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STAFF REPORT

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2017 Annual Report

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PREFACE

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

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

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

The *Natural Gas Research and Development Program 2017 Annual Report* is a staff report prepared by the Energy Commission's Energy Research and Development Division.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

In 2000, Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) was enacted, requiring the California Public Utilities Commission (CPUC) to impose a surcharge on natural gas consumed in California. These monies funded various energy efficiency programs and public interest research and development to benefit natural gas ratepayers. AB 1002 also required the CPUC to designate an entity to administer the research component of AB 1002. In 2004, the CPUC issued Decision 04-08-010, designating the California Energy Commission as the research fund administrator.

The *Natural Gas Research and Development Program 2017 Annual Report* highlights project successes and benefits, and covers results of completed projects and the progress of current research from July 1, 2016, through June 30, 2017. In fiscal year 2016-2017, the California Energy Commission administered $24 million in natural gas research, development, and demonstration projects geared toward improving energy efficiency, renewable energy, advanced generation, and energy infrastructure for natural gas in California

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

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

EXECUTIVE SUMMARY

About 40 percent of the state's natural gas is used to generate electricity; the remainder is used primarily in industrial processes or by the residential and commercial sectors for space and water heating and cooking. California's successful efficiency programs and its reliance on renewable energy sources for electricity have slowed the demand for natural gas. Competition for the state's imported supply, however, is increasing. Although the primary fuels for transportation continue to be oil-based, some transportation technologies — such as natural gas-fueled vehicles — are adding to California's natural gas demand.

Natural gas-related energy research benefits California's economy, environment, and ratepayers by developing technologies, tools, and methods that increase energy efficiency, reduce pollution and greenhouse gas (GHG) emissions, and increase public safety. Consistent with its statutory purpose, the California Energy Commission acts on behalf of the California Public Utilities Commission (CPUC) and the people of California when awarding public interest energy research program funding to California researchers. These researchers include small businesses, universities, California-based national laboratories, utilities, energy companies, and private research organizations. The Energy Commission's transparent, competitive solicitation process maximizes the value of the natural gas research and development program.

The Energy Commission supports research to better understand how the role of natural gas should evolve in the state's energy system. Increasingly, these research and development (R&D) efforts focus on "what is the future of natural gas?" While a consensus remains elusive, it is clear on-going research is required to better define the future role of natural gas, including renewable gas. This research includes ensuring natural gas is used as cleanly and efficiently as possible, fostering the role of natural gas as a low-emission transportation fuel and improving biogas and hydrogen technologies to promote de-carbonization. This natural gas research and development program also includes projects to improve efficiency, reduce leakages and support the safety of the natural gas infrastructure. The research described in Chapter 1 highlights the ways the Energy Commission is advancing the state of natural gas-related science and technology to inform developing state energy goals and supports the future role of natural gas in California's diverse energy system.

Natural gas is often referred to as a "bridge fuel," serving as a transition in California's energy system between the current energy mix and a 100 percent renewable energy future. Natural gas-fueled power plants and vehicles produce significantly less criteria pollutant and carbon emissions compared to dirtier fossil fuels such as coal or oil. Increased natural gas use in the energy system has already significantly contributed to California's short-term GHG reduction goals.

Visionary mandates and goals to reduce GHG emissions in California, such as reducing GHG emissions by 2050 to 80 percent below 1990 levels will have long-term

implications on the use of natural gas in California. Even with a lower carbon content of natural gas in comparison with other fuels, these ambitious mandates and goals suggest natural gas consumption in California should decline. The Energy Commission is funding research that explores how natural gas can be decarbonized as well as used more efficiently to support efforts to achieve these goals. Increasing energy efficiency and lowering methane emissions associated with the natural gas system will assist in the transition. In the near term, it may be desirable to use natural gas as a fuel for certain applications, such as heavy duty vehicles, where air quality benefits can be realized as California continues its transition towards near-zero emission strategies but care should be taken to avoid creating future stranded assets.

Successes and benefits of Energy Commission natural gas research investments include tangible technology advancements and improvements that will help California meet its energy policy and emission reduction goals. For example, the Energy Commission research portfolio has resulted in developing and commercializing three near-zero emission engines that can be used in a variety of heavy-duty vehicles, including school buses, transit buses, beverage delivery, waste haulers, and drayage trucks. These engines have spurred transformation in the heavy-duty market, particularly in transit. California transit authorities such as Los Angeles Metro and Orange County Transportation Authority are aggressively replacing their existing engines with the newly available near-zero emission engines.

Significant near-term air quality benefits are achievable; it would take 200 buses equipped with the near-zero engine to produce emissions equivalent to a single 2000 model year bus. The buses operate in and around disadvantaged communities, which typically have higher rates of asthma and other health conditions related to air pollution. Broad adoption throughout the heavy-duty vehicle sector will improve air quality in the regions near ports and goods movement corridors. Adopting this clean technology will be accelerated as legacy engines are phased out by the engine manufacturer in favor of offering only the near-zero emission engines. Supporting development of emerging, close-to-market and commercially ready technologies like these advanced, near-zero emission natural gas engines will serve an instrumental role in reaching emission reduction goals.

The Energy Commission's research portfolio also includes critical studies to better characterize emissions from the natural gas system and other sources in the built environment. Research supported by the Energy Commission measured methane emissions from all the underground natural gas storage units in California. Though emissions can vary significantly from location to location, or even temporally at the same location, overall, storage facility emissions were found to be generally in agreement with official inventories. Measurements also identified oil refineries as significant contributors of methane emissions since refineries consume enormous amounts of natural gas.

Researchers also found that total methane emissions in the San Francisco Bay Area are equivalent to up to 0.5 percent of natural gas consumption, which is almost double the amount reported in the GHG inventory developed by the Bay Area Air Quality Management District. This does not take into account methane emissions from production basins. Natural gas wells are generally the main source of emissions from the natural gas sector. The research is part of a larger portfolio to quantify emissions from homes, buildings, industry, abandoned wells, and other parts of the natural gas system. A joint study supported by the Energy Commission and the California Air Resources Board (CARB) with NASA's Jet Propulsion Laboratory is using a research airplane with sophisticated cameras that can "see" large methane plumes. This study is identifying large point sources of methane in California.

Energy efficiency research focuses on how to increase the e efficiency of natural gas use to reduce GHG emissions while also being affordable. The University of California Berkeley's Institute of Governmental Studies conducted a recent poll showing nearly half of the state's registered voters indicate that housing affordability is an "extremely serious" problem in California. To meet demand, from market rate to low-income housing, California must double the housing it currently has for this sector. One possible solution is manufactured homes. Manufactured homes, or mobile homes, are built off-site in a factory on a non-removable steel chassis. A recently completed research project developed advanced envelope designs that would substantially improve efficiency with a minimal first-cost increase, estimated at $2,700. The project also engaged key industry stakeholders so the new construction methods from this project could be standard practice in California within five years. By installing state of the art wall and roof insulation to reduce heating and cooling costs, the energy bills of gas-heated homes can be reduced up to 48 percent in mobile homes. These savings mean that homeowners will have more money to spend on other areas besides energy, adding to the affordability of these units.

Because the majority of California's building stock was built before the energy code was adopted, identifying strategies to cost-effectively increase the efficiency of existing buildings is important, especially for the low income, multifamily sector. A recently completed research project focused on a strategy to develop scalable zero energy retrofits for low-income multifamily housing. The project developed practical energy efficiency retrofit packages that integrated energy efficient technologies with renewables such as solar photovoltaic and solar thermal for water heating.

The installed efficiency improvements to the building envelope (e.g., insulation and air sealing), installing smart thermostats and solar water heating, improvements to the ducts and hot water distribution systems and installing LED lighting were effective in delivering energy savings to the residents. For instance, installing the solar water heating and improvements to the hot water distribution systems resulted in a 70 percent reduction in gas use for water heating, and installing envelope and duct improvements and new thermostats contributed to a 34 percent reduction for space

heating and 22 percent reduction in electricity used for space cooling. Overall, the annual net reduction in natural gas use from these combined energy efficiency measures equals about 144 therms per apartment. There were also substantial non-energy benefits for occupants and tenants, such as improved indoor temperature and humidity control resulting in greater comfort in the retrofitted apartments. These resulted in improvements in quality of life for occupants and can be a key benefit of energy efficiency upgrades.

Research and demonstrations completed through the Natural Gas Research and Development Program can help develop commercially viable, affordable state-of-the-art natural gas technologies that benefit natural gas ratepayers. Targeted demonstrations in disadvantaged communities will increase accessibility of clean and efficient technologies, resulting in reduced utility costs and emissions. Innovative research to advance California's natural gas system ensures energy security and safety, improves quality of life, and supports efforts to achieve a sustainable low-carbon energy system.

Program Status

CPUC Resolution G-3519 approved the Energy Commission's FY 2016-17 budget plan and emphasized R&D areas supporting long-term infrastructure reliability, highlighted the long-term role and impact of natural gas in a carbon-constrained context, and reflected recent legislative guidance requiring additional studies with the California Council on Science and Technology.

In FY 2016-17, the Energy Commission awarded Natural Gas R&D funds to 28 projects, encumbering $29.1 million. Since 2004, the Energy Commission has been the R&D administrator of the Natural Gas R&D program with oversight by the CPUC, funding 237 projects totaling $216.6 million through June 30, 2017.

This *Natural Gas Research and Development Program 2017 Annual Report* describes the natural gas research, development, and demonstration program and highlights projects from July 1, 2016, to June 30, 2017. Projects funded by the Energy Commission are consistent with the annual budget plans and policy objectives approved by the CPUC. This includes submission by October 31st of each fiscal year, an annual report detailing the research, development, and demonstration activities approved in each budget plan. All new awards are listed in Appendix A and all completed projects are listed in Appendix B. Appendix C provides project write-ups for active and completed projects for FY 2016.

CHAPTER 1:
Introduction and Program Overview

The Role of Natural Gas Research and Development

California relies on natural gas to meet many of its energy demands, including space and water heating, cooking, industrial processes, natural gas vehicles, and power plants. About 90 percent of California's natural gas supplies come from the southwestern United States, the Rocky Mountains, and Canada. [1] The remaining 10 percent is produced in-state, onshore, and offshore. The safe and efficient production, transportation, and use of this energy resource are critical to California's economy, social vitality, environment, and clean energy future.

Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) recognized natural gas as a vital energy resource for California and directed the California Public Utilities Commission (CPUC) to impose a surcharge on all natural gas consumed in California. This surcharge funds a range of public interest research and development (R&D) activities in energy efficiency, renewable energy and advanced generation, and energy infrastructure. These activities advance science and develop technologies to increase natural gas end-use efficiencies, improve reliability, and reduce environmental impacts that are not adequately addressed by competitive or regulated entities. The California Energy Commission has administered natural gas R&D in the public interest since 2004. The program was updated by Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006), changing how the natural gas research funds are encumbered and managed.

