PREPARED BY:

James Friedrich
Molly O'Hagan
Primary Authors

Tiffany Solorio, Lead
Nicole Smith Dani
Project Managers

Erik Stokes
Manager
ENERGY DEPLOYMENT AND MARKET FACILITATION OFFICE

Laurie ten Hope
Deputy Director
RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.
ACKNOWLEDGEMENTS

The authors appreciate the contributions from these Energy Research and Development Division staff members:

Rizaldo Aldas
Peter Chen
David Erne
Amir Ehyai
Guido Franco
Chuck Gentry
Rey Gonzalez
Yu Hou
Bradley Meister
Kevin Mori
Kevin Uy
Susan Wilhelm
Yahui Yang
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 2018 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 2018 Annual Report highlights project successes and benefits, and covers results of completed projects and the progress of current research from July 1, 2017, through June 30, 2018. In fiscal year 2017-2018, 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

Please use the following citation for this report:

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>i</td>
</tr>
<tr>
<td>PREFACE</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>Internet of Things and Data Science</td>
<td>3</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>3</td>
</tr>
<tr>
<td>Bioenergy</td>
<td>4</td>
</tr>
<tr>
<td>Combined Heat and Power</td>
<td>4</td>
</tr>
<tr>
<td>Medium- and Heavy-Duty Natural Gas Vehicles</td>
<td>5</td>
</tr>
<tr>
<td>Advanced Materials and Manufacturing</td>
<td>5</td>
</tr>
<tr>
<td>CHAPTER 1: Introduction</td>
<td>7</td>
</tr>
<tr>
<td>Reduce Vulnerabilities and Fugitive Methane Emissions in the Natural Gas Infrastructure</td>
<td>8</td>
</tr>
<tr>
<td>Drive Large-Scale Customer Adoption of Energy Efficient and Low-Carbon Technology Solutions for Natural Gas End-Uses</td>
<td>9</td>
</tr>
<tr>
<td>Improve the Cost-Competitiveness of Renewable Gas</td>
<td>9</td>
</tr>
<tr>
<td>Minimize Air Quality Impacts from Natural Gas Use to Zero or Near-Zero Levels</td>
<td>9</td>
</tr>
<tr>
<td>Energy Commission Research and Development Strategy for Natural Gas</td>
<td>9</td>
</tr>
<tr>
<td>Internet of Things and Data Science</td>
<td>10</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>11</td>
</tr>
<tr>
<td>Bioenergy</td>
<td>11</td>
</tr>
<tr>
<td>Combined Heat and Power</td>
<td>12</td>
</tr>
<tr>
<td>Medium- and Heavy-Duty Natural Gas Vehicles</td>
<td>12</td>
</tr>
<tr>
<td>Advanced Materials and Manufacturing</td>
<td>13</td>
</tr>
<tr>
<td>The Natural Gas Research Program</td>
<td>13</td>
</tr>
<tr>
<td>Energy Commission Administration</td>
<td>15</td>
</tr>
<tr>
<td>Bringing Different Perspectives Into R&amp;D</td>
<td>16</td>
</tr>
<tr>
<td>Advancing Legislative Priority for Clean Energy Equity</td>
<td>16</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1: Measurement Setup at a Sample Houses ................................................................. 19
Figure 2: Global Positioning System Device on Excavator and Utility Monitoring Dashboard .... 22
Figure 3: AeroBarrier Sealant for Building Envelopes............................................................ 26
Figure 4: Manufactured Home Project .................................................................................. 28
Figure 5: Schematics of Conventional Flat-Plate Round Tube Solar Thermal Collector With Solar Thermal Collector Designed With Mini-Channels .......................................................................... 30
Figure 6: Cooling Towers Above the Absorption Chiller at the Gallo Cattle Company Cheese Production Facility in Atwater, California ..................................................................................... 33
Figure 7: Combination Oven Testing at the Foodservice Technology Lab ............................... 34
Figure 8: Las Gallinas Valley Biogas Energy Recovery System in San Rafael, California ........ 36
Figure 9: Pilot-Scale Landfill Gas Cleanup Subsystems ............................................................ 38

LIST OF TABLES

Table ES-1: Technology Categories That Support the Strategic Objectives for Natural Gas Investments ................................................................................................................................. 2
Table 1: Technology Categories that Support the Strategic Objectives for Natural Gas Investments ........................................................................................................................................ 10
Table 2: Advanced Absorption Chiller Versus Other Refrigeration Options ......................... 32
Table 3: Tecogen System Compared With Higher Cost CHP Options ...................................... 42
EXECUTIVE SUMMARY

Recent state policies, including Senate Bill 100 (De Leon, 2018) and Governor Edmund G. Brown Jr.’s Executive Order B-55-18, have put California on a path to completely decarbonize its energy sector by 2045. Under Senate Bill 100, the electricity sector is expected to play a major role in achieving the state’s greenhouse gas reduction goals by supplying electricity generation that is 100 percent or near 100 percent renewable. Complementing the supply-side strategy, the state has charted a path towards additional deep greenhouse gas reductions by first electrifying end-uses that can most easily and cost-effectively electrify. While the path is well-paved for new residential construction and programs and incentives are in place to electrify single occupancy transportation such as light-duty vehicles, more must be done to electrify the industrial sector. Research and development (R&D) to enable increased electrification is being conducted under the California Energy Commission’s Electric Program Investment Charge (EPIC). However, significant built infrastructure currently depends on natural gas and a transition strategy is still forming. In the meantime, meaningful greenhouse gas reductions can be made in natural gas use through energy efficiency. Other strategies to decarbonize traditional uses of natural gas include solar thermal for heating, technologies to capture and use biogas, and reduction of methane leaks from gas infrastructure. Meanwhile, the development of renewable gas use as an alternative to diesel in the medium- and heavy-duty vehicle sectors is an important strategy for lowering emissions and improving air quality.

California's residential and commercial sectors rely on natural gas for three key end uses: cooking, space heating, and water heating. While electric options exist for these end uses, current commercial offerings do not meet most consumers’ demands for cost and performance. For California's industrial sectors such as the food processing sector, the high thermal requirements of many industrial processes make them difficult to electrify. For the transportation sector, battery electric vehicles are poised to dominate the light-duty vehicle sector and even segments of the medium-duty vehicle market. However, battery electric vehicles are unlikely to be a viable option for most medium- and heavy-duty vehicle applications for a while until improvements to the energy density and weight of batteries occur.

The natural gas sector can fill important gaps in areas where electrification will be challenging to achieve. However, there are numerous challenges that must be addressed if the natural gas sector is to fulfill this role in California's future energy mix. The California Energy Commission's Natural Gas Research and Development program is designed to accelerate technology advancement and adoption that will better enable the natural gas sector to support California's energy and environmental policy goals. These technology advancements support the following strategic objectives:

- 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 that will be challenging to electrify.
- Improve the cost-competitiveness of renewable gas.
- Minimize air quality impacts from natural gas end-uses to zero or near-zero levels.
The Energy Commission’s strategy for Natural Gas research and development is organized by the six technology categories that are used in concert with one another to support the four strategic objectives. Table ES-1 illustrates how each technology category supports these objectives.

Table ES-1: Technology Categories That Support the Strategic Objectives for Natural Gas Investments

<table>
<thead>
<tr>
<th>Strategic Objectives</th>
<th>Internet of Things and Data Science</th>
<th>Solar Thermal</th>
<th>Bio-energy</th>
<th>Medium- and Heavy-Duty Natural Gas Vehicles</th>
<th>Combined Heat and Power</th>
<th>Advanced Materials and Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Vulnerabilities and Fugitive Methane Emissions in the Natural Gas Infrastructure</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Drive Large-Scale Customer Adoption of Energy Efficient and Low-Carbon Technology Solutions for Natural Gas End-Uses</td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Improve the Cost-Competitiveness of Renewable Gas</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Minimize Air Quality Impacts from Natural Gas Use to Zero or Near-Zero Levels</td>
<td>√</td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: California Energy Commission staff, 2018
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 deployed cheaply and quickly compared to current practices that are labor- and capital-intensive.

In 2016, the Energy Commission awarded funding to the Gas Technology Institute to develop a platform solution that provides real-time visibility and notification to utilities and heavy-equipment operators when construction work is being conducted near natural gas pipelines. The Global Positioning System Excavation Encroachment Notification System integrates a small hardware unit installed on the excavation equipment with geospatial tools and custom-developed algorithms and machine learning capabilities that together provide a rich visual display on excavator status and location in relation to the natural gas pipelines. This unit provides excavator operators with better situational awareness regarding the location of underground pipelines so that they can better avoid accidents. It is anticipated that use of this technology by third-party contractors would result in a 43 percent reduction of nonfatal and noninjury excavation incidents that are caused by excavators, backhoes, and trenchers.

**Solar Thermal**

Solar thermal – using the thermal 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 at dairies 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. For example, solar water heaters can be six to eight times more expensive than conventional natural gas-fired water heaters. The solar collector is the biggest cost component of these systems, accounting for nearly 30 percent of the system cost.

The Energy Commission funded a project with University of California, Merced that developed aluminum mini-channel solar thermal collectors that use flat mini-channels or tiny tubes, as opposed to a conventional, copper flat-plate collector. The mini-channel technology increases the surface area exposed to sunlight for heat transfer, which improves the efficiency of the collector. In addition, aluminum is a significantly cheaper metal and easier than copper to extrude and form into mini-channels. The aluminum mini-channel solar thermal technology has the potential to lower the cost of solar thermal water heating in single-family and multifamily homes by up to 30 percent while improving the efficiency of the solar collectors by 10 to 15 percent. The researchers estimate the cost of the aluminum mini-channel technology at scale could be about $14 per square foot compared to $51 per square foot for conventional solar collectors.
Bioenergy

Techniques such as anaerobic digestion and gasification can produce biofuels for generating energy and provide important alternatives to flaring methane. These techniques are most applicable in managing methane from agricultural and waste, such as dairies, wastewater treatment, landfills, forest tinder, and municipal solid waste. Where economically feasible, biofuels may provide an option for decarbonizing natural gas supplies. However, biogas is not easily used in a raw or unprocessed state and must be converted into renewable gas to expand the potential for use. The clean-up and upgrading process of the gas costs between $6-90 per million British thermal units (compared to retail natural gas costs of $3-$5 per million British thermal units) which limits the cost-competitiveness of renewable gas compared to the fossil fuel counterpart.

A technology developed by Mosaic Materials could lead to breakthrough cost reductions in the largest step in the cleanup and upgrading process – carbon dioxide removal. Conventional wet scrubbers use liquid solvents to remove pollutants like carbon dioxide, but require pumping and operate under high temperature and pressure regeneration conditions, increasing their energy intensity. The Mosaic Materials technology uses low-cost, solid adsorbent pellets instead of a liquid solvent, which eliminates pumping and can be regenerated under milder operating conditions. This technology reduces the energy costs of removing carbon dioxide from biogas by up to 40 percent.

During the project, the solid adsorbent pellets removed carbon dioxide to the purity required to meet pipeline-quality natural gas standards. Mosaic Materials proved the durability of the sorbent when exposed to raw biogas, and the ability of the material to absorb and desorb carbon dioxide over repeated cycles. Each of these tests validated the commercial viability of the technology. In addition, the team performed a cost analysis of its first-generation system, which showed a capital cost reduction of about 14 percent compared to conventional systems thanks to a simpler process and less equipment.

Combined Heat and Power

Combined heat and power 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. For example, absorption chillers, a system that uses thermal energy, such as waste heat, as opposed to electricity to produce chilled water, offer a promising and potentially lower-cost alternative for cold storage at dairies and other food processing plants.

In 2016, the Gallo Cattle Company in Atwater (Merced County) was funded to demonstrate a new type of waste heat absorption chiller application for its cheese making factory. For this project, Gallo demonstrated an ammonia-based absorption chiller called the ThermoSorber™ that overcomes some of the key limitations of standard lithium-bromide absorption chillers, including the ability to cool to lower temperatures required by food processing customers.
part of this project, Maas Energy Works, a subcontractor to Gallo, designed an advanced heat recovery system capable of effectively recovering this low-grade waste heat and using it for high-value cooling. The system is capable of refrigeration output as low as -50°F to deliver chilled water, drive an ice maker or freezer, or be used for process cooling.

**Medium- and Heavy-Duty Natural Gas Vehicles**

The low cost of natural gas relative to diesel fuel is increasing 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. However, there are gaps in natural gas engine product offerings that are optimized to 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 oxides of nitrogen (NOx) compared to the more incremental improvements anticipated in diesel engines.

The Energy Commission’s natural gas research has been instrumental in spurring the development of medium- and heavy-duty natural gas vehicles. The Energy Commission funded the development of Cummins Westport Inc.’s “Near-Zero” natural gas engines to provide low-emission alternatives to diesel engines for the heavy-duty vehicle market to power transit buses, refuse haulers, vocational trucks, and goods movement trucks. With Public Interest Energy Research Natural Gas funding, Cummins Westport Inc. was able to certify a 9-liter and 12-liter variations of the Near-Zero engines that met the California Air Resources Board’s most stringent Optional Low NOx Standard.

Major fleets such as the United Postal Service and Waste Management demonstrated prototype engines throughout the development process, accumulating more than 1.8 million miles on 28 test units. These tests confirmed durability, reliability, and performance of the Near-Zero engines in real-world commercial fleet applications.

Cummins Westport Inc. produced 3,900 Near-Zero engines as of June 2018. Since the introduction of the Near-Zero engines into the market, several state and local clean transportation incentive programs have provided funding for fleets to accelerate adoption of these engines because of their low NOx and greenhouse gas emissions compared to diesel engines. Based on analysis of data from Cummins Westport Inc. and various California incentive programs, an estimated 642 Near-Zero engines have been used in California as of October 2018. This has resulted in nearly 900 tons of NOx reductions over the lifetimes of the vehicles, as calculated using Argonne National Laboratory’s Heavy-Duty Vehicle Emissions Calculator.

**Advanced Materials and Manufacturing**

Advancements in materials and manufacturing have the potential to provide multiple benefits to natural gas ratepayers. For example, materials advancements can enable more effective and economical approaches for sealing building envelopes and natural gas pipeline leaks.

In 2012, the Energy Commission awarded funding to the University of California, Davis Western Cooling Efficiency Center to further develop a portable automated process for sealing gaps and
tightening the envelope of a building. The AeroBarrier system sprays a cloud of waterborne acrylic sealant droplets into a pressurized room. The pressure forces air to escape through leaks, and the sticky particles follow the air flow to the leaks, where the particles are flung from the airstream, coagulating around a leak until it is sealed. In real-world tests, a two-person team reduced the air leakage of a 2,200 square-foot, three-bedroom house by 68 percent in fewer than three hours compared to traditional sealing methods that require more than 20 hours of labor.

AeroBarrier licensed the technology from the University of California, Davis after five years of research and development supported by the Energy Commission's Public Interest Energy Research Program and the Department of Energy’s Building America program and hit the commercial market in January 2018. During this period, AeroBarrier was tested in new and retrofit single family and multifamily homes, including homes built by Habitat for Humanity and retrofits to improve multifamily homes in disadvantaged communities. As of 2017, AeroBarrier has sealed more than 125,000 homes and more than 35 million square feet of commercial space. Most recently, AeroBarrier was used in new homes built by Beazer in Sacramento. The National Association of Homebuilders awarded AeroBarrier the 2018 Most Innovative Building Product and Best in Show in January 2018.
CHAPTER 1:  
Introduction

Recent state policies, including Senate Bill (SB) 100 (De León, 2018) and Governor Edmund G. Brown Jr.’s Executive Order B-55-18, have put California on a path to completely decarbonize its energy sector by 2045.¹ Under SB 100, the electricity sector is expected to play a major role in achieving the state’s greenhouse gas (GHG) reduction goals by supplying electricity generation that is 100 percent or near 100 percent renewable. Complementing the supply-side strategy, the state has charted a path towards additional deep GHG reductions by first electrifying end uses that can most easily and cost-effectively electrify. While the path is well paved for new home construction and programs and incentives are in place to electrify single occupancy vehicles, more must be done to electrify industrial processes. Research and development to enable increased electrification is being conducted under the Electric Program Investment Charge. However, significant built infrastructure now depends on natural gas and a transition strategy is still forming. In the meantime, large GHG reductions can be made in natural gas use through increased efficiency. Other strategies to decarbonize traditional uses of natural gas include solar thermal for heating, technologies to capture and use biogas, and reduction of methane leaks from gas infrastructure. Meanwhile, the development of renewable gas use as an alternative to diesel in the medium- and heavy-duty vehicle sectors is an important strategy for lowering emissions and improving air quality.

California’s residential and commercial sectors rely on natural gas for three key end uses: cooking, space heating, and water heating. While electric options exist for these end uses, current commercial offerings do not meet most consumer demands for cost and performance. A recent Energy Commission-funded study by Energy + Environmental Economics (E3) examined the priority, near-term decarbonization strategies to achieve California's 2030 and 2050 GHG reduction goals. Electric heat pumps are a potential technology to electrify space and hot water heating in homes and businesses and a key strategy for meeting the state’s 2030 and 2050 GHG reduction targets. Under E3’s high electrification scenario, “new heat pump sales must represent no less than approximately 50 percent of new sales of heating, ventilation, and air conditioning (HVAC) and water heating equipment by 2030.”² However, electric heat pumps have struggled to gain market traction in California, making the ability of these pumps to scale to 50 percent of new HVAC sales by 2030 a heavy lift.

The high thermal requirements of many industrial processes similarly make them difficult to electrify. Substantial material advancements are necessary to increase the conversion efficiency


from electric to thermal energy. According to the E3 study, while likely to be “technically feasible for nearly all end uses,” industrial electrification is expected to be high cost because of the “relative inefficiency of using a high-quality final energy carrier such as electricity as a substitute for simple combustion to make heat.” So while emissions from the industrial sector make up a little more than one fifth of California’s GHG emissions, minimizing by electrification is not likely to be cost competitive without major breakthroughs.

For the transportation sector, battery electric vehicles are poised to dominate the light-duty vehicle sector and even segments of the medium-duty vehicle market. However, battery electric vehicles are unlikely to be a viable option for most medium- and heavy-duty vehicle applications without breakthroughs to the energy density and weight of batteries. The low-cost of natural gas relative to diesel fuel is driving adoption of natural gas medium- and heavy-duty vehicles. Yet hydrogen fuel cell trucks are “among the most expensive to purchase and operate,” due to the total fuel storage requirements, according to the E3 study. Even though batteries may be “cheaper than fuel cells per unit of power,” they tend to be more expensive than hydrogen per unit of energy. Therefore, key mitigation scenarios developed by E3 anticipate that by 2050 battery trucks can “displace no more than 50% of truck vehicle miles (those used for shorter-haul distances), while fuel-cell trucks are assumed to serve longer-haul heavy duty trucking. As a result, hydrogen fuel cell heavy-duty trucks are a key reach technology in this scenario.”

Even under the high electrification scenario, decarbonization will be needed in the natural gas sector. Deeper GHG reductions will be needed if the technology options to achieve the high electrification scenario do not reach scale. For the natural gas sector to support the state in meeting California’s multiple energy and environmental policy goals, the following challenges must be addressed:

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

High-profile events such as the San Bruno pipeline explosion (2010)³ and Aliso Canyon gas storage facility leak (2015)⁴ demonstrated the vulnerabilities of the natural gas system, intensifying the need to research and improve its safety and integrity. Moreover, environmental events like the state’s recent prolonged drought, extensive tree mortality, climate change related subsidence, and seawater rise have broadened the research necessary for the natural gas sector to be able to adapt to climate change and contribute to the state's GHG reduction goals.

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

To reach California's energy and climate change goals, energy efficiency is essential for all sectors. However, current technologies do not always meet acceptable payback periods necessary to drive large-scale market adoption of energy efficiency upgrades without policy changes. In addition, the invasive nature of some energy efficiency upgrades that require occupants to temporarily vacate, combined with high customer acquisition costs and low equipment turnover, create a limited window for when customers are receptive to installing energy efficiency upgrades. New technology advancements and strategies are critical to overcome these market barriers.

Improve the Cost-Competitiveness of Renewable Gas

Under E3’s high electrification scenario, 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. “[Renewable gas] does not face the same type of customer adoption and building retrofit challenges as a building electrification strategy.” [E3 study] However, the cost of renewable gas from agriculture and waste is several times greater than traditional fossil fuel natural gas supplies.⁵

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

Large portions of California, most notably Southern California and the San Joaquin Valley, are in air quality non-attainment zones. These are areas considered to have air quality worse than California ambient air quality standards. Industrial and goods movement is a key economic sector of these regions and major producer of air pollution emissions. As these industries move from diesel to natural gas, opportunities exist to reduce air pollution emissions by ensuring natural gas is combusted using technologies that surpass best available control technology limits.

Energy Commission Research and Development Strategy for Natural Gas

The Energy Commission'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 multiple challenges described previously and shown in Table 1.

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

<table>
<thead>
<tr>
<th>Strategic Objectives</th>
<th>Internet of Things and Data Science</th>
<th>Solar Thermal</th>
<th>Bio-energy</th>
<th>Medium-and Heavy-Duty Natural Gas Vehicles</th>
<th>Combined Heat and Power</th>
<th>Advanced Materials and Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Vulnerabilities and Fugitive Methane Emissions in the Natural Gas Infrastructure</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Drive Large-Scale Customer Adoption of Energy Efficient and Low-carbon Technology Solutions for Natural Gas End-Uses</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Improve the Cost-Competitiveness of Renewable Gas</td>
<td></td>
<td></td>
<td>✓</td>
<td>√</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Minimize Air Quality Impacts from Natural Gas Use to Zero or Near-Zero Levels</td>
<td>√</td>
<td></td>
<td>✓</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

Source: California Energy Commission staff, 2018

**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 deployed cheaply 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, the machine
learning capabilities can optimize and automate end-use natural gas appliances for energy efficiency without sacrificing customer preferences.

**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 in buildings, natural gas pipeline detection, fugitive methane emission monitoring.

**Sectors:** Residential, commercial, industrial, natural gas supply.

**Solar Thermal**

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

**Key Challenges and Needs:**

- 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.
- 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 biofuels for generating energy and provide important alternatives to flaring methane. These techniques are most applicable in managing methane from agricultural and waste, such as dairies, wastewater

---

6 Weather, availability of storage, and commodity cycles are all factors that contribute to natural gas price volatility. It is not uncommon to see natural gas prices double or triple during cold winters. For more information, see [https://www.sparklibrary.com/drivers-us-natural-gas-price-volatility/](https://www.sparklibrary.com/drivers-us-natural-gas-price-volatility/).
treatment, landfills, forest tinder, and municipal solid waste. In addition, when used onsite, bioenergy can alleviate some of the 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 biogas into high-quality biomethane.
- Transport costs for biomass feedstocks if not generated on-site.
- Variations in biogas composition from site-to-site based on feedstock differences.

**Applications:** Wastewater treatment, landfill and food processing and dairy operations; agricultural and urban residues (agricultural waste and urban wood waste), forest management.

**Sectors:** Industrial, wastewater treatment, transportation, natural gas supply.

**Combined Heat and Power**

Using the waste heat from onsite generation 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 control technologies capable of optimizing combustion efficiencies and minimizing NOx emissions to near-zero levels.
- Capital costs required to install and interconnect new CHP 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.\(^7\) However, there are gaps in natural gas engine product offerings that are optimized to the specific application and duty

---

\(^7\) National Petroleum Council, 2012, *Advancing Technology for America’s Transportation Future, Part One—Integrated Analyses*
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 NOx 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, advancements in manufacturing can help improve the efficiency of buildings while minimizing the cost.

**Key Challenges:**

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

**Applications:** Building envelope, industrial manufacturing, pipeline safety, heat exchangers, pre-fabricated housing.

**Sectors:** Residential, commercial, industrial, natural gas supply.

**The Natural Gas Research Program**

The California Energy Commission’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 is designed to
meet energy policy goals and standards while maintaining safety and reliability. For more information on select energy policy goals for California’s future, see Appendix A.

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 California Energy Commission 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.

The CPUC established that the Energy Commission’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 public.
- Consider opportunities for collaboration and co-funding with other entities.

Each year the Energy Commission is required to submit to the CPUC a proposed program plan and funding request for the Natural Gas Research and Development Program. 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 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 California Air Resources Board (CARB) and the United States Department of Energy (DOE), respectively.

The CPUC approved the FY 2017-18 plan in September 2017 by Resolution G-3527 and authorized the Energy Commission to administer $24 million for Natural Gas R&D projects during a two-year funding period. In April 2017, the CPUC also approved the Energy Commission’s proposed Reliability and Climate Focused Natural Gas Supplemental Budget Plan for the investment of $5.9 million in previously-allocated unspent funds.

The Energy Commission submitted its most recent funding request in March 2018 and is awaiting CPUC approval. Typically, the CPUC approves the research funding request before, or soon after, the beginning of each fiscal year. The Energy Commission respectfully requests that the Natural Gas Research and Development Program Proposed Program Plan and Funding
Request for Fiscal Year 2018-19 is considered at a CPUC business meeting soon to avoid a hiatus in research projects.

This report highlights project successes and benefits, and covers results of completed projects and the progress of current research from July 1, 2017, through June 30, 2018. For a breakdown of the research area budget expenditures, see Appendix B-1. For a detailed breakdown of Natural Gas R&D project funding of the program history, see Appendix B-3.

**Energy Commission Administration**

The Energy Commission'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), which was recognized in 2017 as part of an independent evaluation of the EPIC program directed by the CPUC. Awarded projects are selected through a transparent process. Each project creates a technical advisory committee composed of diverse professionals to provide guidance in project direction. Research results are widely disseminated and used to guide future policy and research decisions.

In addition to addressing the critical challenges facing the future of natural gas already identified, the Natural Gas R&D program is responding to pressing critical needs that recently elevated the importance of safety and climate adaption. The 2010 explosion at San Bruno highlighted the necessity for improved natural gas infrastructure safety. The large-scale gas leak at Aliso Canyon discovered in October 2015 highlighted the necessity for resilience and improved leak detection. The years of drought and bark-beetle infestation have left 129 million trees dead in California's forests. Over the years, the Natural Gas R&D program has issued specific research solicitations to address these pressing issues. See the following list for specific solicitations that address these urgent issues. For a complete list of Natural Gas R&D program funding opportunities made available in FY 2017-18, see Appendix B-2.

**Pipeline Safety**

- PON-14-502: Infrastructure Improvement Research for Natural Gas Fueling Stations
- PON-14-503: Natural Gas Pipeline Safety and Damage Prevention Grant
- GFO-15-507: Natural Gas Solicitation for Energy-Related Environmental Research
- GFO-17-502: Enhancing Safety, Environmental Performance, and Resilience of California’s Natural Gas System

**Aliso Canyon**

- PON-14-507: Regional Climate Impacts and Adaptation Studies for the Natural Gas System and Other Environmental Related Issues
- GFO-15-507: Natural Gas Solicitation for Energy-Related Environmental Research
• GFO-16-508: Natural Gas Storage Infrastructure Safety and Integrity Risk Modeling Research Grants

Tree Die-Off
• PON-14-505: Advancing Clean Energy from Biogas, Biomethane and Natural Gas

Bringing Different Perspectives Into R&D
Commercializing new energy technologies requires a wide range of stakeholder perspectives and expertise. The Energy Commission 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. Each research project is advised by a technical advisory committee such as subject matter experts, end-users, equipment manufacturers, national labs, academia, technology developers, governmental agencies, local governments, and private research organizations. In addition, in 2017, the Energy Commission conducted seven 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.

