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ENERGY COMMISSION

Energy Research and Development Division

**STAFF REPORT**

# Natural Gas Research and Development Program

2019 Annual Report

**Gavin Newsom, Governor**
**November 2019 | CEC-500-2019-057**

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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 increased 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 2019 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 Research and Development at the Energy Commission's website, or contact the Energy Commission at 916-327-1551.

# ABSTRACT

In 2000, Assembly Bill (AB) 1002 (Wright, Chapter 932, Statutes of 2000) was enacted, requiring the California Public Utilities Commission (CPUC) to 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 2019 Annual Report* highlights project successes and benefits, and covers results of completed projects and the progress of current research from July 1, 2018, through June 30, 2019. In fiscal year 2018-2019, 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, natural gas, energy efficiency, pipeline safety, climate change, drought, buildings end use energy efficiency, industrial, agriculture and water efficiency, renewable energy and advanced generation, energy infrastructure, natural gas pipeline integrity, energy-related environmental research, natural gas-related transportation, disadvantaged communities, low-income communities

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# EXECUTIVE SUMMARY

The California Energy Commission's (CEC) Natural Gas Research and Development program enables the natural gas sector to support California's energy and environmental goals by accelerating technology innovation. Specifically, the program seeks to advance the following strategic objectives: reduce vulnerabilities and fugitive methane emissions in the natural gas infrastructure; improve the cost-competitiveness of renewable gas; and improve the energy efficiency and air quality profile of natural gas end uses.

California is currently charting a path towards decarbonization to achieve the state's goals of statewide carbon neutrality and a 100 percent zero-carbon electricity system by 2045 (Executive Order B-55-18; Senate Bill 100, de León, Statutes of 2018). While electrification is a key strategy to achieve these state goals, the natural gas sector continues to play an important role in meeting the state's objectives for reducing carbon emissions, increasing energy efficiency, and safeguarding health and safety.

The CEC's Natural Gas Research and Development program supports a range of technology categories to meet the program's strategic objectives (Table ES-1). The following sections provide a high-level overview of each of these technology categories as well as example projects that are helping to advance the natural gas sector.

## Internet of Things and Data Science

The Internet of Things – sensors and intelligent devices combined with advances in machine learning and software platforms – has broad applications for the natural gas sector. Internet of Things solutions for detection and monitoring, such as damage to natural gas pipelines caused by digging, grading, trenching, and boring, can be installed cheaply and quickly compared to current practices that are labor- and capital-intensive.

An in-depth assessment of these emerging technologies and tools would help regulators and gas operators to enhance the safety, operation, and management of the natural gas pipeline infrastructure. Gas Technology Institute (GTI), with research funds from the CEC, assessed various emerging sensors and intelligent devices, then cataloged the applicability of the available technologies in a web-based program and database. The Pipeline Safety and Integrity Technologies Search Tool provides a short description of gas monitoring technologies and the status of their development. Driving the adoption of these technologies can result in significant benefits. One of the demonstrated technologies, a meter breakaway fitting, has the potential to reduce annual natural gas leakage by about 310 thousand cubic feet (MCF).

## Solar Thermal

Solar thermal – using the energy of the sun for heating applications - provides a potential low-carbon alternative to natural gas for numerous heating end uses, particularly for hot water heating and process heating for food production facilities, such as dairies, hospitals and large institutions, and industrial and manufacturing customers. However, the market for solar thermal technologies has seen limited growth, due in large part to the capital costs of solar thermal solutions compared to competing natural gas technologies.

**Table ES-1: Technology Categories that Support Strategic Objectives for Natural Gas Investments**

| Strategic Objective | Internet of Things & Data Science | Solar Thermal | Bio-energy | Medium- and Heavy-Duty Natural Gas | Combined Heat & Power | Advanced Materials & Manufacturing |
|---|---|---|---|---|---|---|
| **Reduce Vulnerabilities and Fugitive Methane Emissions in the Natural Gas Infrastructure** | √ | √ | √ | | | √ |
| **Drive Large-Scale Customer Adoption of Energy Efficient and Low-Carbon Technology Solutions for Natural Gas End Uses** | | √ | √ | √ | √ | √ |
| **Improve the Cost-Competiveness of Renewable Gas** | | | √ | √ | √ | |
| **Minimize Air Quality Impacts from Natural Gas Use with Zero or Near-Zero Emission Technologies** | √ | | | √ | √ | |

*Source: California Energy Commission*

Solar thermal systems significantly reduce natural gas use in water heating but have yet to be adopted on a large scale due to high capital costs and having to compete for limited rooftop space with solar photovoltaic (PV) systems. The CEC entered into an agreement with the University of California, Merced (UC Merced) to develop and demonstrate an integrated solar thermal and PV technology that simultaneously produces heat and electricity at efficiencies comparable to stand-alone solar thermal and PV systems respectively. The project team constructed and verified the technical performance of a 20-tube array prototype that generates 150 watts (W) of direct current (DC) electricity and 400 W of thermal output per square meter. The technology was cost competitive at generating electricity as compared to PV panels while also proving the benefit of added solar thermal energy for hot water heating.

## Bioenergy

Techniques such as anaerobic digestion and gasification can produce renewable gas for generating energy. These techniques are most applicable in managing methane from agricultural and waste operations, such as dairies, wastewater treatment, landfills, forest tinder, and municipal solid waste. Where economically feasible, renewable gas may provide an option for decarbonizing natural gas supplies as well as helping waste streams such as forest biomass. However, a number of technological barriers exist to utilizing woody biomass for renewable gas production in an economic and sustainable manner. This includes the cost to transport the biomass to the renewable gas production facility as well as variations in feedstock.

In 2017, the CEC awarded All Power Labs to develop a new type of bioreactor small enough to be moved to the feedstock sources, particularly local loads of dry tree biomass. During this project, the combined cooling, heating, and power Power Pallet system demonstrated the technology with a pre-commercial pilot test with improvements in system performance, reliability, and manufacturing. The technology can be used as a source for emergency generation during grid outages and was proven effective when it provided emergency power to people who lost their homes after the Woolsey Fire in Malibu, California.

## Combined Heat and Power

Combined heat and power (CHP) using the waste heat from onsite generation offers several benefits, including a reduction in natural gas consumption and the associated greenhouse gas emissions. The market for combined heat and power has remained relatively flat. New opportunities exist that can further enable the market for combined heat and power, including using the waste heat for high-value chilling and filling market gaps for small and microscale systems. Small CHP systems typically have low electrical-to-thermal output ratios that make applications for small industrial facilities challenging, which often require higher electrical loads compared to thermal loads.

There is a gap between reciprocating engine CHP systems, which do not produce high enough electrical-to-thermal output ratios, and expensive fuel cell CHP systems, which produce high electrical-to-thermal output ratios. In 2014, the CEC funded EtaGen to demonstrate a 75 kilowatt (kW) prototype CHP system linear generator designed to capture high electrical-to-thermal output ratios at a cost competitive with reciprocating engine CHP systems. EtaGen's demonstration resulted in electrical efficiencies 38 percent, 0.10 lb/MWh $NO_x$ emissions without exhaust after-treatment, and low emissions of carbon monoxide and volatile organic compounds. In 2018, the CEC awarded EtaGen a follow-on project to develop and demonstrate a 250 kW CHP system, with further increased efficiencies and decreased emissions.

## Medium- and Heavy-Duty Natural Gas Vehicles

Natural gas vehicle technologies offer a beneficial alternative for medium- and heavy-duty vehicles to reduce smog-causing nitrogen oxides ($NO_x$) and greenhouse gas emissions. The projects funded by the CEC have resulted in commercial ultra-low $NO_x$ heavy-duty engine offerings, in a wide range of engine sizes, as near-term options. Hybrid powertrains paired with ultra-low $NO_x$ engines and advanced controls can result in further $NO_x$ and greenhouse gas emission reductions. To further decarbonize the heavy-duty vehicle market, natural gas hybrid systems will need further research, development, and demonstration, as full battery electric vehicles have a longer pathway to scale-up to high volume. The CEC is pursuing development of natural gas hybrid electric vehicle technologies with the capability of operating in a partial zero-emission mode known as geofencing. These natural gas hybrid electric platforms are expected to achieve emission levels equal to or below near-zero $NO_x$ emission standards, and will create a transitional pathway to full zero-emission heavy-duty vehicles.

In June 2017, the CEC awarded Terzo Power Systems, LLC, to develop a natural gas, hybrid-electric power system as a low-emission alternative to diesel engines for off-road agricultural equipment. Terzo Power Systems, LLC, is advancing natural gas hybrid technology from a laboratory-scale test skid to demonstration of a prototype nut harvester. By leveraging an electric power system and downsized natural gas engine, the system is designed to reduce fuel consumption by 50 percent compared to conventional diesel equipment. If this hybrid technology can be applied to the estimated 556 nut harvesters in California, reductions in diesel fuel consumption would result in annual emission reductions of 7,600 tons of carbon dioxide ($CO_2$).

## Advanced Materials and Manufacturing

Advancements in materials and manufacturing have the potential to provide multiple benefits to natural gas ratepayers. Advances in products that can reduce overall natural gas consumption are critical in the path forward to meeting California's emission targets. These products apply to a wide variety of items such from industrial machinery to advanced insulators.

Gas Technology Institute (GTI) developed an innovative and highly efficient gas-fired technology, to dry bulk agricultural and food products, called gas-fired thermal-vacuum drying (GFTD) with advanced heat pump system. The grant from the CEC funded the demonstration at Martin Feed LLC, in Corona, California, as well as the development of the system design and ejector manufacturing. This technology improves on the efficiency of rotary dryers, which have an efficiency of 35 to 40 percent per pound of product, with an increase to about 75 percent efficiency per pound of product. The technology can be adapted to other industrial dryer technologies and not only rotary drum dryers or screw dryers, and has the potential to provide annual natural gas savings of 2 billion cubic feet, electricity savings of about 4 mega-watt hours and the potential to recover 80 million gallons of water.