The CPUC established the Energy Commission's Natural Gas R&D projects must[2]:

- Focus on energy efficiency, renewable technologies, conservation, and environmental issues.
- Support state energy policy.
- Offer a reasonable probability of providing benefits to the general public.
- Consider opportunities for collaboration and co-funding with other entities.

The *Natural Gas Research and Development Program 2017 Annual Report* covers the progress and status of Energy Commission activities funded by Natural Gas R&D from

1 2015 Natural Gas Outlook Draft Staff Report. California Energy Commission. CEC-200-2015-007-SD.

2 CPUC Decision (D.) 04-08-010, issued August 19, 2004

July 1, 2016 through June 30, 2017 (fiscal year 2016-2017) This report was prepared according to the requirements in the CPUC Decision 04-08-010.[3]

Policy

Natural Gas Research Meets Policy Objectives

As California's primary energy policy agency, the Energy Commission prepares the state's guiding energy policy document, the *Integrated Energy Policy Report (IEPR)*. Working closely with numerous energy-related state and local agencies and stakeholders for input and support, the *IEPR* evaluates overall supply and demand trends for electricity, natural gas, and transportation fuels in California. These trends include issues associated with energy infrastructure, efficiency, reliability, and cost. This comprehensive plan ensures all parties use consistent information to develop energy policy decisions affecting the state. Based on these assessments, the *IEPR* recommends energy policies to the Governor, including that California must continue to fund cutting-edge research, development, and demonstrations to produce the next generation of clean energy technologies necessary to achieve the policy objectives. The Energy Commission funds natural gas research across a broad spectrum of areas, focused on efficiency, renewable energy, advanced generation, pipeline integrity, transportation technologies, and natural gas-related environmental research (such as reducing methane emissions from the natural gas system).

The Energy Commission's investments also adhere to statutory direction and the state's energy policies. For example, energy efficiency research projects address several state policies and goals, including the CPUC's *Energy Efficiency Strategic Plan,* Governor Edmund G. Brown Jr's *Clean Energy Jobs Plan,* and Assembly Bill 758 (Skinner, Chapter 470, Statutes of 2009), which increases energy efficiency in existing buildings.

Renewable energy research investigates clean alternatives to conventional natural gas resources to bring the most promising technologies to the marketplace. These research projects address several renewable energy generation and greenhouse gas reduction goals, including Assembly Bill 32—the Global Warming Solutions Act of 2006 (Núñez, Chapter 488, Statutes of 2006)—and the California's Renewables Portfolio Standard (as mandated by Senate Bill 1078 [Sher, Chapter 516, Statutes of 2002] and Senate Bill 107 [Simitian, Chapter 464, Statutes of 2006])—and Senate Bill 32 [Pavley, Chapter 249, Statutes of 2016]. These bills and the targets they establish are among the most progressive in the United States. These standards were expanded by Senate Bill X1-2 (Simitian, Chapter 1, Statutes of 2011, First Extraordinary Session), which targets 33 percent of electricity generation be provided by renewable resources by 2020. Senate Bill 350—the Clean Energy and Pollution Reduction Act of 2015 (De León, Statutes of

3 California Public Utilities Commission, Decision 04-08-010 (August, 19, 2004), http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/39314.PDF.

2015) was chaptered establishing a new California target to increase the percentage of the state's renewable electricity sources from one-third to 50 percent and achieve a doubling of statewide energy efficiency savings in electricity and natural gas by 2030.

Research Informs State Energy Policy

The Energy Commission's Natural Gas R&D work fills a critical role. Frequently, the results of this work are incorporated into the state's energy efficiency policies and standards. For example, Energy Commission research provided the justification that led to natural gas pipe insulation requirements for the 2013 Residential Building Energy Efficiency *Standards.*[4] These requirements were adopted by the Energy Commission in May 2012 and took effect January 1, 2014. This change will save California ratepayers an estimated 8.2 million therms per year over a six-year period and reduce ratepayer bills by about $7.9 million every year. Additional benefits include improved air quality (reduced GHG emissions), water use, and safety risk. Numerous projects, including those highlighted in this report, provide lasting benefits to California's economy and natural gas ratepayers.

The Energy Commission's funding decisions are designed to meet energy policy goals and standards while maintaining safety and reliability (Table 1).

Table 1: Select Policy Goals for California's Energy Future

Policy or Standard	Goal
Governor Brown's *Clean Energy Jobs Plan* (2011)	California should produce 20,000 new megawatts (MW) of renewable electricity by 2020, 12,000 MW of distributed energy, 8,000 MW of large-scale renewables, and 6,500 MW from combined heat and power (CHP).
Governor's Aliso Canyon Gas Leak Proclamation (2016)	The order directs further action to protect public health and safety, ensure accountability and strengthen oversight of gas storage facilities.
Executive Order B-18-12 – Greening State Buildings	Calls for efficiency improvements in new or renovated state buildings larger than 10,000 square feet; sets zero-net-energy (ZNE) and GHG emission reduction goals.

4 *2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings* (May 2012) http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf.

Policy or Standard	Goal
Executive Order B-32-15 Integrated Action Plan	Directs improvement of freight efficiency, transition to zero-emission technologies, and increase competitiveness of California's freight system.
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 GHG Reduction Target and Climate Adaptation and Senate Bill 32 (2016)	Sets a GHG reduction target of 40 percent below 1990 levels by 2030.
Senate Bill 32 (2016) − The California Global Warming Solutions Act	Requires the state to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030.
Bioenergy Action Plan to implement Executive Order S-06-06	Set goals for the production and use of electricity and fuels made from biomass.
Executive Order S-01-07 Low Carbon Fuel Standard (LCFS)	Sets goal to reduce carbon intensity of the state's fuels by 10 percent by 2020.
Assembly Bill 1613 (2007)	The Waste Heat and Carbon Emission Reduction Act mandates that California policies advance the efficiency of the state's use of natural gas by using excess waste heat through CHP technologies.
AB 1900 (2012)	Develop standards for constituents in biogas to protect human health and pipeline integrity and safety
Senate Bill 350 (2015)	The Clean Energy and Pollution Reduction Act of 2015 (De León, Statutes of 2015),— which establishes a California target to increase the percentage of the state's renewable electricity sources from one-third to 50 percent and achieve a doubling of statewide energy efficiency savings in electricity and natural gas for customers by 2030

Policy or Standard	Goal
Senate Bill 1383 (2016)	Drives reductions in short-lived climate pollutants and promotes renewable gas by requiring a 50 percent reduction in black carbon and 40 percent reduction in methane and hydrofluorocarbon from 2013 levels by 2030.
Senate Bill X1 2 (2011) – The Renewables Portfolio Standard	Requires all electricity retailers to meet 33 percent of their retail sales with renewable energy by 2020.
Senate Bill 1250 (2006)	Provisions for specified entities to fund cost-effective energy efficiency and conservation activities and public interest research and development not adequately provided by the competitive and regulated markets.
Public Resources Code 25620	Public interest energy research, demonstration, and development projects should advance energy science or technologies of value to California citizens.
Integrated Energy Policy Report	The Energy Commission's biennial energy forecasting and assessment report recommends policies to foster the development of energy efficiency, renewable energy, and more.
CPUC *Energy Efficiency Strategic Plan*	Sets efficiency goals, including zero-net-energy goals for new homes by 2020 and for new commercial buildings by 2030.
California's Loading Order, from the California *Energy Action Plan*	Prioritizes Energy Commission's research investments: 1) energy efficiency and demand response, 2) renewable energy and distributed generation, and 3) clean fossil fuel sources and infrastructure improvements.

Policy or Standard	Goal
Natural Gas: Leakage Abatement. SB 1371 (2014)	SB 1371, Leno. Natural Gas: Leakage Abatement—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.

Source: California Energy Commission staff

Natural Gas Research Budget Plan – Developing the Research Portfolio

The Energy Commission is committed to developing its research portfolios through meaningful engagement with stakeholders. Collaborating with a broad variety of California stakeholders is a critical element for defining continued innovation in energy research. 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, increase adoption of research results, and ensure the research portfolio provides benefits to the state's natural gas ratepayers

The Energy Commission is supporting research to better understand how the role of natural gas should evolve in the state's energy system. Increasingly, these R&D efforts focus on "what is the future of natural gas?" While a consensus on this question remains elusive, it is clear on-going research is required to better define the future role of natural gas, including renewable gas. This research includes ensuring natural gas is used as cleanly and efficiently as possible, fostering the role of natural gas as a low-emission transportation fuel and improving biogas and hydrogen technologies to promote de-carbonization. This natural gas research and development program also includes projects to improve efficiency, reduce leakages and support the safety of the natural gas infrastructure. The research described in Chapter 1 highlights the ways that the Energy Commission is advancing the state of natural gas-related science and technology to inform development of state energy goals and support the future role of natural gas in California's diverse energy system.

Natural gas is often referred to as a "bridge fuel," serving as a transition in California's energy system between the current energy mix and a 100 percent renewable energy future. Natural gas-fueled power plants and vehicles produce significantly less criteria pollutant and carbon emissions compared to dirtier fossil fuels such as coal or oil. Increased natural gas use in the energy system has already significantly contributed to California's short-term GHG reduction goals.

Visionary mandates and goals to reduce GHG emissions in California, such as reducing GHG emissions by 2050 to 80 percent below 1990 levels will have long-term implications from using natural gas in California. Even with a lower carbon content of natural gas in comparison with other fuels, these ambitious mandates and goals suggest natural gas consumption in California should decline. The Energy Commission is funding research that explores how natural gas can be decarbonized and used more efficiently to support efforts to achieve these goals. Increasing energy efficiency and lowering methane emissions associated with the natural gas system will assist in the transition. In the near term, it may be desirable to use natural gas as a fuel for certain applications, such as heavy duty vehicles, where air quality benefits can be realized as California continues its transition towards near-zero emission strategies but care should be taken to avoid creating future stranded assets.

Authorized Budget

Budget Plan Summary

In March 2016, the Energy Commission submitted to the CPUC *the Natural Gas Research, Development, and Demonstration Proposed Program Plan and Funding Request for Fiscal Year 2016-17*. This plan established the direction and budget for natural gas R&D for the 2016-17 fiscal year. The CPUC approved the plan in June 2016 and authorized the Energy Commission to administer $24 million for Natural Gas R&D projects during a two-year funding period. After the two-year encumbrance cycle, the agreements have a four year liquidation period with activities completed within the six year cycle. The Energy Commission expects to encumber all funds for new awards by June 30, 2018 (Table 2). Administration expenses for FY 2016-2017 were allocated for program staffing and technical support. The Energy Commission has 14 staff positions funded with natural gas funds.