Advancing Legislative Priority for Clean Energy Equity
The California Legislature has made clean energy equity—ensuring that the benefits from our programs are equitably shared, especially by those in the most vulnerable communities—a policy priority. Recognizing this, the Energy Commission has prioritized disadvantaged communities in three of its fiscal year 2017-18 solicitations for the Natural Gas Research Program; setting aside specific amounts for projects in these areas or providing bonus points for demonstration or pilot test sites in and benefitting disadvantaged communities. These solicitations were:

• Addressing Barriers to Wider Adoption of Near-Zero Emission Natural Gas Vehicles (GFO-17-503).

• Enhancing Safety, Environmental Performance, and Resilience of California’s Natural Gas System (GFO-17-502).


Furthermore, the Energy Commission held multiple workshops, expos, and stakeholder and working group meetings to support community advocacy for diversity around policy research and policy positions, including six 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 funding under its EPIC program to be allocated to projects sited in disadvantaged communities, and the

---

8 One workshop was held in Fresno, CA and another was held in Diamond Bar, CA.
Natural Gas program has kept pace. Though the Natural Gas program does not have the same statutory requirements, the Energy Commission is committed to equity across programs. Out of the 101 California-based Natural Gas program projects that were active during fiscal year 2017-18, 25 have at least one site within a disadvantaged community.⁹

**Expanding Natural Gas Research**

Despite California’s expanding natural gas research needs, program funding has not increased since 2009. To address this limitation, the Energy Commission is preparing to submit a request to the CPUC to expand its Natural Gas R&D program.

CPUC Resolution G-3519 requested the Energy Commission to assess the overall reasonableness of the natural gas research program, and then provide a detailed accounting as part of an annual proposed program plan and funding request. Energy Commission staff is currently assessing the research program. The assessment will span the history of the program and will include the program’s drivers, administration, funded projects, and results. In particular, the assessment will highlight the research program benefits to California natural gas investor-owned utility ratepayers. This review will assess whether research led to substantial additional public and private investment, resulted in commercially available products, or informed policy, planning, decision making, codes, and standards.

---

⁹ For more information about these and other Energy Commission diversity commitment activities, please visit: http://www.energy.ca.gov/commission/diversity/
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 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 California Energy Commission 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.

Providing a Foundation for Effectively Reducing Methane Emissions

It is estimated that 2 percent of natural gas leaked into the atmosphere during its production, processing, transport, and distribution.\textsuperscript{10} The dominant chemical constituent of natural gas is methane - a potent greenhouse gas. Methane is almost 30 times stronger at trapping heat compared to carbon dioxide over a 20-year period. Identifying sources of leakage is critical to reducing greenhouse gas (GHG) emissions.

Home natural gas consumption accounts for nearly 20 percent of total natural gas consumption in California.\textsuperscript{11} The official GHG inventory prepared by the California Air Resources Board (CARB) assumes that methane emissions from the residential sector are extremely small, and the inventory considers only incomplete combustion of natural gas in furnaces, water heaters, dryers, and stoves to be sources of methane emissions in homes.\textsuperscript{12} However, previous Energy Commission-funded research suggests “after meter” natural gas leakage, specifically leaks that occurs within the home, may be a substantial portion of total unaccounted methane emissions.\textsuperscript{13}

That project measured natural gas leakage within a handful of homes and found that leaks can be large, meaning that estimates of total methane emissions from the residential sector may be


\textsuperscript{11} Calculated using data from https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm.

\textsuperscript{12} AB 2195 (2018) requires CARB to “Quantify and publish annually, commencing January 1, 2020, and based on the best available science and information, the amount of greenhouse gas emissions, expressed in metric tons of carbon dioxide equivalents, resulting from the loss or release of uncombusted natural gas to the atmosphere and emissions from natural gas flares during all processes associated with the production, processing, and transporting of natural gas that is imported into the state from out-of-state sources.”

severely underestimated. More data were necessary to properly characterize the extent of this problem.

A recently completed project with Lawrence Berkeley National Laboratory measured in-home methane emissions in 75 sample houses throughout California to collect more data and test whether assumptions about natural gas leakage in the residential sector were accurate. The research team sealed the test homes and used a blower door (Figure 1) to create a constant flow of air. Researchers then determined methane leaks inside the home by measuring the difference in methane concentration from incoming and outgoing air. The project also experimented with how methane leakage varied during operation and non-operation of natural gas appliances in the home.

**Figure 1: Measurement Setup at a Sample Houses**

Blower door setup to measure methane leakage.

Source: California Energy Commission

Most homes exhibited little leakage (less than 1 gram of methane per day), though a few homes had more substantial leaks (greater than 10 grams of methane per day). Methane emissions caused by incomplete combustion from operating appliances were mostly undetectable. On the other hand, storage water heaters and stoves exhibited meaningful methane leakage (roughly 1 to 3 percent of gas consumed) while in standby. Overall, the project team identified whole house leaks (leakage independent of appliance operation), continuous operation of pilot lights, and episodic operation of appliances such as natural gas water heaters and cooking stoves as the most significant contributors to methane emissions. Based on the sample results, they
estimated that the residential sector emits 35.7 gigagrams (a gigagram is 1 billion grams) of methane per year, equivalent to about 15 percent of California's overall natural gas sector methane emissions or equivalent to 0.5 percent of home natural gas consumption.

These results provide important information that could be used to update the state's GHG inventory, which is a critical tool used to illuminate appropriate strategies for reducing GHG emissions in California. The Energy Commission shared the results with CARB, which plans to evaluate the results from this project and consider updates to its next annual greenhouse gas inventory reporting. The results from this project were also recently published in the *Journal of Environmental Science & Technology*.

The results suggest that repairing leaks, updating combustion appliances (for replacing the pilot light with electronic ignition), and electrifying appliances can greatly reduce methane emissions from the residential sector. Furthermore, eliminating “after meter” natural gas leakage would save ratepayers an estimated $30 million per year.

**Operationalizing Climate Science Into Energy Planning Decisions**

California’s Fourth Climate Change Assessment (Fourth Assessment), released in August 2018, provided a substantial infusion of new science and data regarding what climate change means for California and how Californians can cope with it. This ambitious effort was led by the California Natural Resources Agency, the Governor’s Office of Planning and Research, and the Energy Commission. Results of the Fourth Assessment are all publically available at climateassessment.ca.gov, including 44 peer-reviewed technical reports of which 15 were funded by the Energy Commission to shed light on energy sector vulnerability and resilience.

One Fourth Assessment study supported by the Energy Commission and undertaken by ICF International in collaboration with San Diego Gas & Electric Company (SDG&E) investigated climate-related risks to the natural gas system in SDG&E territory. This study considered multiple hazards, including coastal and inland flooding, wildfire, and extreme heat. The research team used high-resolution projections, data-intensive models, and stakeholder engagement to generate locally specific knowledge of how weather-related extremes may affect particular assets. This locally resolved information provided a scientific foundation for charting “flexible adaptation pathways” that incorporate evolving knowledge and policy into timing and implementing resilience measures.

Another research project supported by the Energy Commission provided new, high-resolution field measurements of mean subsidence rates of about 0.4 to 0.8 inches per year for some levees in the Sacramento-San Joaquin Delta. This subsidence compounds the risk that sea-level rise and storms could cause overtopping or failure of the levees, exposing natural gas pipelines and other infrastructure to damage or structural failure. At this rate of subsidence, some levees may fail to meet the federal height standard between 2050-2080. This research project involved the local natural gas utility on its technical advisory committee to strengthen and accelerate

---

knowledge transfer to utility technical staff. The research will be used to inform adaptation planning by the utility.

**Addressing Vulnerabilities in the Natural Gas Infrastructure**

Damage to natural gas pipelines caused by digging, grading, trenching, and boring is one of the main challenges to safe pipeline operations. The United States Department of Transportation Pipeline and Hazardous Materials Safety Administration reported that excavation damage causes 26 percent of serious incidents to gas transmission and distribution pipeline (involving a fatality or in-patient hospitalization) and nearly 50 percent of these were caused by third-party excavators.\(^\text{15}\) Pipeline infrastructure owners and operators have established free call centers (for example 811 Call Before You Dig) to coordinate with third-party excavators to ensure that excavation is performed safely to prevent damage to underground facilities. However, these existing practices do not address all incidents as many accidents result from failure to follow these existing notification practices before digging.

In 2016, the Energy Commission awarded funding to the Gas Technology Institute to develop a platform solution that provides real-time visibility and notification to utilities and heavy-equipment operators when construction work is being conducted near natural gas pipelines. The Global Positioning System (GPS) Excavation Encroachment Notification System integrates a small hardware unit installed on the excavation equipment with geospatial tools, and custom-developed algorithms and machine learning capabilities that together provide a rich visual display on excavator status and location in relation to the natural gas pipelines. This unit provides excavator operators with better situation awareness regarding the location of underground pipelines so they can better avoid accidents.

As part of the Energy Commission funded project, Gas Technology Institute developed, installed, and tested the hardware device on 150 excavation equipment units owned by Pacific Gas and Electric Company, Southern California Gas Company, and third-party excavation contractors.\(^\text{16}\) The device and dashboard are integrated with the utilities’ geographic information system network. Such implementation provided high-accuracy GPS location of excavation equipment, which can overlay the utility’s geographic information system map services, call center boundaries, or custom geo-fences around the pipeline right of way (Figure 2).

It also displayed real-time indications of the activities of the geospatially-located excavators and sent instant alerts in the form of sound and light signals in the device, plus graphical and text message alerts to the applicable utility’s operators. The system matched actual field observations against the excavators predicted activities of idle, digging, and driving which were about 87 percent, 80 percent, and 85 percent accurate respectively. Accurately predicting excavation activities in real-time then helps predict the risk of encountering a natural gas

---


pipeline. The initial goal is to reduce about 12 percent of the non-fatal and non-injury incidents in California that are caused by first-and second-party excavators and save $1,564,500 annually in private property and operator damage and emergency response.

Figure 2: Global Positioning System Device on Excavator and Utility Monitoring Dashboard

Source: Gas Technology Institute

It is anticipated that use of this technology by third-party contractors would result in a 43 percent reduction of nonfatal and noninjury excavation incidents that are caused by excavators, backhoes, and trenchers. More savings can be achieved if the telecommunication, electrical, water, and agriculture industries adapt the excavation safety technology to their application by identifying their underground networks of equipment, wires, and pipes.

High Accuracy Mapping for Excavation Damage Prevention and Emergency Response

Natural gas operators primarily use manual, paper-based methods to create asset maps and to document asset properties and environmental conditions. These manual methods are time consuming, can lead to human data entry errors, and create delays in making asset and engineering information available to stakeholders. The US Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) regulations for integrity management are incentivizing natural gas operators to implement technology to improve and
increase asset data collection. A more automated, mobile technology is needed to create high quality asset maps and records that can serve as the backbone for future asset and integrity management programs, as well as for routine operations and emergency response.

In 2016, the Energy Commission awarded funding to the Gas Technology Institute (GTI) to develop technology that is able to automatically create and display high accuracy maps of underground natural gas distribution assets. The high accuracy mapping (HAM) technology creates spatially accurate maps populated with traceability data for materials, joints, operator qualification status and pressure test. The HAM hardware includes tablets, GPS receivers, GPS antennas, barcode scanners and seven-foot survey poles (Figure 3). The HAM software application captures high accuracy GPS and material traceability data, automates the creation of GIS maps and related records, and synchronizes data to a cloud-hosted database. The data displayed by the application provides real-time information on underground distribution assets and excavation activity. It offers the utility a common operating picture at any point for more functional communications, planning and ultimately more efficient and safe operation.

**Figure 3: High Accuracy Mapping System – Hardware and Software Interface**

This automated, high-accuracy mapping technology is able to map over 90 percent of the underground assets with an accuracy within 6 inches. It also allows users to electronically collect information on 17 infrastructure features and 190 feet of pipe per day on average, whereas paper-based data collection and sketch creation typically take one or more hours to complete. Moreover, this technology takes only minutes to collect pipeline information
electronically, and it improves the accuracy of data and location information. Pacific Gas & Electric (PG&E) estimated that the technology can reduce excavation damage events by 50 percent, or 300 total damage events annually throughout California, leading to increased reliability and security of natural gas infrastructure and supply. This corresponds to cost savings of $1.5 million and reductions of natural gas emissions by 11,700 million standard cubic feet annually in California. The technology improves system integrity by reducing excavation damage and improves public safety by promoting situational awareness through the visualization of high accuracy maps and related information during emergencies.

In close collaboration with PG&E, the HAM technology has been demonstrated in field by configuring and deploying 22 units to 10 service locations throughout PG&E service territory, and PG&E crews have mapped a total of 37,951 feet of pipe and 3,475 point features (valves, fittings, etc.). The target market for the HAM technology is natural gas infrastructure operators and mapping service providers and the estimated size of total addressable market is 6,000 field crews. A survey of 16 gas utility companies demonstrated a 75 percent interest rate in applying the technology. GTI is working with a subcontractor on a commercialization strategy for the technology and plans to roll out HAM product to several gas utilities in 2018. The research team also expected 50 percent of the largest natural gas distribution companies with over 1 million meters to conduct pilot projects by the end of 2019.

**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, rising 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. Furthermore, energy expenses incurred by municipal buildings and facilities – such as wastewater treatment plants – add costs to residential customers. Moreover, the housing shortage in California has shown the necessity for low-cost, rapidly deployable construction methods.\(^{17}\) Advances in energy efficiency technologies in existing buildings and new construction projects not only save residents money, but can also increase the comfort of homes by more efficiently controlling heating and cooling.\(^{18}\)

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 Energy Commission supports research to develop the next-generation of clean energy technology solutions that help Californians use gas more efficiently.

\(^{17}\) [https://www.sacbee.com/news/politics-government/capitol-alert/article168107042.html]

\(^{18}\) [https://www.energy.ca.gov/renewables/tracking_progress/documents/energy_efficiency.pdf]
Bringing New Clean Energy Technology Solutions to Affordable Housing

Housing affordability is a top concern for residents in California’s disadvantaged and low-income communities. Housing and energy costs can account for more than 50 percent and 16 percent of their income, respectively. To lower their living expenses, residents of these communities need affordable housing that does not sacrifice energy efficiency. However, affordable housing developers typically adhere to smaller, tighter budgets that limit their ability to install high-efficiency appliances. Effectively sealing the envelope of the home – including the roofs, walls, and floors – can go a long way towards improving the energy efficiency and comfort of a home. However, sealing the envelope—a process typically involving caulk, spray foam, weather stripping, or other materials—can be difficult, labor-intensive, and not always effective.

In 2012, the Energy Commission funded the University of California (UC) Davis Western Cooling Efficiency Center to develop a portable automated process for sealing gaps and tightening the envelope of a building. The AeroBarrier system sprays a cloud of waterborne acrylic sealant droplets into a pressurized room. The pressure forces air to escape through leaks, and the sticky particles follow the airflow to the leaks, where the particles are flung from the airstream, coagulating around a leak until it is sealed. A computer controls the temperature, pressure, humidity, and distribution of the sealant, and technicians are able to monitor the progress in real time. In fewer than three hours, a two-person team reduced the air leakage of a 2,200 square-foot, three-bedroom house by 68 percent compared to traditional sealing methods that require more than 20 hours of labor. Tests showed that AeroBarrier can seal holes as tiny as a human hair and as large as a half inch across, and can reduce leaks by up to 90 percent in new buildings. This process is GREENGUARD Gold certified, meaning it meets or exceeds low emissions standards for volatile organic compounds in indoor spaces.

Successful early demonstrations of AeroBarrier in California homes proved the effectiveness of the technology and drew the attention of home builders and designers. AeroBarrier licensed the technology from the University of California, Davis after five years of research and development supported by the Energy Commission's Public Interest Energy Research Program and the DOE’s Building America program and hit the commercial market in January 2018. During this period, AeroBarrier was tested in new and retrofit single family and multifamily housing, including homes built by Habitat for Humanity and retrofits to improve multifamily housing in disadvantaged communities. As of the end of 2017, AeroBarrier has sealed more than 125,000 homes and more than 35 million square feet of commercial space. Most recently, AeroBarrier was used in new homes built by Beazer in Sacramento. The National Association of Homebuilders awarded AeroBarrier the 2018 Most Innovative Building Product and Best in Show in January 2018.

**Increasing Energy Efficiency of Manufactured Homes**

A recent poll conducted by the UC Berkeley Institute of Governmental Studies shows that nearly half of the state's registered voters believe that housing affordability is an “extremely serious”
problem in California. The National Low Income Housing Coalition estimates a shortage of 1.5 million affordable low-income housing units. One possible solution to improving housing affordability and increasing the availability of low-income housing units is building more manufactured homes. Manufactured homes are built off-site in a factory on a non-removable steel chassis and can be a lower cost alternative to standard home construction. Manufactured homes typically cost an average of $60 to $70 per square foot to build at the factory compared to the average price of $120 to $150 per square foot to build a site-built home.

All manufactured homes produced in the nation conform to one set of standards, the Manufactured Housing Construction Safety Standards, enforced and maintained by the United States Department of Housing and Urban Development (HUD). The standards, first established in 1976, contain thermal requirements that were last updated in 1994. The HUD standards preempt California’s Energy Code (Title 24) requirements and have far less stringent energy efficiency requirements. Increasing the energy efficiency of these units makes them more affordable and comfortable for homebuyers. However, to keep home prices low, manufactured home builders are very sensitive to increased cost of construction. The manufactured homes market is competitive and builders may not want to add items that will increase cost and affect future sales. Many of California’s renters and homeowners face high housing costs and any increase in price might mean not qualifying for a home loan or not being able to afford basic amenities.

A PIER research project with The Levy Partnership focused on increasing the energy efficiency of manufactured homes by developing and commercializing the next generation of wall and roof envelope designs that are highly energy efficient and add minimally to first costs (Figure 5). The project was successful in developing advanced envelope designs that add minimally, or about $2,700, to the first cost of a manufactured home. The advanced wall and roof insulation greatly reduces the exchange of heat into and out of the home through the exterior surfaces of the building. This means less warm air escapes during winter and less cool air escapes during the summer, which reduces heating and cooling costs. According to The Levy Partnership’s research, these advanced envelope designs can reduce the energy bills of gas-heated manufactured homes by up to 48 percent and the energy bills of electric-heated homes by up to 56 percent.

The project engaged key industry stakeholders, such as major manufactured home builders in California, and demonstrated the construction methods developed by this project. This advanced envelope design is available as an option to purchasers of manufactured homes and

---


24 California Department of Housing and Community Development, California’s Housing Future: Challenges and Opportunities Final Statewide Housing Assessment 2025, February 2018 http://www.hcd.ca.gov/policy-research/plans-reports/docs/SHA_Final_Combined.pdf


26 https://calbudgetcenter.org/resources/californians-parts-state-pay-can-afford-housing/
could become standard practice if these designs are directly incorporated at the federal level by HUD or are directly promoted with incentives in California. With nearly 10,000 new manufactured homes constructed each year in California, this project can significantly reduce energy use and result in substantial annual cost savings to purchasers of manufactured homes.

**Figure 5: Manufactured Home Project**

Credit: Levy Partnership, Golden West Homes, Perris, California

**Success in New Homes Provide Insight for Hot Water Piping Improvements in Existing Homes**

More than 10 million California homes heat water with natural gas. Water heating accounts for more than 40 percent of all natural gas used in California homes. Households using natural gas for water heating consume about 2.5 billion therms per year and emit more than 13 million metric tons of carbon dioxide equivalent (CO₂e). Prior Energy Commission research indicated that the efficiency of hot water distribution systems in California homes could be near or less than 50 percent — meaning for every 10 units of energy used to heat the water, only

---


29 A metric ton is 2,205 pounds.
half of that energy reaches the faucet.\textsuperscript{30} Improvements in the efficiency of residential water heating distribution could yield huge savings in natural gas and greenhouse gas emissions.

**Big Savings Achieved in New Construction Homes**

Using a variety of heat transfer tests, conducted under various conditions and on a variety of materials and pipe sizes, research funded by the Energy Commission confirmed that adding insulation to buried and unburied hot water pipes led to significant energy savings in new homes. Laboratory tests indicated that heat loss in uninsulated pipes was seven times greater than insulated pipes.\textsuperscript{31} Adding insulation to hot water pipes dramatically reduces pipe heat loss, which reduces energy costs, water waste, and the wait time to receive hot water to fixtures.

The research was directly responsible for improvements to the residential water heating distribution systems incorporated into the *California Building Energy Efficiency Standards* for new construction.\textsuperscript{32,33} Cumulative savings due to implementing the requirement of pipe insulation in new homes are estimated to be about 8.2 million therms and a reduction of 50,000 metric tons of CO\textsubscript{2}e, saving Californians about $7.9 million and roughly 1.3 billion gallons of water between 2014 and 2020.

**Can We Achieve Similar Savings in Existing Homes?**

Homes built prior to 2008 have uninsulated hot water pipes. Retrofitting the uninsulated piping system in these homes is challenging because the pipes are often embedded in concrete slabs. In 2017, a research initiative was approved as part of the Energy Commission’s *Reliability and Climate Focused Natural Gas Supplemental Budget Plan* to determine the technical and economic potential of increasing the efficiency of existing residential hot water distribution systems, especially uninsulated pipes in slab foundations built prior to 2008.

This research hopes to improve hot water distribution in existing homes and strive for similar savings as those in new construction.

**Driving Down Solar Water Heating System Costs**

Natural gas-fired water heaters are the norm for home water heating in California, consuming about 2.5 billion therms per year and emitting more than 13 million metric tons of CO\textsubscript{2}e.\textsuperscript{34} Solar thermal water heating is a viable alternative to natural gas water heating that is more efficient, emits no greenhouse gas, and uses free solar energy as fuel. However, solar water heating


heaters can be six to eight times more expensive than conventional natural gas-fired water heaters because they have additional components and equipment and are costlier to install. Coupled with the low cost of natural gas, these factors make it difficult for solar water heating systems to compete with natural gas water heaters.

Solar thermal water heaters use a solar thermal collector that converts the sun's energy into heat. The solar collector makes up nearly 30 percent of the system cost. Reducing the cost of solar collectors could result in more solar water heating installations.35

The Energy Commission funded a project with University of California, Merced that developed aluminum mini-channel solar thermal collectors that use flat mini-channels, or tiny tubes, instead of the flat plate design with round tubes attached to a flat copper absorber plate used in conventional solar collectors (Figure 6). The flat-plate round tube design has only a small section of the pipe in contact with the absorber. In contrast, the mini-channel technology increases the surface area exposed to sunlight for heat transfer, which improves the efficiency of the collector. The mini-channel tubes placed next to each other become one big solar collector, drawing the sun’s energy directly to the fluid that passes through hundreds of tiny channels. Previous PIER-funded research showed a 10 percent to 15 percent improvement in thermal efficiency compared to conventional copper flat plate collectors.36

**Figure 6: Schematics of Two Designs for Solar Thermal Collectors: Flat-Plate Round Tube Solar Thermal Collectors and Solar Thermal Collector Designed With Mini-Channels**

The image on the left is the flat-plate round tube design (typically copper). The image on the right is the aluminum mini-channel design.

Source: University of California, Merced.

Another advantage of this technology is the use of aluminum instead of copper. Copper is a better thermal conductor than aluminum, which is why it is typically preferred in heat


exchanges. However, aluminum is a substantially cheaper metal and is easier than copper to extrude and form into mini-channels. The researchers estimate that the cost of the aluminum mini-channel technology at scale could be about $14 per square foot compared to $51 per square foot for conventional solar collectors.37

Mini-channels have been used in automotive radiators and HVAC condensers, however it was Energy Commission funding that helped create solar thermal collectors that used mini-channel technology for solar water heating. Depending on the operating conditions required, the aluminum mini-channels can heat water to about 130 degrees, well above the typical 120 degree set point of conventional water heaters. Previous laboratory tests did not use the hot water generated for actual hot water loads in real world use, such as for showers or laundry. This project will test how the aluminum mini-channel technology performs in typical hot water use scenarios and will verify the technology cost and energy savings. The project is demonstrating the use of aluminum mini-channel collectors in actual installations in a single-family home and an apartment building in the Los Angeles area.

The aluminum mini-channel solar thermal technology has the potential to lower the cost of solar thermal water heating in single-family and multifamily homes by up to 30 percent while improving the efficiency of the solar collectors by 10 percent to 15 percent. Greatly reducing the upfront cost of solar collectors could lead to an increase in market penetration of solar water heating, which would reduce natural gas use and greenhouse gas emissions, improve air quality, and lower ratepayer utility bills.

Developing Scalable Technology Solutions for Food Production

Energy consumption is a large operating expense for California's dairies. Much of this energy consumption is for electrical refrigeration in cold storage facilities that store the dairy products and prevent spoilage. While these systems are effective at maintaining the necessary temperatures, they are expensive to operate and use high global warming refrigerants. Absorption chillers that use thermal energy, such as natural gas or waste heat, as opposed to electricity offer a promising and potentially lower-cost alternative for cold storage at dairy and other food processing plants. However, several technical challenges must be addressed before they can become a viable alternative to electric refrigeration systems. Lithium-bromide-based absorption chillers are the standard but cannot provide sufficient chilling temperatures needed for dairy facilities.

Absorption chillers also have the potential to drive-up natural gas consumption if they are widely used for cold storage facilities. One option to minimize this increase in natural gas consumption is using the waste heat from onsite biogas generators. However, current heat recovery technologies cannot effectively recover this low-grade waste heat and use it for high-value cooling. Instead, dairies exhaust the waste heat into the atmosphere or capture it with economizers for low-value process heating applications.

In 2016, the Gallo Cattle Company in Atwater, California (Merced County) received funding to demonstrate a waste heat absorption chiller application for its cheese making facility. The ThermoSorber™ overcomes two of the key limitations of standard lithium-bromide absorption chillers. For this project, Gallo used an ammonia-based absorption chiller over lithium-bromide because of the ability to cool to lower temperatures. As part of this project, Maas Energy Works, a subcontractor to Gallo, designed an advanced heat recovery system that could effectively replace the electrical chiller and provide a warm water loop for heating processes in the cheese production plant.

Table 2 compares the technical differences between conventional electrical refrigeration and absorption chillers. Advanced absorption chillers have the benefit of reaching temperatures as low as electrical refrigeration but using waste heat as a power source, resulting in lower annual operating costs.

Table 2: Advanced Absorption Chiller Versus Other Refrigeration Options

<table>
<thead>
<tr>
<th></th>
<th>Electrical Refrigeration</th>
<th>Absorption Chiller: Lithium-Bromide</th>
<th>ThermoSorber™ Advanced Absorption Chiller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest Reachable Temperature</td>
<td>-80°C</td>
<td>15°C</td>
<td>-70°C</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>N/A</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Energy Intensity</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Power Source</td>
<td>Electricity</td>
<td>Waste heat or natural gas</td>
<td>Waste heat or natural gas</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Uses High Global Warming Potential Refrigerants?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Physical Footprint</td>
<td>Small</td>
<td>Large</td>
<td>Large</td>
</tr>
</tbody>
</table>

Source: California Energy Commission staff estimates and conversations with Gallo

The Gallo Energy Efficiency project (Figure 7) is a successful demonstration with average electrical chilling savings of nearly 80 percent observed over a 12 month period (July 2017 to June 2018) and an additional 20 percent in average natural gas savings observed over a six month period (January 2018 to June 2018).
Targeting Natural Gas Savings in Food Service

In California, commercial kitchens are five times more energy intensive per square foot than typical commercial spaces. High cooking temperatures and always-on control systems are common. Of the 800,000 commercial cooking appliances operating in California, roughly 70 percent are powered by natural gas and a minority have the ENERGY STAR® certification. Commercial food service represents a market sector where strategic improvements in appliance design could result in large energy savings and emission reductions.

