Cost Savings**. The long-haul sector places high value on efficiency and the reduction of operating costs. This research focuses on adopting high TRL engine efficiency technologies that will result in lower GHG emissions and fuel cost savings.
- **Environmental Benefits.** California will benefit from expanded NGV adoption and replacement of diesel long haul trucks due to lower criteria pollutants and reduced greenhouse gas emissions. Targeting the high-fuel-consuming long-haul sector can provide substantial demand for renewable natural gas production and the capture of California's biomethane resources.

Project 2: Research Natural Gas Compression Ignition to Achieve Comparable Performance to Diesel

The Issue

Fuel efficiency deficits of 10 to 20 percent (depending on application and duty cycle) compared to diesel continue to limit the economic and environmental benefits of natural gas as a transportation fuel. A recent study by Argonne National Laboratory evaluated the well-to-wheels environmental implications of natural gas as a transportation fuel. The study identified vehicle fuel efficiency along with methane leakage rates in the natural gas supply chain as the major drivers to the relative GHG emission performance of NGVs.[73] Efficiency losses from spark-ignited stoichiometric natural gas engines stem from throttling, compression ratio limitations, and difficulties with dilute combustion.

Designing an internal combustion engine that combines the attributes of Otto and Diesel engines has long been an engineering goal for engine manufacturers. Recent developments such as Mazda's plan to release a spark-controlled compression ignition gasoline engine in 2019 indicate increasing technology maturity. The technology has

[73] Cai, H., Burnham, A., Chen, R., Wang, M. Wells to wheels: Environmental implications of natural gas as a transportation fuel. Energy Policy 109, 565-578. 2017. http://dx.doi.org/10.1016/j.enpol.2017.07.041

the potential to deliver up to 30 percent higher fuel efficiency, diesel-like low-speed torque, and ultra-low emissions.[74] Natural gas engines share similar characteristics to gasoline engines therefore, they have the potential to demonstrate similar benefits through the use of compression ignition.

The *2015 Natural Gas Vehicle Research Roadmap* identifies natural gas compression ignition engine research as a long-term goal for achieving future performance and emission targets.75 Previous Natural Gas R&D Program efforts have concentrated on efficiency improvements in spark-ignited natural gas engines based on a need for near-term commercialization. Near-term and long-term solutions must be considered to ensure continued advancement of natural gas engine technology.

Additional research is required to test innovative engine designs and verify the benefits of natural gas compression ignition to lay the foundation for the potential commercialization in the NGV market.

The Research

This initiative proposes research to demonstrate the viability of natural gas compression ignition engines. Projects will focus on engine-level R&D with some potential for validation through vehicle demonstration. The research will need to address issues related to natural gas compression ignition such as engine knock, misfires, fuel quality sensitivity, operating range, and controllability.

Potential projects include, but are not limited to:

- Testing high-pressure direct injection using a non-diesel pilot fuel such as dimethyl ether to achieve diesel-like efficiency and performance while minimizing particulate matter and NOx emissions.
- Researching homogenous charge compression ignition for natural gas engines. Focus on controls development and extending the range of compression ignition operation.
- Demonstrating the benefits of reactivity controlled compression ignition using natural gas in combination with a high-cetane pilot fuel.

Projects will aim to achieve performance and efficiency comparable to diesel in addition to low NOx and particulate matter emissions comparable to spark-ignited natural gas engines. Due to the high thermal efficiency potential of this approach, advanced after treatment technologies may be needed with the capability to perform under lower exhaust temperatures. Projects must be cognizant of potential paths to

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[74] Skyactiv-X Next-Generation Gasoline Engine. October 2017. https://insidemazda.mazdausa.com/press-release/mazda-next-generation-technology-press-information/

[75] Ibid.

commercialization and reduce dependency on system complexity or high cost components where possible.

The Benefits

- **Energy Sector.** This research will support continued progress in efficiency improvements for natural gas engines. Closing the gap between NGVs and diesel vehicles will provide energy security and air quality benefits to California's transportation sector by reducing reliance on petroleum fuels.
- **Technology Potential.** This research focuses on advancing low to mid TRL technologies with a long-term goal of using in commercial heavy-duty natural gas engines.
- **Market Connection.** This initiative targets primarily the heavy-duty natural gas truck market. The time to market is expected to parallel similar work done with gasoline compression ignition engines. Depending on project results and manufacturer acceptance, the technology may reach commercialization in five years.
- **Energy and Cost Savings.** Operating costs and capital payback times will be reduced with increased engine efficiency. Research must lead to cost-effective opportunities to support commercialization.
- **Environmental Benefits.** Increased engine efficiency directly results in GHG emission reductions due to lower fuel consumption. Compression ignition technologies have the potential to deliver efficiency benefits of up to 30 percent.[76] This initiative will address challenges in maintaining low criteria pollutant emissions (specifically NO_x) while achieving diesel-like performance in a natural gas compression ignition engine.

[76] Ibid.

LIST OF ACRONYMS

Term	Definition
CARB	California Air Resources Board
BTU	British thermal unit
CHP	combined heat and power
CNG	compressed natural gas
CO_2	carbon dioxide
CPUC	California Public Utilities Commission
DG	distributed generation
GGEs	gasoline gallon equivalents
GHG	greenhouse gas
HVAC	heating, ventilation, and air-conditioning
IEPR	*Integrated Energy Policy Report*
IOUs	investor-owned utilities
MW	megawatts
NAAQS	National Ambient Air Quality Standards
NO_x	nitrogen oxides
NGV	natural gas vehicle
ORNL	Oak Ridge National Laboratory
PG&E	Pacific Gas and Electric Co.
PHMSA	Pipeline and Hazardous Materials Safety Administration
PRCI	Pipeline Research Council International
R&D	Energy Commission's Research and Development Division
SCADA	Supervisory Control and Data Acquisition
SoCal Gas	Southern California Gas Company
WHP	waste heat to power
ZNE	zero –net energy

APPENDICES

Appendix A: Presentation from January 25, 2018 Staff Workshop to Discuss Proposed FY 2018-19 Natural Gas Research Initiatives, and Appendix B: Questions and Answers from January 25, 2018 Staff Workshop to Discuss Proposed FY 2018-19 Natural Gas Research Initiatives are available under separate cover (Publication Number CEC-500-2018-006-APA-B) by contacting Tiffany Solorio at Tiffany.Solorio@energy.ca.gov.