FY 2015-16 Supplemental Climate, Drought and Safety Budget Plan

In December 2015, the CPUC approved the *Climate, Drought and Safety Natural Gas Budget Plan*[5] as a supplement to the *Natural Gas Research, Development, and Demonstration Program, Proposed Program Plan and Funding Request for Fiscal Year 2015-2016*. The supplemental plan identifies $3.6 million in previously authorized, but unspent, funds to be invested in research supporting pipeline safety, drought, and climate change-related impacts on the natural gas system, and the role of natural gas in a carbon-constrained, water-efficient environment. The Energy Commission received a one-time expenditure authority of $3.6 million in the FY 2016-17 state's Budget Act to fund additional natural gas research project awards in these areas (Table 3).

5 CPUC Resolution G-3513,
http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M156/K211/156211249.PDF

Table 2: FY 2016-17 Natural Gas R&D Budget Plan Summary

Research Areas	Approved Budget
Energy Efficiency	**$7,100,000**
Buildings End-Use Energy Efficiency	$0
Industrial, Agriculture, and Water Efficiency (1)	$7,100,000
Renewable Energy and Advanced Generation	**$4,400,000**
Energy Infrastructure	**$6,600,000**
Natural Gas Infrastructure Safety and Integrity	$4,000,000
Energy-Related Environmental Research	$2,600,000
Natural Gas-Related Transportation	**$3,500,000**
Program Administration	**$2,400,000**
TOTAL	**$24,000,000**

(1) In FY 2015-16 and 2016-17, the Energy Efficiency research areas alternated funding between building efficiency and industrial efficiency research. For FY 2015-16, the natural gas research funds focused on building end-use efficiency. In FY 2016-17, the focus is on the industrial, agriculture and water efficiency sector. This approach allows the funding of multiple projects in each research area.

Source: California Energy Commission staff

Table 3: FY 2015-16 Natural Gas R&D Supplemental Budget Plan Summary

Research Areas	Supplemental Budget
Natural Gas Infrastructure Safety and Integrity	$1,500,000
Energy-Related Environmental Research	$2,100,000

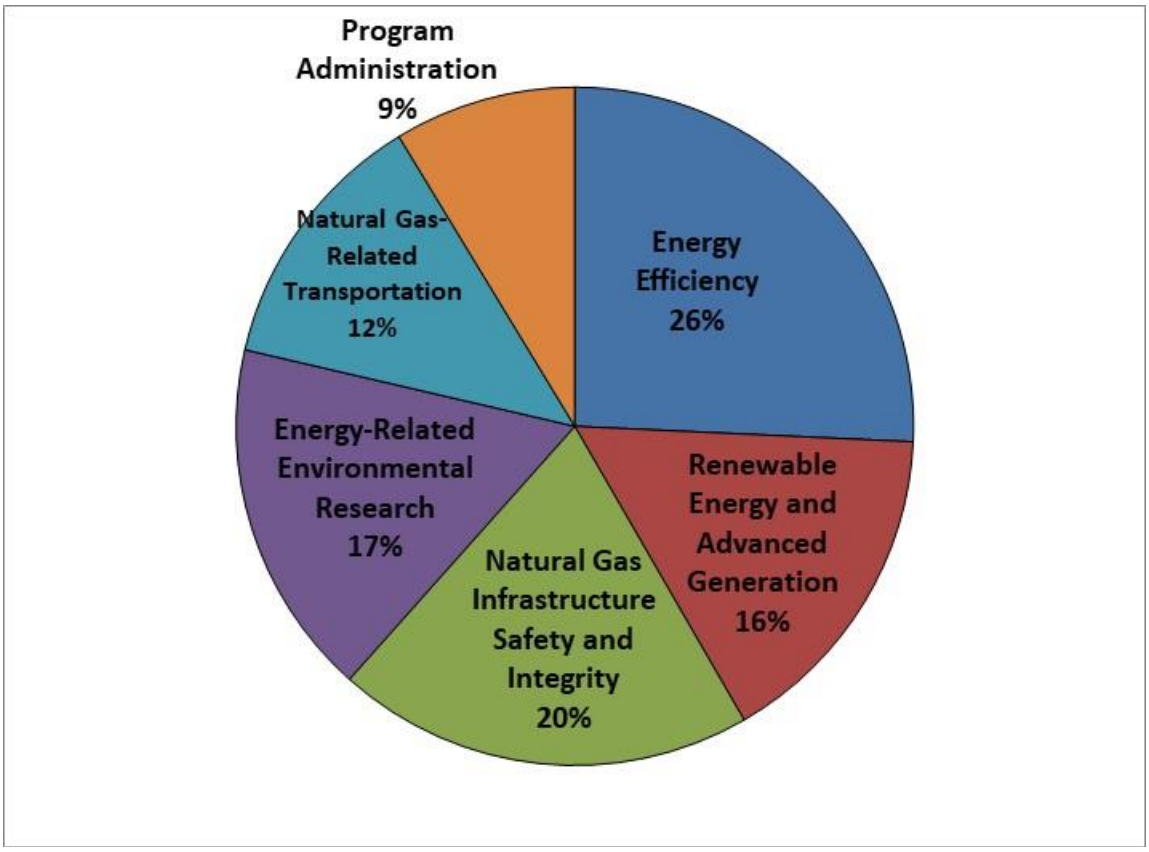
The Natural Gas R&D Supplemental Budget was approved by CPUC on December 7, 2015 and the Energy Commission received a one-time expenditure authority of $3.6 million in the FY 2016-17 state Budget Act to fund additional natural gas research project awards.

Source: California Energy Commission staff

Natural Gas Budget Plan in FY 2016-17

The research area funding for fiscal year 2016-17 Natural Gas R&D and fiscal year 2015-16 Natural Gas R&D Supplemental budget plans is shown in Figure 1.

Figure 1: Natural Gas Budget Plan in FY 2016-17



Source: California Energy Commission staff

Energy Efficiency Research

These research projects improve the energy efficiency of natural gas use in homes, businesses, industrial processes, agricultural operations, water and wastewater systems, and data centers. Improving efficiency of natural gas use is the state's most important strategy to reduce energy use and cost, GHG emissions, and other harmful impacts of energy use.

- **Buildings End-Use Energy Efficiency**: The buildings end-use energy efficiency research program promotes reducing on-site natural gas use and addressing technology gaps that hinder adopting advanced technologies and strategies that improve efficiency, reduce natural gas use and costs, and address environmental challenges associated with both indoor and outdoor air emissions.
- **Industrial, Agriculture, and Water Efficiency:** The industrial, agriculture, and water (IAW) sectors in California produce, process, assemble, or manufacture goods or provide services, such as wastewater treatment. This sector annually uses 30 percent of all natural gas consumed in the state and

relies heavily on an affordable, reliable, and sustained energy supply.[6] This sector benefits from research and development of advanced technologies and strategies that cost-effectively reduce energy use and cost, meet environmental challenges, cope with increasing energy demand, and accelerate renewable resources use.

Renewable Energy and Advanced Generation Research

R&D promotes renewable energy and advanced generation technologies such as improvements in industrial waste heat recovery for power generation, renewable gas conversion technologies, low-emission distributed generation, and combined heat and power (CHP) systems.

- **Distributed Generation and Combined Heat and Power Research**: Current distributed generation (DG), CHP, and combined cooling heating and power (CCHP) research focuses on improving small (<1 MW) and micro-scale (<50 kilowatts (kW)) systems. Research focuses on improving the efficiency, cost-effectiveness, and emissions performance of these small systems for light industrial, small commercial and residential applications. This research also includes enabling technologies such as thermally-driven cooling and thermal energy storage systems which can allow for cooling energy output and increase system flexibility, respectively.
- **Biogas Gas and Renewable Gas Research**: Biogas and Renewable Gas (RG) research examines the numerous barriers and challenges related to their adoption. Biogas research aims to make the production and use of biogas less costly, more efficient, and to open up new or under-used pathways such as forest biomass-derived biogas. RG research focuses on developing and demonstrating new technologies and strategies for cost-effectively cleaning the contaminants out of biogas and upgrading its quality to produce pipeline-quality gas. Addressing the technological and cost issues associated with RG production is critical to future decarbonization of the natural gas system.

Energy Infrastructure

The safety and security of the natural gas infrastructure are important priorities to California.

- **Natural Gas Infrastructure Safety and Integrity:** Infrastructure research projects demonstrate natural gas pipeline integrity monitoring and inspection technologies that are past the "proof-of-concept" stage and are ready for demonstration in a real-world utility setting. Research also includes developing mapping and locational awareness tools for pipeline excavators and first responders. Addressing the recent issues the state encountered with natural gas

6 Natural gas data from http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm.

storage, R&D has expanded to natural gas storage monitoring and inspection technologies and risk assessment tools.

- **Energy-Related Environmental Research:** R&D develops cost-effective approaches to evaluating and resolving environmental impacts of energy production, delivery, and use in California; explores how new energy applications and products can solve/mitigate environmental problems; identifies vulnerabilities of the energy system to climate change; and develops cost-effective climate adaptation approaches to ensure reliable energy services.

Natural Gas-Related Transportation

Transportation research addresses several of the state's policy goals to reduce petroleum consumption, increase alternative fuel use, and reduce GHG emissions in California. This research area supports natural gas engine development and other technology advancements to reduce tailpipe emissions from the transportation sector.

Program Updates

Applying Safety Policy Statement of the CPUC

Adopted by CPUC on July 10, 2014, the safety policy "defines the role of [CPUC] Commissioners, binds together the agency in constantly strengthening [its] safety efforts, and provides a unifying vision and guidance for the organization's multiple and disparate functions." The guiding principles for health and safety were established to help the CPUC fulfill its commitment for "protection for the public, for utility workers, and CPUC employees in their work, for the environment, and for utility infrastructure and systems."

The Energy Commission invests in research and technologies that support implementing and practicing the CPUC's guiding principles on health and safety. Examples of Natural Gas R&D projects that assess and reduce safety risk or support health and safety include Real-Time Active Pipeline Integrity Detection for gas pipeline safety monitoring, Healthy Homes – Exposure to Unvented Combustion Gases, and Innovative Air Cleaner for Improved Indoor Air Quality and Energy Savings.

Commitment to Diversity

California is a diverse state, in its geography and its people. To better serve all Californians, the California Energy Commission must better represent that diversity in its outreach, funding opportunities, and planning. In 2014, the Energy Commission formed a diversity working group to create a commissionwide approach for this priority and help coordinate diversity efforts within the agency.

In 2015, the Energy Commission adopted a diversity policy resolution outlining and strengthening its commitment to ensuring all Californians have an opportunity 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.

AB 865 authorizes the Energy Commission to establish a diversity task force 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.