The Energy Commission funded research by the Gas Technology Institute and the California Food Service Technology Center on technology improvements that would provide energy savings in several key product areas affecting commercial food service. The project evaluated energy and operating patterns using a variety of standard commercial cooking appliances in six types of commercial kitchens, from light batch cooking at a grocery store to heavy use at a 24-hour airline catering business. From this evaluation, the project team identified common technology and operation shortcomings that hinder efficient natural gas use.

What researchers found is commercial food service appliances tend to have low heat use efficiencies, with peak (full-load) efficiencies in the 20 to 30 percent range and actual in-kitchen use efficiencies in the 5 percent to 10 percent range. Appliances are typically operated under

---

38 ENERGY STAR® Guide for Cafes, Restaurants and Institutional Kitchens, p3,

39 ENERGY STAR® unit shipment dataset, p5:


---
full-load conditions for only a small portion of their daily operating hours. The remaining time
the appliances are operated under part-load and idle conditions, and most appliances do not
have a setback mode to lower the temperature during non-cooking periods. The necessity for
advanced or on-demand controls that sensed when appliances must be used was identified as
an important strategy for eliminating wasted energy. Existing equipment also tend to use
burners that transfer heat to the food product inefficiently. This finding emphasizes the
necessity for advanced heating technologies including power burners, infrared burners,
advanced heat exchangers, improved insulation, and combination hot air and steam heating.

The team replaced these food service appliances with more efficient, ENERGY STAR®
equipment. The new appliances included more efficient burners and heat exchangers, improved
insulation, and more sophisticated controls that allowed operators to optimize using energy in
the kitchen without compromising performance. These sites were then monitored for energy
use (Figure 8). Monitored sites reduced their gas use by 19 percent to 68 percent after the
energy-efficient appliance replacements. One major success was the replacement of steamers
and steam kettles to ENERGY STAR® steamers – two case studies showed an 80 to 90 percent
reduction in energy consumption and 76 percent reduction in water consumption.

**Figure 8: Combination Oven Testing at the Foodservice Technology Lab**

In addition to appliance replacements, the project gathered real-time feedback from food
service staff and provided training to help staff increase productivity while dramatically
reducing energy consumption. Productivity increased in most of the test sites after equipment
replacement while reducing energy consumption. In some cases, productivity increased because
smaller, inefficient equipment was replaced by larger and more efficient models but in other
cases, the kitchen staff were able to change a recipe or modify food preparation procedures to
better use the new equipment. The project team found that training was critical to successfully
having the staff integrate using the new equipment with existing operations. Without adequate
training, staff either didn't use the equipment or used it incorrectly, thereby hindering the
potential productivity benefits of the advanced technologies.
This project included strong links to the food service market and manufacturers with the team showcasing the results to food service operators, engineers, equipment manufacturers, contractors and installers to inform them of the energy efficiency and productivity benefits possible with food service equipment upgrades. Ultimately this project showed industry stakeholders that the initial investment in efficient appliance upgrades results in long-term energy savings that justify the higher purchase price.

Replacing current food service equipment with energy-efficient equipment will reduce energy use and operating cost for food service operators. Assuming a 25 percent market share after five years, equipment improvements and replacements recommended in this research could result in annual savings of 23.2 million therms and reducing 123,000 metric tons of greenhouse gases. Substantial energy cost reductions help California’s food service industries stay competitive, and the early adoption of advanced, efficient technologies often confers an additional competitive advantage. Industry stakeholders were interested mostly in long-term potential for energy savings and performance improvements characterized by better cooking uniformity and reduced cook times. Advancements to food service technologies, and the associated adoption by the market, also help drive industry attention and investment in further technological improvements.

**Improving the Cost-Competitiveness of Renewable Gas**

Biogas 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.

**Demonstrating New, Economical Applications for Biogas Recovery**

There are more than 900 wastewater treatment plants (WWTP) in California that collect and treat roughly 4 billion gallons of wastewater per day. These WWTPs are energy-intensive to operate and produce residuals (such as biosolids) that are costly to manage. They also produce substantial amounts of biogas, about 17 billion cubic feet annually, which could be captured on-site and used to produce renewable energy for heating, electricity, or for transportation fuel. There is a market demand for biogas recovery systems that are designed and optimized for small WWTPs specifically processing fewer than 5 million gallons per day (MGD) where historically it has not been economical to operate these systems.

The Las Gallinas Valley Biogas Energy Recovery System project with Las Gallinas Valley Sanitary District installed a pre-commercial biogas energy recovery system at a small WWTP in San Rafael, California (Marin County) (Figure 9). Compared to an average WWTP, which processes nearly 18 MGD of wastewater, the Las Gallinas Valley Sanitary District processes about 3 MGD. The system cleans and upgrades biogas produced by the plant into renewable gas, which is used to produce heat for the anaerobic digester of the plant, to produce electricity via two 65

---

kilowatt (kW) microturbines for plant operations (for example pumping, mixing), and to produce transportation fuel for natural gas vehicles that replace diesel vehicles onsite. Despite being a small WWTP, it is able to economically incorporate a biogas recovery system because the system uses all the available biogas at the plant. Biogas volumes are normally cyclical by season and by time of day. As a result, biogas recovery systems tend to be sized to use a lower volume of biogas with any additional gas being wasted by flaring it into the atmosphere. This system instead captures and uses the gas that would otherwise be flared to power vehicles onsite.

**Figure 9: Las Gallinas Valley Biogas Energy Recovery System in San Rafael, California**

The biogas recovery system demonstrated by this project will result in important cost and environmental benefits for the WWTP and local community. The project team estimates that converting from diesel to renewable gas to fuel their vehicles will save roughly $34,000 and 180 tons of CO₂e per year. Electricity generation from the microturbines powered by renewable gas displaces electricity purchased from the grid saving nearly $70,000 per year. In addition,
because the microturbines replaced an old reciprocating engine at the site, the system is expected to reduce oxides of nitrogen (NOx) emissions by more than 8 tons annually. These results will be validated through one year of data collection which concludes at the end of 2018. Successful demonstration of this system will help expand the market for biogas energy systems in small wastewater treatment plants by proving they can operate cost-effectively at a smaller scale.

**Reducing the Cost of Biogas Clean-up and Upgrading**

California’s biogas resources offer an opportunity for renewable energy production with much lower greenhouse gas emissions compared to fossil-derived natural gas. However, biogas is not easily used in a raw or unprocessed state and must be converted into renewable gas to expand the potential for use. Producing renewable gas requires a complex process of cleaning and upgrading biogas to remove contaminants that are not only harmful to human health, but also corrode and damage natural gas pipelines. Though many technologies exist for producing renewable gas they require extensive custom engineering and use large amounts of energy to regenerate the filter media. Some filter materials, such as activated carbon, are not easily regenerated and instead become waste material that is sent to landfills. Current state-of-the-art technologies are costly, complex, and energy intensive, produce waste material, and have a large physical footprint. The clean-up and upgrading process costs between $6-$90/mmBTU (compared to retail natural gas costs of $3-$5/mmBTu) which limits the cost-competitiveness of renewable gas compared to the fossil fuel counterpart.

The Energy Commission is funding several projects to improve the biogas cleanup and upgrading processes, looking for low-cost, energy-efficient solutions. One such project conducted by the Gas Technology Institute is developing and demonstrating a novel pathway to producing renewable gas from landfill gas, and is aiming for cost and complexity reductions across the entire biogas to renewable gas pathway.

Gas Technology Institute’s flexible system is made up of three subsystems that are designed to remove a specific set of contaminants. The first subsystem removes water and carbon dioxide from the biogas, the second removes hydrogen sulfide, siloxanes, and oxygen, and the third removes nitrogen (Figure 10). Typically, each contaminant requires a specific subsystem for removal, while this system can remove multiple contaminants within one subsystem. Plants can identify which contaminants are most prevalent in the respective biogas source, then scale up or down the capacity of each subsystem to optimally reduce this unique mix of contaminants. This technology also uses less toxic and acidic compounds than conventional wet scrubbers and requires substantially less energy to regenerate the solvents for reuse after they have absorbed the contaminants.

---

Pilot-scale landfill gas cleanup subsystems which will sequentially remove water/carbon dioxide (left), nitrogen (middle), and oxygen/hydrogen sulfide/siloxanes (right).

Source: Gas Technology Institute

This system was designed and tested using actual landfill gas and each subsystem has demonstrated the ability to remove their targeted contaminants. To validate long-term operation, the project team is demonstrating a pilot-scale (100 standard cubic feet per minute) version of the system at the Coyote Canyon Landfill in Newport Beach, (Orange County) California. This size is comparable to the small end of commercially available systems that range from 50-500 standard cubic feet per minute.

While the Gas Technology Institute is targeting the entire biogas to renewable gas pathway, Mosaic Materials (PIR-14-021) aims for breakthrough cost reductions in the largest step in the process – carbon dioxide removal. Conventional wet scrubbers use liquid solvents to remove pollutants like carbon dioxide, but require pumping and operate under high temperature and pressure regeneration conditions, increasing their energy intensity. The Mosaic Materials technology uses low-cost, solid adsorbent pellets instead of a liquid solvent, which eliminates pumping and can be regenerated under milder operating conditions. This technology reduces the energy costs of removing carbon dioxide from biogas by up to 40 percent.

During the project, the solid adsorbent pellets removed carbon dioxide to the purity (less than 2 percent) required to meet pipeline-quality natural gas standards. Mosaic Materials proved the durability of the sorbent when exposed to raw biogas, and the ability of the material to absorb and desorb carbon dioxide over repeated cycles. Each of these tests validated the commercial viability of the technology. In addition, the team performed a cost analysis of its first-generation system, which showed a capital cost reduction of around 14 percent compared to conventional systems thanks to a simpler process and less equipment.

Successful demonstration of these systems will help expand the market potential for biogas to renewable gas systems in California. When commercially mature, both systems are expected to
reliably and cost-effectively produce high quality renewable gas with a payback period of five years or less for potential customers such as landfills, wastewater treatment plants, organic waste recycling facilities, and dairy farms. In September 2018, Mosaic Materials received $1.4 million in follow-up funding from the DOE to demonstrate the efficacy of the product at a wastewater treatment plant with the Napa Sanitation District.

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

The transportation sector accounts for about 39 percent of the state’s greenhouse gas emissions and about 50 percent when including refinery emissions. Heavy-duty vehicles are the second largest contributor in the transportation sector. In addition to carbon emissions, motor vehicles are the largest source of air pollution that harms human health, accounting for nearly 80 percent of NOx emissions and 90 percent of diesel particulate emissions. The Energy Commission is supporting development of advanced near-zero emission natural gas engines that use renewable gas and hybrid gas/electric fuels.

Similarly, combined heat and power (CHP) technologies can provide air quality benefits and reduce greenhouse gas 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. The Energy Commission supports innovations in CHP technologies to lower the air quality impact of natural gas use.

Advancing Low-Carbon Transportation Technologies

Medium- and heavy-duty vehicles (MHDVs) such as trucks and buses account for more than 40 percent of NOx emissions. MHDVs are also responsible for nearly 20 percent of the GHG emissions from the transportation sector despite representing only 3 percent of registered vehicles in California.

On-road vehicles with gross vehicle weights of 26,000 to 80,000 pounds are categorized as heavy-duty vehicles (HDV) with the majority powered by diesel engines. Producing and consuming diesel fuel results in high amounts of carbon dioxide (CO2) emissions from upstream crude oil recovery and refinery processes and the high carbon content of the fuel. Diesel engines also emit high levels of NOx, especially when operated at low speeds when diesel after-treatment systems are inactive because of low exhaust temperatures.

---


According to CARB, even a highly aggressive scenario with full-fleet penetration of engines that meet the United States Environmental Protection Agency’s 2010 emission standards for heavy-duty on-road engines (0.20 grams per brake horsepower-hour [g/bhp-hr] NOx) would not provide sufficient NOx reductions to attain the federal ambient ozone standard.\textsuperscript{47} NOx emissions from heavy-duty on-road engines must be reduced beyond the 2010 emission standards to meet California’s air quality goals.

The Energy Commission funded the development of Cummins Westport Inc.’s (CWI) “Near-Zero” natural gas engines to provide low-emission alternatives to diesel engines for the HDV market to power transit buses, refuse haulers, vocational trucks, and goods movement trucks. CWI built on its previous natural gas engine platform with three primary innovations to achieve low NOx emissions:

1. An improved passive three-way catalyst after-treatment system that simultaneously reduces carbon monoxide, hydrocarbon, and NOx emissions. The catalyst coating, volume, and sensor locations were optimized to meet the NOx reduction target and provide on-board diagnostic capabilities.

2. Optimized engine software maintains tight control over the air-fuel ratio to ensure stoichiometric combustion occurs across the full range of engine operation. Stoichiometric combustion, where the air and fuel is burned completely, is necessary for the catalyst to effectively reduce emissions.

3. A closed crankcase ventilation (CCV) system reduces engine emissions by capturing and redirecting crankcase methane emissions back into the combustion chamber. Previous natural gas engines did not have a CCV system, which meant unburned methane leaked from the crankcase into the atmosphere. The CCV system uses a filter to separate oil from the captured crankcase gases, which helps maintain combustion, reduces NOx emissions, and increases the engine’s durability by preventing excessive oil consumption.

Since 2007, the Energy Commission has funded developing natural gas engines for on-road vehicles to reduce petroleum consumption, criteria pollutant emissions, and GHG emissions from the transportation sector. Past awards supported these natural gas engines that were designed to meet the 2010 emissions standard. In 2013, the Energy Commission, South Coast Air Quality Management District, and Southern California Gas Company supported research with CWI (500-12-002) to drive an additional 90 percent reduction in NOx emissions from the 2010 standard on a 9-liter natural gas engine. The success of this work led to continued efforts (500-16-002) to expand the market by developing a larger 12-liter low NOx natural gas engine that can support the performance demands of Class 8 trucks.

CWI certified the 9-liter and 12-liter variations of the Near-Zero engines to meet CARB’s most stringent Optional Low NOx Standard (0.02 g/bhp-hr NOx) and began commercial production in 2016 and 2018, respectively.

Compared to a modern 2010 standard-compliant diesel engine, the Near-Zero engines emit 90 percent fewer NOx emissions and 10 percent fewer CO₂ emissions. The 9-liter and 12-liter Near-Zero engines underwent in-use emissions testing at the UC Riverside’s chassis dynamometer center. The results validated the ability of the engines to consistently maintain low NOx emissions, even during low speed operation where diesel engines have been shown to emit much higher NOx emissions.48

Major fleets such as the United States Postal Service and Waste Management demonstrated prototype engines throughout the development process, accumulating more than 1.8 million miles on 28 test units. These tests confirmed the durability, reliability, and performance of the Near-Zero engine’s in real-world commercial fleet applications.

CWI produced 3,900 Near-Zero engines as of June 2018. Since the introduction of the Near-Zero engines into the market, several state and local clean transportation incentive programs have provided funding for fleets to accelerate adopting these engines because of the associated low NOx and GHG emissions compared to diesel engines. For example, 774 trucks equipped with the Near-Zero engines have received funding assistance through the Proposition 1B Goods Movement Emission Reduction Program managed by the San Joaquin Valley Air Pollution Control District and South Coast Air Quality Management District, which will result in 2,400 tons of NOx reductions over the vehicle lifetimes.49 With funding assistance through the CARB’s Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project and Low NOx Engine Incentives, 644 Near-Zero engines have been distributed. These vouchers require the vehicles to be fueled with renewable gas, which has a 50 percent lower average carbon intensity than diesel.50 This translates to a reduction of nearly 900 tons of NOx and 1.1 million tons of CO₂ equivalent emissions over the vehicle lifetimes.51

Reducing Installation Costs for Combined Heat and Power in Commercial Buildings

Interconnection is a major cost component for installing new CHP systems. In 2003, California’s Electric Rule 21 (a standardized interconnection process to the electricity grid) opened up the opportunity for distributed generation products to follow a simplified interconnection process


49 Data acquired from South Coast Air Quality Management District and San Joaquin Valley Air Pollution Control District in May 2018.


if they were tested to be compliant or certified by a national laboratory such as Underwriters Laboratory (UL), and if the host facility met certain guidelines. However, at the time only higher-cost CHP options such as microturbines and fuel-cell combined CHP modules were able to meet the certification requirements.

In 2004, the Energy Commission funded Tecogen to begin developing an engine-driven CHP product that would meet the certification requirements of Rule 21, have ultra-low air emissions on par with fuel cells, and a small footprint with easy plug and play and operational compatibility to lower installation costs.52

Tecogen’s engine-based CHP module uses a water-cooled “permanent magnet” generator that produces electricity at much higher efficiency than conventional generators but without voltage and frequency regulation. The inverter power electronics of the module meet the interconnection and safety criteria required for UL 1741 certification. In addition, the module is equipped with sophisticated control algorithms that allows the unit to be operated as part of a microgrid because of the ability to blackstart (restore the system to operation without relying on external electric power grid). The simple interface of the module makes it easy to install in multiple unit applications and is internationally adaptable (50/60 Hertz) via a software change.

In addition, through a proprietary process developed by Tecogen with funding from the California Energy Commission and Southern California Gas Company, Tecogen’s ultra-low emissions technology substantially reduces criteria pollutants by using a two-stage exhaust after-treatment catalyst. Emissions measurements from Tecogen systems equipped with the ultra-low emissions technology conform to the current CARB 2007 carbon monoxide (CO) and NOx standards for distributed power generation (Table 3). Tecogen’s CHP module is now commercially available with 315 units sold in the United States and Europe and 13 units installed in California as of October 2018.

<table>
<thead>
<tr>
<th></th>
<th>Fuel Cells</th>
<th>Microturbines</th>
<th>Typical Engines-Genset</th>
<th>Tecogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Operation and Maintenance Costs</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Meets Rule 21 Certification</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Air Pollution Emissions</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low*</td>
</tr>
<tr>
<td>Physical Footprint</td>
<td>Large</td>
<td>Large</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Response Time</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
<td>Fast</td>
</tr>
</tbody>
</table>

*Post-treatment with ultra-low emissions technology

Source: California Energy Commission staff, 2018, based on communication with Tecogen

52 The Energy Commission funded the development of the Tecogen system under agreement 500-03-039 followed by another agreement PNG-06-002. The Final Report for the first agreement is found here: https://www.energy.ca.gov/2010publications/CEC-500-2010-006/CEC-500-2010-006.PDF
# ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>Assembly Bill</td>
</tr>
<tr>
<td>BTU</td>
<td>British thermal unit</td>
</tr>
<tr>
<td>CARB</td>
<td>California Air Resources Board</td>
</tr>
<tr>
<td>CCV</td>
<td>Closed crankcase ventilation</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined heat and power</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CO$_2$e</td>
<td>Carbon dioxide equivalent</td>
</tr>
<tr>
<td>CPUC</td>
<td>California Public Utilities Commission</td>
</tr>
<tr>
<td>CWI</td>
<td>Cummins Westport, Inc.</td>
</tr>
<tr>
<td>E3</td>
<td>Energy + Environmental Economics</td>
</tr>
<tr>
<td>EPIC</td>
<td>Electric Program Investment Charge</td>
</tr>
<tr>
<td>g/bhp-hr</td>
<td>Grams per brake horsepower-hour</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
</tr>
<tr>
<td>GFO</td>
<td>Grant Funding Opportunity</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HDV</td>
<td>Heavy-duty vehicle</td>
</tr>
<tr>
<td>HUD</td>
<td>United States Department of Housing and Urban Development</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, ventilation, and air-conditioning</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>MGD</td>
<td>Million gallons per day</td>
</tr>
<tr>
<td>MHDVs</td>
<td>Medium- and heavy-duty vehicles</td>
</tr>
<tr>
<td>mm/Btu</td>
<td>Million British Thermal Units</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>Oxides of nitrogen</td>
</tr>
<tr>
<td>PIER</td>
<td>Public Interest Energy Research</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>PON</td>
<td>Program Opportunity Notice</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SB</td>
<td>Senate Bill</td>
</tr>
<tr>
<td>UC</td>
<td>University of California</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriters Laboratory</td>
</tr>
<tr>
<td>WWTP</td>
<td>Wastewater treatment plant</td>
</tr>
</tbody>
</table>
## APPENDIX A: Select Policy Goals for California’s Energy Future

<table>
<thead>
<tr>
<th>Policy or Standard</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly Bill 1900 (2012)</td>
<td>Develop standards for constituents in biogas to protect human health and pipeline integrity and safety.</td>
</tr>
<tr>
<td>Assembly Bill 193 (2018)</td>
<td>Creates the Zero-Emission Assurance Project, which will provide a rebate for the purchase of a replacement battery or fuel cell component for a used zero-emission vehicle for qualified consumers. This will build consumer confidence in the purchase of a used zero emission vehicle by providing additional assurance that replacement of a battery or fuel cell component will not impose a cost burden on low-income consumers.</td>
</tr>
<tr>
<td>Assembly Bill 2006 (2018)</td>
<td>Makes permanent an existing agricultural worker vanpool program, which will result in zero-emission and hybrid vans taking passenger vehicles off the road in communities most impacted by California’s poor air quality.</td>
</tr>
<tr>
<td>Assembly Bill 2127 (2018)</td>
<td>Supports the state’s goal of achieving 5 million zero-emission vehicles on the road by 2030 by affirming the California Energy Commission’s authority to assess the need for charging infrastructure to support adoption of zero-emission vehicles, including freight and off-road vehicles.</td>
</tr>
<tr>
<td>Assembly Bill 2195 (2018)</td>
<td>Requires the California Air Resources Board to quantify and publish annually the amount of greenhouse gas emissions resulting from the loss or release of uncombusted natural gas to the atmosphere and emissions from natural gas flares during all processes associated with the production, processing, and transporting of natural gas imported into the state from out-of-state sources.</td>
</tr>
<tr>
<td>Assembly Bill 2195 (2018)</td>
<td>Will help the public access information regarding the greenhouse gas emissions from gas leakage and flaring resulting from natural gas imported into and consumed in California.</td>
</tr>
<tr>
<td>Assembly Bill 2885 (2018)</td>
<td>Continues the legislative priority of ensuring that California’s incentive programs serve all communities, by extending the requirement that the California Air Resources Board conduct outreach to low-income households and communities as part of the Clean Vehicle Rebate Project. The bill also requires California Air Resources Board to continue to prioritize rebates to low-income applicants until Jan 1, 2022.</td>
</tr>
</tbody>
</table>
## APPENDIX A: Select Policy Goals for California’s Energy Future

<table>
<thead>
<tr>
<th>Policy or Standard</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly Bill 3232 (2018)</td>
<td>Directs state agencies to work together to assess what actions should be taken to reduce emissions from the state’s residential and commercial buildings, recognizing the important work needed to reduce our greenhouse gas emissions from the building sector.</td>
</tr>
<tr>
<td>Bioenergy Action Plan to implement Executive Order S-06-06</td>
<td>Set goals for the production and use of electricity and fuels made from biomass.</td>
</tr>
<tr>
<td>California’s Loading Order, from the California Energy Action Plan</td>
<td>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.</td>
</tr>
<tr>
<td>CPUC Energy Efficiency Strategic Plan</td>
<td>Sets efficiency goals, including zero-net-energy goals for new homes by 2020 and for new commercial buildings by 2030.</td>
</tr>
<tr>
<td>Executive Order B-18-12 – Greening State Buildings</td>
<td>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.</td>
</tr>
<tr>
<td>Executive Order B-29-15</td>
<td>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.</td>
</tr>
<tr>
<td>Executive Order B-30-15 GHG Reduction Target and Climate Adaptation and Senate Bill 32 (2016)</td>
<td>Sets a GHG reduction target of 40 percent below 1990 levels by 2030.</td>
</tr>
<tr>
<td>Executive Order B-32-15 Integrated Action Plan</td>
<td>Directs improvement of freight efficiency, transition to zero-emission technologies, and increase competitiveness of California’s freight system.</td>
</tr>
<tr>
<td>Executive Order S-01-07 Low Carbon Fuel Standard (LCFS)</td>
<td>Sets goal to reduce carbon intensity of the state’s fuels by 10 percent by 2020.</td>
</tr>
</tbody>
</table>
## APPENDIX A: Select Policy Goals for California’s Energy Future

<table>
<thead>
<tr>
<th>Policy or Standard</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governor Brown’s Aliso Canyon Gas Leak Proclamation (2016)</td>
<td>The order directs further action to protect public health and safety, ensure accountability and strengthen oversight of gas storage facilities.</td>
</tr>
<tr>
<td>Governor Brown’s <em>Clean Energy Jobs Plan</em> (2011)</td>
<td>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).</td>
</tr>
<tr>
<td>Integrated Energy Policy Report</td>
<td>The Energy Commission’s biennial energy forecasting and assessment report recommends policies to foster the development of energy efficiency, renewable energy, and more.</td>
</tr>
<tr>
<td>Public Resources Code 25620</td>
<td>Public interest energy research, demonstration, and development projects should advance energy science or technologies of value to California citizens.</td>
</tr>
<tr>
<td>Senate Bill 1000 (2018)</td>
<td>Requires the state to assess whether vehicle-charging infrastructure is sufficient to encourage the purchase of electric vehicles and ensures that both plug-in electric vehicles and zero-emission vehicles have equal access to charging infrastructure. By increasing accessibility to electric vehicle charging infrastructure and managing the costs of electricity, SB 1000 will support the transportation electrification needed to meet California’s greenhouse gas and clean air goals.</td>
</tr>
<tr>
<td>Senate Bill 1013 (2018)</td>
<td>In the face of federal reversals, this bill provides a critical backstop to ensure California does not backslide on emissions of hydrofluorocarbons and achieves its short-lived climate pollutant reduction goals. The bill also creates the Fluorinated Gases Emission Reduction Incentive Program to promote the adoption of low-global warming potential refrigerants.</td>
</tr>
<tr>
<td>Senate Bill 1014 (2018)</td>
<td>Directs the state to develop emissions reduction targets for ride-hailing services, which represent a growing element of California’s transportation sector. This bill will help ensure that work the Governor has set into motion to increase adoption of zero-emission vehicles in public and private fleets throughout the state continues.</td>
</tr>
<tr>
<td>Senate Bill 1016 (2018)</td>
<td>Prohibits homeowner associations from unreasonably restricting an owner’s ability to install or use an electric vehicle time-of-use meter and modifies current liability policies.</td>
</tr>
</tbody>
</table>
## APPENDIX A: Select Policy Goals for California’s Energy Future