# CHAPTER 1: Introduction

The California Energy Commission's (CEC) Natural Gas Research and Development (R&D) program enables the natural gas sector to support California's energy and environmental goals by accelerating technology innovation. Specifically, the program seeks to advance the following strategic objectives: reduce vulnerabilities and fugitive methane emissions in the natural gas infrastructure; improve the cost-competitiveness of renewable gas; and improve the energy efficiency and air quality profile of natural gas end uses.

California is currently charting a path towards decarbonization to enable more energy end uses to utilize the power from an increasingly renewable electricity grid. Electrification is critical to achieving the state's goals for statewide carbon neutrality and a 100 percent zero-carbon electricity system by 2045 (Executive Order B-55-18; Senate Bill 100, de León, 2018). While electrification is a key decarbonization strategy for the state, the natural gas sector continues to play an important role in meeting the state's goals for reducing carbon emissions, increasing energy efficiency, and safeguarding health and safety.

## Reduce Vulnerabilities and Fugitive Methane Emissions in the Natural Gas Infrastructure

California has 118,000 miles of natural gas pipelines[1] and 14 underground gas storage facilities to meet the state's large energy consumption that is the second highest in the nation.[2] The integrity and resiliency of natural gas infrastructure are essential to public safety and avoiding catastrophic events, such as the San Bruno pipeline explosion (2010)[3] and Aliso Canyon gas storage facility leak (2015).[4]

Better technologies are needed to ensure and improve natural gas infrastructure safety against a broad range of challenges including natural forces, human activities, and, system defects such as corrosion, cracks, and material failures. Moreover, environmental events associated with climate change such as drought, land subsidence,

1 PHMSA Pipeline Miles and Facilities.

2 U.S. Energy Information Administration, State Energy Data System.

3 The explosion of a PG&E natural gas pipeline occurred on September 9, 2010, in San Bruno, California, a suburb of San Francisco, causing the death of eight people, destroying or damaging dozens of homes, neighborhood roads and infrastructure.

4 Natural gas escaping from a Southern California Gas Company's underground storage facility in the Santa Susana Mountains near Los Angeles, California occurred October 23, 2015, causing the relocation of more than 11,000 area residents.

extensive tree mortality, wildfires, and sea level rise underscore the need for the research that will provide a foundation for analyzing changes in environmental risks to the natural gas system. The significant role of fugitive methane emissions, which include leaks downstream of customer meters, has recently been acknowledged by inclusion of residential "downstream" emissions in ARB's official inventory and merits further inquiry for comprehensive inclusion in buildings, commercial, and industrial settings. Recent research emphasizes the importance of identifying and addressing super-emitters—a small fraction of sources responsible for a disproportionate fraction of emissions—as a source of fugitive methane emissions in California.

# Drive Large-Scale Customer Adoption of Energy Efficient and Low-Carbon Technology Solutions for Natural Gas End Uses

California's industrial, residential, and commercial sectors produce about 36 percent of the state's greenhouse gas emissions (GHG); historical trends between 2000 and 2017 for these sectors show very little reduction in emissions between 2000 and 2017.[5] To reach the state's 2050 GHG reduction goals building and industrial energy use will require at least 34 percent and 30 percent reductions in emissions relative to 2015 respectively. A substantial portion of the reductions must come from existing buildings and industries. Research on technologies focused on reducing the implementation costs of low-carbon technologies for space, water, and process heating, maximizing heat recovery opportunities, increasing building envelope and water distribution system efficiency, and overcoming technical and market barriers are a key strategy for the CEC to help meet California's GHG emission goals.

# Improve the Cost-Competiveness of Renewable Gas

With broad electrification, the largest remaining source of GHG emissions will be from non-combustion emissions, including methane from agriculture and from waste such as wastewater treatment, landfills, and municipal solid waste. Capturing and converting this methane for energy purposes will become a critical strategy for meeting the 2050 GHG emission reductions targets, both by reducing GHG emissions from non-combustion emissions and decarbonizing natural gas supplies. However, the cost of renewable gas from agriculture and waste is several times greater than traditional fossil fuel natural gas supplies, and the limited supply available from these sources constrains

5 California Air Resources Board, 2017 GHG Emission Inventory.

their prospects for decarbonizing the natural gas system, suggesting targeted use in transportation or industrial sectors.[6]

As such, there is a continuing research and technological development to lower the costs of capturing and upgrading the biogas into renewable gas for such targeted use to abate emissions from the renewable sources already mentioned.

# Minimize Air Quality Impacts from Natural Gas Use with Zero or Near-Zero Emission Technologies

Large portions of California, most notably the South Coast and San Joaquin Valley Air Basins, are in severe non-attainment of the National Ambient Air Quality Standards for ozone and particulate matter. While the industrial and shipping sectors are important to the region's economy, the sectors are also major contributors of the region's air pollutant emissions. Opportunities exist to reduce air pollutant emissions by ensuring natural gas is combusted with low-emissions technologies while maintaining economic competitiveness.

# Energy Commission Research and Development Strategy for Natural Gas

The CEC's strategy for Natural Gas R&D is organized by six technology categories that identify key market sectors. Many of these technology categories are used in concert with one another and address the multiple challenges shown in Table 1.

6 Jaffe, A.M., Dominguez-Faus, R., Parker, N., Scheitrum, D., Wilcock, J., Miller, M., 2016. The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute. Sacramento, CA.

**Table 1: Technology Categories that Support Strategic Objectives for Natural Gas Investments**

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| **Minimize Air Quality Impacts from Natural Gas Use with Zero or Near-Zero Emission Technologies** | √ | | | √ | √ | |

*Source: California Energy Commission*

## Internet of Things and Data Science

The Internet of Things (IoT) - sensors and intelligent devices combined with advances in machine learning and software platforms - has broad applications for the natural gas sector. IoT solutions for detection and monitoring can be installed inexpensively and quickly compared to current practices that are labor- and capital-intensive. In addition, IoT solutions can provide more granular data to better target technology and policy solutions. Furthermore, enhanced data through IoT solutions can advance modeling capabilities that enable improvements in pipeline monitoring, resulting in reduced maintenance costs and increased pipeline safety.

**Key Challenges and Needs:**

- Demonstrating the value proposition of IoT solutions for natural gas sector-specific applications
- Developing user interfaces and visualization tools capable of more effectively and efficiently operationalizing the data
- Improving the accuracy, cost, and capabilities of sensors

**Applications:** Building and Appliance Controls, Detecting Thermal Losses an Buildings, Natural Gas Pipeline Monitoring, Fugitive Methane Emission Monitoring, Climate Adaptation

**Sectors:** Residential, Commercial, Industrial, Natural Gas Supply and Distribution

## Solar Thermal

Solar thermal provides a potential low-carbon alternative to natural gas for numerous heating end uses, particularly for dairies, industry, and manufacturing. Beyond the small carbon footprint, solar thermal can help customers lower operational costs and reduce exposure to the price volatility of natural gas.[7] However, the market for solar thermal technologies has seen limited growth, primarily because solar thermal system costs are high.

**Key Challenges and Needs:**

- Reducing capital costs of solar thermal solutions compared to competing natural gas technologies
- Demonstrating that new solar thermal technologies can meet the thermal requirements of specific market segments

7 Weather, availability of storage, and commodity cycles are all factors that contribute to natural gas price volatility. It is common to see natural gas prices double or triple during cold winters. For more information, see Sparklibrary's webpage *Drivers of US Natural Gas Price Volatility*.

- Physical footprint of solar thermal technologies and competing uses for land and rooftop space

**Applications:** Residential and Commercial Hot Water Heating, Industrial and Food Processing, Desalination

**Sectors:** Residential, Commercial, Industrial

## Bioenergy

Techniques such as anaerobic digestion and gasification can produce renewable gas for generating energy. These techniques are most applicable in managing methane from agricultural and waste, such as that from dairies, wastewater treatment, landfills, forest tinder, and municipal solid waste. In addition, when used onsite, bioenergy can alleviate some natural gas supply issues such as methane leakage and natural gas price volatility. However, current commercially available bioenergy systems are not economically feasible under market conditions without support mechanisms like the Bioenergy Market Adjusting Tariff.

**Key Challenges and Needs:**

- Energy- and capital-intensive processes required to convert renewable gas into high-quality biomethane
- Fuel processing and transportation costs of biomass for industrial and other processing
- Variations in renewable gas composition from site-to-site based on feedstock differences
- Limited availability of biomass to meet natural gas demand

**Applications:** Wastewater Treatment, Landfill and Food Processing and Dairy Operations; Agricultural and Urban Residues (Agricultural Waste and Urban Wood Waste), Forest Management, Emergency Power

**Sectors:** Industrial, Wastewater Treatment, Transportation, Natural Gas Supply and Distribution

## Combined Heat and Power

Using waste heat from onsite generation or other energy sources offers several benefits, including a reduction in natural gas consumption and the associated GHG emissions. The market for CHP has remained relatively flat. New opportunities exist that can further enable the market for CHP, including using the waste heat for high-value chilling and filling market gaps for small and microscale systems. Technology advancements are necessary to realize these market opportunities.

**Key Challenges and Needs:**

- Economically converting waste heat into high value thermal energy

- Advanced technologies capable of optimizing combustion efficiencies and minimizing NOx emissions to near-zero levels
- Capital costs required to install and interconnect new equipment
- Matching thermal and electrical loads

**Applications:** Process Heating, Water Heating, Thermal Chilling

**Sectors:** Commercial, Industrial

## Medium- and Heavy-Duty Natural Gas Vehicles

The low cost of natural gas relative to diesel fuel is driving adoption of natural gas medium- and heavy-duty vehicles. A National Petroleum Council study estimates that about 20 percent of Class 7 and Class 8 vehicles will be fueled by natural gas by 2025.[8] However, there are still gaps in natural gas engine product offerings that would further optimize the specific application and duty cycles of medium- and heavy-duty vehicle market segments. Transitioning the medium- and heavy-duty vehicle market to natural gas provides an opportunity, through more advanced engine designs, for significant reductions in $NO_x$ emissions compared to the more incremental improvements anticipated in diesel engines. Finally, technology advancements in refueling and onboard storage for natural gas vehicles can also be leveraged for hydrogen vehicles as fuel cells and renewable hydrogen production become more economical.