Energy Commission staff conducts activities to meet these commitments, including outreach efforts to:

- Engage with disadvantaged and underrepresented groups throughout the state.
- Notify potential new applicants about the Energy Commission's funding opportunities.
- Assist applicants in understanding how to apply for funding from the Energy Commission's programs.
- Survey participants to measure progress in diversity outreach efforts.

In 2017, the Energy Commission held multiple workshops and expos, and stakeholder and working group meetings to support community advocacy for diversity around policy research and policy positions, including two workshops to discuss incorporation of community-focused equity in Energy Commission research grant funding opportunities. The Energy Commission has committed to a 25 percent target of Technology Demonstration and Deployment (TD&D) funding under its Electric Program and Investment Charge (EPIC) program to be allocated to projects sited in disadvantaged communities.[7] The Natural Gas program has kept pace: Out of the 103 California-based, active and completed Natural Gas projects in FY 2016-17, 31 have at least one site within a disadvantaged community.[8]

For more information about these and other Energy Commission diversity commitment activities, please visit: http://www.energy.ca.gov/commission/diversity/.

Stakeholder Outreach – Avoiding Research Duplication

When creating the budget plan and developing the research portfolio, the Energy Commission receives input from experts in energy research, including the state's investor-owned gas utilities, state and federal agencies, industrial experts, academic researchers, and other interested parties. Each year the Energy Commission, in

7 Under Senate Bill 350 (De León, 2015)

8 Defined as the 25 percent highest scoring census tracts in CalEnviroScreen 3.0. For more information on CalEnviroScreen, go to: http://www.calepa.ca.gov/EnvJustice/GHGInvest/

conjunction with the CPUC, holds a workshop to explore research initiatives across all natural gas technical subject areas considered for the next funding cycle. Other workshops are held throughout the year to gather input on various research areas and topics. These workshops help avoid research duplication; generate new research ideas; create the best research industry practices; and bring together utilities, researchers, manufacturers, end users, and policy makers from state and federal agencies, such as the CARB and the U.S. Department of Energy, respectively.

For example, the Energy Commission conducted a joint agency workshop with the CARB and the CPUC on Development and Use of Renewable Gas, Biomethane, and Biogas to Reduce Short-Lived Climate Pollutants as part of the *2017 Integrated Energy Policy Report (2017 IEPR)* proceeding. The workshop focused on actions to develop and use renewable gas and the requirements under Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016). Program staff also held a workshop on March 16, 2017 on Potential Areas of Research on Climate Change for the Electricity and Natural Gas Systems, which featured presentations from leading academia and research institutions to discuss active and completed research around methane emissions from the natural gas system and gain input on scope for pending research.

The Energy Commission also supports and participates in the activities of the Emerging Technologies Coordinating Council (ETCC). The members include the major electric and natural gas investor-owned utilities and several public utilities with oversight by the CPUC. The ETCC provides a path to the marketplace for promising technologies and a forum for members to meet and exchange information on energy efficiency research and projects.

Furthermore, annually, the Energy Commission holds a public workshop to review the research plans for the next fiscal year and to receive feedback from stakeholders and experts in the field. The workshop also allows the Energy Commission to verify that the planned research does not duplicate efforts planned or in progress by other government or industry research organizations.

Careful oversight of public funds signals to investors that California is a supportive, innovative, and responsible state advancing energy development.

Contracts and Solicitation Updates: Enhancing Investments for California

To ensure that most natural gas funds are spent in California and benefit California ratepayers, the Energy Commission continues to expand its efforts to contract with California-based entities[9] through competitive selection processes. These improvements are a response to feedback from stakeholders and policy makers, and they increase the effectiveness of the program to generate California energy investments.

[9] Public Resources Code Section 25620.5 (h) and (i).

A California-based entity is a corporation or other business form organized to transact business that either:

- Has its headquarters in California **and** manufactures the specific product in the state.
- Has an office in California to transact business and manufacture the product, or perform the awarded research in California.
- Has an office for the transaction of business in California and substantially manufactures the product or substantially performs the research within California.

Natural Gas R&D funds are typically awarded competitively through grant solicitations. A competitive solicitation is a public request for proposals to provide services, provide a specified product, solve a defined problem under an agreement, or all three. The Energy Commission uses grant funding opportunity (GFO) for grants and request for proposals (RFP) for contracts. The procedures for competitive solicitations follow the applicable requirements under the *State Contracting Manual*, State Public Contracts Code, Public Resources Code, and other laws and regulations, such as civil service restrictions, prevailing wages, and the California Environmental Quality Act. This open solicitation process ensures these funds are awarded through a transparent process, and any entity has the ability to provide comments or recommendations to the Energy Commission on information relevant to a particular solicitation.

Energy Commission proposal scoring criteria favor proposals where the majority of the funding is directly supporting research with low overhead and general and administrative costs.

Natural Gas Research Projects Awarded in FY 2016-17

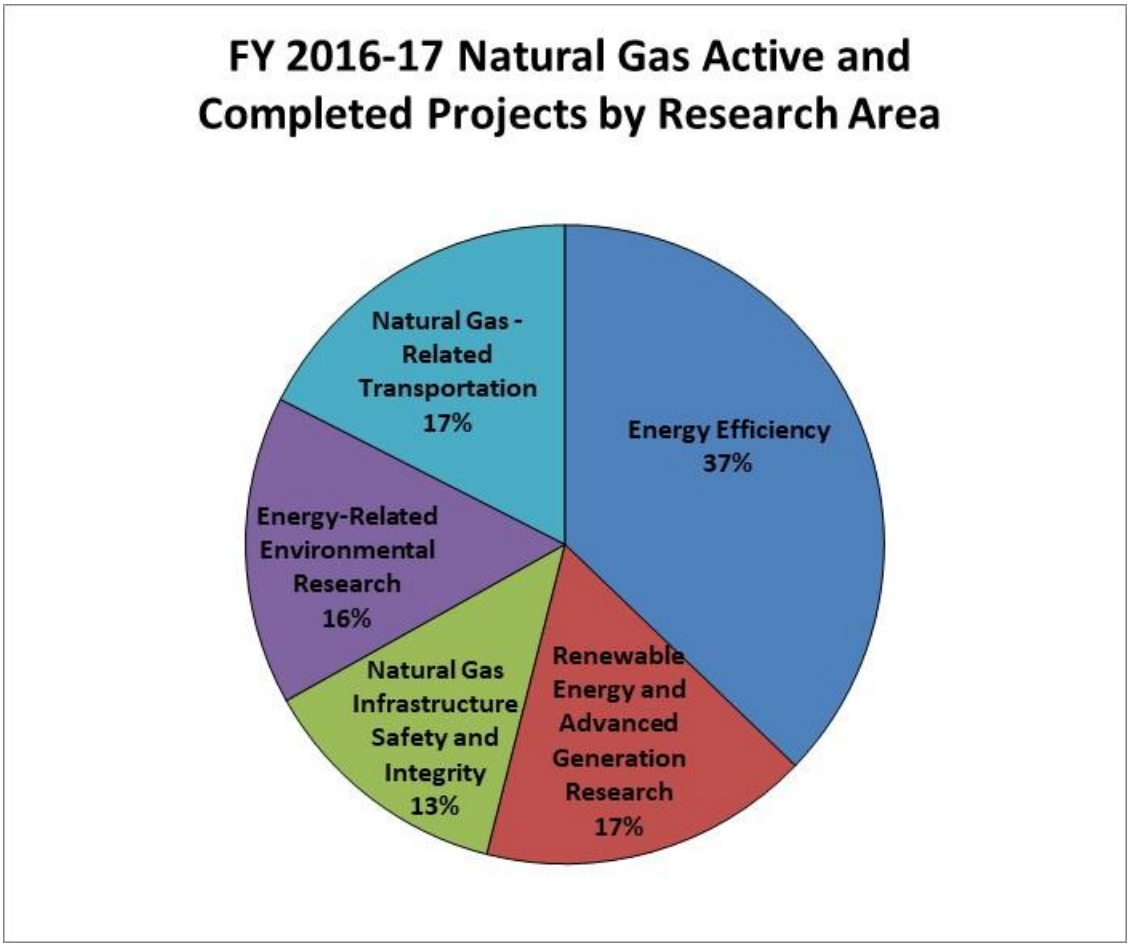
In fiscal year 2016-17, $29.1 million in natural gas funding from FY 2015-16 and FY 2016-17 budget plans were awarded to 28 research projects. Appendix A provides a list of projects awarded in FY 2016-17.

Active and Completed Projects by Research Area in FY 2016-17

In FY 2016-17, there were 103 Natural Gas R&D active and completed projects with a total funding amount of $100.28 million (Figure 2). This funding leveraged $36.07 million in match funding procured or provided by award recipients. A list of all completed projects is in Appendix B. Also, a summary of active and completed project write-ups are highlighted in Appendix C. Since 2004, the Energy Commission has made 237 project awards, encumbering a total of $216.6 million through June 30, 2017. A small percentage of project funding was provided by the Public Interest Energy Research Electric (PIER-E) Program. The PIER Electric and Natural Gas R&D programs

historically provided joint funding for research projects that benefit electric and natural gas ratepayers simultaneously.[10]

Figure 2: FY 2016-17 Natural Gas Active and Completed Projects by Research Area



Source: California Energy Commission staff

Planned Funding Opportunities

Natural Gas R&D Program's Active Funding Opportunities

The Energy Commission will continue to implement R&D consistent with the CPUC-approved budget plans for FY 2016-17 and 2017-18. Information about funding opportunities will be posted to http://www.energy.ca.gov/contracts/pier.html as it becomes available and can change.

10 The last agreements with joint Natural Gas and PIER Electric Program funding were awarded at an Energy Commission Business Meeting in June 2013.

Table 4 shows solicitations that were released and approved for funding through a Notice of Proposed Award (NOPA) totaling $23.6 million in FY 2016-17. Table 5 lists committed funds for $23 million in active solicitations released as of October 31, 2017. These active solicitations are funded with FY 2016-17 and FY 2017-18 budget plans and have not yet posted a NOPA at the time of this report. To receive an email when solicitations are released, interested parties can subscribe to the list server at http://www.energy.ca.gov/research/.