<table>
<thead>
<tr>
<th>Policy or Standard</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senate Bill 1017 (2018)</td>
<td>Establishes a regional climate collaborative program to assist under-resourced communities with accessing statewide public and other grant money for climate change mitigation and adaptation-related projects. The bill also requires the Strategic Growth Council to develop technical assistance best practices that state agencies may use and identify state grants that could benefit from technical assistance best practices.</td>
</tr>
<tr>
<td>Senate Bill 1250 (2006)</td>
<td>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.</td>
</tr>
<tr>
<td>Senate Bill 1371 (2014) – Natural Gas: Leakage Abatement</td>
<td>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.</td>
</tr>
<tr>
<td>Senate Bill 1383 (2016)</td>
<td>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.</td>
</tr>
<tr>
<td>Senate Bill 1403 (2018)</td>
<td>Ensures that the state’s incentive dollars are invested strategically and are incentivizing the adoption of zero and near-zero emission heavy duty vehicles and equipment, including school buses. The bill requires the California Air Resources Board to develop three-year investment plans for these vehicles starting in 2019. It is critical that investments are prioritized—demand for the state’s incentive programs that support zero and near-zero emission heavy-duty vehicles and equipment vastly outstrips the resources available.</td>
</tr>
<tr>
<td>Senate Bill 1477 (2018)</td>
<td>Establishes two incentive programs aimed at reducing emissions from buildings—one to provide financial incentives for the deployment of near-zero emission building technologies and a second to incentivize the installment of low-emission space and water heating equipment for new and existing buildings.</td>
</tr>
<tr>
<td>Senate Bill 32 (2016) – The California Global Warming Solutions Act</td>
<td>Requires the state to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030.</td>
</tr>
</tbody>
</table>
APPENDIX A: Select Policy Goals for California’s Energy Future

<table>
<thead>
<tr>
<th>Policy or Standard</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senate Bill 350 (2015)</td>
<td>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</td>
</tr>
<tr>
<td>Senate Bill 957 (2018)</td>
<td>Facilitates further growth of the used zero-emission vehicle market by opening carpool lanes to low-income drivers of used clean air vehicles.</td>
</tr>
<tr>
<td>Senate Bill X1 2 (2011) – The Renewables Portfolio Standard</td>
<td>Requires all electricity retailers to meet 33 percent of their retail sales with renewable energy by 2020.</td>
</tr>
</tbody>
</table>

Source: California Energy Commission staff
APPENDIX B-1:
FY 2017-18 Natural Gas Approved Funding

<table>
<thead>
<tr>
<th>Natural Gas Research Areas</th>
<th>FY 2017-18 Approved Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Efficiency</td>
<td>$6,600,000</td>
</tr>
<tr>
<td>Renewable Energy and Advanced Generation</td>
<td>$4,000,000</td>
</tr>
<tr>
<td>Energy Infrastructure</td>
<td>$8,000,000</td>
</tr>
<tr>
<td>Natural Gas-Related Transportation</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Program Administration</td>
<td>$2,400,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$24,000,000</strong></td>
</tr>
</tbody>
</table>
## APPENDIX B-2:
FY 2017-18 Natural Gas Funding Opportunities

<table>
<thead>
<tr>
<th>Solicitation Title</th>
<th>Release Date</th>
<th>Program Area</th>
<th>Funding Amount</th>
<th>Application Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhancing Safety, Environmental Performance, and Resilience of California’s Natural Gas System (GFO-17-502)</td>
<td>September 11, 2017</td>
<td>Energy-Related Environmental Research</td>
<td>$8,900,000</td>
<td>November 17, 2017</td>
</tr>
<tr>
<td>Addressing Barriers to Wider Adoption of Near-Zero Emission Natural Gas Vehicles (GFO-17-503)</td>
<td>September 26, 2017</td>
<td>Natural Gas-Related Transportation</td>
<td>$3,400,000</td>
<td>December 6, 2017</td>
</tr>
</tbody>
</table>
APPENDIX B-3:
Natural Gas Project Funding 2004 - Present
## APPENDIX C:
### FY 2017-18 Natural Gas Active and Completed Agreements List

<table>
<thead>
<tr>
<th>Agreement #</th>
<th>Recipient</th>
<th>Title</th>
<th>Agreement Amount</th>
<th>Match Amount</th>
<th>Business Mtg</th>
</tr>
</thead>
<tbody>
<tr>
<td>500-13-006</td>
<td>California Air Resources Board</td>
<td>Identification and Evaluation of Constituents Found in Biogas in California</td>
<td>$400,000</td>
<td>$400,000</td>
<td>2/12/14</td>
</tr>
<tr>
<td>500-13-008</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Assessment of Residential Natural Gas Emissions</td>
<td>$500,000</td>
<td>$0</td>
<td>6/18/14</td>
</tr>
<tr>
<td>500-14-001</td>
<td>U.S. Geological Survey Earthquake Science Center</td>
<td>High Resolution Measurement of Levee Subsidence Related to Natural Gas Infrastructure in the Sacramento-San Joaquin Delta</td>
<td>$325,000</td>
<td>$0</td>
<td>8/27/14</td>
</tr>
<tr>
<td>500-14-003</td>
<td>The Regents of the University of California on behalf of the Berkeley campus</td>
<td>Visualizing Climate-Related Risks to the Natural Gas System Using Cal-Adapt</td>
<td>$300,000</td>
<td>$0</td>
<td>4/8/15</td>
</tr>
<tr>
<td>500-14-004</td>
<td>CO2Nexus, Inc.</td>
<td>CO2 Cleaning Project</td>
<td>$900,300</td>
<td>$1,110,732</td>
<td>5/13/15</td>
</tr>
<tr>
<td>500-14-005</td>
<td>The Regents of the University of California, San Diego</td>
<td>Weather Related Scenarios for the Natural Gas System: California’s Fourth Climate Change Assessment</td>
<td>$600,000</td>
<td>$0</td>
<td>6/10/15</td>
</tr>
<tr>
<td>500-15-002</td>
<td>South Coast Air Quality Management District</td>
<td>On-Road, In-Use Emissions and Fuel Usage Assessment</td>
<td>$2,000,000</td>
<td>$1,510,000</td>
<td>12/9/15</td>
</tr>
<tr>
<td>500-15-004</td>
<td>The National Aeronautics and Space Administration</td>
<td>California Baseline Methane Survey: Identification of Large Fugitive Methane Emitters from the Natural Gas Sector</td>
<td>$600,000</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>500-15-005</td>
<td>The Regents of the University of California, Irvine</td>
<td>A Multi-Hazard Investigation of Climate Vulnerability of the Natural Gas Energy System in Southern California</td>
<td>$893,692</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>500-15-006</td>
<td>University of California Merced</td>
<td>Solar Water Heating for the Residential, Commercial and Industrial Sectors</td>
<td>$999,806</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>500-15-007</td>
<td>University of California, Santa Cruz</td>
<td>Investigate Climate-change-induced Vulnerability of the Northern California Natural Gas Energy System and Identify Resilience Options</td>
<td>$600,000</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>500-16-002</td>
<td>South Coast Air Quality Management District</td>
<td>Low NOx 12-Liter Natural Gas Engine Development</td>
<td>$1,000,000</td>
<td>$3,375,915</td>
<td>9/14/16</td>
</tr>
<tr>
<td>500-17-003</td>
<td>San Francisco State University</td>
<td>Technical Assistance for the Energy Commission Food Processing Program</td>
<td>$249,947</td>
<td>$0</td>
<td>1/17/18</td>
</tr>
<tr>
<td>PIR-13-001</td>
<td>Regents of the University of California (University of California, Davis)</td>
<td>Air Quality Implications of using Biogas (AQiB) to Replace Natural Gas in California</td>
<td>$775,064</td>
<td>$0</td>
<td>5/14/14</td>
</tr>
<tr>
<td>PIR-13-002</td>
<td>EtaGen, Inc.</td>
<td>High Compression Ratio Free Piston Engine for CHP</td>
<td>$796,247</td>
<td>$1,099,580</td>
<td>5/14/14</td>
</tr>
<tr>
<td>PIR-13-004</td>
<td>The Regents of the University of California, Irvine Advanced Power and Energy Program</td>
<td>Low Cost Micro DG/CHP for Use in Laundry Facilities</td>
<td>$994,307</td>
<td>$95,000</td>
<td>5/14/14</td>
</tr>
<tr>
<td>PIR-13-007</td>
<td>Agricultural Research Services, United States Department of Agriculture</td>
<td>Commercial Demonstration of Innovative, Energy Efficient Infrared Processing of Healthy Fruit and Vegetable Snacks</td>
<td>$884,810</td>
<td>$291,203</td>
<td>6/18/14</td>
</tr>
<tr>
<td>PIR-13-009</td>
<td>Trevi Systems Inc.</td>
<td>Forward Osmosis Desalination of Industrial Waste Water</td>
<td>$1,700,000</td>
<td>$600,000</td>
<td>6/18/14</td>
</tr>
<tr>
<td>PIR-13-010</td>
<td>UC Davis</td>
<td>Demonstration and Commercial Implementation of Energy Efficient Drying for Walnuts</td>
<td>$1,118,285</td>
<td>$280,000</td>
<td>6/18/14</td>
</tr>
<tr>
<td>PIR-13-011</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Demonstration of Industrial System with Real-time Response to Fuel Stock Variability</td>
<td>$1,600,000</td>
<td>$460,504</td>
<td>6/18/14</td>
</tr>
<tr>
<td>PIR-13-014</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Optimized Natural Gas Hybrid-Electric Drayage Truck Demonstration</td>
<td>$900,000</td>
<td>$300,000</td>
<td>6/18/14</td>
</tr>
<tr>
<td>PIR-14-001</td>
<td>Gas Technology Institute</td>
<td>High Efficiency Indirect-Fired Rotary Dryer with Advanced Heat Pump for Bulk Foods Processing</td>
<td>$2,600,000</td>
<td>$700,000</td>
<td>7/22/14</td>
</tr>
<tr>
<td>PIR-14-003</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Measurement and Control of Ventilation Rates in Commercial Buildings in California</td>
<td>$750,000</td>
<td>$0</td>
<td>9/10/14</td>
</tr>
<tr>
<td>PIR-14-004</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Demonstration of a Novel Ultra-Low NOx Boiler for Commercial Buildings</td>
<td>$798,788</td>
<td>$525,000</td>
<td>9/10/14</td>
</tr>
<tr>
<td>PIR-14-007</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Healthy and Efficient New Gas Homes</td>
<td>$1,250,000</td>
<td>$400,995</td>
<td>9/10/14</td>
</tr>
<tr>
<td>PIR-14-010</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>High Frequency Corona Discharge Ignition System Demonstration</td>
<td>$750,000</td>
<td>$0</td>
<td>4/8/15</td>
</tr>
<tr>
<td>PIR-14-011</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Advanced Plasma Ignition Systems for Class 3-8 Natural Gas Engines</td>
<td>$749,868</td>
<td>$300,699</td>
<td>4/8/15</td>
</tr>
<tr>
<td>PIR-14-012</td>
<td>Olson-Ecologic Engine Testing Laboratories, LLC</td>
<td>Research of Advanced Spark Ignited Prechambers Utilizing Turbulent Jet Ignition</td>
<td>$750,000</td>
<td>$984,700</td>
<td>4/8/15</td>
</tr>
<tr>
<td>PIR-14-013</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Advanced Fueling Method to Achieve Full Fill for Natural Gas Vehicles</td>
<td>$400,000</td>
<td>$300,000</td>
<td>4/8/15</td>
</tr>
<tr>
<td>PIR-14-014</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Pipeline Right of Way Monitoring and Notification System</td>
<td>$1,049,978</td>
<td>$0</td>
<td>5/13/15</td>
</tr>
<tr>
<td>PIR-14-015</td>
<td>Acellent Technologies, Inc.</td>
<td>Rapid+ System for Natural Gas Pipeline Integrity Management</td>
<td>$1,633,093</td>
<td>$103,000</td>
<td>5/13/15</td>
</tr>
<tr>
<td>PIR-14-017</td>
<td>Gas Technology Institute (GTI)</td>
<td>Demonstration of an Advanced Low NOx Ribbon Burner Combustion System for Industrial Bakeries</td>
<td>$950,000</td>
<td>$245,000</td>
<td>5/13/15</td>
</tr>
<tr>
<td>PIR-14-018</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Showcase Field Demonstrations of a 25 kWe Low-Emission Reciprocating Engine CHP System at the SoCal Gas Energy Resource Center</td>
<td>$562,820</td>
<td>$175,000</td>
<td>6/10/15</td>
</tr>
<tr>
<td>PIR-14-019</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Advancing Novel Biogas Cleanup Systems for the Production of Renewable Natural Gas</td>
<td>$1,000,000</td>
<td>$214,650</td>
<td>6/10/15</td>
</tr>
<tr>
<td>PIR-14-020</td>
<td>Las Gallinas Valley Sanitary District</td>
<td>Las Gallinas Valley Biogas Energy Recovery System (BERS) Project</td>
<td>$999,070</td>
<td>$3,101,203</td>
<td>6/10/15</td>
</tr>
<tr>
<td>PIR-14-021</td>
<td>Mosaic Materials, Inc.</td>
<td>Cost Reduction for Biogas Upgrading via a Low-Pressure Solid-State Amine Scrubber</td>
<td>$1,000,000</td>
<td>$220,000</td>
<td>6/10/15</td>
</tr>
<tr>
<td>PIR-14-022</td>
<td>Biogas Energy Inc.</td>
<td>Improvements to biogas production using micronutrients, operational methodologies, and biogas processing equipment to enable pipeline injection of biomethane</td>
<td>$415,000</td>
<td>$112,100</td>
<td>6/10/15</td>
</tr>
<tr>
<td>PIR-14-023</td>
<td>The Regents of the University of California, San Diego</td>
<td>Renewable Natural Gas Production from Woody Biomass via Gasification and Fluidized-Bed Methanation</td>
<td>$1,000,000</td>
<td>$237,000</td>
<td>6/10/15</td>
</tr>
<tr>
<td>PIR-15-002</td>
<td>Regents of the University of California (University of California, Davis)</td>
<td>Understanding and Improving Solar Water Heater Effectiveness in California Households</td>
<td>$500,000</td>
<td>$40,000</td>
<td>11/12/15</td>
</tr>
<tr>
<td>PIR-15-003</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Assessment of Fugitive Emissions from the Natural Gas System-Commercial Buildings</td>
<td>$599,891</td>
<td>$0</td>
<td>11/12/15</td>
</tr>
<tr>
<td>PIR-15-004</td>
<td>ICF Incorporated, L.L.C.</td>
<td>Investigate Climate Vulnerability of the Natural Gas System and Identify Resilience Options in the San Diego Area</td>
<td>$456,703</td>
<td>$166,200</td>
<td>11/12/15</td>
</tr>
<tr>
<td>PIR-15-005</td>
<td>The Regents of the University of California, San Diego</td>
<td>Probabilistic Seasonal and Decadal Forecasting for the Natural Gas System</td>
<td>$399,467</td>
<td>$0</td>
<td>11/12/15</td>
</tr>
<tr>
<td>PIR-15-008</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Development, Integration, and Demonstration of 6.7 Liter Natural Gas Engine in Medium Heavy-Duty Vehicles</td>
<td>$1,000,000</td>
<td>$1,641,643</td>
<td>3/9/16</td>
</tr>
<tr>
<td>PIR-15-010</td>
<td>ergSol, Inc.</td>
<td>Integration of Advanced Solar Thermal Technology into Industrial Processes</td>
<td>$1,200,000</td>
<td>$300,000</td>
<td>3/9/16</td>
</tr>
<tr>
<td>PIR-15-012</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Pipeline Safety and Integrity Monitoring Technologies Assessment</td>
<td>$1,006,812</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>PIR-15-013</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Demonstration of Water Recovery from Hot, Humid Industrial Exhaust Gases</td>
<td>$1,294,032</td>
<td>$325,000</td>
<td>6/14/16</td>
</tr>
<tr>
<td>PIR-15-014</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>High Accuracy Mapping for Excavation Damage Prevention and Emergency Response</td>
<td>$1,481,426</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>PIR-15-015</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>GPS Excavation Encroachment Notification System Implementation</td>
<td>$1,301,288</td>
<td>$170,000</td>
<td>6/14/16</td>
</tr>
<tr>
<td>PIR-15-016</td>
<td>DNV GL USA, Inc.</td>
<td>Demonstration of a Multi-Analytic Risk Management Tool for the California Pipeline Industry</td>
<td>$1,309,305</td>
<td>$411,761</td>
<td>6/14/16</td>
</tr>
<tr>
<td>PIR-15-017</td>
<td>ICF Incorporated, L.L.C.</td>
<td>Characterization of Fugitive Methane Emissions from Commercial Buildings in California</td>
<td>$599,683</td>
<td>$0</td>
<td>6/14/16</td>
</tr>
<tr>
<td>PIR-16-001</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Demonstrating Natural Gas Heat Pumps for Integrated Hot Water and Air-Conditioning in Restaurants</td>
<td>$864,294</td>
<td>$260,748</td>
<td>1/25/17</td>
</tr>
<tr>
<td>PIR-16-002</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Demonstration of Advanced High-Efficiency, Low Capacity HVAC Systems</td>
<td>$750,000</td>
<td>$182,000</td>
<td>1/25/17</td>
</tr>
<tr>
<td>PIR-16-003</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Demonstration and Assessment of Residential Gas Heat Pump Water Heaters in the Los Angeles Basin</td>
<td>$1,084,230</td>
<td>$310,500</td>
<td>1/25/17</td>
</tr>
<tr>
<td>PIR-16-004</td>
<td>Advanced Microgrid Solutions, Inc.</td>
<td>Advanced HVAC Technology Demonstration Project to Reduce Natural Gas Use in Hospitals</td>
<td>$1,216,707</td>
<td>$902,463</td>
<td>1/25/17</td>
</tr>
<tr>
<td>PIR-16-007</td>
<td>The Regents of the University of California, Merced</td>
<td>A Novel Low-Cost, High-Efficiency Solar Powered Micro-CHP System for Electricity, Hot Water, and Space Heating</td>
<td>$816,659</td>
<td>$118,472</td>
<td>2/15/17</td>
</tr>
<tr>
<td>PIR-16-008</td>
<td>ICF Incorporated, L.L.C.</td>
<td>A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California</td>
<td>$200,000</td>
<td>$20,000</td>
<td>2/15/17</td>
</tr>
<tr>
<td>PIR-16-009</td>
<td>Element 16 Technologies, Inc</td>
<td>Small-CCHP Packaged System with Innovative Quick-Response, Compact, and High-Temperature Thermal Energy Storage</td>
<td>$1,500,000</td>
<td>$150,000</td>
<td>2/15/17</td>
</tr>
<tr>
<td>PIR-16-010</td>
<td>All Power Labs, Inc.</td>
<td>Development and Demonstration of an Innovative Micro-scale Biomass Gasifier Combined Cooling, Heating, and Power System</td>
<td>$1,500,000</td>
<td>$326,272</td>
<td>2/15/17</td>
</tr>
<tr>
<td>PIR-16-012</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Effective Kitchen Ventilation for Healthy ZNE Homes with Natural Gas Appliances</td>
<td>$1,000,000</td>
<td>$200,000</td>
<td>3/8/17</td>
</tr>
<tr>
<td>PIR-16-013</td>
<td>The Regents University of California, Davis</td>
<td>Quantification of Methane from California's Plugged &amp; Abandoned Gas Wells: Effects of Land Subsidence and Other Factors</td>
<td>$597,433</td>
<td>$0</td>
<td>3/8/17</td>
</tr>
<tr>
<td>PIR-16-015</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Characterize Actual and Future Impact of California's Drought on Three-component Ground Deformations and their Influence on the Natural Gas Infrastructure</td>
<td>$1,599,584</td>
<td>$145,000</td>
<td>3/8/17</td>
</tr>
<tr>
<td>PIR-16-017</td>
<td>The Regents of the University of California, Irvine Advanced Power and Energy Program</td>
<td>Using Renewable Natural Gas in Common Appliances and Implications on Emissions, Fuel Stability and Operational Performance</td>
<td>$250,000</td>
<td>$0</td>
<td>4/12/17</td>
</tr>
<tr>
<td>PIR-16-018</td>
<td>Olson-Ecologic Engine Testing Laboratories, LLC</td>
<td>Research, Development and Demonstration of Low-Emission CNG Engines for Construction Vehicles</td>
<td>$1,500,000</td>
<td>$1,970,000</td>
<td>4/12/17</td>
</tr>
<tr>
<td>PIR-16-019</td>
<td>Terzo Power Systems, LLC.</td>
<td>CNG Hybrid Power System for Mobile Vehicles</td>
<td>$1,497,400</td>
<td>$5,150</td>
<td>4/12/17</td>
</tr>
<tr>
<td>PIR-16-021</td>
<td>Electric Power Research Institute (EPRI)</td>
<td>Data Driven Approaches to Understanding Occupant Natural Gas Use in Low-Income Multifamily Communities</td>
<td>$260,145</td>
<td>$78,712</td>
<td>4/27/17</td>
</tr>
<tr>
<td>PIR-16-022</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Costs and Benefits of Community vs. Individual End-Use for Solar Water Heating</td>
<td>$250,000</td>
<td>$0</td>
<td>4/27/17</td>
</tr>
<tr>
<td>PIR-16-023</td>
<td>The Regents of the University of California, Los Angeles</td>
<td>Evaluation of Community-Scale Solar Water Heating in Los Angeles County</td>
<td>$240,404</td>
<td>$0</td>
<td>4/27/17</td>
</tr>
<tr>
<td>PIR-16-024</td>
<td>Transient Plasma Systems, Inc.</td>
<td>Development and Demonstration of a Production-Intent Transient Plasma Ignition System for High Efficiency Natural Gas Engines</td>
<td>$899,139</td>
<td>$62,711</td>
<td>6/14/17</td>
</tr>
<tr>
<td>PIR-16-025</td>
<td>Southwest Research Institute</td>
<td>Research and Development of Natural Gas D-EGR Engine for Improved On-Highway Efficiency</td>
<td>$891,580</td>
<td>$250,000</td>
<td>6/14/17</td>
</tr>
<tr>
<td>PIR-16-027</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>An Integrated Risk Management and Decision-Support System for Ensuring the Integrity of Underground Natural Gas Storage Infrastructure in California</td>
<td>$2,975,761</td>
<td>$0</td>
<td>6/14/17</td>
</tr>
<tr>
<td>Project Number</td>
<td>Recipient</td>
<td>Description</td>
<td>Total Budget</td>
<td>Total Spent</td>
<td>Start Date</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------</td>
<td>-------------</td>
<td>--------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>PIR-16-028</td>
<td>DNV GL USA, Inc.</td>
<td>A Barrier-Based Quantitative Risk Management Approach for Underground Storage of Natural Gas</td>
<td>$2,398,939</td>
<td>$373,725</td>
<td>6/14/17</td>
</tr>
<tr>
<td>PIR-17-001</td>
<td>T2M Global LLC</td>
<td>High Efficiency Waste Heat to Osmotic Power</td>
<td>$1,299,109</td>
<td>$132,535</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-002</td>
<td>Altex Technologies Corporation</td>
<td>Advanced Thermo Electric Generator System (ATEGS)</td>
<td>$1,222,850</td>
<td>$167,885</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-003</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Demonstration of 4.5 and 25 kW CARB-compliant Reciprocating Engine Micro-CHP Systems</td>
<td>$1,499,406</td>
<td>$167,600</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-004</td>
<td>Element 16 Technologies, Inc</td>
<td>Low Temperature, Efficient Heat Capture to Reduce Natural Gas Consumption in the Chemical Industry</td>
<td>$1,500,000</td>
<td>$300,000</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-005</td>
<td>University of California, Riverside</td>
<td>Demonstration of Smart Combustion Technology Using Natural Gas Fuel Quality Sensors</td>
<td>$1,499,910</td>
<td>$193,900</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-006</td>
<td>EtaGen, Inc.</td>
<td>High Efficiency and Ultra-Low Emissions Linear Generator Demonstration Project in Southern California</td>
<td>$995,659</td>
<td>$1,386,066</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-007</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Emerging Energy Efficiency Technologies in California’s Chemicals and Allied Products Industry-Estimating Energy Efficiency Cost Curves and Identifying Technology R&amp;D Needs and Gaps</td>
<td>$300,000</td>
<td>$0</td>
<td>3/21/18</td>
</tr>
<tr>
<td>PIR-17-008</td>
<td>Transportation Power, Inc.</td>
<td>Demonstration of a CNG-Hybrid Electric Super-Truck (CHEST)</td>
<td>$1,500,000</td>
<td>$259,926</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-009</td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
<td>Optimization and Demonstration of a Near-Zero, Heavy-Duty, Hybrid-Electric Truck</td>
<td>$1,499,381</td>
<td>$253,999</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-010</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>Using Chemical and Isotopic Analyses to Improve Life-Cycle Assessments of the Natural Gas Consumed in California</td>
<td>$549,978</td>
<td>$53,633</td>
<td>5/9/18</td>
</tr>
<tr>
<td>PIR-17-011</td>
<td>The Regents of the University of California, Irvine</td>
<td>Developing a Methodology to Determine Chemical and Isotopic Composition of Natural Gas Consumed in California</td>
<td>$550,000</td>
<td>$88,881</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-012</td>
<td>The Regents of the University of California</td>
<td>Developing Next-generation Cal-Adapt Features to Support Natural Gas Sector Resilience</td>
<td>$1,000,000</td>
<td>$0</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-013</td>
<td>InfraTerra, Inc.</td>
<td>Development of an Integrated Methodology for Assessing Integrity of Levees Protecting Natural Gas Infrastructure</td>
<td>$549,500</td>
<td>$500</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-014</td>
<td>Eagle Rock Analytics</td>
<td>Developing Next-Generation Cal-Adapt Features to Support Natural Gas Sector Resilience</td>
<td>$200,000</td>
<td>$0</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-015</td>
<td>Lawrence Berkeley National Laboratory</td>
<td>SUper eMitters of Methane Detection Using Aircraft, Towers, and Intensive Observational Network (SUMMATION)</td>
<td>$6,000,000</td>
<td>$14,425,970</td>
<td>4/11/18</td>
</tr>
<tr>
<td>PIR-17-017</td>
<td>Institute of Gas Technology Institute</td>
<td>High Efficiency Process Heating</td>
<td>$1,405,947</td>
<td>$1,480,000</td>
<td>5/9/18</td>
</tr>
</tbody>
</table>

**Total**

|            | $102,939,714 | $48,944,760 |

Terminated Project with no Funds Spent (Not included in project count)

One project was approved at an Energy Commission Business Meeting in 2017, but later terminated by the recipient, North American Repower, LLC (PIR-16-026); however, no work was done on this project and no funds were spent.
**APPENDIX D: FY 2017-18 NATURAL GAS ACTIVE AND COMPLETED PROJECT WRITE-UPS**

<table>
<thead>
<tr>
<th><strong>Project Name:</strong></th>
<th>Identification and Evaluation of Constituents Found in Biogas in California - [500-13-006]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recipient/Contractor:</strong></td>
<td>California Air Resources Board</td>
</tr>
<tr>
<td><strong>Natural Gas Funding Plan:</strong></td>
<td><strong>Project Term:</strong></td>
</tr>
<tr>
<td>Natural Gas Research</td>
<td>3/26/2014 to 3/29/2019</td>
</tr>
<tr>
<td><strong>Research Area:</strong></td>
<td>Energy-Related Environmental Research</td>
</tr>
<tr>
<td><strong>Issue:</strong></td>
<td>Biogas is a gas produced by converting biomass to a gaseous mixture of carbon dioxide and methane. Biogas can be used directly to produce electricity or can be cleaned and upgraded to biomethane by removing carbon dioxide and other impurities. Biogas often contains many trace compounds with a composition that varies depending on the feedstock and degree of cleanup. Some of the trace compounds are contaminants of concern that may adversely impact public health.</td>
</tr>
<tr>
<td><strong>Project Description:</strong></td>
<td>The project identifies constituents of concern found in California biogas to meet Assembly Bill 1900 public health requirements. The focus is on constituents in biogases at concentrations that significantly exceed the AB 1900 requirements in California natural gas to determine if introducing biogas to the natural gas pipeline could pose risks to human health.</td>
</tr>
<tr>
<td><strong>How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:</strong></td>
<td>Prior to this project, only limited information has been available regarding constituents of concern in biomethane produced from different feedstocks. This project identifies and evaluates potential toxic and hazardous constituents in various potential California-specific biomethane sources, providing important new information to regulators and policy makers such as the Public Utility Commission and Air Resources Board, on air quality, pipeline safety, and potential health implications of using biogas.</td>
</tr>
<tr>
<td><strong>Applicable Metrics:</strong></td>
<td><strong>Public Health:</strong> The identification of hazardous constituents will assess potential public health risks from the possible introduction of biomethane to the natural gas pipeline. The information will help the Public Utilities Commission and Air Resources Board determine the requirements for biomethane injection into the natural gas system.</td>
</tr>
<tr>
<td><strong>Natural Gas Funds Encumbered:</strong></td>
<td>$400,000</td>
</tr>
<tr>
<td><strong>Update:</strong></td>
<td>The Air Resources Board’s (ARB) portion of the project (phase 1) is complete. The Energy Commission’s portion (phase 2) is managed by ARB. In the phase 1 study, measurements were conducted for 10 different biogas/biomethane sample streams from 5 different production sources. The methane content of the raw biogas ranged from 35 to 70.5 percent. Biomethane from food waste digesters had methane content above 90 percent.</td>
</tr>
</tbody>
</table>
Other targeted constituents include ammonia, alkanes, sulfur compounds, VOCs, siloxanes, metals, bacteria, pesticides, and others. In phase 2, ARB selected the same research team from the University of California, Davis, which is collecting field measurements. The samples include biogas from similar sources as in phase 1, but also include biogas from wastewater treatment plants.