**Key Challenges and Needs:**

- Filling gaps in natural gas engine product offerings including gas/electric hybrids
- Advanced control technologies capable of optimizing combustion efficiencies and minimizing NOx emissions to near-zero levels
- Cost and weight required for onboard storage

**Applications:** Drayage, Regional Haul, Refuse, Transit

**Sectors:** Transportation

## Advanced Materials and Manufacturing

Advancements in materials and manufacturing have the potential to provide important benefits to natural gas ratepayers. Materials advancements can enable more effective and economical approaches for sealing building envelopes and natural gas pipeline leaks. Breakthroughs at the nanoscale level (ultra-small particles) can provide new coatings and materials that greatly improve heat transfer capabilities of thermal systems at lower manufacturing costs than current technologies. Furthermore,

8 National Petroleum Council, 2012, *Advancing Technology for America's Transportation Future, Part One —Integrated Analyses.*

advancements in manufacturing and industrial appliances can help improve the efficiency of processing while minimizing costs.

**Key Challenges:**

- Long development times for new materials
- Customer concerns about performance, longevity, quality, costs and market acceptance of the resulting product
- Technology learning needed among downstream actors responsible for installation and operation

**Applications**: Building Envelope, Food Processing, Industrial Manufacturing, Pipeline Safety, Heat Exchangers, Pre-Fabricated Housing

**Sectors:** Residential, Commercial, Industrial, Natural Gas Supply and Distribution

# Natural Gas Research Program

The CEC's Natural Gas Research and Development (R&D) program is designed to 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 Natural Gas R&D program supports energy policy goals and standards while maintaining safety and reliability.

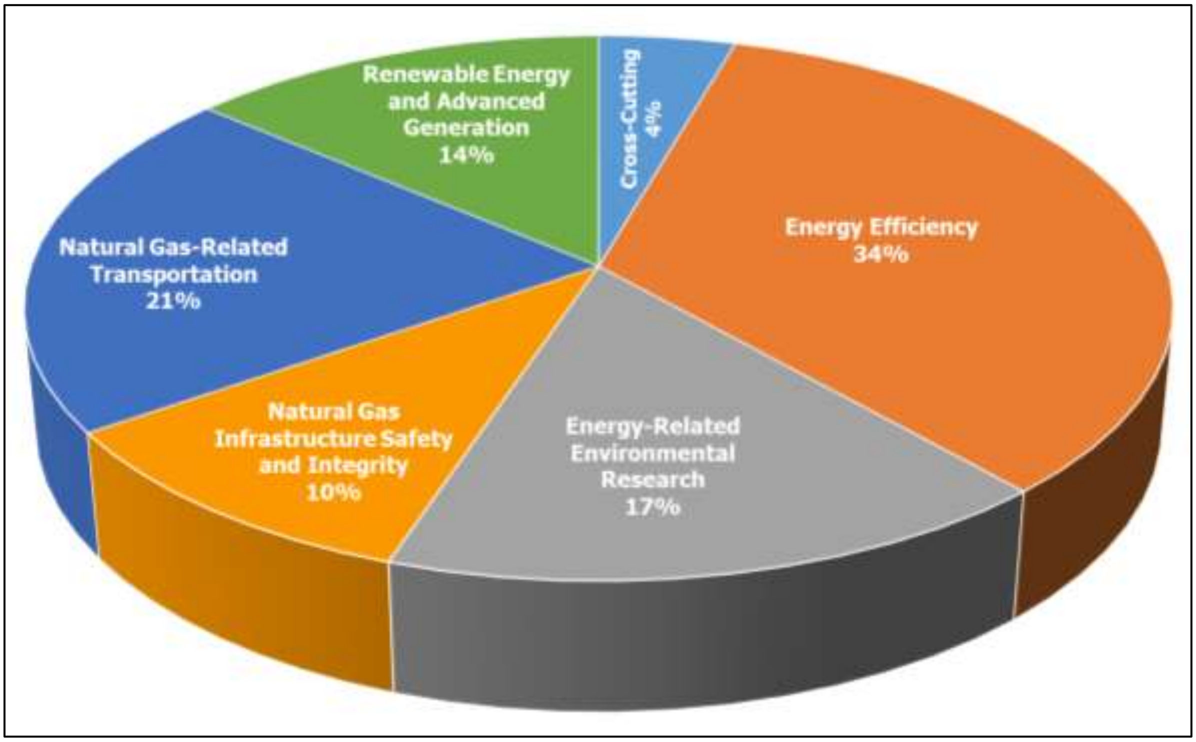
Assembly Bill (AB) 1002 (Wright, Chapter 932, Statutes of 2000) created the program, recognizing natural gas as a vital energy resource for California. AB 1002 directed the California Public Utilities Commission (CPUC) to impose a surcharge on all natural gas consumed in California. This surcharge funds a range of public interest R&D activities in energy efficiency, renewable energy and advanced generation, and energy infrastructure. The CEC has administered natural gas R&D in the public interest since 2004. SB 1250 (Perata, Chapter 512, Statutes of 2006) updated the program, changing how the natural gas research funds are encumbered and managed. Appendix A of this report provides more information on select energy policy goals for the future of natural gas in California.

The CPUC established that the CEC's Natural Gas R&D projects must:

- 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.

Since the beginning of the program, CEC has invested $256 million towards natural gas research. Figure 1 summarizes Natural Gas R&D project funding during the program's history.

**Figure 1: Natural Gas Research Program Funding – 2004 to June 2019**




*Source: California Energy Commission*

## Authorized Budget Plan Summary

Each year the CEC is required to submit to the CPUC a proposed program plan and funding request for the Natural Gas R&D program. When creating the budget plan and developing the research portfolio, the CEC 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 CEC 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 California Air Resources Board (CARB) and the United States Department of Energy (U.S. DOE), respectively.

In March 2018, the CEC submitted to the CPUC the *Natural Gas Research, Development, and Demonstration Proposed Program Plan and Funding Request for Fiscal Year 2018-19*. This plan established the direction and budget for natural gas research and development. The CPUC approved the plan in January 2019 and authorized the CEC to administer Natural Gas R&D projects. The CEC has 14 staff positions funded with Natural Gas R&D Program funds. The authorized funds have a two-year funding period, after which the agreements have a four-year liquidation period with activities to be completed within the six-year cycle. Table 2 provides a breakdown of the Fiscal Year 2018-19 (FY 18-19) authorized budget by research area.

**Table 2: Approved Fiscal Year 2018-19 Natural Gas Budget**

| Research Areas | FY 2018-19 Natural Gas Budget |
|---|---|
| Energy Efficiency | $6,000,000 |
| Renewable Energy and Advanced Generation | $3,000,000 |
| Natural Gas Infrastructure Safety and Integrity | $5,600,000 |
| Energy-Related Environmental Research | $3,000,000 |
| Natural Gas-Related Transportation | $4,000,000 |
| Program Administration | $2,400,000 |
| TOTAL | $24,000,000 |

*Source: California Energy Commission*

In accordance with CPUC Resolution G-3495, the CEC also identified $1.96 million in previous-cycle unspent funds. A supplemental budget request for those funds was not made for the FY 2018-19 budget period.

In March 2019, the CEC submitted its *Natural Gas Research, Development, and Demonstration Proposed Program Plan and Funding Request for Fiscal Year 2019-20.* The requested 2019–2020 budget included the maximum $24 million and a one-time supplement of $8.1 million in previously encumbered but unspent funds. The CPUC approved the $32.1 million FY 2019-20 budget request with Resolution G-3555 on August 1, 2019. The CEC plans to submit the *Natural Gas Research and Development Program Results for the period FY 2014-2015 to FY 2018-2019* report, as requested in Resolution G-3555 (pg. 14), and due 120 days from issuance of the resolution.

## Energy Commission Administration

The CEC's administration of the Natural Gas Research Program is in line with best practices for public research programs. The Natural Gas Research Program follows similar practices and procedures to the Electric Program Investment Charge (EPIC), and was recognized in 2017 as part of an independent evaluation of the EPIC program directed by the CPUC. The CEC's administration practices for R&D programs can be found in the 2018 EPIC Annual Report on the CEC's website at Investment Plans and Annual Reporting of the Energy Research & Development Program.

This annual report highlights Natural Gas R&D FY 2018-19 activities including funding opportunities, key administrative activities, project successes and benefits, as well as results from completed projects, and the progress of current research.

### Funding Opportunities and Awards

The Natural Gas R&D program is responsive to state energy policy and the critical needs and challenges facing the future of natural gas. The program's funding opportunities consistently align with CPUC direction to: support state energy policy; to collaborate with other entities; and, to address recommended target areas such as methane leakage, GHG emissions reductions, pipeline safety, and wildfire impacts. Table 3 provides FY 2018-19 funding opportunities.

**Table 3: Fiscal Year 2018-19 Natural Gas Funding Opportunities**

| Solicitation Title | Release Date | Program Area | Funding Amount | Application Deadline |
|---|---|---|---|---|
| GFO-18-503: Advancing Natural Gas Energy Efficiency Research in Existing Buildings and Baking Industry | 12/20/2018 | Energy Efficiency | $9,470,000 | 2/15/2019 |
| GFO-18-502: Natural Gas Infrastructure Safety and Integrity - Seismic Risk Assessment and Enhanced Training | 12/20/2018 | Natural Gas Infrastructure Safety and Integrity | $6,700,000 | 2/4/2019 |
| GFO-18-501: Demonstrating Innovative Solutions to Convert California's Residual Forest Biomass Resources in Renewable Gas | 10/24/2018 | Renewable Energy and Advanced Generation | $4,000,000 | 12/21/2018 |

*Source: California Energy Commission*

In FY 2018-19, the CEC awarded $20.7 million in natural gas funding to eight research projects. The CEC expects to award the remaining 2018-19 funds by June 30, 2020. Appendix B provides a list of the 78 active, completed or terminated (with funds spent) projects for FY 2018-19.