Table 4: Natural Gas R&D Solicitations Released in FY 2016-17

Solicitation Title	Release Date	Program Area	Funding Amount
Natural Gas Solicitation for Energy-Related Environmental Research (GFO-15-507)	July 28, 2016	Energy-Related Environmental Area	$5.7 million
Novel Solutions to Accelerate Deployment of Small and Micro-Scale Combined Cooling Heating and Power Systems (GFO-16-503)	July 28, 2016	Renewable Energy and Advanced Generation	$5.4 million
Off-Road Heavy-Duty Natural Gas Vehicle Research and Development (GFO-16-506)	October 21, 2016	Transportation Research	$4.4 million
Natural Gas Engine Improved Efficiency Research and Development (GFO-16-507)	December 13, 2016	Transportation Research	$2.7million
Natural Gas Storage Infrastructure Safety and Integrity Risk Modeling Research Grants (GFO-16-508)	January 18, 2017	Natural Gas Infrastructure Safety and Integrity	$5.4 million
Total			**23.6 million**

Source: California Energy Commission staff

Table 5: Natural Gas R&D Active Funding Opportunities in FY 2017-18

Solicitation Title	Deadline to Submit Applications	Program Area	Funding Amount
Improving Natural Gas Energy Efficiency, Waste Heat-to-Power, and Near-Zero Emission Distributed Generation Systems (GFO-17-501)	Phase 1: October 10, 2017 Phase 2 December 19, 2017	Energy Efficiency and Renewable Energy and Advanced Generation	$10.7 million
Enhancing Safety, Environmental Performance, and Resilience of California's Natural Gas System (GFO-17-502)	November 17, 2017	Environmental Research	$8.9 million
Addressing Barriers to Wider Adoption of Near-Zero Emission Natural Gas Vehicles (GFO-17-503)	November 27, 2017	Transportation Research	$3.4 million
Total			**$23 million**

Source: California Energy Commission staff

CHAPTER 2:
Program Theme Highlights

Decarbonizing Natural Gas

Decarbonizing the Fuel

Biogas Research Decarbonizes the Natural Gas System

California is committed to reducing greenhouse gas (GHG) emissions to 1990 levels by 2020. Beyond 2020, even more ambitious goals have been set including a 40 percent GHG emission reduction compared to 1990 levels by 2030, and an 80 percent reduction by 2050.[11] Transformations in the energy sector are required to achieve these goals, from the supply side (where energy is sourced) and the demand side (how energy is used). One pathway to reach these goals is using more of biogas, which can be produced from several in-state biomass resources including forest- and agriculture-derived woody biomass, food waste and the organic fraction of municipal solid waste, municipal wastewater, landfill waste, and dairy manure.

Using biogas in place of natural gas can potentially decarbonize a significant portion of California's energy mix, contributing to the state's renewable energy and GHG reduction goals.

Using biogas in place of natural gas can potentially decarbonize a significant portion of California's energy mix, contributing to the state's renewable energy and GHG reduction goals. For example, a 2016 UC Davis Biomass Collaborative study estimated that if the largest 225 dairies in California installed anaerobic digesters for manure management, the annual GHG emission reduction compared to current practices would equal up to 8.3 metric tons of CO2 equivalent.[12] To promote biogas use in California, technological advancements are necessary in all stages of the biogas energy pathway, including biogas production, cleanup and upgrading of the biogas to RG, and using biogas in end-use applications. To realize the potential of biogas for supporting decarbonization goals, research was conducted in different areas: biogas production, applications for onsite use, emission control, and advancing cutting-edge technologies for converting biogas.

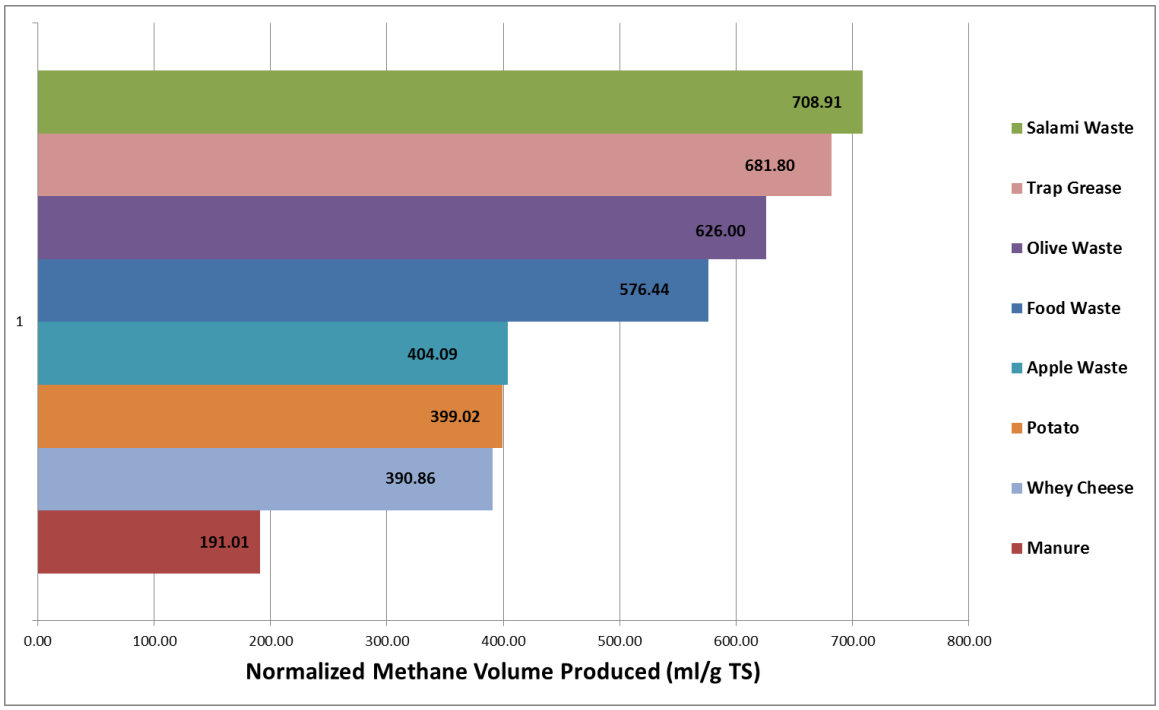
[11] See Executive Order B-30-15, https://www.gov.ca.gov/news.php?id=18938, and the SB32 (2016) law for information on the requirement to reduce GHG emissions to 40 percent below 1990 levels by 2030.

[12] Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California. UC Davis Biomass Collaborative. http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf

Biogas and Renewable Gas Production

Research has been conducted to improve biogas production and the technologies which clean and upgrade biogas into pipeline-quality and transportation-quality renewable gas. A recently completed project studied how to optimize the anaerobic digestion process, a process that converts organic waste into biogas (PIR-14-022) (Figures 3 and 4). This project quantified the biogas potential for more than 25 feedstocks at the lab and commercial-scale, investigated the effect of micronutrients additives on biogas production, and studied operational modifications to maximize biogas production potential. The project produced guidelines and best practices for other digester operators on how to optimally operate anaerobic digester systems including feedstock procurement and selection, feedstock loading rates and strategies (such as keeping certain feedstocks 'in reserve'), avoiding and responding to digester 'crash' events, and optimizing biogas plant operation. These guidelines will assist new and operating anaerobic digester facilities with their day-to-day operation and long-term planning, minimizing the need for costly private consulting and consequently lowering the cost of biogas produced.

Figure 3: Biomethane Yield for 8 of the Feedstocks Tested



Laboratory experiments quantified methane potential for several anaerobic digester feedstocks showing large variations from one feedstock to another and emphasizing the need for feedstock diversity (PIR-14-022).

Credit: Biogas Energy

Figure 4: North State Rendering Anaerobic Digester Facility

The North State Rendering anaerobic digester facility in Oroville (Butte County) converts organic waste into renewable electricity, heat, and vehicle fuel (PIR-14-022)

Credit: Biogas Energy

An ongoing project is examining a novel bioenergy pathway that converts woody biomass into RG via gasification and fluidized bed methanation (PIR-14-023). This project uses a pilot-scale gasification system to convert wood chips into a producer gas (raw gaseous fuel, which is a mixture of different gases, produced by biomass gasification) followed by a bench-scale fluidized bed methanation reactor to convert the producer gas into RG. Methanation is the process of forming methane, a primary component of the renewable gas. The reactor is the system component that enables the methanation to occur. Key aspects of the project include removal of contaminants from the producer gas (in other words, tars, sulfur species) that inhibit production of RG, as well as the methanation itself. When complete, this project will produce a technical and economic assessment of a hypothetical full-scale woody biomass to RG facility. Because the performance and cost-effectiveness of biomass facilities can change drastically based on scale, this assessment is critical in determining if the technology can be economically deployed at a full-scale facility.

Biogas Application for Onsite Use

Improving of biogas use in energy generation systems will also provide valuable data on how biogas systems can operate more effectively. One completed project integrated an absorption chiller into a directed biogas-fueled,[13] molten carbonate fuel cell installed at the University of California, San Diego (UC San Diego) (Figure 5). The absorption chiller captures waste heat from the fuel cell and converts it into cooling energy for the campus as chiller water. This system displaced 224 kW of electric chiller load from the

[13] The term "directed biogas" refers to biogas that is cleaned and injected into a natural gas pipeline, then used as fuel at a different location.

campus and, when installed, was the largest integrated fuel cell-absorption chiller system in the world.

This project estimates annual GHG emissions reductions of approximately 275 metric tons of CO_2 equivalent.

Since project completion, UC San Diego has installed 2 million gallons of chilled water storage to further maximize efficiency from its fuel cell-absorption chiller system. Another ongoing project installed a biogas cleanup system, microturbines, and a refueling station at a small wastewater treatment plant (PIR-14-020). This system replaced an inefficient internal combustion engine and diesel-fueled vehicles with cleaner, more efficient technologies. The system combines existing technologies into a configuration new to California and is installed at a small wastewater treatment plant where gas is typically flared. The system will use 100 percent of the biogas produced to provide renewable electricity, heat, and vehicle fuel. The project estimates annual GHG emissions reductions of approximately 275 metric tons of carbon dioxide (CO2) equivalent (e) (roughly 180 tons CO2e from vehicle emissions and 95 tons CO2e from electrical generation).

Figure 5: 2.8 MW Fuel Cell Integrated with Absorption Chiller at UC San Diego Campus

The 330 ton absorption chiller system installed at UC San Diego converts waste heat from the 2.8 MW fuel cell into cooling energy for the campus (PIR-13-008).

Source: UC San Diego

Advanced Biogas Power Conversion Technology

While biogas can improve efficiency of energy systems, it is also being used as a source of generation by using advanced systems to convert biogas into electricity. One project focused on prototype- scale development and demonstration of a fuel-flexible combined heat and power system capable of using untreated biogas and achieving near-zero emissions of priority pollutants. This system demonstrated near-zero emissions by using

chemical looping, which is a process that uses metal oxide as bed material in a dual-circulating fluidized bed system to provide oxygen for the combustion of fuel. Cyclic oxidation/reduction of a copper impregnated substrate in a fluidized bed was used to oxidize the fuel instead of a conventional combustion process, eliminating production of oxides of nitrogen (NOx) and capturing oxides of sulfur in a fluidized bed. Electricity is then generated through a closed-loop steam system using heat exchangers and a conventional Rankine cycle. An additional benefit of this method is that the products of combusting the fuel consist entirely of carbon dioxide and steam (compared to the conventional method that uses air as a source of oxygen and will have nitrogen and nitrogen-based compounds in the product). The carbon dioxide portion of the product could be separated, making the process readily amenable to carbon capture activities and the associated benefits.