![Researcher explaining the sampling setup at a wastewater treatment plant.](image)
### Project Name:
Assessment of Residential Natural Gas Emissions - [500-13-008]

### Recipient/Contractor:
DOE- Lawrence Berkeley National Laboratory

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
8/18/2014 to 12/31/2017

### Research Area:
Energy-Related Environmental Research

### Issue:
Natural gas leakage emissions from California’s energy infrastructure are estimated to be ~40 billion cubic feet/year, or ~2% of total natural gas consumption. Identifying and controlling these losses would provide benefits for local safety, regional air quality, and global climate. One important subsector of natural gas infrastructure that has not been carefully evaluated is residential structures, including single-family homes and multi-unit buildings. While this leakage is typically assumed to be small, residential usage accounts for ~22% of total natural gas consumption in California and the potential for losses could easily constitute a significant fraction of total emissions.

### Project Description:
This project estimates methane emissions from the "after meter" natural gas system in California residences. The research team designed a study and trained subcontractors to conduct building methane leakage measurements in approximately 75 sample houses. The researchers analyzed the field data to quantify the emission rates from these homes.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project measures post-meter natural gas methane leaks in a representative sample of single-family California residences, estimates the distribution of likely leaks, and determines total residential methane leakage. The results will be very important for the California Air Resource Board to update the state GHG inventory and to give greater insight to the climate impacts of natural gas consumption.

### Applicable Metrics:
**Environmental Benefits:**
Methane is a potent greenhouse gas. The project identifies and quantifies after-meter sources of methane leakage from this sector. Project results found emissions from appliances to be about 10 times the 2015 state inventory estimates for residential natural gas methane emissions. The results provide critical information for greenhouse gas emission inventory and potential mitigation efforts by state and local agencies.

**Natural Gas Funds Encumbered:**
$500,000

### Update:
Researchers completed field measurements of methane emission from homes. About 75 single-family homes from both northern and southern California were measured. Researchers found that emissions come from a combination of whole house leaks,
continuous operation of pilot lights, and episodic operation of combustion appliances. Analysis shows that under the quiescent condition (no operation of appliances), the pilot lights contribute about 30% of the indoor emissions. The results suggest that repairing leaks, updating combustion appliances (e.g. replacing the pilot light with electronic ignitions), and electrification of appliances will greatly reduce methane emissions from the residential sector. The final report is posted on the Commission website, publication number CEC-500-2018-021. The results have been shared with the Air Resource Board to advise the greenhouse gas inventory database.

Field measurement on sample house.
**Project Name:**
High Resolution Measurement of Levee Subsidence Related to Natural Gas Infrastructure in the Sacramento-San Joaquin Delta - [500-14-001]

**Recipient/Contractor:**
U.S. Geological Survey

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
10/8/2014 to 1/31/2018

**Research Area:**
Energy-Related Environmental Research

**Issue:**
Although State-sponsored research has made significant strides in investigating the impacts of climate change on the energy system, to date most of this research has focused on the electricity system. Prior research revealed significant subsidence in the Delta Island levee system but did not offer sufficient detail to assess and safeguard against risks to the natural gas system. This research responded to issues identified in a 2013 IEPR workshop, namely, the need to safeguard the natural gas system against the risks posed by a failing Delta Island levee infrastructure and aggravated by sea level rise.

**Project Description:**
The researchers measured subsidence in the Delta Island levee system with unprecedented detail in space and time. Researchers studied the most critical areas of the Delta's energy infrastructure, which includes natural gas pipelines and storage as well as electricity transmission lines. Initial surveying occurred at the Rio Vista Gas Field, followed by Pacific Gas & Electric's (PG&E) McDonald Island gas storage, and then systematic scanning of levees associated with gas pipelines. A broader view of the levees in the Delta, including areas with important transmission lines, is needed to determine if levee subsidence is a local or a Delta-wide effect. This work improves on DWR's past monitoring of Delta subsidence, and may be incorporated into PG&E's risk management activities and the DSC's Delta Stewardship Investment Plan.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:**
The portable LIDAR measurement system developed as part of a prior Energy Commission project and that final report is found here: [http://climateassessment.ca.gov/techreports/energy.html](http://climateassessment.ca.gov/techreports/energy.html)

The system was further enhanced under this project and allows for very low cost measurement of subsidence in the Delta and other regions. Traditionally this is done using airplanes, which increases costs considerably. This study contributes to California's Fourth Climate Change Assessment.

**Applicable Metrics:**
Greater Reliability:

California is at risk to major natural gas supply disruptions due to levee failures. This risk is compounded by sea level rise, which affects hydrodynamics in the Delta and can lead to inundation during extreme storm events. Research to identify the most vulnerable areas will inform efforts to boost resilience of California's natural gas system.
### Natural Gas Funds Encumbered:
$325,000

**Update:**
This project team met with UC Berkeley contract 500-11-016 team, to identify and confirm areas of interest for subsidence monitoring; namely, areas with natural gas infrastructure expected to experience levee overtopping due to extreme storms and sea level rise within a century. The team performed field monitoring and sought feedback from the Technical Advisory Committee, including utility representatives, Department of Water Resources (DWR), and Delta Stewardship Council (DSC). The research team concluded that subsidence and sea level rise would result in some levees being outside engineering specifications by the middle of this century. The final report is found here: [http://climateassessment.ca.gov/techreports/energy.html](http://climateassessment.ca.gov/techreports/energy.html)
### Project Name:
Visualizing Climate-Related Risks to the Natural Gas System Using Cal-Adapt - [500-14-003]

### Recipient/Contractor:
The Regents of the University of California on behalf of the Berkeley campus

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
5/13/2015 to 12/29/2017

### Research Area:
Energy-Related Environmental Research

### Issue:
Research supported by the State continues to investigate climate risks and adaptation opportunities facing the energy system, including the natural gas sector. For example, PIER Natural Gas research (report no. CEC-500-2017-008) investigates vulnerabilities to sea level rise of pipeline infrastructure. A recently initiated contract sheds light on how sea level rise-related risks in the Delta are compounded by subsidence. These and other efforts feed directly into the current project, which leverages visualization and data-sharing capabilities of the State's existing Cal-Adapt (http://cal-adapt.org/) resource to enable direct exploration of climate-related risks to the natural gas system.

### Project Description:
The natural gas system is vulnerable to climate-related changes and events such as sea level rise and storm surge, inland flooding, subsidence of the delta and levees, and climate-related fluctuations in natural gas supply and demand. This work ensures that the best peer-reviewed scientific results are visualized in a readily accessible, understandable form to support planning and adaptation efforts. This project provides critical support to communicate scientific advances regarding climate-related risks to the natural gas sector and foster planning to protect infrastructure and vulnerable populations. Use cases include supporting design of a compressor station in Blythe; and eventual intention (expressed by an IOU in an IEPR workshop) of supporting General Rate Cases through use of data on Cal-Adapt.

The Technical Advisory Committee includes IOUs, a publicly owned utility, and the California Office of Emergency Services.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project enhances Cal-Adapt, an interactive website designed to enable exploration of high-resolution peer-reviewed data portraying projected climate risks, with new data sets, visualizations, and tools that portray natural gas sector vulnerabilities and fosters planning to protect infrastructure and vulnerable populations. These enhancements respond directly to input from IOUs, so that data visualizations, custom tools, and options for downloading data are developed specifically to support use by natural gas IOUs to foster resilience and protect natural gas infrastructure.

### Applicable Metrics:
Greater Reliability:
Fosters planning to avoid major disruptions and for resilience to risks to the natural gas system posed by a changing climate.
Increase Safety:
Greater reliability associated with timely resilience planning and implementation will protect against loss of service as well as damage to natural gas infrastructure, both of which can pose threats to health and safety.

Public Health:
Greater reliability associated with timely resilience planning and implementation will protect against loss of service as well as damage to natural gas infrastructure, both of which can pose threats to health and safety.

Natural Gas Funds Encumbered:
$300,000

Update:
The team launched Cal-Adapt 2.0, improving the original platform by providing higher-resolution climate projections with improved capture of temperature extremes and precipitation; an Applications Programming Interface that supports development of custom tools; a data download tool that clips to the precise area of interest as well as desired models and parameters; an improved extreme heat tool incorporating input from utility representatives and public health colleagues; aggregation options requested by utility representatives; and more. This project was part of California’s Fourth Climate Assessment and the final project report can be found here: http://www.climateassessment.ca.gov/techreports/docs/20180827-Projections_CCCA4-CEC-2018-015.pdf.
### Project Name:
CO2 Cleaning Project – [500-14-004]

### Recipient/Contractor:
CO2Nexus, Inc.

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
6/30/2015 to 3/31/2019

### Research Area:
Energy Efficiency

### Issue:
Cleaning and processing textiles and garments, from uniforms to technical garments such as ballistic vests to oily waste rags, is difficult, costly, and both energy (natural gas/electrical) and water intensive. Current cleaning processes require extensive use of energy, chemicals, and water. In addition, many technical garments, such as ballistic vests are not effectively cleaned in water without potential damage to the properties of the garment.

### Project Description:
This project hoped to demonstrate and evaluate the performance and operational cost of the Tersus liquid carbon dioxide technology for cleaning of hazardous cleaning rags, uniforms, ballistic vests, flame resistant garments, and other miscellaneous textile or fabric items (e.g., sleeping bags, tents, field gear).

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project hoped to create a new approach to processing and cleaning difficult to clean garments and textiles, including uniforms, hazardous cleaning rags, ballistic vests, and flame resistant garments and reduce water and energy use.

### Applicable Metrics:
**Lower Costs:**
The project hoped to eliminate water consumption and reduce energy use by at least 50% relative to conventional industrial laundry machines for processing difficult to clean garments.

**Natural Gas Funds Encumbered:**
$900,300

### Update:
The CO2Nexus company has liquidated their assets and the Energy Commission is taking steps to remove the equipment from the test site. BTI Appraisal has completed an equipment appraisal (500-17-005).
Tersus Solutions carbon dioxide washing machine at Port Hueneme Naval Base.
## Project Name:
On-Road, In-Use Emissions and Fuel Usage Assessment - [500-15-002]

### Recipient/Contractor:
South Coast Air Quality Management District

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
1/4/2016 to 6/28/2019

### Research Area:
Natural Gas-Related Transportation

### Issue:
Results based on U.S Environmental Protection Agency (EPA) test procedures for heavy-duty on-road engine emissions show that oxides of nitrogen (NOx) and particulate matter emissions meet the EPA and California Air Resources Board (CARB) emissions standards. However, in-use emissions testing of the engines operating under real-world load conditions on vehicles have shown increased ammonia emissions from natural gas vehicles and NOx from diesel vehicles. Additional studies are needed to assess in-use emissions, fuel usage, and the impact of new technology; particularly those used in goods movement, delivery, refuse, transit, and school bus applications.

### Project Description:
This project is conducting in-use vehicle emissions and activity tests for heavy-duty vehicles used in transit, school bus, refuse, delivery, and goods movement applications. Up to 200 vehicles will be recruited from a variety of California fleets to represent a pool of different vehicle types. All recruited vehicles will be tested with portable activity monitoring systems (PAMS) to gather route and activity data. Up to 100 vehicles will be tested with portable emissions measurement systems (PEMS) to gather in-use emissions data. Up to 60 vehicles will be tested with a chassis dynamometer using vocation-based drive cycles developed from analyzing the PAMS and PEMS data. Up to 10 goods movement vehicles will be tested with a mobile emissions laboratory to gather high fidelity data to compare with previous tests.

The results will be used to develop vocation-based drive cycles, develop deterioration factors, identify technology shortfalls and paths for improvement, prioritize resources to support advanced engine and after-treatment technology research programs, and match vehicle technologies to appropriate vocations for which technology benefits can be maximized.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Identifying the shortfalls of current natural gas vehicle technology can help prioritize specific research efforts that can maximize benefits to ratepayers. Test results will also be used to match vehicle technologies to vocations for which technology benefits can be maximized. This can assist in maximizing benefits of deploying alternative fuel vehicles. In addition, in-use vehicle emissions data is highly valuable for the refinement of test cycles and emissions modeling tools.
Applicable Metrics:

Lower Costs:
The results assist in developing vocation-optimized drive cycles to maximize fuel efficiency. Deterioration effects will also be investigated in real-world testing, which can better determine optimal maintenance intervals for natural gas vehicles.

Environmental Benefits:
This project investigates potential issues causing heavy-duty engines to potentially consume more fuel than expected during real-world operation, leading to increased carbon emissions. These issues can be identified and targeted with future research efforts to improve fuel efficiency.

Public Health:
This project investigates potential issues causing heavy-duty engines to potentially emit more pollutants than the allowable certification standard during real-world use. Once identified, these issues can be targeted and mitigated to improve air quality. Technologies with greater air quality benefits can also be identified to guide further deployment efforts.

Natural Gas Funds Encumbered:
$2,000,000

Update:
A critical project review meeting was held in May 2018 with participants from SoCalGas, CARB, SCAQMD, UC Riverside, and West Virginia University to evaluate project progress. The subcontractors were having trouble recruiting vehicles at the desired pace, so SCAQMD leveraged fleet contacts through their incentive programs to accelerate the recruitment process. As of June 2018, the research team has recruited over 130 out of the target 200 vehicles to participate in the test program. The research team is traveling to the fleet sites to install PAMS that will gather vehicle activity data. PEMS are also being installed on select vehicles to gather in-use emissions data.

Image:
UCR’s Mobile Emissions Laboratory and Chassis Dynamometer (top) and WVU’s Transportable Emissions Measurement System (bottom)
**Project Name:**
California Baseline Methane Survey: Identification of Large Fugitive Methane Emitters from the Natural Gas Sector - [500-15-004]

**Recipient/Contractor:**
The National Aeronautics and Space Administration

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/11/2017 to 1/4/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy-Related Environmental Research

**Issue:**
Knowledge of the sources and distribution of fugitive methane emissions is critical given the importance of this high global warming potential greenhouse gas and ozone precursor. Methane emissions from the natural gas system can substantially degrade the climate benefits of natural gas in comparison with other fuels. Preliminary evidence suggests that a small number of emitters contribute a large portion of total emissions in the natural gas system. To mitigate the climate impact, it is critical to quickly and accurately identify these emission sources.

**Project Description:**
This project delivers a database of methane point source candidates with spatial coordinates, plume imagery, and a summary report, including attribution analysis. Researchers conducted a systematic survey of California methane point sources of the natural gas system. The results help identify large methane emitting facilities. This product can both inform near-term decision-making by California agencies and facility operators and serve as a baseline to enable potential future monitoring and verification of mitigation efforts.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:**
This project will generate a dataset of methane point source emissions locations, sourced primarily from the natural gas energy sector, that can be used to plan reduction measures for fugitive natural gas emissions from super emitters in California. This dataset will be used by state agencies such as the Air Resource Board, the Department of Food and Agriculture, and the Department of Resources Recycling and Recovery. It can also be used by local air quality districts and other stakeholders.

**Applicable Metrics:**

**Environmental Benefits:**
The project provides an effective method to quickly identify large methane emitters from California's natural gas system. It also generates a database of emitting sources. The results help state and local agencies and stakeholders to prioritize mitigation efforts of the large contributors.

**Natural Gas Funds Encumbered:**
$600,000

**Update:**
The project is phase II of a larger study co-funded with the Air Resources Board. The work supported by the Energy Commission began in June 2017. NASA researchers have
completed the flight survey that covered 59,000 km², including nearly 200,000 individual pieces of energy infrastructure. Over 1,600 distinct methane plumes were identified and confirmed. The research team is working through methane flux estimation from these plumes. The final project report is expected to be posted in late 2018. During both phases of the study the research team has engaged various stakeholders, such as the local air districts, state agencies, and industry groups.

IMAGE

Typical Methane Plume from a Gas Storage Tank.
### Project Name:
A Multi-Hazard Investigation of Climate Vulnerability of the Natural Gas Energy System in Southern California - [500-15-005]

### Recipient/Contractor:
The Regents of the University of California, Irvine Campus

### Natural Gas Funding Plan: Project Term:
Natural Gas Research 2/24/2017 to 9/20/2019

### Research Area:
Energy-Related Environmental Research

### Issue:
Extreme climatic events are growing more severe and frequent, calling into question how prepared our infrastructure is to deal with these changes. Increases in frequency of extremes (e.g., floods, heatwaves, dry spells) can lead to damages to infrastructure, such as levees, dams, roads, and energy infrastructure systems. Most previous studies focus solely on changes and impacts by 2100. This agreement focuses on assessing climate change impacts on the natural gas energy system in southern California (SoCalGas) from now to the middle of this century.

### Project Description:
The research develops a system-level risk analysis, using the Non-stationary Extreme Value Analysis model, to address vulnerability of the southern California natural gas infrastructure system to current and future climate extremes. This is critical to preparing for and mitigating the negative effects of climatic change and variability as well as extreme weather events on natural gas infrastructure.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project will provide a system-level risk analysis and regional roadmap on vulnerability to individual and joint climatic extremes (e.g., compounding effects of droughts and heatwaves). Researchers will develop statistical frameworks that can be used for assessing the impacts of a changing future climate on southern California's natural gas infrastructure.

### Applicable Metrics:
**Greater Reliability:**
This project will identify infrastructure at risk of failure under different future hazard conditions associated with compounding effects of drought, subsidence, and extreme precipitation. This will improve future reliability by identifying what parts of the natural gas system operated by SoCalGas are vulnerable to mid-century climate impacts.

**Increase Safety:**
This project will develop a regional map identifying places where pipelines are at high risk of failure due to changing climate conditions. Natural gas system operators can use this map to identify where and when upgrades are needed.

### Natural Gas Funds Encumbered:
$893,692
**Update:**
The research team is coordinating assumptions and selection of data sets with those being used for California's Fourth Climate Change Assessment, which was released in August 2018. The team contributed a core technical report to the Assessment regarding projected changes in extreme precipitation events. Specifically, the team parameterized those changes in a manner that coheres with familiar frameworks in place for infrastructure planning. The team has met with SoCalGas to present preliminary results. The team is implementing the comments provided by SoCalGas and preparing new analysis.

![Proof of concept image for potential inundation.](image_url)
**Project Name:**
Solar Water Heating for the Residential, Commercial and Industrial Sectors - [500-15-006]

**Recipient/Contractor:**
University of California Merced

<table>
<thead>
<tr>
<th><strong>Natural Gas Funding Plan:</strong></th>
<th><strong>Project Term:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2016 to 3/30/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Recent natural gas leaks, such as the leak in Aliso Canyon in Southern California, and the continued need to improve air quality in Southern California, have placed a higher priority on reducing natural gas use. Hot water in buildings is one of the primary uses of natural gas. Conventional solar water heating systems displace natural gas, but are expensive and complicated to install. In a previous Energy Commission Public University Energy Efficiency Project under contract 500-10-048, UC Merced researchers tested a prototype mini-channel based solar collector for buildings that could compete with conventional systems. Early research results show cost reductions of up to 30 percent, however real world demonstrations are needed to verify performance and system costs.

**Project Description:**
The project demonstrates aluminum mini-channel solar water heating collectors on residential single and multifamily buildings in the Los Angeles basin. Copper-based solar collectors produce low-grade steam for such uses as dry cleaning, steam cleaning, produce drying, sterilization, and blanching of vegetables and this will be tested at a commercial or food processing facility in the San Joaquin Valley. Data is being collected on system performance, cost, and customer preferences of mini-channel solar water heating versus conventional solar water heating technology. Project goals include promoting wider adoption of cost-effective solar water heating technology, and overcoming the technological, economic and market challenges of solar thermal water heating.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The mini-channel technology has the potential to reduce the upfront cost of solar water heating collectors and thus increase market penetration of this technology. Replacing natural gas-fired systems with solar water heating will reduce natural gas use and greenhouse gas emissions, especially for residential water heating and industrial processes.

**Applicable Metrics:**

**Lower Costs:**
This project aims to lower the upfront cost of solar thermal water heating systems by up to 30 percent by utilizing lower cost materials and increasing the efficiency of solar collectors utilizing aluminum in collector construction. The reduction in natural gas consumption will also lower ratepayer utility bills.

**Environmental Benefits:**
This project aims to improve air quality and reduce greenhouse gas emissions through reducing the consumption of natural gas by using solar thermal energy to heat water.
### Natural Gas Funds Encumbered:

$999,806

### Update:

The team selected demonstration sites for the project. Solar collector systems will be installed at a 25-unit apartment complex and a single family home in Southern California. The recipient has ordered the solar collector materials and will begin assembly of the units.

**IMAGE**

Sample of a mini-channel strip. Water or heat transfer fluid would pass through the channels seen on the edge of this strip.
**Project Name:**
Investigate Climate-change-induced Vulnerability of the Northern California Natural Gas Energy System and Identify Resilience Options - [500-15-007]

**Recipient/Contractor:**
The Regents of the University of California, on behalf of the Santa Cruz campus

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2016 to 11/20/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy-Related Environmental Research

**Issue:**
Climate-change-induced hazards are likely to increase the risks of the California natural gas energy system, due to either its physical condition or its location in climate-change hazardous areas. While the existing infrastructure is mainly designed to sustain 100-year events, the effects of climate change might skew the underlying distributions, leading to a more frequent occurrence of those events in the near future. The situation could be exacerbated by the fact that there is significant uncertainty in predicting the timing and location of climate-change-induced hazards.

**Project Description:**
Researchers are investigating climate-related hazards (specifically, wildfire and sea-level rise) in the context of where projected changes might pose risks to operations and infrastructure in northern California. Based on locations of interest vis a vis climate-related hazards, researchers are working to build a model of the natural gas energy system, coupled with statewide or regional economic models, to assess vulnerability and impacts of the northern California natural gas energy system to climate-change-induced weather events and to identify resilience options.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This research will develop a system-level risk-analysis framework that builds upon bottom-up modeling of the natural gas system coupled with regional economic models. The project will promote resilience of the Northern California natural gas system to climate-change-induced weather events by identifying infrastructure investment needs and the timing of their implementation.

**Applicable Metrics:**

**Greater Reliability:**
This project will result in ratepayer benefits of greater natural gas reliability by developing a technical-economic model, in collaboration with PG&E, to identify system vulnerabilities related to infrastructure and operations.

**Increase Safety:**
This project will help determine circumstances under which infrastructure (e.g., pipelines) might fail with sufficient lead time to address these vulnerabilities.

**Natural Gas Funds Encumbered:**
$600,000
**Update:**

Since the project kicked off on May 11, 2017, the research team has held multiple meetings with PG&E to clarify and refine the team's data request. In August 2017, the research team traveled to PG&E's Bishop Ranch site to discuss with staff arrangements that could fulfill the researchers' needs and protect sensitive data. In November 2017, the Energy Commission agreement manager and natural gas unit accompanied the project research team to PG&E's gas control center. In spring of 2018, the research team developed a geospatial model of wildfire and SLR-related hazards to delineate a more focused data request, and then briefed the Energy Commission's natural gas unit on its approach. Currently, the research team and PG&E technical staff are in discussion to further clarify specific data needs and methodological approach.

---

Researchers are investigating the economic implications of climate-related risks to the natural gas system in Northern California, including inundation associated with various increments of sea level rise.
### Project Name:
Low NOx 12-Liter Natural Gas Engine Development - [500-16-002]

### Recipient/Contractor:
South Coast Air Quality Management District

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
10/3/2016 to 10/5/2018

### Research Area:
Natural Gas-Related Transportation, Renewable Energy and Advanced Generation

### Issue:
Heavy-duty on-road diesel vehicles are among the top sources of NOx emissions in the South Coast Air Basin. This source category is still projected to be one of the largest contributors to NOx emissions even as the legacy fleet of higher polluting vehicles are replaced with vehicles meeting the 2010 U.S Environmental Protection Agency (EPA) emissions standards. There is a need to develop an ultra-low emission engine to significantly reduce emissions from heavy-duty vehicles, especially Class 8 vehicles that cannot be addressed with battery electric technologies in the near-term.

### Project Description:
This project is developing and demonstrating an ultra-low emission natural gas engine for heavy-duty trucks that is capable of reducing NOx emissions to near-zero levels (90 percent below the 2010 EPA standard). Simulations and calculations were done to establish the design changes from the base 12-liter engine, the Cummins Westport ISX12 G. The primary changes include an improved fuel system, on-board diagnostics, optimized engine controls, an enhanced three-way catalyst, and a closed crankcase ventilation system. Test cell activities characterize the engine’s specific performance characteristics in relation to the design goals. Prototype testing through actual vehicle operation in real world environments are used to accumulate mileage to prove reliability and durability targets. The goal of the project is to develop a commercially viable ultra-low emission engine that is certified to California Air Resources Board’s (CARB) optional low NOx standard.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The ISX12N uses three primary innovations to achieve near-zero NOx emissions. The closed crankcase ventilation system prevents methane emissions from escaping to the atmosphere and reduces unnecessary oil consumption, which can lead to increased NOx. The three-way catalyst after-treatment system simultaneously reduces carbon monoxide, hydrocarbon, and NOx emissions. Optimized engine controls maintain a tight air-fuel ratio to ensure stoichiometric combustion occurs across the full range of engine operations. Maintaining stoichiometry is key for reducing NOx using the three-way catalyst. The commercial availability of the engine gives fleets a market-ready alternative to diesel engines that can significantly reduce NOx emissions and help improve air quality.