Two projects active during FY 2018-19 experienced issues affecting project progress and were terminated. Terminated projects with expended funds are included in Appendix C, Project Write-Ups. However, terminated projects with no funds expended are not included.

## Maintaining an Open and Accessible Process in Research and Development Funding

Commercializing new energy technologies requires a wide range of stakeholder perspectives and expertise. The CEC plays a vital role in bringing together stakeholders that can collectively enable the commercialization of new energy technologies to meet California's energy and climate change goals.

In FY 2018-2019, the CEC held several public workshops to solicit stakeholder input on how Natural Gas R&D funding opportunities can be most impactful, and to provide an opportunity for stakeholders to provide feedback to research priorities and solicitation requirements. For example, one workshop sought stakeholder feedback on the goals and focus areas of the proposed research as well as mechanisms for engaging the investor-owned gas utilities in a collaborative process.

Staff also presented and participated in numerous workshops and meetings that enable coordination and inform the Natural Gas R&D Program's activities. Some examples are:

- CPUC workshop on safety related research for renewable natural gas and hydrogen blending. Discussions included the steps needed to develop and finalize standards for interconnecting and authorizing the injection of renewable methane/renewable hydrogen into the natural gas pipeline system.
- Workshop presentation on preliminary results of a research project with Energy + Environmental Economics on natural gas infrastructure and decarbonization targets. Topics covered were: (1) overview of the research goals and objectives; (2) technology characterization of options to reduce or eliminate the GHG emissions footprint of the natural gas system in the long term; (3) potential transformation pathways of the natural gas system considering the overall potential evolution of the energy system to comply with GHG reduction targets and goals.
- Meetings with the U.S. DOE's Building Technologies Office on building envelopes, water heating, solar thermal and commercial cooking focused on sharing respective research project information, and results and potential opportunities for future collaboration.
- Webinar discussions on high performance attics, solar water heating, display cases using natural refrigerant, and efficiency improvements for computer gaming systems.
- Expo on real-world commercial applications of the latest clean transportation technologies in the development of near-zero and zero emission cargo handling equipment at the Port of Los Angeles.
- Conference on alternative low-carbon fuels, transportation electrification, 21st century ports, and freight distribution centers.

- Forum on near-zero and zero emission on- and off-road transportation technologies, community clean air action, and insights from public policy leaders. Staff leveraged information from this event including discussions of key topics such as sustainable freight and off-road vehicles.
- Global Climate Action Summit: China Pavilion and California-China Clean Tech Showcase: This event focused on California-China collaborations, policy strategies for fighting air pollution, and transportation and corporate innovation. Staff leveraged insights gained on global transportation technology advancements, international case studies, and industry trends to inform Natural Gas R&D Program activities.

Additionally, each research project benefits from a technical advisory committee composed of diverse professionals and subject matter experts in the following areas: end users, public interest environmental groups, applicable trade groups, equipment manufacturers, national labs, academia, product and technology developers, governmental agencies, local governments, and private research organizations.

To help ensure a public process, the CEC includes the following on its Energy Research and Development Web page:[9]

- Program information including the Natural Gas Program
- Energy Innovation Showcase; Highlighting Energy Innovation by the Numbers, an online project database and graphical web page
- Energy Research and Development Reports and Publications
- Research Funding Opportunities

The following is available on the Natural Gas Program's homepage.[10]

- Natural Gas Program Overview
- Frequently Asked Questions
- Natural Gas Funding Opportunities
- Natural Gas Feedback Opportunities
- Investment Plans and Annual Reporting
- Information for Bidders, Recipients, and Contractors

The CEC website also includes the Research Ideas Exchange, in which interested stakeholders can file their ideas for consideration in future solicitations. Public comment about the CEC's research is welcome and encouraged. Research ideas can be submitted online through Docket Number 19-ERDD-01.

9 CEC's *Research and Development* Website.

10 CEC's *Natural Gas Program* Website.

The CEC also maintains the following social media webpages to educate and inform the public about activities and opportunities:

- California Energy Commission's official blog
- California Energy Commission's LinkedIn profile
- California Energy Commission's Facebook page
- California Energy Commission's Twitter profile
- Empower Innovation social networking platform

Announced at the October 11, 2019, CEC Business Meeting, the Empower Innovation platform is the latest exciting online solution created to address the many barriers to launching a successful cleantech company and bringing innovative solutions to where they are the most needed. Entrepreneurs require help setting up their businesses and finding funding to reach commercial success. People who would benefit from cleantech solutions, like communities affected by air quality issues, need help identifying the right solutions and partnerships that work for them.

The Empower Innovation website breaks down these barriers by connecting innovators from across the cleantech ecosystem to each other and to many helpful resources that can accelerate their journey.

## Advancing Clean Energy Equity

The CEC, in response to legislation and CPUC direction, has prioritized energy equity in its research programs to ensure that the most vulnerable communities benefit from emerging clean energy technologies. The CPUC recently highlighted its directive, in Resolutions G-3546 and G-3555, for the CEC to enhance its outreach and engagement with representatives and members of disadvantaged communities. The Energy Research and Development Division is committed to reducing barriers preventing low-income, disadvantaged, and tribal communities from accessing clean energy opportunities.[11]

On April 8, 2015, the CEC adopted the Diversity Policy Resolution outlining its commitment to ensure all Californians have an opportunity to participate in and benefit from CEC programs that lead to job creation and training, improved air quality, and energy efficiency and environmental gains.

In addition, according to SB 350 (Clean Energy and Pollution Reduction Act of 2015) the CEC and the CPUC created the Disadvantaged Communities Advisory Group[12] to review and provide advice to both agencies on programs designed to achieve clean energy and reduce pollution. In particular, the advisory group determines whether proposed

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11 Research and Development's *Commitment to Diversity* at the CEC's Website.

12 *Disadvantaged Communities Advisory Group* at the CEC's website.

programs will be useful and effective in providing benefits to disadvantaged communities,[13] including small businesses and hard-to-reach customers (including rural and tribal communities).

Assembly Bill 523 (Reyes, Chapter 551, Statutes of 2017) requires the CEC to target a minimum of 25 percent of EPIC Technology Demonstration and Deployment funding to projects located in disadvantaged communities and 10 percent to projects located in low-income communities. The Energy Research and Development Division has developed a three-pronged strategy for meeting and exceeding these requirements that it also uses for the Natural Gas program. As a result, the CEC has been able to make similar progress towards supporting vulnerable communities in the Natural Gas program as it has in EPIC.

In the last fiscal year, there were 78 active Natural Gas R&D Program projects with 129 project sites, representing $82 million in allocated research funds. Forty-one of the 129 project sites were located in either a disadvantaged community, low-income community, or both. Twenty-nine percent ($23.5 million) of the $82 million was allocated to project sites in either a disadvantaged or low-income community or both (Table 4). Figure 2 shows the locations of the project sites.

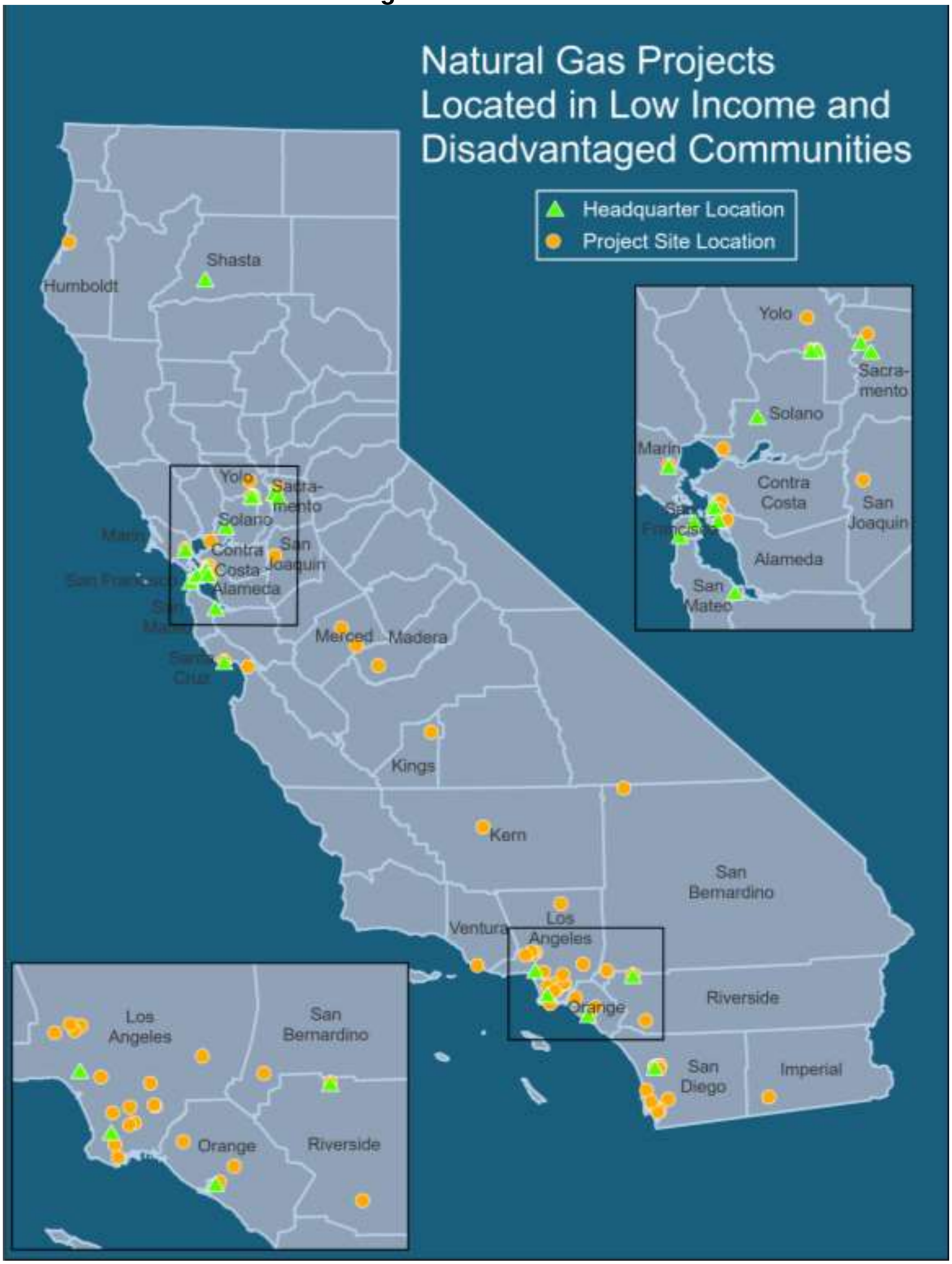
**Table 4: Fiscal Year 2018-19 Active Project Sites in Disadvantaged/Low-Income Communities**

| Diversity Category | # of Project Sites | Estimated Funding (millions) | Percent of Funding |
|---|---|---|---|
| Disadvantaged Community | 7 | $6.4 | 8% |
| Low-Income Community | 34 | $17.1 | 21% |
| Sum of Disadvantaged and Low-Income Community | 41 | $23.5 | 29% |
| Overlapping Disadvantaged and Low-Income Community | 27 | $19.2 | 23% |

*Source: California Energy Commission*

13 "Disadvantaged Communities" in SB 350 are defined by Health and Safety Code 39711 as the most burdened census tracts in California. Burden scoring is determined by 20 pollution/health and socio-economic factors.