Another ongoing research project (PIR-13-002) is developing and demonstrating a novel combined heat and power system that consists of a single cylinder engine with dual opposed pistons capable of variable compression ratios, resulting in high efficiencies and low emissions. Compression ratio is the ratio of the volume of the combustion chamber from the largest to smallest capacity, as the piston moves inside the chamber, and is fundamental specification for internal combustion engines. Variable compression ratio combined with proprietary control strategies allow the engine to operate using a variety of fuel gases with a wide range of ignition properties—from natural gas to biogas and other low British thermal unit (BTU) content fuels. Because of the nature of the homogeneous charge compression ignition (HCCI) (refers to point where a well-mixed fuel and oxygen will auto-ignite) combustion reaction, the gas temperatures within the cylinder are relatively uniform with no hot spots, such as a flame front or spark. This allows ultra-low NOx emission rates by keeping the peak gas temperature below the temperature at which the NOx formation reaction occurs.

Emission Control

Ensuring that other emissions resulting from biogas production are mitigated is also being researched. On-going research continues focusing on limiting the criteria pollutant emissions in various biogas production systems used for energy generation, including emissions created by biogas-fueled generators. Biogas contains hydrogen sulfide H2S and siloxanes which cause engine damage and poison catalysts often used for NOx control. These impurities must be removed which require expensive biogas treatment systems. As NOx emission standards have become more stringent, it has become more difficult and expensive to meet these standards.

The project team found that an integrated NOx adsorption with onsite microwave reactivation system would be the most cost-effective way to meet CARB 2007 NOx standards and determined that it would reduce the NOx removal cost by $15,300 per ton, a cost reduction of about 62 percent.

Research has also been conducted to improve the cost effectiveness of biogas emission control. A recently completed project developed and demonstrated an integrated microwave system that addresses the challenges and costs for biogas-fueled engines to meet the emission standards (PIR-13-006). The integrated pre- and post-combustion NOx emission control process consists of two systems. The pre-combustion system removes H2S and siloxanes and then generates hydrogen for pre-combustion NOx control. The post-combustion system uses granular activated carbon to remove NOx and other pollutants from engine exhaust. CHA Corporation built and tested the system on biogas made from food waste by generating electricity with an engine at the CleanWorld site in Sacramento.

When the carbon used for the post combustion NOx control became saturated with NOx, a microwave system developed in a previous project was used to regenerate the activated carbon so it could be reused instead of discarded. This project demonstrated a new emission-prevention technology that significantly reduces NOx and other harmful emissions from biogas engines. This technology addresses the barrier for biogas engines to successfully meet the amended Rule 1110.2 and CARB 2007 NOx emission standards for stationary engines. The project team found t an integrated NOx adsorption with onsite microwave reactivation system would be the most cost-effective way to meet CARB 2007 NOx standards. The team determined it would reduce the NOx removal cost by $15,300 per ton, a cost reduction of about 62 percent. [14]

The pre-and post-combustion NOx control with microwave energy will meet CARB 2007 NOx emission standards for biogas-powered engines, and result in cost savings compared to the existing process of controlling NOx emissions with a selective catalytic reduction (SCR). The NOx removal cost for SCR is $24,500 per ton of NOx removed or 5 cents per kWh of power produced. The NOx removal cost for the post combustion NOx control integrated with microwave reactivation is $9,200 per ton of NOx removed or 1.8 cents per kWh power produced. SCR is also poisoned by hydrogen sulfide (H_2S) and other sulfur components and siloxanes of biogas. Eliminating these chemicals is expensive with high NOx removal costs. The SCR uses ammonia or urea for NOx reduction, which generates harmful byproducts such as ammonia emissions. This advanced post-combustion NOx control integrated with microwave reactivation technology is not poisoned with hydrogen sulfide and siloxanes, and removes volatile organic compounds and sulfur oxides from exhaust.

Results from this project will help biogas producers create renewable fuel that is less costly and friendlier to the environment. California presently has 15 anaerobic digester dairy systems operating, plus a growing number of food waste anaerobic digester systems. The number of anaerobic digester systems required to reduce methane emissions from farming and landfills is expected to increase because of ambitious goals

[14] Staff estimate based on Chang, Yul Cha et al, 2017, Pre and Post-Combustion NOx Control for Biogas Engine with Microwave Energy, Final Report under review for publication

set under AB32. SMUD estimates about 1,400 dairy operations in California must install anaerobic digester systems within the next five years to help meet emission reduction targets. The system developed under this research project could also be used to produce hydrogen from biogas, providing a renewable fuel source for fuel cells.

Decarbonizing Heavy Duty Transportation: Natural Gas as a Low Carbon Transition Fuel

According to the 2015 Emission Inventory the transportation sector accounts for roughly 38 percent of the state's greenhouse gas emissions, with heavy-duty vehicles as the second largest contributor in the transportation sector[15]. Heavy-duty vehicles are also the largest contributors to harmful NOx emissions in California's heavily polluted air basins.

Projections show that even if California's entire on-road fleet of heavy-duty vehicles complies with the CARB 2010 heavy-duty on-road engine emission standards, pending National Ambient Air Quality Standards (NAAQS) requirements for ozone attainment cannot be achieved in the state's most heavily polluted air basins without further reducing NOx emissions from heavy-duty fleets.

Alternative fuel options that can maximize environmental and air quality benefits for heavy-duty vehicles include advanced near-zero emission natural gas engines, battery-electric technology, and hydrogen fuel cells. While battery-electric and hydrogen fuel cell vehicles are being explored for zero tailpipe emissions, these technologies are highly limited as near-term solutions for heavy-duty vehicle applications due to high costs and low operational range. Natural gas represents a low carbon transition fuel for heavy-duty vehicles and near-term solution to California's air quality issues when used to power near-zero emission natural gas engines.

Advanced Powertrains

A natural gas hybrid-electric configuration has the opportunity to leverage the advancements in zero-emission powertrain technologies while using low emission natural gas engines to meet range and performance requirements.

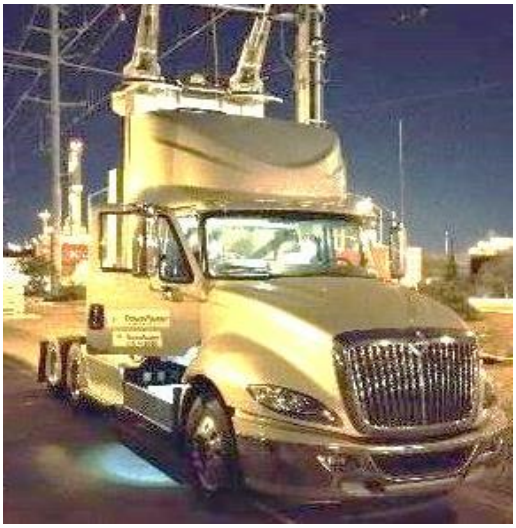
Natural Gas hybrid-electric trucks have the potential to result in an economically viable payback period of 4.5 years by 2020.

[15] Staff estimate based on Chang, Yul Cha et al, 2017, Pre and Post-Combustion NOx Control for Biogas Engine with Microwave Energy, Final Report under review for publication

[15] California Greenhouse Gas Emission Inventory: 2000-2015. California Air Resources Board. June 2017. https://www.arb.ca.gov/cc/inventory/pubs/reports/2000_2015/ghg_inventory_trends_00-15.pdf

The Natural Gas-Related Transportation research area funded three projects that developed and demonstrated natural gas hybrid-electric powertrains for heavy-duty vehicles. The research included development and testing of a delivery truck in California's Central Valley and drayage trucks in the Port of Los Angeles and Port of Long Beach – which are adjacent to highly impacted disadvantaged communities that can benefit from air quality improvements (Figure 6).

Figure 6: Natural Gas Hybrid-Electric Truck



TransPower hybrid-electric drayage truck in the port of Los Angeles (PIR-13-012)

Source: TransPower Inc.

Project results confirmed the emission reduction and range extension potential of natural gas hybrid-electric vehicles. Emission reductions for carbon monoxide and particulate matter were measured at about 89 percent and 70 percent, respectively. While there were some NOx emission reductions, the demonstrations showed certain operating modes resulted in emission increases. Fuel economy improvements were consistent, with an increase of up to 40 percent for the delivery truck. Scaling up the production of natural gas hybrid-electric trucks has the potential to result in an economically viable payback period of 4.5 years by 2020, making them viable near-term options for fleets looking to transition to cleaner and more efficient vehicles. These results provide valuable information for future research on optimizing hybrid powertrains leading to further emission reductions for various driving modes.

Engine Efficiency

Project results confirmed the emission reduction and range extension potential of natural gas hybrid-electric vehicles. Emission reductions for carbon monoxide and particulate matter were measured at about 89 percent and 70 percent, respectively. While there were some NOx emission reductions, the demonstrations showed certain operating modes resulted in emission increases. Fuel economy improvements were

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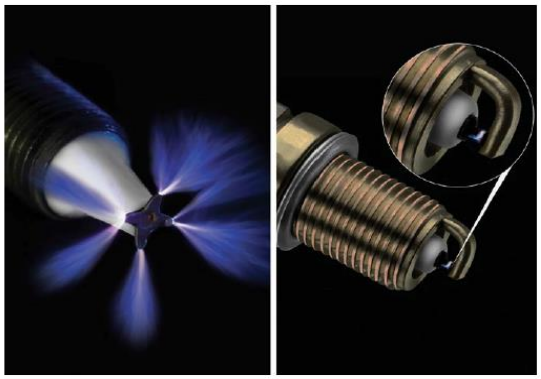
The Natural Gas-Related Transportation research area funded four advanced ignition projects to evaluate the benefits of advanced ignition technologies on natural gas engines, including various high-energy ignition technologies such as high-frequency corona discharge, plasma ignition, and pre-chamber turbulent jet ignition.

Engine efficiency improvements can directly lead to greenhouse gas emission reductions of 10 to 16 percent and increased market competitiveness of natural gas vehicles.

These projects aimed to consistently ignite dilute fuel mixtures under high boost conditions to avoid misfires and partial burns, eliminating major barriers to current and future high efficiency engine development efforts. An additional three projects were funded to develop and demonstrate several natural gas engine efficiency improvement technologies, including transient plasma ignition, dedicated exhaust gas recirculation, and lean-burn combustion with selective catalytic reduction after-treatment. These projects expanded on the lessons learned from the previous advanced ignition projects by focusing on engine integration and optimization, and novel ignition strategies. High-energy ignition concepts showed limited benefits as drop-in solutions, requiring certain engine conditions to take full advantage of the technology. For example, the high-frequency corona ignition did not show substantial performance benefits because of the high inherent exhaust gas recirculation tolerance of the test engine. The advanced ignition project however did indicate a general increase in lean limit compared to conventional spark ignition (Figure 7).