### Applicable Metrics:
Environmental Benefits:
The engine uses closed crankcase ventilation to reduce methane emissions by 70 percent. The engine has been certified to the EPA’s 2018 GHG standards for carbon dioxide emissions. The engine can also use renewable natural gas (RNG) instead of fossil gas to...
provide significant GHG reductions in addition to air quality benefits. RNG is cleaned and processed biogas captured from waste streams such as landfills, wastewater treatment plants, and dairies.

**Public Health:**
Reducing smog-forming emissions like NOx in heavy-duty vehicles will support efforts to improve air quality, particularly in neighborhoods most affected by freight transportation traffic. The engine has been certified at 0.02 g/bhp-hr NOx, a 90 percent reduction from the current EPA standard. Chassis dynamometer tests validated the engine's near-zero emissions, showing an average of between 0.0012 and 0.02 g/bhp-hr NOx for various hot start tests (low load and cruise).

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000,000</td>
</tr>
</tbody>
</table>

**Update:**
In December 2017, the ultra-low emission engine, dubbed the ISX12N, was certified to the CARB optional low NOx standard of 0.02 g/bhp-hr. The engine is commercially available as of March 2018 for refuse trucks, day cab, vocational, and coach bus applications through major vehicle manufacturers such as Freightliner, Peterbilt, and Kenworth. State and local clean transportation incentive programs including HVIP, Carl Moyer Program, and the Prop 1B Goods Movement Emission Reduction Program are offering financial support to fleets looking to deploy vehicles with the ISX12N. Chassis dynamometer testing done by UC Riverside verify that the ISX12N can maintain NOx emission levels below the optional standard, in real-world conditions, even on low load port drayage cycles. UC Riverside’s report with detailed chassis dynamometer test results is available online at: https://ucrtoday.ucr.edu/wp-content/uploads/2018/08/CWI-LowNOx-12L-NG_v03.pdf. The final report has been received and is in the publications process.
**Project Name:**
Technical Assistance for the Energy Commission Food Processing Program - [500-17-003]

**Recipient/Contractor:**
Trustees of the California State University – San Francisco

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>3/1/2018 to 12/31/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
The California food processing industry has experienced increased costs for labor, energy, and transportation over time. The industry generally has small profit margins, short processing seasons, and is limited in its ability to pass the costs of regulatory programs through to customers. Although some incentive programs exist, equipment is expensive and the economics may be poor, especially for seasonal food processing operations. There is need to find technological solutions for reducing greenhouse gas emissions to maintain the food processing industries competitiveness in California.

**Project Description:**
The purpose of this agreement is to: identify and recommend market-ready and advanced energy technologies that will reduce energy costs, increase efficiency, and reduce greenhouse gas (GHG) emissions and other pollutants for California’s food processing industry. The focus includes technologies that could be implemented immediately (2018-2020) and those that have potential for implementation in a longer timeframe, such as by 2030 and beyond. Additionally, the recommendations resulting from this agreement hope to: mitigate pain points faced by California’s food processing industry; and improve common operations and processes to maintain their industrial competitiveness in California. Lessons learned during this process will also inform future Energy Commission solicitations related to energy technology upgrades targeted at California’s food processing industry.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This agreement will identify market-ready and advanced, natural gas saving energy technologies for the California food processing industry. For those advanced technologies, the recipient will identify research needed to improve the technology to overcome barriers to adoption, and help assess actual installations to determine whether actual match estimated savings. By so doing, the work resulting from this agreement will benefit the food processing industry in reducing energy costs, increasing efficiency, reducing GHG emissions and other pollutants and mitigating pain points faced by California’s food processing industry.

**Applicable Metrics:**
**Environmental Benefits:**
This project will report on advanced commercially available and emerging technologies with the greatest potential for natural gas savings, GHG (and criteria/toxic) emissions reductions in the short and long term and provide recommendations for overcoming barriers to implementation by the food processing sector. As a result, implementation of technologies identified through this project could reduce energy use, operating costs and GHG emissions and other pollutant reductions.
### Natural Gas Funds Encumbered:

$249,947

### Update:

This agreement was approved at the January 2018 business meeting and the kick-off was held in September 2018. The contractor is currently developing a document summarizing California food industry’s energy needs and barriers; followed by developing a report on energy technologies with the most potential for the food processing industry to identify market-ready and advanced, natural gas saving technologies that can be used by the California food processing industry to meet their energy and business needs.
Project Name:
Air Quality Implications of using Biogas (AQIB) to Replace Natural Gas in California - [PIR-13-001]

Recipient/Contractor:
The Regents of the University of California on behalf of the Davis campus

Natural Gas Funding Plan:
Natural Gas Research

Project Term:
7/8/2014 to 12/30/2017

Research Area:
Energy-Related Environmental Research

Issue:
Biogas/biomethane has great potential as a source of renewable energy for California, but this fuel often contains compounds that are not found in natural gas and that vary depending on the feedstock and the degree of purification. Some of the biological organisms and trace chemical compounds found in biogas/biomethane have the potential to adversely impact air quality either in their unburned state or after their combustion products age in the atmosphere. Testing of biogas/biomethane combustion exhaust at atmospherically relevant conditions is difficult and has not been carried out to date.

Project Description:
The project measured biogas/biomethane chemical and biological composition over a range of possible applications. The sources of the biogas/biomethane include landfills, dairy digesters, and food waste digesters. The applications tested include mobile sources, in-home appliances, and on-site electricity generators.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The study provides real emission data on raw biogas combustion, upgraded biomethane onsite power generation, and biomethane combustion in natural gas applications such as home appliances and vehicles. This information will assist state agencies such as the California Air Resources Board, utility companies, and renewable natural gas producers in developing future biogas adoption strategies while protecting public health and air quality for the residents of California. This goal directly supports the objectives of AB 32 (2006) and the Governor's Clean Energy Jobs Goal of 12,000 MW of localized energy production by providing information to stakeholders, such as gas producers, that may reduce barriers to allowing increased use of local renewable energy sources that produce or use biogas.

Applicable Metrics:
Public Health:
The real emissions data on raw biogas combustion, upgraded biomethane onsite power generation, and biomethane combustion in natural gas applications such as home appliances and vehicles, is critical for the Air Resource Board as the State moves toward using more renewable natural gas while protecting public health. The current data collected is not sufficient to determine the public health implication. Additional data should be collected before wide adoption of biomethane.

Natural Gas Funds Encumbered:
$775,064
Update:
Combustion exhaust from biomethane has similar chemical composition to that of natural gas on standard target compounds, but the results from bioassay tests on bacteria suggest that the potential health effects of biomethane combustion exhaust and natural gas combustion exhaust may differ. The most significant potential health impacts identified in the current study were DNA damage and mutagenicity. Increased levels of mutagenicity were correlated with a large number of chemical compounds outside the list of standard targets. Further testing should be conducted to verify these chemical components and to determine whether they cause similar health impacts in humans. Understanding the relationship between fuel composition and combustion exhaust mutagenicity could reveal new criteria that are currently not included in the list of standard target compounds, although they are critical to protecting public health.

IMAGE

Gas Sample Cleaning Unit.
### Project Name:
High Compression Ratio Free Piston Engine for CHP - [PIR-13-002]

### Recipient/Contractor:
EtaGen, Inc.

### Natural Gas Funding Plan:
Natural Gas Research

<table>
<thead>
<tr>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/30/2014 to 3/31/2018</td>
</tr>
</tbody>
</table>

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
Small-scale combined heat and power (CHP) systems have not been able to gain serious traction in the California market in part because existing CHP technologies lack the performance and cost attributes to provide a compelling economic solution for the majority of CHP-favorable commercial, institutional and industrial applications. The weaknesses of available technologies vary by type, but they include lackluster efficiencies, high capital and operating costs, and poor emissions performance. Low to modest electric efficiencies may lead to under sizing the systems electric capacity, or to incomplete thermal utilization in commercial applications with high electrical demand.

### Project Description:
This project designs, builds, and field tests an advanced generation CHP product that complies with the CARB 2007 emissions standards for distributed generation and exhibits higher electric performance over conventional natural gas-fired internal combustion engine CHP. Key to the project is the recipient’s high compression, ratio-free piston engine: a homogenous-charge compression ignition engine that features a variable compression ratio and allows operators to maximize the engine’s thermal efficiency relative to the peak combustion temperature. This minimizes the formation of NOx, which is characteristic for other piston engines. Oil-less operation also avoids formation of volatile organic compounds and reduces carbon monoxide (CO) formation. A key project goal is to achieve 40 percent electric efficiency and 80 percent CHP efficiency with a 50 kWe generator. The long-term goal is to achieve 45 percent electric and 85 percent CHP efficiencies for a 100 kWe commercial unit.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Achieving high efficiency, low capital and maintenance costs, and superior emissions performance, with free-piston technology and heat capture will be economical where existing CHP technologies are not. Over a ten year period following commercial introduction, EtaGen estimates the following benefits for California: 699 MW in avoided new centralized generation capacity, 68 billion-cubic-feet in natural gas savings, $978 million in energy costs savings, and 4 million tonnes of CO2 emissions reduced.

### Applicable Metrics:
**Lower Costs:**
High electrical efficiency combined with low capital costs results in higher economic returns than current existing prime movers. Spark-less and oil-less operation reduce the frequency and cost of regular maintenance. Ultra-low criteria emissions at or below CARB standards reduces or even eliminates the need for NOx after-treatment, reducing the installed cost.
Greater Reliability:
Having only two moving parts reduces the number of failure modes, significantly improving the reliability/availability when compared to existing prime movers.

Economic Development:
EtaGen estimates for the ten-year period following full commercial introduction, the cumulative benefits to California include, 34 MMBTU natural gas savings from boilers, $3 billion electricity and capacity savings, 5,716 metric-ton CO2 emissions reductions, and 4 GW in avoided centralized generation.

Consumer Appeal:
Linear generator technology offers a CHP solution for customers with low thermal to electric power ratios. High electric and thermal efficiencies also make it an attractive option for electric-only customers. Having a variable compression ratio, the linear generator fuel-flexible, allowing for operation with biogas without employing extensive fuel treatment as currently required for fuel cells and engines with catalysts.

**Natural Gas Funds Encumbered:**

$796,247

**Update:**

The recipient installed the free-piston engine and CHP test package at its Menlo Park, California facility in the spring of 2017. The fully installed system with enclosure has the footprint of 20 feet by 8 feet by 8 feet, which is about the size of a typical shipping container. EtaGen performed performance testing and operational data collection activities through the end of the project and reported the results in the project Final Report to be published in late 2018.

**IMAGE**

Packaged CHP system in Partially Completed Enclosure.
### Project Name:
Low Cost Micro DG/CHP for Use in Laundry Facilities - [PIR-13-004]

### Recipient/Contractor:
The Regents of the University of California, on behalf of the Irvine campus

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2014 to 12/31/2017</td>
</tr>
</tbody>
</table>

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
Distributed generation (DG) and combined heat and power (CHP) are critical components needed to support reliability of the electric grid in regions of Southern California impacted by the closure of the San Onofre Nuclear Generating Station. However, widespread deployment of DG and CHP continues to encounter barriers, especially at scales appropriate to smaller commercial applications including: (1) perception of technology as risky, (2) difficulty meeting local air quality standards and obtaining permits, (3) matching of electric and waste heat loads for maximum efficiency, and (4) cost, both initial and continuing operations and maintenance.

### Project Description:
To improve grid reliability in the San Onofre Nuclear Generating Station (SONGS) territory and increase market options for small-scale combined heat and power (CHP), this research developed and deployed a low cost automotive engine based micro-distributed generation (DG)/CHP system (with 35 kW max output) using a Mazda Rotary Engine. Initially targeting commercial/industrial laundry facilities, the potential in the SONGS territory is more than 3,700 installation sites at hotels, hospitals, jails/prisons, and laundromats representing an estimated 130-260 MW of electric grid support. This project specifically addressed engine operation and control in a generator application with emphasis on engine availability/reliability and serviceability. Further, the project addressed waste heat recovery to maximize utilization and overall thermal efficiency of the micro DG/CHP system specifically for commercial laundry facilities.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The system addresses small power need markets that have not been satisfactorily addressed by existing DG/CHP systems. It addresses and is expected to help overcome the current deployment hindrances identified for DG/CHP systems. The rotary engine has advantages in size, noise, and vibration, over conventional piston engines. Analysis shows improvements in initial capital cost, and lifetime operation and maintenance costs compared to existing benchmark systems.

### Applicable Metrics:
Greater Reliability:
There is potential for widespread grid support in the SONGS territory in commercial/industrial laundry facilities that can benefit from micro-DG/CHP with an estimated potential of 130-260 MW.
Economic Development:
There is potential for the application of the low cost rotary engine micro-DG/CHP system to the more than 3,700 commercial laundry sites in the SONGS territory and to nearly 10,000 commercial laundries in California.

Environmental Benefits:
The project develops a system that is compliant with California Air Resources Board’s 2007 and 2013 air emissions standards and can be readily sited.

Natural Gas Funds Encumbered:
$994,307

Update:
The project has been completed. The final report will be available on the Energy Commission website in late 2018. With appropriate engine tuning, the system could attain emission levels below those required by the California Air Resources Board for oxides of nitrogen and carbon monoxide. The overall efficiency of the system was 75 percent, which indicates total savings potential of approximately $1,300 per month in the winter and $2,080 per month in the summer, based on relevant utility rates.

Cabinet and internal view of DG/CHP system installed at the University of California, Irvine. The system has a maximum electrical output of 35 kW and uses a Mazda rotary engine as the prime mover.
**Project Name:**
Commercial Demonstration of Innovative, Energy Efficient Infrared Processing of Healthy Fruit and Vegetable Snacks - [PIR-13-007]

**Recipient/Contractor:**
Agricultural Research Services, United States Department of Agriculture

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2014 to 3/20/2018</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Drying is one of the most energy intensive operations in the food processing industry. The most common method of producing fruit and vegetable based snacks uses freeze-drying. However, freeze-drying is an energy intensive technology and has high capital cost. Hot air drying is widely used; however, when it is used alone it cannot produce crisp snacks with the desired flavor and texture. It is also energy intensive due to prolonged drying times.

**Project Description:**
The Sequential Infrared Dry-blanching/Dehydration and Hot Air-drying (SIRDBHAD) technology replaces the current blanching and freeze-drying methods to produce vegetable and fruit based crisp snacks with potential for up to 82% energy savings, without using any water. Vegetables are fed into an infrared blancher/dryer equipped with a catalytic infrared emitter, then conveyed into a hot air dryer to finish drying. The surface structure is changed during IR blanching and dehydration and makes the final product crisp. At the same time, IR energy is transferred as radiant energy, which makes this technology very efficient compared to freeze-drying and hot air drying. The catalytic chemical reaction does not generate any NOx emissions or greenhouse gases.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:**
The SIRDBHAD technology has the potential to replace the current blanching and freeze-drying methods to produce vegetable and fruit based crisp snacks with potential for up to 82% combined thermal and electric energy savings, without using any water. The benefits include energy savings, while at the same time producing healthy snacks with a desirable texture and flavor at a reduced cost.

**Applicable Metrics:**

**Lower Costs:**
This energy efficient technology is estimated to reduce drying energy by 40% compared to conventional methods and could result in lower energy costs.

**Public Health:**
The catalytic chemical reaction of this technology does not generate any NOx emissions or greenhouse gases.

**Natural Gas Funds Encumbered:**
$884,810
Update:

The technology was successfully demonstrated at the Treasure Brand facility in Richmond. The technology was able to show up to 82% energy savings compared to freeze drying while inactivating up to 99% peroxidase enzymes. The final report is anticipated to be posted in late 2018. The project has been highlighted at exhibits, such as the California League of Food Processors Expo 2018 and UC Davis's Picnic Day, and was the subject of an article in the California Food Producers magazine, Edition 2, 2017. The team demonstrated the technology to produce processors and processing equipment manufacturers who were impressed by the technology and the taste and flavor of the dried products. The recipient will seek further assistance in moving the technology to market from BlueTech Valley - a regional energy innovation cluster in Fresno, which is supported by EPIC grant EPC-15-038.

IMAGE

Dried apple slices leaving the SIRDBHAD.
**Project Name:**
Forward Osmosis Desalination of Industrial Waste Water - [PIR-13-009]

**Recipient/Contractor:**
Trevi Systems Inc.

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
6/30/2014 to 3/31/2018

**Research Area:**
Energy Efficiency

**Issue:**
The Orange County Water District (OCWD) is a global leader in ground water replenishment for over four years, purifying wastewater and then re-injecting it into underground aquifers. However, OCWD has reached the limit of their re-use ability as the reverse osmosis (RO) plant does not have access to additional treated wastewater nor can the RO plant extract additional water from the RO plant wastewater (brine solution). In order to keep up with projected demand, OCWD requires another 30 million gallons per day of RO treated recycled water. One potential source of additional water could be the RO brine wastewater by using methods that could further concentrate this brine solution.

**Project Description:**
Trevi Systems partnered with the OCWD on a demonstration project using Forward Osmosis (FO) technology. This technology concentrates OCWD's Reverse Osmosis produced brine wastewater to increase water yield, reduce brine volume and use waste heat (instead of natural gas) to drive the FO process. The uniqueness of Trevi System's FO desalting process rests in its use of osmotic pressure as a "driving" force to pass water through a semi-permeable membrane, and then using thermal energy in the form of waste heat to produce water. It is a simple and elegant method of creating an extra source of water while conserving energy.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:**
Potential to reduce energy use and cost at wastewater treatment plants while producing additional water from the RO system brine. The project determined that pre-treatment of the brine was needed to minimize fouling of the forward osmosis membranes. This research will help inform others working in this area in the future.

**Applicable Metrics:**
Lower Costs:
This project uses waste heat as its energy source to concentrate the brine wastewater, and operates at low pressure, which reduces energy use and fouling of the membranes. Trevi Systems estimates that its forward osmosis process pilot project at OCWD could produce annual savings of $500,000 - $900,000.

Environmental Benefits:
Forward osmosis filtration system is driven by waste heat to produce additional potable water from the wastewater (brine solution) of a reverse osmosis plant.
Natural Gas Funds Encumbered:
$1,700,000

Update:
The project completed in March 2018 and the final report is expected to be posted in late 2018. Trevi conducted forward osmosis pilot tests on reverse osmosis concentrate at the OCWD for over two years under various conditions. After testing the traditional enclosed modules, the project team realized that without pretreatment, these membrane modules were fouling quickly. The project team was able to experiment with challenging water; find issues with the Trevi forward osmosis system at a small scale, and find solutions that would not have been possible without piloting the system using real wastewater. Based on the information gained, Trevi Systems now has a clear path to design a system that will work on the type of wastewater provided by the OCWD.

Laboratory test setup for forward osmosis membranes.
Project Name:
Demonstration and Commercial Implementation of Energy Efficient Drying for Walnuts - [PIR-13-010]

Recipient/Contractor:
The Regents of the University of California, Davis

Natural Gas Funding Plan:
Natural Gas Research

Project Term:
6/30/2014 to 3/31/2018

Research Area:
Energy Efficiency

Issue:
The walnut drying process, the most energy intensive step in nut processing, is a large consumer of natural gas and electricity. Even though the processors have attempted different approaches to reduce energy consumption for walnut drying, the average energy consumption is still high. Walnut drying requires an average of 12 therms of natural gas or 13 gallons of propane and 24 kWh of electricity per ton of dried nuts and inefficient operations may even use twice this much.

Project Description:
This project demonstrates a novel infrared technology for walnut drying at pilot and commercial scales to achieve up to 25 percent energy (natural gas and electricity) savings and reduce walnut drying time. This new technology uses infrared as an efficient heat source to quickly remove the surface and shell moisture of walnuts, followed by the final drying using hot air. Nuts are required to meet strict USDA standards for moisture content. With traditional methods, walnuts are washed and then moved to large drying bins where hot air is circulated for 12 to 24 hours. The wettest nuts are dried to the safe storage moisture to prevent mold development, resulting in 6 to 8 hours of additional drying time. As a result, nuts with low moisture are over dried. In addition to energy savings, the new infrared technology will improve product quality, and decrease product loss due to over drying. This new technology could also be used for drying other types of nuts.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
As walnut drying is one of the most energy intensive processes, consuming natural gas for heating and electricity for blowers and motors. The IR drying technology demonstrated overall energy savings compared to current drying technology and the potential to produce a superior product. This technology has the potential of increasing the revenue in walnut production by reducing energy costs and producing a quality product by avoiding over-drying of nuts. These can have a major effect on the environmental and economic sustainability of the walnut industry. *

This technology reduces natural gas consumption and reduces GHG emissions, as the infrared emitters do not produce any NOx.

**Applicable Metrics:**

**Lower Costs:**
This technology demonstrated a reduction in energy consumption for walnut drying by up to 25 percent, compared to currently used practices, while also improving the quality of the final product.

**Environmental Benefits:**
Reductions in natural gas use for drying will result in GHG and other emission reductions.

**Natural Gas Funds Encumbered:**
$1,118,285

**Update:**
The Infrared (IR) walnut drying unit was installed at Emerald Farms and showed that drying times were reduced by 10-22 percent and removed between 3.5 and 4 percent of moisture from high and low moisture walnuts. Considering that the unsorted (mixed) walnuts generally consume more energy for drying than sorted walnut, and the added energy savings from reducing the heat loss of the IR dryer, IR drying could save up to 25 percent of energy use without affecting the quality. The IR pre-dried walnuts maintained the color values stipulated by the California Walnut Industry after storing for about 6 months. The pilot scale and commercial scale IR walnut dryer was demonstrated to walnut processors, walnut growers, walnut drying equipment manufacturers and others. The manufacturing partner was Wizard Manufacturing, Incorporated, a manufacturer of nut processing and drying equipment.

Infrared Walnut Dryer at Emerald Farms in Maxwell, CA.
## Project Name:

## Recipient/Contractor:
Lawrence Berkeley National Laboratory

## Natural Gas Funding Plan:
Natural Gas Research

## Project Term:
6/30/2014 to 3/29/2018

## Research Area:
Energy Efficiency

## Issue:
California has the potential to produce 500 million therms of biogas from organic waste, but very little of this potential is being realized. Renewable biogas can offset the use of natural gas. However, there are considerable barriers to the use of biogas fuel. Biogas has a variable supply, inconsistent energy content, and contaminants that require cleaning. If economic and technical barriers are removed or significantly reduced, fugitive methane emissions could be lowered if on-site biogas could be used rather than flared. Methane is a potent greenhouse gas contributing to climate change.

## Project Description:
This project hoped to demonstrate an advanced, pre-commercial package burner combustion system that responds, in real-time to biogas fuel-stock variability and availability while meeting system output demand and maintaining system operability with high efficiency and low pollutant emissions. The real-time fuel switching package burner system incorporates state-of-the-art fuel/air sensors developed at the University of California Irvine and controls, flow conditioning components, and the low-swirl burner technology from the Lawrence Berkeley National Laboratory.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The project can advance technology that can economically lead to greater use of renewable biogas especially from small methane/biogas generators. Dual fuel burners systems offer a potential cost effective way for smaller sized facilities to use their biogas, while improving air quality and lower facility operating costs. The two technologies developed as a result of this research are a fuel sensor to provide feedback on fuel constituency and a fuel flexible burner that can maintain a stable flame with ultra-low emissions. These are ready for commercialization in a wide range of gas heating systems, per the researchers.

## Applicable Metrics:

### Lower Costs:
The ability to use available biogas as an alternative fuel could reduce the need to purchase natural gas.

### Environmental Benefits:
Real time fuel switching burner systems capability could encourage some small biogas/methane generators to capture biogas and use it or sell it as a fuel supply, rather than allowing the gas to escape as fugitive GHG emission - or to be flared.
**Natural Gas Funds Encumbered:**

$1,600,000

**Update:**

Most of the technical work for the project was completed, including customization and assembly of the burner system, the fuel delivery infrastructure, the fuel sensors and controller circuitry. These were delivered with the boiler to the Chiquita Water Reclamation Plant (CWRP). However, real-world testing at CWRP did not occur because the burner system could not light properly and the system could not be modified within the agreement term. Though the final test could not occur, the project yielded knowledge and insights of real-time fuel switching for commercial waste-to-energy systems. Examples include development of the following: a) speed-of-sound fuel sensor for fuel switching for identifying variations in natural gas constituency; b) prototype and full scale low-swirl burner (LSB) with real time fuel switching capability; and c) fuel switching controls.
Appendix D-39

Project Name:
Optimized Natural Gas Hybrid-Electric Drayage Truck Demonstration - [PIR-13-014]

Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

Natural Gas Funding Plan: Natural Gas Research
Project Term: 6/30/2014 to 3/30/2018

Research Area:
Natural Gas-Related Transportation

Issue:
Medium and heavy-duty vehicles are critical to California’s economy, yet they contribute a significant amount of greenhouse gas GHG emissions and consume much of the fuel used in California fleets. The Energy Commission’s 2011 Integrated Energy Policy Report anticipates that diesel consumption will continue to grow by 22.3% from 2009 to 2030 due to increased use of diesel in freight. While hybridization is not a new concept, hybridization combined with the use of natural gas has not been fully explored, and the hybridization technologies and strategies being used do not offer a competitive option for fleets.

Project Description:
Gas Technology Institute, US Hybrid Corporation, and University of California-Riverside performed research and development to design a natural gas engine hybrid-electric Class 8 truck to reduce NOx emissions and improve vehicle fuel efficiency. This project utilized a commercially available, dedicated NG, Cummins Westport Inc. (CWI) ISL G 8.9L engine and enhanced the system to make it representative of an engine meeting CARB’s optional low NOx near-zero standard. Both engine technologies were reviewed and evaluated at UCR to provide an in-depth characterization of emissions and fuel consumption results. UCR updated the emissions test laboratory in order to quantify such low emission. Two primary observations were identified: 1) up to 90% of the emissions are the results of either rapid engine speed transients (i.e. hot start tests) or cold starts emissions and 2) the impact of transient and cold start emissions is more critical at the lower NOx emission standard (0.02 g/bhp-hr) when compared to the 2010 certified, ISL G standard. This suggests emissions differences may be significant between drivers, vocations, and vehicle configuration (automatic vs. manual transmissions).

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project advances the heavy-duty natural gas vehicles through hybridization that proved beneficial for heavy-duty applications that have different power needs and duty cycles and in areas where geofencing is adopted where heavy-duty vehicles can operate in different modes, e.g. as all-electric in the port areas. The technology resulted in a 70% reduction in NOX emissions and a fuel economy improvement of 5% and provided valuable information on emission and fuel economy benefits of hybridization moving forward.

Applicable Metrics:
Environmental Benefits:
The hybrid equipped natural gas engine showed hot transient emissions of 0.057 g/bhp-hr (70% lower than the 0.2 g/bhp-hr standard) and an overall cold start weighted emissions of 0.19 b/bhp-hr. The fuel economy of the hybrid system was slightly improved (5%) from the baseline system over the cycles tested.
Public Health:
The commercial benefit of this project would be in repowering goods movement fleets (Class 8 tractors with 15-liter engines) with hybrid systems in order to achieve significantly higher fuel economy while meeting near-zero emissions standards. Additional NOx and fuel consumption reductions are possible by integrating cutting edge Intelligent Traffic Systems (ITS) research conducted at UC Riverside with this fully integrated heavy-duty chassis demonstration project and open source engine/hybrid controller.