**Figure 2: Public Interest Energy Research Natural Gas Headquarters and Project Sites in Disadvantaged and Low-Income Communities**




*Source: California Energy Commission*

# CHAPTER 2: Project Highlights

## Reduce Vulnerabilities and Fugitive Methane Emissions in the Natural Gas Infrastructure

An aging infrastructure and a changing climate threaten the safety and resiliency of California's energy systems. Climate change impacts have led to increased sea levels and major increases in the frequency, size, and destructiveness of wildfires, while leaks in the natural gas infrastructure have created major safety and environmental concerns. To address these and other challenges, the CEC is supporting new scientific and technological advancements to equip California's stakeholders with the solutions they need to build a safe and resilient energy system.

### Project Highlight: Technologies Assessment for Pipeline Safety and Integrity Monitoring

**Technology Category:** Internet of Things/Data Science, Advanced Materials and Manufacturing

**Sector(s):** Natural Gas Supply and Distribution

**Application(s):** Pipeline Safety

**Key challenges and needs addressed:**

- Customer concerns about performance, longevity, quality, and market acceptance of the resulting product
- Technology learning needed among downstream actors responsible for installation and operation

The aging of pipeline infrastructure is becoming an increasing concern for pipeline operators and regulators, and there are ongoing national efforts to increase the safety and integrity of natural gas systems. Gas transmission and distribution pipeline operators use a variety of technologies to detect damage to pipelines and assess the potential risks to natural gas infrastructures in accordance with the guidelines of the integrity management program administered by the Pipeline and Hazardous Materials Safety Administration. Given the number of different technologies and tools available nationally and in California, the CEC identified the need to research existing, emerging, and new technologies to enable gas operators to be more aware of the available technologies that can address specific threats, site conditions, and operational requirements.

> One of the field demonstrations, of the meter breakaway fitting, showed that the valves were successful in shutting off the gas line in 75 percent of the tests when the vehicle had direct hits to the riser-side of the meter setup.

In 2016, the CEC awarded funding to the Gas Technology Institute (GTI) to research instrumentations, devices, and systems, available to regulators and gas operators to enhance the safety, operation, and management of the natural gas pipeline infrastructure. GTI reviewed more than 200 referenced sources and searched for recently completed and close-to-commercialization technologies, which are two to four years from entering the market. GTI identified commercial, new, and emerging technologies and classified the technologies into three main categories: (1) damage prevention and mitigation; (2) threats and integrity management; (3) risk assessment and information management. The data was built into a web-based program that provides a description of each technology, the status of the technology, and additional information such as performance data (Figure 3).

**Figure 3: Pipeline Safety and Integrity Technologies Search**


**The Pipeline Safety and Integrity Database is a database of all the assessed technologies has been available since March 2018 to help select the best technologies to use for specific threats, site conditions, and operational requirements.**

*Source: Gas Technology Institute*

This research also demonstrated five technologies identified as "emerging" to determine how they can best fit in to utility safety programs. The technology demonstrations included: (1) technologies to detect obstacles during horizontal directional drilling; (2) meter breakaway fitting for vehicle collisions; (3) electromagnetic acoustic transducer for detecting cracks and weld defects in small-diameter unplug-able gas pipelines; (4) coating assessment tool for aboveground pipelines; (5) automated material traceability of steel pipes. The field demonstrations enabled the operators to interact with the technology developers to address utilities specific requirements and further develop the technologies to meet the utility specifications as well as identify further research needs.

One of the field demonstrations, of the meter breakaway fitting, showed that the valves were successful in shutting off the gas line in 75 percent of the tests when the vehicle had direct hits to the riser-side of the meter setup. Reported incidents by the CPUC show that these hits result in an annual California natural gas leakage of about 310 MCF.[14] The California gas utilities are evaluating the breakaway device for further field demonstrations and implementation at their service areas to address pipeline safety issues. More data on other specific technologies are available through the web database and can be accessed through the link provided with the following figure.

## Project Highlight: Assessing Environmental Risks to Natural Gas Infrastructure

**Technology Category:** Internet of Things/Data Science

**Sector(s):** Natural Gas Supply and Distribution

**Application(s):** Climate Adaptation

**Key challenges and needs addressed:**

- Demonstrating the value proposition of IoT solutions for natural gas sector-specific applications
- Developing user interfaces and visualization tools capable of more effectively and efficiently operationalizing the data
- Improving the accuracy, cost and capabilities of sensors

The Sacramento-San Joaquin Delta (Delta) contains natural gas infrastructure including underground storage systems and transport pipelines that support demand centers in California. Levees in the Delta prevent islands from flooding and thereby protect the integrity of this natural gas infrastructure. However, the combined effects of land subsidence (downward vertical movement of the surface of the Earth) and sea level rise associated with climate change threaten these levees and thereby put the natural gas infrastructure in the Delta at risk. To understand and effectively manage these risks, it is important to obtain robust estimates of subsidence and combine that with best-available sea level rise projections.

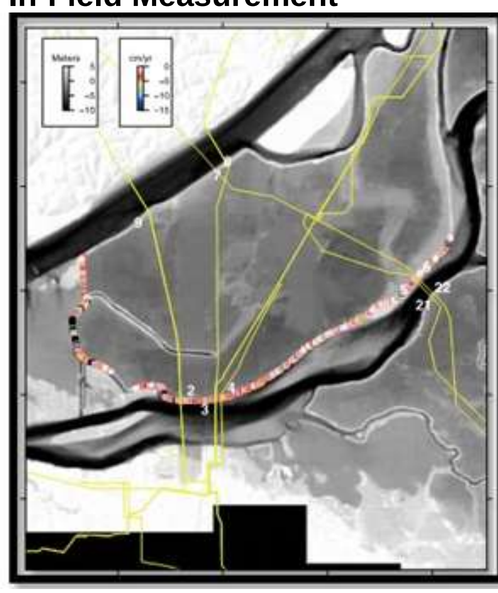
The goal of this research project was to validate and refine earlier subsidence measurements with higher spatial resolution measurements using Light Detection and Ranging (LIDAR) surveys. Prior estimates of subsidence generated using satellite interferometric synthetic aperture radar (InSAR) only indirectly provides information

14 U.S. Energy Information Administration. Natural Gas Summary – California. (2019).

about the vertical movement of the surface of the Earth at coarse resolution. The project also sought to use the improved subsidence data together with new sea level rise projections for the San Francisco Bay region to estimate when the compounding effect of subsidence and sea level rise will jeopardize natural gas infrastructure in the Delta.

The research team used a low-cost portable LIDAR system in 2015 and 2016. Other researchers had measured baseline conditions in the Delta in 2007 using airplane-mounted LIDAR, which provided a reference for comparison with 2015 and 2016 data (Figure 4). The research team developed the portable LIDAR as part of a prior study, enabling more frequent measurements and higher geographical resolution at lower overall cost. Using a geographical information system (GIS), the research team combined three datasets to project when exceedances of a federal engineering standard of 1.5 feet above water during 100-year flood events for levees (PL84-99) will start occurring. The data sets included: (1) the measured subsidence rates; (2) new sea level projections produced by Scripps Institution of Oceanography for California's Fourth Climate Change Assessment; and (3) estimates of the 100-year flood stage.

**Figure 4: Light Detection and Ranging In-Field Measurement**



**(Left photo) The portable LIDAR system on top of a truck performing measurements on the Delta levee. (Right image) A map of measured subsidence rates in the Sherman Island region of the Delta, with yellow lines indicating natural gas pipelines.**

*Source: Ben Brooks (USGS)*

The research team found that subsidence rates vary from zero to two inches per year with average values around one inch per year. Variations in subsidence rates along the levees are pronounced, and some of the largest gradients in subsidence are near pipeline crossings. The Sherman and Grizzly Island regions have subsidence rates of around two inches per year. The projections indicate that if current trends continue, the levees could be in violation of federal engineering in some locations as soon as the

2050s, increasing the risk of flood damage to natural gas infrastructure. This research project and prior work have provided state and local planners with information to help identify and implement adaptation measures.

# Drive Large-Scale Customer Adoption of Energy Efficient and Low-Carbon Technology Solutions for Natural Gas End Uses

Energy plays a critical role in the affordability, health, and comfort of California's residential customers and the communities in which they live. However, energy costs burden low-income communities disproportionately because residents in these communities typically spend a larger share of their income on energy than other households. Moreover, the housing shortage in California has shown the necessity for low-cost, rapidly deployable construction methods.[15] Advances in energy efficiency technologies in existing buildings and new construction projects save residents money, and can also increase the comfort of homes by more efficiently controlling heating and cooling.[16]

California is the fifth largest economy in the world and the energy sector is a vital contributor of the necessary goods, products, and services that have helped achieve that status. California's agricultural, commercial, and industrial sectors are large users of natural gas. To help maintain California's global competitiveness and continue the state's leadership in advancing low carbon opportunities, the CEC supports research to develop the next generation of clean energy technology solutions that help Californians reduce natural gas usage.