Figure 7: Advanced Ignition



Plasma plug (left) in comparison to conventional spark plug (right)

Source: Gas Technology Institute

For example, turbulent jet ignition demonstrated consistent lean limit extension (up to three times as much air as theoretically required) with the highest pressure benefit from a prechamber nozzle design using multiple diverging jets. Engine efficiency improvements can directly lead to greenhouse gas emission reductions of 10 to 16 percent and increased market competitiveness of natural gas vehicles. The research is also expected to demonstrate NOx emissions at the 0.02 g/bhp-hr level, equivalent to the cleanest natural gas engine available and 90 percent below the U.S. Environmental Protection Agency (U.S. EPA) standard.

Emission Reduction

Air quality remains a critical issue in some of California's most polluted regions, particularly the effects of transportation emissions on their communities. Seven of the nation's top 10 most ozone-polluted cities are in California and more than 90 percent of the state's population is living under at-risk levels of ozone pollution.[16] State and local agencies are currently implementing aggressive initiatives in an effort to mitigate harmful pollutants including NOx, which is a precursor for smog formation.

In October 2016, CWI's 8.9-liter ISL G Near Zero was commercially offered with an emissions certification at lowest ARB's lowest optional low NOx standard of 0.02 g/bhp-hr; 90 percent below the U.S. EPA standard.

Mobile sources account for more than 70 percent of all NOx emissions in the heavily polluted South Coast[17] and San Joaquin Valley Air Basins,[18] with heavy-duty on-road vehicles as the single largest source of NOx emissions. The South Coast Air Quality Management District (SCAQMD) estimates that even with the entire on-road fleet of heavy-duty vehicles compliant with the 2010 standard, upcoming NAAQS requirements for ozone attainment cannot be achieved without significant reductions in NOx emissions from heavy-duty fleets. Moreover, the SCAQMD Plan indicates that NOx emissions must be reduced by at least 60 percent to meet expected future NAAQS requirements.

The Energy Commission partnered with the SCAQMD and Southern California Gas Company (500-12-012) to challenge natural gas engine original equipment

[16] American Lung Association. State of the Air 2017. http://www.lung.org/assets/documents/healthy-air/state-of-the-air/state-of-the-air-2017.pdf

[17] South Coast Air Quality Management District. Final 2016 Air Quality Management Plan: Chapter 3 Base Year & Future Emissions. http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/final-2016-aqmp/chapter3.pdf?sfvrsn=4

[18] San Joaquin Valley Air Pollution Control District. About the District: Making Progress. http://www.valleyair.org/General_info/aboutdist.htm#Mission

manufacturers to develop a low NOx natural gas engine that would reduce NOx emissions to levels 90 percent below the 2010 CARB emission standards, Cummins Westport, Inc. (CWI) was successful in upgrading its existing 8.9-liter natural gas engine with improved controls, closed crankcase ventilation, and a modified three-way catalyst to meet the emission objectives of the research without sacrificing performance (Figure 8).

Figure 8: Advanced NOx Natural Gas Engine

Cummins Westport, Inc.'s low NOx 8.9-liter natural gas engine

Source: Cummins Westport, Inc.

In October 2016, CWI's 8.9-liter ISL G Near Zero engine was commercially offered with an emissions certification at CARB's lowest optional low NOx standard of 0.02 g/bhp-hr, 90 percent below the U.S. EPA standard. The 8.9-liter engine is well positioned to achieve near-term benefits with an established market share of 46 percent of the refuse hauler market and 33 percent of the transit bus market. Las Angeles Metro recently purchased 360 new transit buses equipped with the 8.9-liter near-zero emission engine. This is in addition to the 395 near-zero emission engines for repowers they are buying over three years.[19] San Diego is converting their entire refuse truck fleet from diesel to natural gas with 92 trucks equipped with the near-zero emission engine.[20] By adopting the near-zero emission engine, these two fleets alone can see NOx reductions of 108 and 34 annual metric tons, respectively. When fueled with low carbon RNG, vehicles operating with near-zero emission engines can maximize both GHG and criteria pollutant emission reductions. Los Angeles Metro has also embarked on a one-year pilot with Clean Energy to fuel roughly 200 buses with RNG with an additional option to

[19] Fleets and Fuels. LA Metro Orders e-Buses, CNG too. July 31, 2017. http://www.fleetsandfuels.com/fuels/cng/2017/07/la-metro-leans-toward-electric-buses/

[20] The City of San Diego. City Opens New Facility to Power Trash Trucks with Cleaner Fuel. May 2, 2017. https://www.sandiego.gov/mayor/news/releases/city-opens-new-facility-power-trash-trucks-cleaner-fuel

provide RNG to the entire fleet of 2,200 natural gas vehicles. This can reduce Los Angeles Metro's GHG emissions by 150,000 annual metric tons of CO2 equivalent.[21]

Based on work completed on this engine, advanced 6.7-liter and 12-liter engines are being developed (PIR-15-008 & 500-16-002) with expected commercial release dates in early 2018 to widen the availability of low-NOx natural gas engines to other vehicle applications such as school buses, port yard trucks, and regional haul. The prototype 12-liter near-zero engine has shown average NOx emissions of 0.011 to 0.016 g/bhp-hr and a 2 to 9 percent fuel economy improvement over the current engine offering. The prototype engine has been integrated into heavy-duty trucks in Los Angeles and is being demonstrated with positive preliminary feedback on performance. As of July 2017, the engine has reached more than 615,000 total demonstration miles with participation from key manufacturers (Figure 9) and fleets such as FedEx, UPS, Frito Lay, TTSI, and Waste Management. This broad demonstration and chassis integration effort represents a critical pre-commercialization step to better enable wide-scale market adoption. The numerous major vehicle manufacturers participating in the demonstration effort is also a testament to the anticipated high demand for vehicles powered by near-zero engines.

Successful large scale deployment of low NOx natural gas engines will result in significant air quality improvements in California. With a projected growth of 5 percent per year in market share for transit buses and refuse trucks, deployment of the near-zero engine in these markets is expected to reduce NOx emissions by up to 2.2 tons per day in the South Coast Air Basin.

Figure 9: Expected Vehicle Availability for 12-Liter Near-Zero Natural Gas Engine

TRUCK							COACH	
OEM	Freightliner	Peterbilt	Kenworth	Volvo	Mack	Autocar	OEM	MCI
								
Model	Cascadia Day Cab, Sleeper 114SD	320 384 365 579 567	W900S T660 T800 SH T680 T880	VNL	Pinnacle	Xpeditor	Model	Commuter Coach
Application	Tractor	Refuse Tractor Vocational	Tractor Vocational	Tractor	Tractor	Refuse	Application	Motorcoach

Source: Cummins Westport, Inc

[21] Fleets and Fuels. Clean Energy RNG for LA Metro Buses. May 29, 2017. http://www.fleetsandfuels.com/fuels/cng/2017/05/clean-energy-redeem-for-la-metro-buses/

Decarbonization Through Efficiency While Improving Affordability

The Natural Gas Research program invests in building energy efficiency to advance technology that supports healthy, comfortable, and energy efficient buildings, while helping California reduce its energy demand to avoid adding costly generation capacity and infrastructure. These efforts also move the state closer to its zero net energy goals.

Bills for natural gas customers can be high for those in the residential and commercial sectors. Installation of gas efficiency measures can lower customer bills in addition to increasing comfort, reducing GHG emissions, and improving building operation. For many customers, high first costs for installation and purchase of efficient equipment may prevent them from undertaking an efficiency improvement. Access to capital, utility finance programs, and program incentives can help customers overcome the first-cost barrier.

Affordable and Energy Efficient Manufactured Homes

A recent poll conducted by the UC Berkeley Institute of Governmental Studies shows that nearly half of the state's registered voters indicate that housing affordability is an "extremely serious" problem in California.[22] To meet demand, from market rate to low-income housing, California must double the housing it has for this sector—amounting to a 1.5 million unit shortfall on the number of affordable low-income housing units.[23] One possible solution to lower housing construction costs are manufactured homes (Figure 10).

Figure 10: Manufactured Homes

Source: The Levy Partnership

Manufactured homes, or mobile homes, are built off-site in a factory, on a non-removable steel chassis. These homes typically cost an average of $60 to $70 per

[22] Berkeley IGS Poll, Release #2017-16, September 19, 2017, http://escholarship.org/uc/item/65s716jf#page-1

[23] http://www.sacbee.com/news/politics-government/capitol-alert/article168107042.html

square foot to construct at the factory, depending on amenities and excluding land.[24] In comparison, the average price of $120 to $130 per square foot for a site built home depending on amenities and excluding land.[25]

By installing state of the art wall and roof insulation to reduce heating and cooling costs, the energy bills of gas-heated manufactured homes can be reduced by up to 48% and 56% in electric-heated homes.

California has more than 500,000 manufactured homeowners able to afford their homes because they are manufactured.[26] Most families are living in as much home as they can afford, and any increase in price of only a few thousand dollars might mean not qualifying for a home loan or not being able to afford basic amenities.

Manufactured housing must conform to the Manufactured Housing Construction Safety Standards enforced and maintained by the U.S. Department of Housing and Urban Development (HUD Code) and not the State Energy Code (Title 24).[27] This set of requirements preempts California's requirements and is far less stringent than Title 24. A recently completed research project (PIR-12-028) resulted in the developing advanced envelope designs that would add minimally to first cost, estimated at $2,700. The project also engaged key industry stakeholders so the new construction methods from this project could be standard practice in California within five years.[28] By installing state-of-the-art wall and roof insulation to reduce heating and cooling costs, the energy bills of gas-heated manufactured homes can be reduced by up to 48 percent and 56 percent in electric-heated homes.[29] These savings in energy bills means that home owners have more money to spend on other areas besides energy—adding to the affordability of these units.

[24] California State Board of Equalization, Residential Building Costs, January 2017, Class 7, for a 1000 square foot home; https://www.boe.ca.gov/proptaxes/pdf/ah53117.pdf

[25] Ibid. D Construction, Shape A or B, 1000 square foot home

[26] Ibid. Levy, E.; Rath, P.; et al., Levy Partnership, Inc., 2017. Advanced Envelope Systems for Factory Built Homes, California Energy Commission. Draft.

[27] Ibid, page 1.

[28] Ibid, page 157.

[29] Ibid, page 154.