Natural Gas Funds Encumbered:
$900,000

Update:
Based on demonstration and test results from this project, the project team recommended that future hybrid demonstrations consider the new advanced Cummins Westport natural gas engine, which has shown in-use emissions as low as 0.001 g/bhp-hr NOx emissions (99% below the 2010 standard). Incorporation of this projects hybrid technology with advanced low-emission engine technology has the potential to bring significant fuel reductions while maintaining low-emissions port drayage activity in California’s port areas. Additional benefits could be obtained from a charge depletion mode strategy where plug in charging is utilized. Such an approach is realistic if geofenced zero emissions regulations are adopted near ports. Such a strategy could maximize the potential of hybrids and 25% fuel economy benefits observed, but at the added cost of a dual power (engine plus electric) system.

IMAGE

Natural Gas Hybrid-Electric Vehicle Integration.
**Project Name:**
High Efficiency Indirect-Fired Rotary Dryer with Advanced Heat Pump for Bulk Foods Processing - [PIR-14-001]

**Recipient/Contractor:**
Institute of Gas Technology dba Gas Technology Institute

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>7/31/2014 to 3/31/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
The drying fruits and vegetables can improve storage life, meet the technological material requirements and reduce transportation costs. It is one of the oldest and most commonly used agricultural and industrial operations. In California alone, dried and dehydrated fruit and vegetable processing consumes over 6.2 trillion Btu per year (approximately 62 million therms) and the fuel consumed is mainly natural gas. Drying is an energy intensive operation often consuming over 50-60 percent of total energy input required for the entire process of processing, modifying, and transporting a material. Less energy intensive processes are needed to reduce energy use, cost and air emissions.

**Project Description:**
This project demonstrates the rotary drum dryer technology integrated with a heat pump versus the traditional low-efficient tunnel dryers that use conventional metal cylinders, which are heated from the inside by condensing steam or direct-fired air heating. This technology brings to the California market a natural gas-fired drying technology providing both cost and environmental benefits in a broad range of agricultural and industrial applications.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The project demonstrates the unique combination of an indirect gas fired rotary drum dryer with off-the-shelf low NOx ribbon burners and integrated with a heat pump. Typical industrial heat pumps use electrically driven compressors while this project on uses waste heat/steam in the thermally driven heat pump. The combination of high efficiency low NOx burners with a waste heat driven heat pump is a major technical advancement that is expected to increase the average energy efficiency of dryers from 35-40% to at least 75%.

**Applicable Metrics:**
**Lower Costs:**
The rotary drum dryer technology has the potential to improve the efficiency of a typical tunnel dryer from 35 percent to 75 percent. The integration of the heat pump could potentially decrease natural gas consumption by another 63 percent. Overall the drying process could consume an estimated 81 percent less natural gas than conventional dryers.

**Environmental Benefits:**
This project can reduce greenhouse emissions due to more efficient combustion of natural gas.

**Natural Gas Funds Encumbered:**
$2,600,000
**Update:**

Design and engineering are complete. The system is installed on site and is ready for data collection, pending permit approval by the local air district. Energy Commission staff inspected the unit on 6/5/18.
## Project Name:
Measurement and Control of Ventilation Rates in Commercial Buildings in California – [PIR-14-003]

## Recipient/Contractor:
DOE- Lawrence Berkeley National Laboratory

## Natural Gas Funding Plan: Project Term:
Natural Gas Research  
11/1/2014 to 9/30/2017

## Research Area:
Energy Efficiency, Energy-Related Environmental Research

## Issue:
Minimum ventilation rates in commercial buildings affect health, work and school performance, and energy consumption. In addition, minimum ventilation rates are often poorly controlled, and energy is wasted in some buildings that have excess ventilation. Indoor air quality, health, and work performance are substandard in buildings with insufficient ventilation.

## Project Description:
This project uses modeling to analyze peak energy demand and indoor air quality advantages of controlled minimum ventilation rates (VR); evaluates multiple technologies applicable to real-time measurement and control of ventilation rates; and uses the results to develop occupancy specific guidelines for using carbon dioxide (CO2) sensors in demand controlled ventilation systems and for measurement of ventilation rates.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The project developed methods for improved measurement and control of VRs in buildings. Better control systems for VRs can avoid excessive ventilation that wastes energy and increases energy costs, as well as insufficient ventilation that increases adverse health effects and decreases school and work performance.

## Applicable Metrics:
### Public Health:
Results of this research were used to develop occupancy-specific guidelines (http://ventcon.lbl.gov/guidance-development) for using CO2 sensors in demand controlled systems, for measuring ventilation rates, and for development of guidance on selection and use of technologies for measuring outside air intake rates.

## Natural Gas Funds Encumbered:
$750,000

## Update:
The research team modeled different demand control ventilation (DCV) strategies that varied minimum ventilation rates and found similar energy savings between the types of DCV strategies applied. While the central estimates of ventilation rates agree reasonably well with respect to the reference values, researchers found large errors resulting from data uncertainties and assumptions. Testing two commercially available outdoor airflow measurement technologies, the researchers found substantial measurement errors under challenging conditions (e.g., high wind).
| Improvements in technologies that measure ventilation rate and outdoor airflow rates are needed. |
| IMAGE |

Building Ventilation Testing Unit.
**Project Name:**
Demonstration of a Novel Ultra-Low NOx Boiler for Commercial Buildings - [PIR-14-004]

**Recipient/Contractor:**
Institute of Gas Technology dba Gas Technology Institute

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
11/1/2014 to 3/31/2018

**Research Area:**
Energy Efficiency

**Issue:**
Oxides of nitrogen (NOx) emissions from combustion are a leading cause of air pollution, resulting in this criteria pollutant being heavily regulated. In Southern California, commercial boilers are required to emit less than 9 ppm NOx. Current commercial technology capable of meeting these emission requirements are inefficient and costly. Retrofit costs associated with bringing commercial-scale boilers into compliance are 50% greater than costs for large industrial-scale retrofits. There is a significant need for low-cost NOx control strategies that can allow California-based commercial boiler operations to achieve regulatory compliance, without reducing efficiency.

**Project Description:**
This project demonstrates a novel ultra-low-NOx burner design in a boiler for a commercial steam distribution system at Mission Linen Supply Inc. in Santa Barbara, California (the burner technology is referred to as dynamic stage entrainment (DSE)). The DSE burner offers a cost-competitive alternative to equipment currently available to the California commercial steam generation market, but not widely used. Extensive laboratory evaluation of the technology has shown the DSE burner design is capable of meeting less than nine parts per million NOx levels while operating with relatively low excess oxygen and high efficiency levels.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
DSE technology offers the potential for a cost competitive and efficient alternative that can reduce natural gas consumption, reduce operating cost and greenhouse gas emissions while maintaining compliance with local air district requirements. Successful completion of this demonstration will move the DSE technology towards commercialization, ultimately helping to bring to market a cost-competitive and efficient alternative for California commercial boiler operators who are seeking to reduce operating costs and greenhouse gas (GHG) emissions while maintaining compliance.

**Applicable Metrics:**

**Lower Costs:**
This technology will reduce costs of boiler operation through reduced natural gas costs. Commercial operators will also save money on costs of NOx mitigation. The DSE burner offers a cost-competitive alternative to equipment currently available to the California commercial steam generation market.

**Environmental Benefits:**
The technology aims to reduce natural gas usage which has the potential to reduce NOx levels and GHG emissions.
### Public Health:
The technology aims to lower NOx levels which will help reduce a criteria pollutant responsible for respiratory illnesses.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$798,788</td>
</tr>
</tbody>
</table>

### Update:
The ultra-low NOx burner (DSE burner) technology was successfully demonstrated and showed wide operational latitude in satisfying market needs and meeting requirements for <9, <12, and <20 vppm NOx. The DSE burner achieves comparable or slightly increased efficiency relative to other systems, such as flue gas recirculation (FGR) and high excess air (HEA) burners. The DSE burner also has lower blower pressure/power requirements compared to HEA burners, thus reducing electricity consumption and equipment cost. To bring the technology to market, GTI has partnered with Power Flame. Given the high performance of the technology and the low-cost design, the recipient is optimistic that the product could be brought to market with competitive pricing, enabling broad deployment. The final report is under review and planned for posting in the fall.
### Project Name:
Demonstration of High-Efficiency Hot Water Systems in Commercial Foodservice – [PIR-14-006]

### Recipient/Contractor:
Fisher-Nickel, Inc.

### Natural Gas Funding Plan: Project Term:
Natural Gas Research  
10/1/2014 to 3/30/2018

### Research Area:
Energy Efficiency

### Issue:
Most of the changes to commercial hot water systems have concentrated on efficiency improvements at the heater and water-reduction measures at end-use fixtures. Taking this single component-based approach has not significantly improved the efficiency or performance of modern hot water systems installed in commercial kitchens. Innovative and emerging technologies exist that can contribute towards reducing this load by greatly improving the efficiency of hot water systems. Combined with the design of optimized distribution systems, these technologies can deliver much-improved delivery performance.

### Project Description:
This project validates the natural gas savings of high-efficiency advanced hot water distribution system designs, measurement of energy savings, and optimization techniques to encourage the design community to adopt these measures. The project includes a dissemination program and includes development of design tools and a cost calculator to help the industry with decision-making regarding appropriate technology.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project compared different hot water systems and distribution systems used in commercial food service to determine optimal systems that would reduce water and energy use, increase system efficiencies, and provide high hot water delivery performance. The results show significant water and energy savings and improved system performance through the demonstration of higher efficiency equipment, superior system design, distribution system controls, and operating best practices. Improvements showed over 40 percent energy savings compared to baseline. This information forms the basis of improving system designs and targets commercial kitchen designers, plumbing professionals and regulatory bodies for potential inclusion in future Title 20 and Title 24 energy regulations. This information can help pivot the design industry away from inefficient 20th century hot water system designs.

### Applicable Metrics:
**Lower Costs:**
Improved hot water system delivery efficiency of up to 54 percent based on recent test results.

**Environmental Benefits:**
Reduction in natural gas use will result in reductions in greenhouse gas emissions.

### Natural Gas Funds Encumbered:
$889,036
Update:

Research results indicate that making a number of modifications can have significant benefits. For example, replacing a non-condensing water heater with a condensing heater, adding pipe insulation, lowering the recirculation flow rate, and changing the recirculation return location could increase heating efficiency by up to 54 percent. The next steps include continuing to work with the commercial kitchen designers, plumbing professionals and regulatory bodies to utilize these findings. Additional demonstrations are need to show best-in-class equipment and design techniques and to document savings and benefits.

IMAGE

Advanced hot water heating distribution system.
### Appendix D-49

**Project Name:**
Healthy and Efficient New Gas Homes - [PIR-14-007]

**Recipient/Contractor:**
Lawrence Berkeley National Laboratory

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>11/1/2014 to 3/31/2018</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency, Energy-Related Environmental Research

**Issue:**
Reducing infiltration and duct leakage in homes saves energy but may result in health impacts due to decreased ventilation. The 2018 Title 24 Building Standards require mechanical ventilation in new homes. It is not known how much ventilation reduces the level of contaminants or what type of ventilation is best for achieving zero net energy targets. There is a need for additional and better data on field performance of mechanical ventilation and its impacts on indoor air quality.

**Project Description:**
This project studied indoor air quality conditions after the implementation of building standards required mechanical ventilation in 2008. This project includes a two-tiered field study, analysis and modeling that extrapolate the field study results, and investigation of the changes in indoor air quality associated with further tightening of the building envelope. The field study gathered data directly from occupants and natural gas homes meeting or exceeding the 2008 standards. The study measured indoor air quality (IAQ) and characterized mechanical ventilation, and then used that data to provide recommendations to stakeholders, such as the Energy Commission and homeowners, on how to achieve adequate ventilation while reducing the energy associated with conditioning infiltration air.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
Using direct field IAQ measurements, the researchers showed that pollutant levels decreased in new homes compared to the previous study (CEC-500-2009-085) from a decade ago. Indoor formaldehyde and PM2.5 average concentration levels decreased 45% and 38%, respectively. The researchers conclude that the Title 24 ventilation requirement is effective, and should continue to be included in codes to ensure healthy indoor environments for California ratepayers.

**Applicable Metrics:**

**Public Health:**
The results and analysis from the field study provide a diagnostic on how effective the mechanical ventilation Title 24 requirement has been on improving indoor air quality. The Energy Commission Efficiency Division will use this information in future building codes development.
**Natural Gas Funds Encumbered:**
$1,250,000

**Update:**
The project measured indoor air pollutants in 70 new California homes with gas appliances. The measurements included PM2.5, formaldehyde, NO2, CO2, temperature and humidity. The measurements were made over one week and included samples both from outdoor and indoor locations for each home. The results show pollutants were at acceptable levels in the homes with ventilation systems operating, and the levels have generally decreased in new homes compared to those from previous studies. The results suggest the new proposed 2016 ventilation fan sizing for minimum air flow in Title 24 is a significant improvement over earlier methods. Results also suggest that occupants have limited awareness of their actions’ effect on health-related air quality, such as using a range hood when cooking to minimize pollutants in the home. The final report is expected to be posted in late 2018.

**IMAGE**

Different Measurement Devices Installed.
**Project Name:**
Demonstration of High-Efficiency Commercial Cooking Equipment and Kitchen Ventilation System - [PIR-14-008]

**Recipient/Contractor:**
Fisher-Nickel, Inc.

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
11/3/2014 to 3/30/2018

**Research Area:**
Energy Efficiency

**Issue:**
Food service facilities consume up to five times more energy per square foot than any other type of commercial building. They are commonplace and include cafeterias in commercial buildings, schools, healthcare facilities, and restaurants. With an estimated 93,300 commercial food service facilities operating in California, the total gas load of these establishments approaches 40% of the overall commercial gas consumption in the state. Across all California’s foodservice establishments, there are roughly 560,000 major commercial gas-fired cooking appliances, accounting for 475 million therms consumed annually, producing approximately 2.5 million metric tons of CO2e.

**Project Description:**
This project demonstrates natural gas savings potential resulting from installation of innovative energy-efficient commercial food service technologies in a holistic approach to kitchen cook line design. The demonstration of natural gas and cost savings, and other benefits accelerates the adoption of the advanced energy-efficient cooking equipment within the food service industry. The project includes a kitchen exhaust ventilation optimization process and incorporates best practices from the Commercial Kitchen Ventilation Design Guides and includes a demand control ventilation system for selected sites.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project evaluated the energy and operating patterns of a variety of standard and advanced, high efficiency commercial cooking appliances in six different commercial kitchens, representing a wide range of usage, from light batch cooking at a grocery store to very heavy use at a 24-hour airline catering facility. The cooking appliances focused were fryers, broilers, griddles, ovens, and ranges. The standard equipment was then replaced with advanced, high efficiency units, including power burners, infrared burners, advanced heat exchangers, combination hot air & steam heating, and advanced controls. The project identified the highest energy consuming appliances and showed that a targeted appliance replacement can have significant energy cost savings over the ten-year life cycle of the equipment. The target audience for the study is food service operators.

**Applicable Metrics:**

**Lower Costs:**
With roughly 100,000 foodservice facilities operating in California, most of which having at least some combination of range, fryer, griddle, or oven, there is large market potential for implementing energy-efficient appliances. Sites in this project demonstrated up to 68% energy savings.
As an industry that accounts for an estimated 475 million therms in annual gas consumption, the average demonstrated gas savings of 35% for food service establishments is significant. This indicates a potential 166 million therm reduction in annual gas consumption.

**Environmental Benefits:**
The reductions in natural gas and electricity savings results in a reduction of 14.4 metric tons of greenhouse gas emissions.

**Natural Gas Funds Encumbered:**
$909,515

**Update:**
Monitored sites experienced cookline gas usage reduction after the energy efficient appliance replacements, ranging from 19% to 68%. Average gas savings were about 35% for the entire cookline. NOx emissions were evaluated on five appliance types: fryers, broilers, griddles, ovens, and ranges. NOx concentration ranged from 10 to 110 ppm (corrected to 0% oxygen) across these appliance categories. Various high efficiency cookline equipment is now used by a large catering company, a university hospital, a hotel, a restaurant & bar, a grocery store, and a full-service restaurant. The results have been communicated to the food service industry, engineers, designers and other key decision makers through the Food Service Technology Center website and case studies: https://fishnick.com/about/casestudies/.

The Werewolf Restaurant in San Diego replaced an outdated broiler using about five therms per day to a lidded broiler that can use up to 50 percent less natural gas.
APPENDIX D: FY 2017-18 NATURAL GAS ACTIVE AND COMPLETED PROJECT WRITE-UPS

<table>
<thead>
<tr>
<th>Project Name:</th>
<th>Comparison of Advanced Ignition Systems for Near-Zero-Emission Heavy-Duty NG Trucks - [PIR-14-009]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipient/Contractor:</td>
<td>North American Repower, LLC</td>
</tr>
<tr>
<td>Natural Gas Funding Plan:</td>
<td>Project Term:</td>
</tr>
<tr>
<td>Natural Gas Research</td>
<td>5/8/2015 to 12/1/2017</td>
</tr>
<tr>
<td>Research Area:</td>
<td>Natural Gas-Related Transportation</td>
</tr>
<tr>
<td>Issue:</td>
<td>The ignition characteristics of natural gas fuel represent challenges to engine manufacturers working to reduce harmful emissions and achieve lower fuel consumption and higher engine performance, while responding to market pressure to reduce operating and maintenance costs. While exhaust gas recirculation (EGR) is a promising solution, this approach comes at the cost of reduced ignition stability with increased potential for misfire. Original Equipment Manufacturers (OEM) have tried to overcome this problem by increasing the spark energy, but this leads to rapid deterioration of spark plug electrodes necessitating more frequent costly engine maintenance and increased fleet downtime.</td>
</tr>
<tr>
<td>Project Description:</td>
<td>The goal of this project was to optimize, test and demonstrate two advanced ignition systems for heavy-duty natural gas (NG) engines. These unique systems will facilitate the stable and efficient ignition of NG fuel under conditions of high-boost pressure and elevated levels of exhaust gas recirculation. The advanced ignition development for engines under this agreement will enable existing engines to improve fuel economy by up to 18 percent and attain or surpass the voluntary CARB NOx emissions goal of 0.02 grams per brake-horsepower-hour (g/bhp-hr), while demonstrating required levels of performance, drivability, and cost-effectiveness. The next stage in this product development will be to install the engine(s) in a vehicle(s) and demonstrate their performance in commercial service. Once this is done, the engines and/or vehicles can be marketed and sold based on their low emissions coupled with their low cost of ownership. A similar technical approach can then be applied to other engines of different sizes and OEMs in order to benefit a wider range of vehicles.</td>
</tr>
<tr>
<td>How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:</td>
<td>Testing, integration, and demonstration of the two ignition systems will enable these spark-ignited HD NG engines to attain or surpass the voluntary CARB goal for NOx emissions of 0.02g/bhp-hr while demonstrating required levels of performance, drivability, and cost-effectiveness in comparison with standard diesel engines.</td>
</tr>
<tr>
<td>Applicable Metrics:</td>
<td>Lower Costs: With the integration of this advanced ignition system into natural gas engines, this technology has the potential to reduce fuel consumption by approximately 1,111 gasoline gallon equivalents per vehicle per year, resulting in over $1,000 in annual fuel costs. Environmental Benefits: The advanced ignition technology will result in approximately 12-18 percent in fuel savings and mitigate performance loss issues in natural gas vehicles as compared to their diesel counterparts.</td>
</tr>
</tbody>
</table>

Appendix D-53
### Public Health:
The advanced ignition technology will improve fuel efficiency, leading to reduced emissions. This system has the potential to contribute to natural gas engines for heavy-duty vehicles meeting or exceeding the CARB optional low NOX standard of 0.02 g/bhp-hr as well as reducing methane emissions to the 2016 optional standard of 0.10 g/bhp-hr.

### Natural Gas Funds Encumbered:
$750,000

### Update:
During initial testing, issues with the ignition system required North American Repower to redesign the system for testing that would provide real world results. Engine components were installed and revised to support dynamometer testing and at the end of the project term, testing was ongoing to confirm and finalize results. The results from this testing were to be used for follow-on research funded by the CEC (PIR-16-026) in order to improve the efficiency gap between HD natural gas and baseline diesel engines, as well as improve emissions. At the request of North American Repower, the follow-on research and demonstration agreement was terminated due to funding and staffing issues. The lean/dilute burn engine is at a lower TRL than comparable stoichiometric engines, but it holds the promise of higher potential efficiency and more reliable low NOx, and lower CO2 operation.

![Image](image.png)

The Advanced Corona Ignition System (ACIS) ignition system. One of two tested under this project.
## Project Name:
High Frequency Corona Discharge Ignition System Demonstration - [PIR-14-010]

## Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

## Natural Gas Funding Plan:
### Project Term:
Natural Gas Research
5/8/2015 to 3/30/2018

## Research Area:
Natural Gas-Related Transportation

## Issue:
Conventional ignition systems, which use a transistor coil ignition (TCI) architecture and are widely used in spark-ignited engines, are limited in their ability to operate at very high dilution levels driven by high levels of exhaust gas recirculation, which is commonly used as a strategy to reduce high levels of NOx. Modern commercial medium-duty natural gas engines with TCI typically require spark plug replacement at 1,500 hour intervals to avoid instances of misfire and/or damage to the exhaust aftertreatment system. Longer service intervals for ignition components would be very desirable for end-users, as it reduces cost of maintenance and reduces time when vehicles are not in service.

## Project Description:
This project developed ways to improve efficiency using an advanced ignition method based on the corona discharge principal for use in medium-duty natural gas engines. The emerging ignition technology improved the robustness of the ignition and combustion performance in engines with high dilution or at high boost pressures. Benefits include reduction in fuel consumption, GHG emissions, and NOx emissions. The project also developed a better understanding of the potential for long ignition service life relative to the conventional technology (i.e. conventional spark plugs).

The project team of Gas Technology Institute (GTI), Westport Fuel Systems, Inc. (Westport), and BorgWarner Beru (BorgWarner) demonstrated an advanced engine and ignition technology to test for emissions, performance, and fuel economy improvements over traditional architectures. High Frequency Corona Discharge Ignition technology has a large corona ignition region that is almost 1,000 times that of a tradition spark plug and has been shown to reduce ignition delay and enhance the early ignition process, stabilize main combustion, and reduce some throttling/pumping losses.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Advanced ignition systems for heavy-duty natural gas engines can lead to improved performance and efficiency while reducing tailpipe emissions. The corona ignition system developed by this project demonstrated increased exhaust gas recirculation tolerance by up to 40 percent, thereby reducing pumping losses due to higher work cycles during the intake and exhaust stroke.

## Applicable Metrics:
### Lower Costs:
The corona ignition system itself is a non-thermal plasma and the gas temperature is much lower than the thermal plasma that forms in a traditional spark plug using transistor coil ignition.
Preliminary experience with light-duty gasoline engines has so far lead researchers to expect electrode life expectancy greater than 60,000 miles, or greater than 150 million ignition event, which can reduce maintenance costs.

Environmental Benefits:
CO2 emission results show 75% of the brake specific CO2 data maps are below 425 g/hp-hr. With the pretest target being 424 g/hp-hr on the SET cycle, there is adequate room to further trade off CO2 for fuel economy while still meeting the target, which is based on expected EPA regulations through model year 2027.

Public Health:
The technology supports public health through reduced pollutant emissions. The technology warms up the after-treatment more quickly than diesel while the idle condition runs hot enough to supply 350°C turbine temperatures, which allows the catalyst to work effectively during warm up. This allows the catalyst to clean up 98-99% of the NOx coming out of the engine so it is expected that the ignition systems would attain CARB optional low NOx certification of 0.02 g/hp-hr.

**Natural Gas Funds Encumbered:**
$750,000

**Update:**
Research was completed on the advanced high-efficiency spark-ignited engine (HESI) with a traditional transistor coil ignition (TCI) and the advanced high-frequency EcoFlash ignition system. The high frequency ignition corona discharge technology is transitioning from alpha-level prototypes, on test benches and in engine cells, to beta-level prototypes. Newer prototypes are expected to improve the energy efficiency in the DC to high frequency circuitry. The newer design will also have more advanced communication interface features. The technology has demonstrated faster initial burn rates from the start of ignition and better EGR tolerance in gasoline engines. For these reasons, the project team believes this to be a most promising technology for future ignition work with advanced natural gas engines.

*IMAGE*

GTI plasma ignition (left) next to conventional spark ignition (right).
### Project Name:
Advanced Plasma Ignition Systems for Class 3-8 Natural Gas Engines - [PIR-14-011]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan: Project Term:
Natural Gas Research 5/8/2015 to 12/1/2017

### Research Area:
Natural Gas-Related Transportation

### Issue:
Current ignition systems using conventional spark plugs have shown limited ability to ignite natural gas fueled engines in either lean Air to Fuel (A:F) ratios or stoichiometric mixtures with Exhaust Gas Recirculation (EGR) dilution due to the poor energy transfer arising from electrical resistance in the circuit. As California has established low NOx emission targets for transportation, it is necessary to configure these engines to operate with even leaner A:F ratio and higher levels of EGR dilution. This increases their competitiveness as an alternative to diesel engines and contribution toward attaining California’s aggressive NOx and greenhouse gas emission reduction targets.

### Project Description:
Under this project, the Project Team of Gas Technology Institute, Enerpulse, and Ricardo developed two advanced ignition systems that have demonstrated the ability to improve combustion stability of high dilution natural gas fueled engines. The two advanced ignition systems both build on the existing, commercially available high-energy ignition product currently offered by Enerpulse. In both systems, the spark event begins with the Capacitive Discharge Ignition (CDI) power supply charging on the rising edge of the trigger signal. On the falling edge of the trigger signal, the CDI supply is discharged through the CDI coil and current begins flowing to the spark plug.

In the first system, the Enerpulse Nano-Plasma C2 Discharge Ignition System (C2 System), the pulse forming network will discharge into the spark gap creating a larger and longer lasting plasma kernel. The follow-on current is controlled by the length of the trigger signal and the control voltage. In the second advanced ignition system, the Enerpulse High Frequency Discharge Ignition System (HFD System), the second coil fires repeating the spark event. This sequence repeats until all four coils have fired.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
Through the development and demonstration of two advanced plasma ignition systems, this project aims to increase ionization levels in the combustion chamber for a faster burn rate and a decrease in engine out emissions while simultaneously improving engine stability and fuel economy to a level that is comparable to similar diesel engines.

### Applicable Metrics:
Greater Reliability:
While there were constraints due to the experimental test system, the Enerpulse system showed promise of extending the dilution tolerance of an engine, further helping to improve fuel economy and reduce engine out emissions. Results indicated that even with the systems operating at partial power, the EGR dilution tolerance could be extended as much...
as 30%, from the baseline ignition system at 15.4% EGR. In addition, the lean limit was able to be extended by 3.4% from the baseline case. Further improvements are probable with the systems operating consistently at full power.

Environmental Benefits:
The C2 and HFD Systems when fully developed will enable natural gas engines to approach fuel economy on par with diesel engines with significantly lower emissions. The ability to reduce NOx emissions with HFD and C2 Systems is directly related to the resulting increased ionization of the fuel mix. The C2 and HFD systems are capable of 15 to 20 times more ionization than other (advanced high-energy) systems demonstrated the ability to achieve higher levels of EGR leading to much lower (engine out) NOx emissions. When HFD and C2 are integrated with cooled EGR and advanced three-way catalyst systems, the potential to meet or exceed 0.02 g/HP-hr can be realized.