## Project Highlight: Demonstrating an Integrated Solar Thermal and PV Technology

**Technology Category:** Solar Thermal, Combined Heat and Power

**Sector(s):** Residential, Commercial

**Application(s):** Residential and Commercial Hot Water Heating

**Key challenges and needs being addressed:**

- Capital costs of solar thermal solutions compared to competing natural gas technologies

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15 Angela Hart. The Sacramento Bee. *How California's Housing Crisis Happened*. 2017.

16 California Energy Commission. *California Energy Commission - Tracking Progress Energy Efficiency*. 2018.

- Demonstrating that new solar thermal technologies can meet the thermal requirements of specific market segments
- Physical footprint of solar thermal technologies and competing uses for land and rooftop space

California is facing the challenge of reducing natural gas to mitigate global climate change and improve indoor and local air quality. An essential process that has been a large consumer of natural gas is water heating for residential and industrial processes. Solar thermal systems along with combined heat and power (CHP) systems significantly reduce natural gas use in water heating, but have remained uncompetitive at a large scale due to high capital costs.

The CEC entered into an agreement with the University of California, Merced (UC Merced) to develop and demonstrate a modular CHP collector that simultaneously produces heat and electricity at efficiencies comparable to stand-alone solar thermal and PV systems respectively. The system offers the potential to reduce natural gas consumption by providing thermal energy to meet building hot water and space heating needs, while simultaneously providing distributed electricity generation. The stacked values per footprint provide significant cost savings over separated PV and solar thermal systems installed side-by-side due to decreased installation costs and higher capacity.

Commercially available solar CHP systems combine traditional solar PV panel architectures with traditional thermal collector models, limiting their cost competitiveness. The system developed under this grant integrates several components packaged in a glass tube including aluminum channels and commercially available PV-cells to leverage both thermal and electrical energy generation. The project team constructed and verified the technical performance of a twenty-tube array solar CHP collector prototype (Figure 5).

The prototype generates 150 watts of direct current electricity and 400 watts of thermal power per square meter; in a single day, one square meter of collector can heat 25 gallons of water to 60 °C in addition to producing electricity (Table 5).

The experiment successfully demonstrated the potential to produce electricity and heat at efficiencies of 40 percent and 15 percent respectively. The results from the demonstration provide data that the technology can be cost competitive with solar PV while also providing the benefit of solar thermal generation. During a year, each square meter installed in California will generate an average 205 kilowatt-hours (kWh) of electricity and 547 kWh (19 therms) of heat, reducing natural gas consumption by 1163 kWh (40 therms), and eliminating 167 kg of $CO_2$ emissions.

**Figure 5: Micro-Combined Heat and Power Collector Testing Set-Up**

*Source: University of California, Merced*

**Table 5: Solar Collector Competition Matrix**

| Solar Collector | Thermal Output ($W/m^2$) | Electrical Output ($W/m^2$) | Estimated at Scale Electrical & Thermal System Cost (550W) | Significance |
|---|---|---|---|---|
| UC Merced CHP Solar System | 400 | 150 | $1.59 W Thermal + Electrical* | Potential to save 30 percent more roof space and $0.29 per watt with UC Merced's CHP Solar System |
| Solar Water Heater | 800 | 0 | $1.88 W Thermal + Electrical* | Same |
| PV Solar | 0 | 170 | $1.88 W Thermal + Electrical* | Same |

**The CHP solar system effectively combines heat and electricity generation at competitive rates compared to separate solar water heaters and PV solar systems. The data provided are estimates based on available average data and do not represent a specific product.**

***The estimated electrical and thermal system cost is modeled to include installation and match UC Merced's CHP solar system output, which produces a ratio of 400W/m2 of Thermal Output to 150 W/m2 of Electrical Output per square meter.**

*Source: U.C. Merced*

## Project Highlight: Improving Natural Gas Efficiency of Industrial Burners

**Technology Category:** Advanced Materials and Manufacturing

**Sector(s):** Industrial

**Application(s):** Food Processing

**Key challenges and needs addressed:**

- Customer concerns about performance, longevity, quality, costs and market acceptance of the resulting product
- Technology learning needed among downstream actors responsible for installation and operation

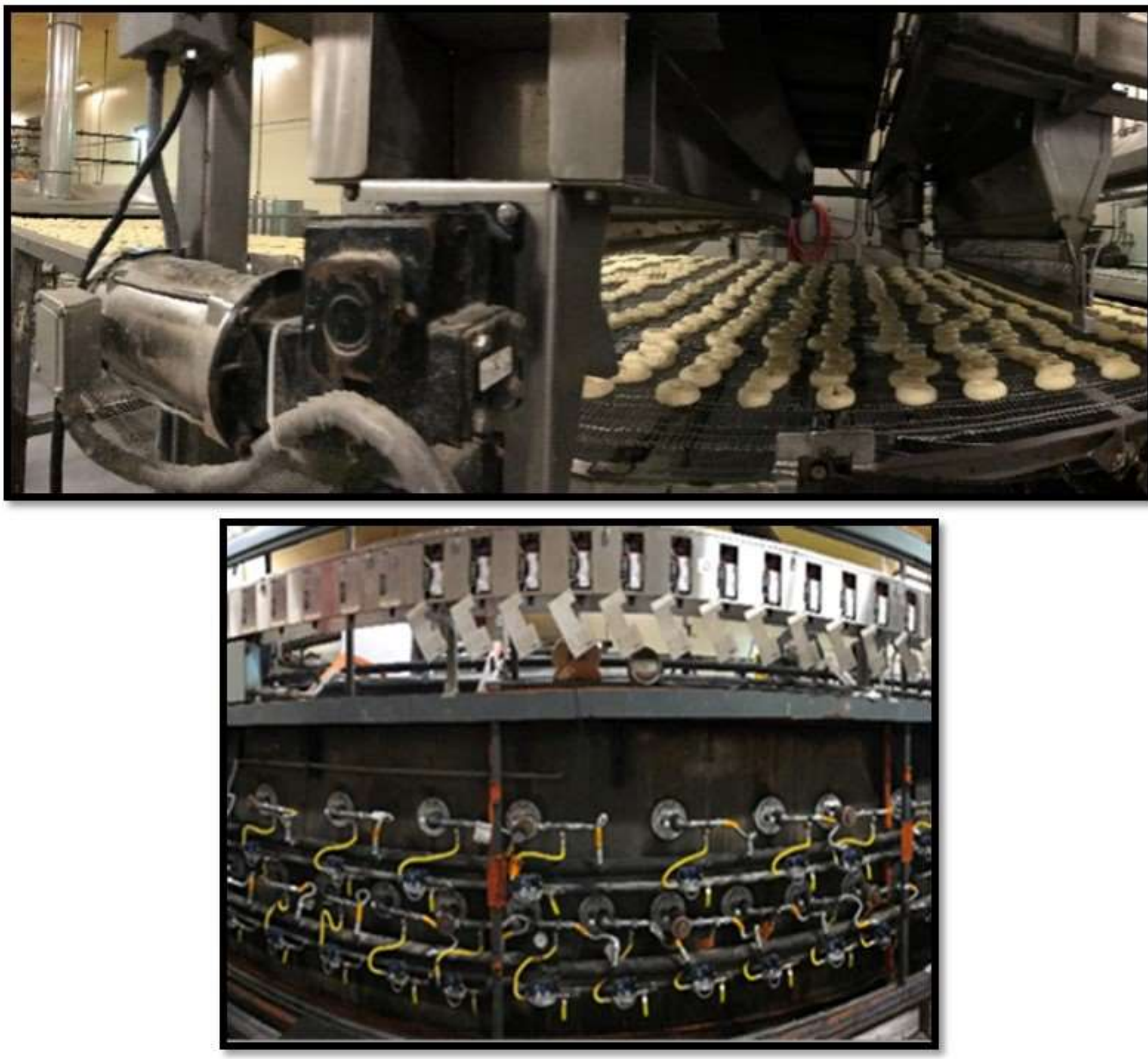
Ribbon burners are used widely in industrial cooking and drying applications. There are currently 250 facilities with ribbon burners in Southern California alone. These burners are fueled by natural gas and are coming under stricter air emission regulations, especially in California. Economic and regulatory pressures necessitate either the conversion of existing ribbon burners to other technologies, or modification to improve efficiency and reduce oxides of nitrogen ($NO_x$). As a result, there is a significant need for a cost-effective, low-emission solution to upgrade traditional ribbon burners to meet current regulations.

The ALN burner technology lowered $NO_x$ emissions by 50 percent and improved the energy efficiency by reducing fuel consumption by up to 5 percent.

With a grant from the CEC, GTI developed an advanced low $NO_x$ (ALN) ribbon burner combustion system focused primarily on the application for industrial baking burners. The ALN combustion system has the potential of supporting the baking industry in meeting and exceeding emission requirements while increasing efficiency and maintaining product quality through a solution for traditional direct-fired ribbon burners. The ALN approach is based on the use of flue gas recirculation (FGR) where a portion of exhaust gas is mixed with the combustion air. This results in reduction of the oxygen concentration in the combustion air, thus lowering the combustion temperatures and production of $NO_x$. Use of FGR reduces $NO_x$ emissions without requiring significant burner redesign.

The ALN concept initially underwent lab scale evaluation followed by pilot testing at an industrial baking oven manufacturer (C.H. BABB Company) before demonstration at a wholesale bakery, Western Bagel in Van Nuys (Figure 6). The installation included 90 new ribbon burners with individual flame controls for each burner and an oven control unit that modulates the oven temperature based on demand. A controlled portion of the exhaust was collected and routed back to the primary combustion air source. The results confirmed that the ALN technology lowers $NO_x$ concentration in the oven and with further burner tuning to enable higher FGR, even greater $NO_x$ reductions could be achieved. The ALN burner technology lowered $NO_x$ emissions by 50 percent and improved the energy efficiency by reducing fuel consumption by up to 5 percent. Based on this improvement, the use of this technology by the California baking industry could result in reductions of natural gas consumption of 1.3 million to 1.5 million therms per year.