Efficient Industrial Operations

Affordable energy and operating costs are important to industrial facilities. These facilities are faced with high energy costs and must meet stringent environmental regulations. A reduced energy bill that avoids compromising local air quality and emission requirements would help keep California operations competitive. At Mission Linen Supply in Santa Barbara (PIR-14-004), a novel ultra-low emission boiler was installed to supply steam for laundry operations (Figure 11).

Figure 11: Ultra Low Emission Boiler

Source: Hurst Boiler and Welding Company

The boiler uses a unique ultra-low NOx burner design, known as dynamic stage entrainment (DSE), to offer a cost competitive and efficient alternative to current technology that has the potential to reduce natural gas use while maintaining compliance with local air district requirements for NOx emissions. Laboratory tests have shown that the DSE technology can meet local air district emissions requirements for NOx, while operating with relatively low excess oxygen (which contributes to high NOx emissions) and high efficiency levels. Testing at Mission Linen in 2018 will verify the findings of the laboratory tests.

Efficient Hospital Operations

Hospitals have some of the highest energy use per square foot when compared to other building types. They are also large consumers of natural gas—primarily for space and water heating. Hospitals rely on legacy or older mechanical ventilation methods resulting in energy inefficiency from over ventilation. The net result is a significant amount of unnecessary natural gas used for heating and cooling. One researcher estimated that hospitals could use 40 percent more natural gas than is necessary to meet indoor air quality standards for safety and occupant comfort.[30]

[30] Advanced Microgrid Solutions, Project Narrative in Response to GFO-16-502, *Advanced HVAC Technology Demonstration Project: Integrated Approach to Reduce Natural Gas Use in High-Consuming Commercial Buildings*, August 2016.

At the Kaiser South Bay Medical Center in Harbor City (Los Angeles County) (Figure 12), an advanced air distribution design approach will be demonstrated that integrates air quality sensors with existing heating, ventilation and cooling (HVAC) systems to reduce natural gas consumption while meeting health and safety standards for indoor air quality. On-site natural gas consumption could be reduced by 30 to 50 percent.

Figure 12: Kaiser South Bay

Source: Advanced Microgrid Solutions

The technology works by monitoring indoor air quality in real time, and using diagnostic software to determine how often air exchange is necessary in a particular location. Existing technology exchanges the air at regular intervals, regardless of need. If successful, this technology could improve air quality and reduce natural gas-related operating expenses in hospitals throughout California.

Efficient and Affordable Multifamily Buildings

Affordability is a particularly salient issue for low-income renters in apartment buildings. About 3.3 million low-income households rent housing in California, and about 1.7 million low-income renter households are spending more than half of their income on housing and more than 16 percent of their income on energy costs.[31]

Low-income families are often in uncomfortable, inefficient dwellings and do not have the financial means to upgrade their units or pay a higher rent for the property owner to recoup an investment in retrofitting the rental properties with energy-efficiency upgrades.[32]

The installed measures were effective in delivering energy savings to the residents and the results indicated a 70 percent reduction in gas usage for water heating, 34 percent for space heating and 22 percent reduction in electricity.

Energy bills can be paid by the tenant, shared with the landlord, paid entirely by the landlord or included as part of the rent. This complicated arrangement of energy bill payments can be a disincentive for the building owner to do any energy efficiency upgrades if the owner does not see a return on investment and cannot recoup the

[31] Narayanamurthy, Ramachandran; Zhao, Peng (Electric Power Research Institute); Hammon, Rob; Hammon-Hogan, Ian (BIRAenergy); Larson, Samara (LINC Housing, LLC); Kliewer, Ron (Southern California Edison). *Scalable Near Zero Energy Retrofits of Low- Income Multifamily Housing*. California Energy Commission – Draft.

[32] Ibid, page 1.

additional costs for the upgrades. As an example, if the tenants pay the utility bills, the landlord cannot recoup the savings from lower bills and cannot raise rents to recoup the costs. Thus, there is a *split incentive* between the tenant and the landlord.

The Scalable Near-Zero Energy Retrofits of Low-Income Multifamily Housing project, led by the Electric Power Research Institute (EPRI), attempted to address these affordability issues. This project developed practical energy efficiency retrofit packages that integrated energy efficient technologies with renewables such as solar PV systems and solar thermal water heating systems. These retrofits and installation of on-site renewables demonstrated a near zero net energy multifamily retrofit. The retrofit packages were implemented in 30 units of a low-income multifamily property in Lancaster, California at The Villages at Beechwood (Los Angeles County) (Figure 13).

This project also identified barriers to adoption of these technologies, including an evaluation of existing financing models to increase scalability and investment in energy efficiency improvements. Groups of measures with different magnitudes of savings were evaluated and resulted in the installation of duct insulation, sealing the building envelope, solar thermal water heating, LED lighting, smart thermostats, and spray foam roof insulation.

Figure 13: The Villages at Beechwood

Source: Electric Power Research Institute

The installed measures were effective in delivering energy savings to the residents and the results indicated a 70 percent reduction in gas usage for water heating, 34 percent for space heating and 22 percent reduction in electricity used as shown in Table 6.[33] Overall, the annual net reduction in natural gas use from these combined energy efficiency measures equals about 144 therms/unit. With an estimated 2 million apartment units in California, and assuming similar savings across climate zones, these retrofits have the potential to save more than 250 million therms in California's multifamily sector. The potential benefit for California in terms of GHG reduction from reduced gas use resulting from these retrofits is about 1.3 million metric tons of CO_2 equivalent. In addition, improvements to HVAC efficiency and performance provided significant electricity savings for residents at 5 kWh/day/unit.

There were also substantial non-energy benefits to the occupants and tenants. Improvement in quality of life for occupants can be a key benefit of energy efficiency upgrades.

33 Ibid, page 3.

Table 6: Estimated EE Benefits of Energy Efficiency Measures

Measure	Unit	Modeled (per unit)	Measured (per unit)
Envelope Improvement Package (GAS) – duct replacements, insulation and semi-conditioned attic, air sealing	Therms	60 percent (451 out of 753 Therms)	34 percent (based on rooftop unit operation)
Envelope Improvement Package (ELECTRIC) – duct replacements, insulation and semi-conditioned attic, air sealing	kWh	45 percent (145 out of 239 Therms)	22 percent (based on rooftop unit operation)
Air sealing ACH improvement	percent	Not modeled	30 percent
Smart Thermostats – Average (gas)	Therms	5 percent	14 percent (estimated)
Smart Thermostats – average (electric)	kWh	5 percent	14 percent (estimated)
Water Heating Improvements – Solar Thermal	Therms	55 percent (118 Therms)	70 percent savings (100 Therms/unit)
Water Heating Improvements – distribution improve	Therms	35 percent (82 Therms)	
LED lighting	kWh	55 percent	Not measured directly
Spray Foam Roof Insulation	kWh	35 percent	17 percent

Source: Electric Power Research Institute

CHAPTER 3:
Conclusion

Key Results for the Year

Implementing the Natural Gas Research Program and developing the 2016-2017 Natural Gas Research Program Budget Plan achieved these following milestones in FY 2016-17:

- The Energy Commission filed its *2016 Natural Gas Annual Report* to the CPUC as required by October 2016, for activities during the period of July 1, 2015, through June 30, 2016.
- In FY 2016-17, the Energy Commission awarded $29.1 million to 28 new natural gas research projects.
- The Energy Commission filed its *FY 2015-16 Natural Gas R&D Proposed Supplemental Climate, Drought and Safety Budget Plan and Funding Request* for a budget of $3.6 million to the CPUC. In addition, the Energy Commission received a one-time expenditure authority in the FY 2016-17 state Budget Act to fund additional natural gas R&D projects.
- On September 29, 2016 CPUC Resolution G-3519 approved the allocation of $5.9 million unspent funds to future research. The Energy Commission provided the CPUC with a *Supplementary Reliability and Climate Focused Natural Gas Budget Plan* on January 13, 2017, addressing R&D areas supporting long-term infrastructure reliability, addressing the long term role and impact of natural gas in a carbon-constrained context, and reflecting recent legislative guidance requiring additional studies with California Council on Science and Technology. The Energy Commission received a one-time expenditure authority of $5.9 million in the FY 2017-18 state Budget Act to fund additional natural gas research project awards.
- In January 2017, the Energy Commission held an annual public workshop with stakeholders and experts in natural gas energy research for input to develop the FY 2017-18 budget plan. The Energy Commission filed its *FY 2017-18 Natural Gas Research and Development Program, Proposed Program Plan and Funding Request* (*FY 2017-18 Natural Gas R&D Budget Plan*) with a budget of $24 million to the CPUC as required in March 2017. CPUC approved the budget plan on September 28, 2017, by Resolution G-3527.

Next Steps for Natural Gas Research Program Budget Plan

The Energy Commission's next steps for the continuation of Natural Gas administration include the following:

- The Energy Commission continues to release competitive solicitations and requests for comment according to the schedule available on the Energy Commission's web page (http://www.energy.ca.gov/research/pier/) and provide updates to the schedule, as necessary.
- Consistent with its budget plans, the Energy Commission continues to release a notice of proposed award for each competitive solicitation and approve each award at a public business meeting.
- The Energy Commission will hold an annual public workshop when developing each budget plan.
- The Energy Commission will submit its *FY 2018-19 Natural Gas Research and Development Program, Proposed Program Plan and Funding Request* to the CPUC by March 31, 2018.
- The Energy Commission plans to submit an application for program enhancement in Spring 2018 to accelerate improved safety, methane emission control, and climate adaptation for the natural gas system. This application will include the proposed funding amount for the expanded program, the program schedule, and a summary of planned research initiatives. Before this application, the Energy Commission will host public workshops to solicit input from the natural gas utilities and other interested stakeholders. This application plans to propose roughly double the current funding amount and will primarily focus research on infrastructure safety and climate adaptation.

LIST OF ACRONYMS

Term	Definition
BTU	British thermal unit
CARB	California Air Resources Board
CCHP	Combined cooling, heat, and power
CHP	Combined Heat and Power
CNG	Compressed natural gas
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
DG	Distributed generation
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air-conditioning
IEPR	*Integrated Energy Policy Reports*
IOUs	Investor-owned utilities
MW	Megawatts
NAAQS	National Ambient Air Quality Standards
NO_x	Nitrogen oxides
PG&E	Pacific Gas and Electric Co.
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

APPENDIX A:
Natural Gas Research New Awards in FY 2016-17

In fiscal year 2016-17, $29.1 million in natural gas funding from FY 2015-16 and FY 2016-17 budget plans were awarded to 28 research projects.

APPENDIX B:
Natural Gas Research Completed Projects in FY 2016-17

In fiscal year 2016-17, 19 projects were completed, encumbering $19.3 million in natural gas funds.

APPENDIX C:
Natural Gas Research Active and Completed Project Write-ups in FY 2016-17

A summary of active and completed project write-ups is highlighted in Appendix C.