**Figure 6: Demonstration Oven at Western Bagel**



**The project was successful at meeting or exceeding all performance targets to improve emission from industrial burners.**

*Source: Flynn Burner Corporation*

As the ALN burner system does not require any burner or baking oven redesign, but rather modification of the oven's flue gas exhaust and air supply arrangements, the cost of the add-on is expected to be about $50,000 per bakery. Assuming a bakery consumes approximately 600,000 therms/year at a cost of $0.50/therm and a 5 percent improvement in fuel efficiency, annual savings is about $15,000 a year. This results in the ALN burner system having a simple payback of 3.5 years (Table 6).

GTI collaborated with key market players during the course of this agreement including two dominant ribbon burner manufacturers, Selas Heat Technology and Flynn Burner Corporation, to discuss the potential of incorporating the technology into their systems. Preliminary discussions on the licensing of this promising technology have been initiated with the participating industrial partners and baking ovens manufacturers. Developments in California will likely be picked up and spread to other emerging markets, including Oregon, Washington, and internationally.

**Table 6: Demonstrated Burner Performance Improvements**

| Performance Metric | Pre-Installation Performance | Demonstrated Performance | Significance |
|---|---|---|---|
| $NO_x$ Emissions | 30 ppmv corrected to 3% $O_2$ | 15 ppmv corrected to 3% $O_2$ | 50 percent reduction in $NO_x$ emissions |
| Natural Gas Consumption | 476 Btu/lb | 454 Btu/lb | 5 percent improvement in natural gas efficiency |
| CO Emissions | < 800 ppmv corrected to 3% $O_2$ | < 800 ppmv corrected to 3% $O_2$ | Maintained SCAQMD Compliance |

## Project Highlight: Decreasing Natural Gas Use in Industrial Drying Processes

**Technology Category:** Advanced Materials and Manufacturing, Combined Heat and Power

**Sector(s):** Industrial

**Application(s):** Process Heating

**Key challenges and needs addressed:**

- Customer concerns about performance, longevity, quality, and market acceptance of the resulting product
- Capital costs required to install and interconnect new equipment

This technology improves on the efficiency of rotary dryers, which have an efficiency of 35 to 40 percent per pound of product, with an increase to about 75 percent efficiency.

Drying materials to improve storage life, meet technological requirements, or reduce transportation costs is one of the oldest and most commonly used operations. Drying is an energy-intensive operation often consuming between 50 to 60 percent of total energy input required for processing of the material.[17] In many cases, drying is the most energy-intensive and temperature-critical aspect of food, chemical, and pharmaceutical product processing while the drying of fruits and vegetables consumes more than 6.2 trillion Btus annually, and has a high potential for cutting consumption dramatically through improvements in energy efficiency for technological advancements and deployments.[18] Improving the energy efficiency performance of industrial drying equipment will have a highly beneficial effect on energy conservation and greenhouse gas (GHG) reduction in numerous food and chemical industries.

GTI developed an innovative and highly efficient gas-fired technology to dry bulk agricultural and food products called gas-fired thermal-vacuum drying (GFTD) with advanced heat pump system. The GFTD technology is able to use waste heat that is currently exhausted in rotary and non-rotary dryers. By directing the steam to thermal ejectors and creating a vacuum that lowers the pressure inside the rotary dryer, less natural gas is required in the drying process. This technology improves the efficiency of rotary dryers, which have an efficiency of 35 to 40 percent per pound of product, with an increase to about 75 percent efficiency.[19] The thermal ejectors themselves have no moving parts and are relatively inexpensive when mass produced. Additionally, the

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17 Yaroslav Chudnovsky et al. Gas Technology Institute. 2019. *Indirect Gas-Fired Dryer with Thermal Driven Ejector System for Bulk Food Processing: Development and Demonstration in California*. California Energy Commission, Draft Report.

18 Chudnovsky, Yaroslav. 2011. *High Efficiency Gas-Fired Drum Dryer for Food Processing Applications. California Energy Commission*, PIER Industrial/Agricultural/Water End-Use Energy Efficiency Program. CEC-500-2010-043.

19 Ibid.

thermal ejectors cool and condense the steam so the facility can capture and reuse the water for secondary use.

The grant from the CEC funded the demonstration at Martin Feed, LLC, in Corona, California, as well as the development of the technology's system design and ejector manufacturing (Figure 7). Martin Feed, LLC is a family-owned and operated feed business that collects waste bakery material and produces feed for dairy farms. The GFTD technology reduced natural gas consumption by 61 to 65 percent (from about 18,687 cubic feet per hour to 7,000 cubic feet per hour) and electric savings by at least 40 percent.[20] Table 7 provides more detailed results from the demonstration.

**Figure 7: Demonstration Thermos-Vacuum Rotary Dryer**

*Source: Gas Technology Institute*

The GFTD technology can be adapted to other dryer technology and not just rotary drum dryers or screw dryers, and has the potential to provide significant benefits to the industrial drying industry of California. Assuming 500,000 tons per year of dried products produced in California adopt this technology, annual natural gas savings would be about 2 billion cubic feet and electricity savings about 4 MWh along with the potential to recover 80 million gallons of water. This technology could result in annual natural gas savings of $20 million and reduction of 200,000 metric tons GHG annually.[21] In addition to food and feed products, the GFTD technology could also be marketed to other sectors

20 Ibid.

21 Ibid.

requiring drying of bulk materials, such as chemical granules, biomass pellets, and pharmaceutical products.

**Table 7: Demonstrated Dryer Performance Improvements**

| Performance Metric | Pre-installation Performance | Demonstrated Performance | Significance |
|---|---|---|---|
| Natural Gas Consumption | 9-18 MMBtu/h | 5-7 MMBtu/h | Reduced natural gas consumption by 61-65 percent |
| Drying Time | 8-30 min | 4-8 min | Decreased drying times can allow for higher throughput or allow for less operating equipment |
| Operating Temperature | 230-250°F | 150-180°F | Decreased temperatures can improve safety and reliability |
| Operating Pressure | 14.7 psi | 14.7-6.5 psi | Decreased pressures improve safety and reliability |

**The project was successful at meeting or exceeding all performance targets to improve initial drying process performance.**

*Source: Gas Technology Institute*

# Improving the Cost-Competitiveness of Renewable Gas

Renewable gas represents a source of low-carbon energy to California that can help minimize the climate change impacts of continued gas use. Renewable gas can be used as a substitute for conventional natural gas in a variety of applications with similar reliability and performance attributes. Commercially available bioenergy systems are not economically feasible under market conditions due to cost of transporting and processing of biomass. Thus, research and technological developments are ongoing to improve the efficiency and lower the cost of systems at two fronts: biochemical processes to produce high quality renewable gas from high moisture organic wastes such as manure and food wastes; and thermochemical processes and upgrading systems to produce renewable gas from woody biomass.

## Project Highlight: Onsite Biomass Conversion to Renewable Gas and Power

**Technology Category:** Bioenergy, Combined Heat and Power

**Sector(s):** Forestry

**Application(s):** Forest Management, Emergency Power

**Key challenges and needs addressed:**

- Variations in renewable gas composition from site-to-site based on feedstock differences
- Transportation costs for biomass in industrial production processes

In California, five years of drought (2012-2017) contributed to tree mortality and increased fire risk to communities through the greater abundance of dry biomass. The U.S. Forest Service estimated that 129 million trees died during this period in California's national forests from the combined effects of the severe drought, bark beetle infestation, and high tree densities. As of the end of 2018, about 1.2 percent of standing dead trees had been removed, suggesting a demand for incentives to collect the high amount of biomass from dead trees that remain uncollected in the forest and therefore not used for energy production.[22] Current value streams for the available biomass use in energy production are limited by the lack of available technology for converting biomass to electricity in addition to high costs of transportation and processing of varying forest material.

One technological pathway is to create distributed generators that are able to use forest biomass for onsite energy production to reduce transportation costs and account for local biomass composition and processed feedstock characteristics. In 2017, the CEC awarded a grant to All Power Labs to develop and test a 25 kW combined cooling, heating, and power (CCHP) Power Pallet system that uses wood biomass as a feedstock. The CCHP Power Pallet System, a small-scale biomass gasifier technology, is able to reliably produce renewable heat and power onsite by addressing material flow challenges for multiple regionally sourced biomass feedstock, such as woodchips and walnut shells.

During this project, the CCHP Power Pallet system was able to demonstrate the technology with a pre-commercial pilot test with improvements in system performance, reliability, and manufacturing (Figure 8). Key advancements were made in the fuel feed system by defining and abiding by strict fuel characteristics, as well as improvements to the gasifier technology including, fuel feed automation, vessel design relating to the defined fuel characteristics, and an improved char removal system that no longer clogs.

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22 Stephanie Gomes. USDA Forest Service. 2017. *Record 129 Million Dead Trees in California*.

**Figure 8: Prototype of Combined Cooling, Heating, and Power – Power Pallet**

*Source: All Power Labs.*

The project team tested the system and demonstrated that the gas to electricity system efficiency is 44 percent, while the heated gas to electricity system efficiency is 80 percent. Overall, the system was demonstrated to be 88 percent efficient at converting biomass into usable power (Table 8).

**Table 8: Demonstrated Power Pallet Performance**

| Performance Metric | Natural Gas Micro-CHP Reciprocating Engine Performance | Power Pallet Demonstrated Performance | Significance |
|---|---|---|---|
| Continuous Electrical Power | 19.2 kW | 25 kW | Can produce comparable power as natural gas micro-CHP engines. |
| Electrical Efficiency & Heat Output Efficiency | 28.1% & 55.8% | 26.4% & 53.9% | Has competitive efficiencies as natural gas micro-CHP engines. |
| Carbon Monoxide Emissions | < 70 ppmvd | 34 ppmvd | Produces less than half the emissions as compared to natural gas micro-CHP engines standards. |
| Nitrogen Oxide Emissions | < 11 ppmvd | 0 ppmvd | Produces no $NO_x$ emissions. |

**The technology has competitive CHP efficiencies as compared to natural gas micro-CHP engines but with fewer emissions.**

**Note: The data provided are estimates based on available average data and do not represent a specific product.**

*Source: IFC & All Power Labs.*

This microscale (< 50 kW) technology can be used as a source of generation for microgrids and for supporting critical operations and services during grid outages, extreme weather events, and other emergencies. During the project, the CCHP Power Pallet provided emergency power to people who lost their homes after the Woolsey Fire in Malibu, California. Leveraging the project and a partnership with All Power Labs in 2018, the social impact group Skysource received the Water Abundance X-Prize by integrating the CCHP Power Pallet with Skywater equipment to demonstrate the production of 2,000 liters of water per day using 100 percent renewable energy. In 2018, reflecting the market readiness of the technology, CAL FIRE awarded funds to Mendocino County to install 10 CCHP Power Pallet units to process wood waste and reduce wildfire risk.

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# Minimizing Air Quality Impacts from Natural Gas Use to Zero or Near-Zero Levels

The transportation sector accounts for about 40 percent of the state's GHG emissions while electricity and industrial thermal generation account for an additional 16.5 percent.[23] In addition to carbon emissions, motor vehicles are the largest source of air pollution that harms human health, accounting for nearly 80 percent of $NO_x$ emissions and 90 percent of diesel particulate emissions. The CEC is supporting development of advanced near-zero emission natural gas engines and generators that use renewable gas, hybrid gas/electric fuels, and CHP technology. CHP technologies can provide air quality benefits and reduce GHG emissions from industrial and commercial plants. CHP systems require less fuel to produce energy because they capture and use heat that would otherwise be wasted.

### Project Highlight: Advancing Natural Gas Linear Generators through Combined Heat and Power

**Technology Category:** Combined Heat and Power

**Sector(s):** Commercial, Industrial

**Application(s):** Small Commercial, Light Industrial

**Key challenges and needs addressed:**

- Advanced control technologies capable of optimizing combustion efficiencies and minimizing NOx emissions to near-zero levels
- Capital costs required to install and interconnect new equipment
- Matching thermal and electrical loads

Many small commercial and light industrial facilities — with loads less than 1 MW — have highly predictable electrical loads, but small or highly variable thermal loads. These are generally industrial and commercial processes that use a high amount of natural gas. Small CHP systems typically have low electrical-to-thermal output ratios that make these applications challenging. Additionally, sub-megawatt conventional natural gas engines have relatively low electrical efficiency and high waste heat output. Fuel-cell based systems have high electrical-to-heat output ratios, but have higher capital costs.

In 2014, the CEC funded EtaGen to demonstrate a 75 kW prototype CHP system linear generator (Figure 9). EtaGen's high electrical-to-thermal output linear generation technology enables highly efficient, low-$NO_x$ electricity generation while also being capable of serving thermal loads. The linear generators are able to achieve this

23 California Air Resources Board. California Greenhouse Gas Emissions for 2000 to 2016. June 2018.

performance through homogeneous charge compression ignition. EtaGen's generator does not require any exotic materials, can be manufactured at low cost, and is expected to have low maintenance costs due to its design that avoids the use of oil, valves, sparkplugs, and fuel cell catalysts.

EtaGen's demonstration resulted in electrical efficiencies of 38 percent, 0.10 lb/MWh $NO_x$ emissions without exhaust after-treatment, and low emissions of carbon monoxide and volatile organic compounds. The demonstration had levels of emissions below the standards that the South Coast Air Quality Management District set for generators and the team is hoping to exceed these standards in future developments to reach the California Air Resources Board's (CARB) standards for distributed generator standards, which currently does not apply to linear generators (Table 9).

In 2018, the CEC awarded EtaGen a follow-on project to develop a high-efficiency 250 kW CHP system. Deployment is planned for the spring of 2020. The 250 kW system, which is composed of two 125 kW units packaged in a single container is expected to meet or exceed the CARB standard of 0.07 lb/MWh. Based on tests to date, the targeted electrical efficiencies for the system are aimed at being comparable to fuel cells at 45 percent. Commercialization of EtaGen's ultra-clean, high-efficiency, and cost-effective linear generator technology fills a market gap for small-scale CHP and pushes market readiness for low emission natural gas generators.

**Figure 9: Enclosed Installation of Etagen Linear Generator Combined Heat and Power System**


*Source: EtaGen*

**Table 9: Small Scale Distributed Generator Competition Matrix**

| Generator | Power Stack Size | Electrical Efficiency (LHV net AC)* | Estimated Cost ($/kW) | SCAQMD Compliance Without After-treatment |
|---|---|---|---|---|
| EtaGen's Demonstrated Linear Generator (2019) | 75 kW (To be increased to 125kW) | 38% (Estimated to increase to 45%) | $2,500 | Yes |
| Small Natural Gas Fuel Cell | 300kW (100-400 kW) | 42.5% (40-60%) | $10,000 | Yes |
| Small Natural Gas Reciprocating Engines | 100kW (10kW-10MW) | 30% (30-40%) | $1,650 | No |

**EtaGen's Linear generator provides generation at high efficiencies at costs below that of fuel cells.The data provided are estimates based on available average data and do not represent a specific product.**

*** Net alternating current production efficiency performance at lower heating value**

*Source: EtaGen & Department of Energy*

**Project Highlight: Creating Natural Gas Engine Configurations for Off-road Applications**

**Technology Category:** Medium- and Heavy-Duty Natural Gas Vehicles

**Sector(s):** Transportation

**Application(s):** Off-Road Vehicles

**Key challenges and needs addressed:**

- Filling gaps in natural gas engine product offerings including gas/electric hybrids

California's agriculture industry relies heavily on diesel engines to power mobile off-road equipment. Diesel-powered equipment has remained the industry standard due to competitive costs, high torque-to-horsepower ratio, and ease of integration for various applications. Diesel-powered equipment is a major contributor of criteria pollutants such as $NO_x$ and diesel particulate matter (PM), as well as GHGs. Low-emission alternatives to diesel equipment are necessary to realize air quality and climate mitigation benefits while maintaining competitive performance and cost.

In June 2017, the CEC awarded a grant to Terzo Power Systems, LLC, to develop a natural gas, hybrid-electric power system as a low-emission alternative to diesel engines for off-road agricultural equipment. The hybrid system uses a ruggedized battery pack to power electrified propulsion and hydraulic systems, while a natural gas engine provides extended range to maintain longer operating times between refueling cycles.

Terzo Power Systems, LLC advanced natural gas hybrid technology from a laboratory-scale test skid to demonstration of a prototype nut harvester (Figure 10).

**Figure 10: Prototype Natural Gas Hybrid-Electric Nut Harvester**

*Source: Terzo Power Systems, LLC*

Conventional diesel equipment typically uses mechanical power take-off systems to transfer power from the diesel engine to auxiliary components such as hydraulic pumps needed for work functions. In the hybrid-electric power system, it is possible to decouple the engine from the auxiliaries, helping deliver emissions and efficiency benefits by allowing the engine to be downsized and operated at optimal steady-state conditions. By leveraging this quality, the system is designed to reduce fuel consumption by 50 percent compared to conventional diesel equipment.

The system is designed to reduce fuel consumption by 50 percent compared to conventional diesel equipment.

The initial target market will be nut orchards, but the electrified subsystems and hybrid architecture can be adapted to serve other applications in the mobile off-road equipment industry. If this hybrid technology can be applied to the 556 estimated nut harvesters in California,[24] reductions in diesel fuel consumption could result in annual emission reductions of 7,600 tons of $CO_2$, 290 tons of $NO_x$, and 16 tons of PM. Terzo Power Systems, LLC is working on an initial commercialization strategy with Orchard Machinery Corporation, a nut harvester manufacturer, and Anderson Industrial Engines, an off-road natural gas engine distributor, with the goal of entering production in 2020 (Table 10).

**Table 10: Hybrid vs Conventional Nut Harvester Competition Matrix**

| Generator | Conventional Diesel System | Terzo Hybrid System | Significance |
|---|---|---|---|
| Power Consumption | 130 KW | 64 kW | 50 percent reduction in emissions realized through decreased power requirement and fuel consumption |
| Emissions (CO) | ~0.97 tpy per harvester | ~0.485 tpy per harvester | 50 percent reduction in emissions |
| Emissions ($NO_x$) | ~1.05 tpy per harvester | ~0.525 tpy per harvester | 50 percent reduction in emissions and fuel consumption |
| Emissions (PM) | ~0.058 tpy per harvester | ~0.029 tpy per harvester | 50 percent reduction in emissions |

**Note: The data provided are estimates based on available average data and do not represent a specific product.**

*Source: Terzo Power Systems, LLC*

24 California Air Resources Board, 2018: Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower.

# LIST OF ACRONYMS

| Term | Definition |
|---|---|
| AB | Assembly Bill |
| CARB | California Air Resources Board |
| CHP | Combined heat and power |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| CPUC | California Public Utilities Commission |
| EPIC | Electric Program Investment Charge |
| GHG | Greenhouse gas |
| GFO | Grant Funding Opportunity |
| HVAC | Heating, ventilation, and air-conditioning |
| IoT | Internet of Things |
| kW/kWh | Kilowatt/ kilowatt-hours |
| MCF | metric cubic feet |
| MGD | Million gallons per day |
| mm/Btu | Million British Thermal Units |
| $NO_x$ | Oxides of nitrogen |
| PIER | Public Interest Energy Research |
| PON | Program Opportunity Notice |
| R&D | Research and Development |
| SB | Senate Bill |
| UC | University of California |

# APPENDICES

Appendix A: Select Natural Gas Policy Goals for California’s Energy Future

Appendix B: FY 2018-19 Natural Gas Active, Completed, and Terminated Project List

Appendix C: FY 2018-19 Natural Gas Active, Completed, and Terminated Project Write-Ups

Appendices are available as a separate volume, Publication Number CEC-500-2019-057-AP.