Consumer Appeal:
The use of n-PAC® plasma ignition on which these systems are based has shown great benefits in testing and real-world application. In a test performed by Roush Engineering, a GM 6.0L engine running on CNG had a 2.7% reduction in fuel use through the use of n-PAC® plasma ignition in an FTP 75 test. Enerpulse engine bench testing has demonstrated from 3.5% to 6.0% reduction in fuel consumption in steady state testing on a GM 5.7L engine.

**Natural Gas Funds Encumbered:**
$749,868

**Update:**
Based on results from this project, GTI and its partners recommend further testing beyond the scope of this project. This additional testing may include improving the internal circuitry of the Enerpulse system to improve durability. Another area of interest would be to provide multiple spark plug designs for testing, in order to form the flame kernel over a larger volume. Enerpulse will be seeking a partnership with a vehicle or engine manufacture or a large fleet end user as well as exploring research grant opportunities.

**IMAGE**

GM 5.7L Natural Gas Engine equipped with in-chamber sensors for pressure and ions.
### Project Name:
Research of Advanced Spark Ignited Prechambers Utilizing Turbulent Jet Ignition - [PIR-14-012]

### Recipient/Contractor:
Olson-Ecologic Engine Testing Laboratories, LLC

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/1/2015 to 12/31/2017</td>
</tr>
</tbody>
</table>

### Research Area:
Natural Gas-Related Transportation

### Issue:
The low fuel cost and efforts to reduce both criteria emissions and greenhouse gases are incentivizing the transition to natural gas as a transportation fuel in heavy duty on-road applications. Basic conversion of an engine from diesel to natural gas typically results in a reduction of available power and thermal efficiency of over 30%. Operating at higher dilution levels will allow higher engine output and fuel efficiencies but also increases the demands on the ignition system. Additional research is needed to improve ignition systems in natural gas engines to address these issues and improve engine efficiency.

### Project Description:
Olson Ecologic used turbulent jet prechambers to ignite natural gas engines as a means of overcoming some current natural gas ignition challenges. The Olson Ecologic team demonstrated that its prototype engine can be ignited with an air to fuel ratio double the current practice (dilute) while satisfying tighter emission standards and achieving the lower fuel consumption rates.

The Olson EcoLogic team explored the use of prechambers which ignite the fuel outside but adjacent to the main chamber. Gases ignited in the prechamber are instantly conveyed by turbulent jets to foster rapid combustion in the main chamber. The team evaluated two ignition scenarios. The first scenario involved the high boost pressure from the turbocharger with heavy exhaust gas recirculation. The second scenario high boost pressure with high rates of dilution air.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Through this project and the utilization of a turbulent jet ignition system in a Navistar 7 liter engine, this project targeted a 90 percent reduction and 80 percent reduction in NOx emissions by developing several configurations suitable for heavy-duty vehicles.

### Applicable Metrics:

**Greater Reliability:**
Although lean operations normally mean sacrifice of power, the test engines met full power of 300 horsepower at dilute levels of 1.8 with the turbulent jet prechambers. High boost pressure was sustained and good fuel efficiency was also observed.

**Public Health:**
At lean conditions the test engine matches the fuel efficiency of the stoichiometric Cummins Near-Zero 8.9 liter Natural Gas Engine, which is the most efficient natural gas engine on the market. Testing showed CO2 levels of 392 g/bhp-hr, and when adjusted for methane and CO
oxidation, the value is 411 grams per bhp-hr, which is equivalent to the near-zero engine at 414 g/bhp-hr. The engine, if outfitted with Selective Catalytic Reduction also has the potential to meet the low NOx standard of 0.1 grams per bhp-hr.

Consumer Appeal:

This technology has the potential to be advantageous for repowering off road applications to lean CNG with fueled prechambers. It is an attractive option for construction fleet owners who may be faced with more expensive options to repower diesel engines or replace their machines to meet the CARB compliance deadlines. According to Omnitek, the commercialized cost of repowering an existing machine, such as a 966G Loader with a 9 liter engine, to the fueled turbulent jet prototype engine, aftertreatment and CNG storage tanks is $105,000. The lean application of this engine is deemed attractive for commercial development because of fuel efficiency benefits and lower exhaust temperature.

**Natural Gas Funds Encumbered:**

$750,000

**Update:**

Project results show potential for further research and potential commercialization in some markets. However, additional research is needed to address emission issues found during testing and to test on the lean-burn configuration. Additionally, since testing has been limited to steady-state cycles, the electronic control module calibration needs to be expanded to address transient testing.

---

**Figure 1. Fueled TJI prechamber in light duty engine [source SAE 2012-01-0823]**

Fueled TJI prechamber in light duty engine [source SAE 2012-01-0823].
### Project Name:

Advanced Fueling Method to Achieve Full Fill for Natural Gas Vehicles - [PIR-14-013]

### Recipient/Contractor:

Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan:

Natural Gas Research

### Project Term:

5/8/2015 to 11/30/2018

### Research Area:

Natural Gas-Related Transportation

### Issue:

Safely and accurately achieving a “full fill” in a compressed natural gas (CNG) natural gas vehicle (NGV) is a technical challenge the NGV industry continues to struggle with when using a “fast-fill” CNG dispenser. The inaccuracies that cause under filling, largely the result of ambient temperature and heat generation within a CNG cylinder as it is filled with high pressure gas, are typically compensated for by slightly over pressurizing a cylinder in an effort for the settled pressure to be near the proper fill level. The shortcomings of this approach is a significant obstacle to improve safety, reliability, and consistency of CNG dispensers. Under filling results in reduced vehicle range.

### Project Description:

This project is developing an advanced characterization technique that uses communication between the vehicle and dispenser to identify tank volume, pressure, and temperature prior to filling. The improved characterization helps improve consistency and safety of fills by validating when the vehicle is near the full fill target. The Gas Technology Institute (GTI) is also optimizing an existing thermodynamic simulation tool to model a typical CNG station. The tool simulates the results of current state-of-the-art fueling methods and improved fueling algorithms developed using the characterization technique. Using GTI's environmental test chamber and a commercial CNG storage system, the improved fueling method will be tested and validated under a variety of real world conditions to evaluate its benefits.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:

This project addresses major industry concerns with fast fill CNG stations by improving their effectiveness in achieving full fills. Under filling CNG vehicles leads to reduced operating range and the need for storage compensation with larger storage volumes. Addressing these concerns can increase adoption rates of natural gas vehicles in key market segments that rely on fast fill stations such as goods movement. Heavy-duty vehicles in this sector are predominantly diesel and represent a major source of greenhouse gas and pollutant emissions in California. Displacing these vehicles with cleaner natural gas options will improve air quality and reduce the carbon impact of the transportation sector.

### Applicable Metrics:

**Lower Costs:**

Achieving consistent full fills improves economics of fleet operations for natural gas vehicles by maximizing vehicle range and reducing frequency of refueling. The capital costs for CNG on-board storage systems can be reduced by 10 percent ($5,000 per vehicle for some heavy-duty vehicles) if the storage tanks can be consistently filled to their maximum capacity.
**Consumer Appeal:**
Heavy-duty natural gas vehicles with a 20 percent under fill can result in 30 gasoline gallon equivalent of missing fuel, which directly translates to reduced maximum range. Consistent full fills will effectively increase the maximum range of natural gas vehicles and improve their competitiveness to diesel vehicles.

**Natural Gas Funds Encumbered:**
$400,000

**Update:**
The simulation tool showed that communication between the vehicle and dispenser can lead to significant improvements in fill consistency. Pre-cooling may be necessary to achieve full fills in cases with high ambient temperature. GTI investigated a variety of potential hardware options, but additional research is needed to provide low cost pre-cooling to CNG stations. GTI is conducting final testing of their advanced fueling method using wireless communication between the tank and the station by filling a 160 diesel gallon equivalent CNG storage system under a variety of initial conditions. Test results will be incorporated into the final report, which will be delivered in September 2018.

**IMAGE**

![CNG Compressor and Station Storage Testing.](image)
### Project Name:
Pipeline Right of Way Monitoring and Notification System - [PIR-14-014]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan: Project Term:
Natural Gas Research
6/30/2015 to 12/31/2018

### Research Area:
Natural Gas Infrastructure Safety and Integrity

### Issue:
The greatest threat to buried pipelines is the operation of third party digging equipment within the pipeline right-of-way (ROW). Current methods to continuously monitor the ROW, such as distributed fiber optic sensors, are difficult to retrofit to existing pipelines in populous areas. It is these high consequence areas that require a cost-effective retrofit method for ROW monitoring and notification; there are none at this time.

### Project Description:
This project is developing and demonstrating a system to alert operators to the presence of threats in the pipeline ROW. The system includes multiple in-ground and on-pipe sensors that wirelessly monitor vibration and electrical potentials on a pipeline at regular intervals, a mobile monitor on excavation machinery, and a dashboard that combines data from the pipeline and excavation monitors. The system will process the data generated by these devices and infer when digging equipment or other threats to the pipeline are present in the ROW prior to damage occurring.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The system consists of existing low-cost, low-power radio systems and off-the-shelf sensors. These technologies will lower the deployment costs to the extent that multiple sensors can be installed at discrete points in a given mile of pipeline. The overlapping coverage of multiple stationary sensors along with mobile sensors on pipelines aims to provide the same functionality as continuous fiber optic sensors in a form that can be more easily retrofitted to existing pipelines.

### Applicable Metrics:
**Greater Reliability:**
This system improves reliability and damage prevention of natural gas pipeline infrastructure by reducing the probability of incidents that would require repairs to the system or produce outages. Such incidents include the failure to detect corrosion (internal or external); cracks, dents, or gouges; defective welds; or other anomalies.

**Increase Safety:**
This results in an improved ability to detect leaks and damage, increasing safety of the natural gas pipeline infrastructure by detecting, locating, recognizing and responding to a leak or rupture in a timely basis and reducing the risk of a hazardous incident due to third party damage.
Environmental Benefits:
This reduces incidents of damage that cause the release of methane, a potent greenhouse gas, to the atmosphere

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,049,978</td>
</tr>
</tbody>
</table>

**Update:**
GTI installed a total of 15 sensors and gauges at three locations along the 8000 ft. natural gas pipeline in Bakersfield. One strain gauge, one soil sensor (to detect possible flooding under the pipeline), two vibration sensors and one geophone (seismic sensors) were installed at 1500 ft., 2500 ft., and 8000 ft. from the end of natural gas pipeline. Data collection started on July 2, 2018, and continues, and testing will commence for two months once the construction is complete in late August 2018.

Right of Way Violation and Alert System will prevent damage and improve safety of natural gas pipelines in California.
**Project Name:**
Rapid+ System for Natural Gas Pipeline Integrity Management - [PIR-14-015]

**Recipient/Contractor:**
Acellent Technologies, Inc.

**Natural Gas Funding Plan:** Natural Gas Research

**Project Term:**
8/3/2015 to 11/30/2018

**Research Area:**
Natural Gas Infrastructure Safety and Integrity

**Issue:**
Safety and the reliable operation of natural gas pipelines is jeopardized by degradation of the pipeline from corrosion and cracking; as well as pipeline impacts caused by encroachments. There is a need to detect pipeline degradation and encroachments to avoid catastrophic events such as the 2010 San Bruno incident.

**Project Description:**
This project is developing and demonstrating the Real-time Active Pipeline Integrity Detection (RAPID+) system. The system is designed to detect degradation to the pipeline and detect pipeline impacts due to external encroachments, which are the two most common causes of pipeline leaks. This system will include a surface-mounted ultrasonic sensor array that can identify corrosion damage on or inside a pipe and sensors both on and near the pipeline that will enable detection of vibrations from encroachments. The project involves the underground deployment and field-testing of the system at a California natural gas utility.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The system, consisting of degradation and impact detection along with wireless communication, improves the ability to detect defects and monitor and provide immediate feedback to pipeline operators on critical and highly susceptible-to-damage regions of pipeline in California.

**Applicable Metrics:**
- **Lower Costs:** Installing sensors on pipes will avoid the high costs of monitoring pipelines in the field with inspection personnel.

- **Greater Reliability:**
  The use of the system helps to prevent damage of natural gas pipelines before accidental third party impacts occur, as well as assess corrosion damage in underground pipelines which will improve reliability of the pipelines.

- **Increase Safety:**
  The sensors can detect pipeline encroachment and thereby improve safety of natural gas pipeline infrastructure in real time with monitoring technology that can accurately report the pipeline condition; thus reducing the risk of catastrophic events due to third party impacts.

**Natural Gas Funds Encumbered:**
$1,633,093
## APPENDIX D-66

**Update:**
The design of the encroachment detection system was completed and a test plan was developed and performed. The sensors were manufactured and tested for installation, after minor modifications were made with input from the utility and project partner. The device was installed for field testing at a SoCal Gas natural gas pipeline in Bakersfield until October 2018, and data collection and analysis will be conducted during this time.

### IMAGE

Acellent's Encroachment Detection System will prevent damage to natural gas pipelines and improve safety in California.
## Project Name:
Demonstration of an Advanced Low NOx Ribbon Burner Combustion System for Industrial Bakeries - [PIR-14-017]

## Recipient/Contractor:
Gas Technology Institute

## Natural Gas Funding Plan: Project Term:
Natural Gas Research 6/30/2015 to 3/29/2019

## Research Area:
Energy Efficiency

## Issue:
The heating, baking and drying of food products in California uses exclusively conventional ribbon burner combustion systems. The California baking industry alone uses an estimated 1.3 billion therms per year of natural gas. Annual emissions are estimated to be 6,892,600 metric tons of greenhouse gas (CO2 equivalent). These combustion systems are fueled with natural gas and reduction of CO2e and NOx emissions are critical for the baking industry in California.

## Project Description:
This project demonstrates a technique for NOx mitigation in natural gas fired systems by reducing the temperature in the combustion zone. This project adjusts the ribbon burner design to enhance the combustion system and therefore reduce the process temperature, emissions and increase energy efficiency. This approach is based on modification of primary air composition by recirculation of carbon dioxide and other combustion products from the exhaust stream and will be demonstrated at a large industrial bakery in Southern California.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Successful development, demonstration and testing of this advanced ribbon burner combustion technology provides an advanced low NOx and fuel-efficient ribbon burner system for use in industrial bakeries and other industrial facilities. This technology will help bakeries and other industries meet or exceed local air district air emission requirements while also being energy efficient.

## Applicable Metrics:

| Lower Costs: | This technology has the potential to reduce natural gas use by at least 10% in industrial operations compared to standard ribbon burner combustion systems. |
| Environmental Benefits: | Successful development of this combustion technology could reduce NOx emissions by at least 50%. |

## Natural Gas Funds Encumbered:
$950,000

## Update:
The system installation is complete and performance verification of the advanced low NOx combustion system is complete. The project team is analyzing the data and will provide recommendations for commercial system design adjustments and operating protocol.
APPENDIX D: FY 2017-18 NATURAL GAS ACTIVE AND COMPLETED PROJECT WRITE-UPS

IMAGE

Combustion Oven during Installation process.
Appendix D-69

**Project Name:**
Advancing Novel Biogas Cleanup Systems for the Production of Renewable Natural Gas - [PIR-14-019]

**Recipient/Contractor:**
Institute of Gas Technology dba Gas Technology Institute

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
6/30/2015 to 12/31/2018

**Research Area:**
Renewable Energy and Advanced Generation

**Issue:**
Biogas use in California offers an opportunity for lower cost renewable energy production that has a dramatically reduced carbon footprint when compared to fossil fuels. Currently, the cleaning and upgrading of biogas to high quality renewable natural gas (RNG) can be costly, complex, energy intensive, and often consume raw materials that cannot be easily or cost-effectively regenerated. To expand the opportunities for RNG use in California including injection into the natural gas pipeline, direct use for transportation, or more sophisticated electric power applications including turbines and fuel cells, RNG will need to more closely resemble the cost and complexity of fossil natural gas.

**Project Description:**
The recipient developed a novel biogas cleanup system for the production of pipeline quality RNG. This project designed a three-stage cleanup system which removes water and carbon dioxide (stage 1), hydrogen sulfide, siloxanes, and oxygen (stage 2), and nitrogen (stage 3) from raw landfill gas. By combining these systems, the various undesirable compounds typical of biogas can be removed to generate pipeline quality gas. The biogas cleanup system has been designed and tested using actual landfill gas and has demonstrated its ability to separate and remove the various compounds listed above. In order to validate long term operation, the project team will demonstrate a pilot-scale (100 Standard Cubic Feet per Minute feed) version of the designed biogas cleanup system at an existing landfill in California.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The novel cleanup technologies will increase efficiency and reduce the cost of removing contaminants from landfill gas and upgrading to pipeline quality renewable natural gas (RNG). Lower cost biogas cleanup and upgrading technologies will expand the market for low carbon renewable fuels for both electricity generation and transportation application.

**Applicable Metrics:**

- **Lower Costs:**
  This project demonstrated a low-cost bioenergy pathway that converts woody biomass into RNG. Techno-economic analysis indicates that a full-scale facility would produce RNG at approximately $8/therm. Although this is two to three times the price of natural gas, it is competitive with RNG produced from other biogas sources, such as anaerobic digestor gas.

  **Increase Safety:**
  This project demonstrated a bioenergy pathway that could ultimately harness the growing...
supply of dead trees. Dead trees present a large wildfire risk as they are dry and more prone to catch fire. Utilizing these trees for bioenergy could aid in reducing wildfire risk, increasing safety for surrounding communities.

Environmental Benefits:
Results from this project can help design and commercialize a full-scale woody biomass to renewable natural gas facility. Such a facility would result in decreased impacts to climate change by decreasing dependence on fossil natural gas and by reducing harmful environmental emissions (namely black carbon) associated with wildfires.

Energy Security:
Successful commercialization of this technology will result in decreased dependence on fossil natural gas by introducing a new renewable natural gas pathway.

Natural Gas Funds Encumbered:
$1,000,000

Update:
Design and testing of the novel cleanup system was completed using both real and simulated landfill gas. Fabrication of the pilot-scale, skid-mounted cleanup system is complete and preparation for onsite testing is ongoing. The pilot-scale system will convert 100 SCFM of landfill gas into 41 SCFM of renewable natural gas of suitable quality for pipeline injection. Key targets during demonstration are to reduce hydrogen sulfides to below 4 ppm, to reduce siloxane to non-detectable levels, and produce renewable natural gas with over 96% methane content. The project demonstration commenced in summer 2018 and will collect data for 6 months.

Chilled biodiesel scrubber for removal of water and tars from the producer gas.
**Project Name:**
Las Gallinas Valley Biogas Energy Recovery System (BERS) Project - [PIR-14-020]

**Recipient/Contractor:**
Las Gallinas Valley Sanitary District

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2015 to 3/30/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Renewable Energy and Advanced Generation

**Issue:**
Wastewater treatment facilities are energy-intensive to operate and produce greenhouse gas emissions and residuals that are costly to manage. The potential to generate renewable energy for the mesophilic anaerobic digestion of wastewater sludge at facilities is significant. However, due to barriers – mainly cost – most facilities flare the gas produced from daily operations and do not utilize it as a source of renewable energy.

**Project Description:**
The purpose of this project is to install and operate a pre-commercial biogas energy recovery system (BERS) that will convert biogas from a wastewater treatment plant into conditioned digester gas for combined heat and power generation and renewable compressed natural gas for use as transportation fuel.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The BERS is a first-of-its-kind demonstration of combined heat and power and vehicle refueling at a wastewater treatment plant, and serves as a reference demonstration for the industry. In addition, the Las Gallinas Valley Sanitary District is a small wastewater treatment plant, where economics are often less favorable due to scale dependency of the equipment. Demonstrating economical operation at small-scale proves that wastewater treatment plants small and large could install a similar system. In addition, the BERS provides local benefits to the community and environment by leveraging a renewable fuel stream to produce power and vehicle fuel while reducing local pollutants and greenhouse gas emissions.

**Applicable Metrics:**

- **Lower Costs:**
  This project reduces operating costs for the wastewater treatment facility while also reducing the demand on non-renewable natural gas supplies. Conservative operational cost savings are over $100,000 per year.

- **Greater Reliability:**
  The BERS will convert 30 standard cubic feet per minute of biogas into approximately 130 kW of renewable electricity, 145,000 BTU/hr of heat, and 10,000 diesel gallons equivalent per year of fuel. The wastewater treatment plant will provide all biogas required to operate the BERS. By eliminating the need for external natural gas supplies, the project will provide energy stability to the wastewater treatment plant and reduce the load and demand from the grid leading to greater grid reliability.

- **Environmental Benefits:**
  The BERS and natural gas fueled vehicles significantly reduce emissions compared to the out-of-compliance internal combustion engine and diesel fueled vehicles, which were replaced. For example, estimated NOx reductions are over 1400 grams per megawatt-hour.
## Natural Gas Funds Encumbered:

$999,070

## Update:

Construction of the Biogas Energy Recovery System is complete, and includes installation of the gas cleanup system, microturbines, hydronic boiler, and refueling station. Initial system startup was delayed due to required digester upgrades at the wastewater treatment facility. The gas cleanup system and microturbines commenced operation in December 2017, while the hydronic boiler and refueling station commenced operation in Summer 2018. Data collection will occur until the end of 2018, after which the data will be analyzed and the results reported.

![Image](image-url)

View of the two Capstone microturbines with a third foundation for future installation. The H2S removal tank is in the background, in front of the digester.
### Project Name:
Cost Reduction for Biogas Upgrading via a Low-Pressure Solid-State Amine Scrubber – [PIR-14-021]

### Recipient/Contractor:
Mosaic Materials, Inc.

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
6/30/2015 to 9/30/2018

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
In California, more than 10% of biogas is flared due to insufficient on-site demand and only 15% (approximately) of overall biogas capacity is utilized. The high Carbon Dioxide (CO2) content in biogas makes upgrading to pipeline quality biomethane for transport extremely energy intensive. While there are several commercial CO2 removal technologies, they are cost prohibitive for most facilities and therefore not widely adopted.

### Project Description:
This project is developing a solid-state amine scrubbing technology for biogas upgrading that provides a 40 percent reduction in capital and operating costs compared to current state-of-the-art aqueous amine scrubbers. The solid-state scrubber for cleaning biogas will increase efficiency and reduce the cost of removing contaminants from wastewater treatment plant biogas and upgrading to pipeline quality renewable natural gas. The developed sorbent material will undergo durability testing at a wastewater treatment plant, and extended gas separation testing in a laboratory environment.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The solid-state sorbent material developed is able to absorb significantly more carbon dioxide compared to the same volume of conventional liquid amines used for gas absorption. The material is also able to be recharged using significantly less energy. Lower cost biogas cleanup and upgrading technologies will expand the market for low carbon renewable fuels for both electricity generation and transportation applications.

### Applicable Metrics:

**Lower Costs:**
The reduced footprint and significant energy saving of the solid-amine scrubber will bring down both capital and operating costs in biogas upgrading for high quality biomethane (40% reduction vs. current amine scrubbers).

**Increase Safety:**
This technology improves safety over conventional scrubbers by operating at a low pressure and avoiding the handling of hazardous amine solvents.

**Economic Development:**
Biogas utilization converts waste from agriculture, livestock, and forestry into an energy source. This brings economic benefits to those rural operations and creates jobs for those who build and operate biogas facilities.
## Environmental Benefits:
Increased adoption of renewable biomethane will reduce consumption of conventional natural gas, reducing carbon dioxide emissions while also promoting more biogas facilities to convert biogas to biomethane, and reduce flaring emissions.

## Natural Gas Funds Encumbered:
$1,000,000

## Update:
Formulation and testing of solid state sorbent material using simulated biogas was completed in 2016. Several other tests were completed in early 2018 including: scale-up testing to prove the sorbent could be produced on a kilogram scale, and slipstream testing at a wastewater treatment plant to prove the material durability when exposed to raw biogas. Finally, long term gas separation testing was completed in summer 2018 to test the sorbent material's performance over repeated cycling and long periods of time. The demonstration proved the sorbent material's ability to maintain high selectivity for carbon dioxide over methane over hundreds of absorption/desorption cycles. A key next step for the technology will be to perform a pilot-scale demonstration to prove the technology can be scaled-up and operated with actual biogas while maintaining the same performance characteristics.

## Image
Small-scale batch of sorbent material for separating carbon dioxide from biogas. Formulation will be scaled-up from gram to kilogram-sized batches.
**Project Name:**
Improvements to biogas production using micronutrients, operational methodologies, and biogas processing equipment to enable pipeline injection of biomethane - [PIR-14-022]

**Recipient/Contractor:**
Biogas Energy Inc.

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2015 to 11/17/2017</td>
</tr>
</tbody>
</table>

**Research Area:**
Renewable Energy and Advanced Generation

**Issue:**
There are over a dozen anaerobic digester facilities in California which convert organic waste into biogas to produce renewable heat, power, and vehicle fuel. The number of facilities is expected grow substantially in the near future as California aims to meet its ambitious waste diversion, greenhouse gas reduction, and renewable energy goals. Despite the rapid growth of this industry many aspects of the anaerobic digestion process are not well understood causing digesters to operate sub-optimally. There is a need to better understand the anaerobic digestion process, including the effect of individual feedstocks on overall performance.

**Project Description:**
This project conducted a study on operation of the anaerobic digestion process; improving biogas production through the use of micronutrients, co-digestion efficiencies, feedstock analysis, and operational modifications. The project leveraged existing anaerobic digester infrastructure at North State Rendering to perform detailed analysis of the biology of the digesters at the site. The project simultaneously performed laboratory experiments at CSU Chico using various feedstocks and digestate harvested from the commercial digester. Detailed analysis of the effects of feedstock supply, micronutrient management, and operational improvements were performed by the team with the aim of generating a set of best practices for the optimization of biogas production.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project led to technological advancements by demonstrating a system with increased biogas production per unit of feedstock, improved quality of biogas production, and lower costs for system operation, which improves the economics of organic waste conversion to energy, compared to conventional practices.

**Applicable Metrics:**
- **Lower Costs:**
  By understanding the effect of different feedstocks on digester performance, the results of this project were used to optimally select digester feedstocks and subsequently lower the cost (per standard cubic foot produced) of biogas production. The project provides optimization recommendations that could increase biogas production at existing digesters by up to 10 percent.

- **Environmental Benefits:**
  Environmental benefits include an increase in biogas capture, increased diversion of landfill waste, and contributions to the reduction of fossil fuel use in the state.
Natural Gas Funds Encumbered:
$415,000

Update:
Biomethane potential for over 25 digester feedstocks were evaluated at the lab-scale to analyze the composition and volume of biogas produced. Many feedstocks, some unconventional, were introduced to the commercial-scale digester and their effect on digester performance and biogas output was monitored. Some feedstocks previously thought to harm digester operation exceeded expectations. For example, olive waste was expected to inhibit biogas production due to its high sodium content, however, it proved to be an excellent feedstock with little adverse effects on digester performance. Results of the study were compiled in order to produce best practices recommendations in the final report.

Image

North State Rendering anaerobic digester facility with refueling station (foreground) and digesters (background).
### Project Name:
Renewable Natural Gas Production from Woody Biomass via Gasification and Fluidized-Bed Methanation - [PIR-14-023]

### Recipient/Contractor:
The Regents of the University of California, San Diego

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
6/30/2015 to 6/29/2018

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
California has 32 million bone dry tons of sustainable undeveloped biomass equivalent to 512 trillion BTUs a year. A large portion of this biomass could be economically converted to renewable natural gas (RNG) by methanation, but the cost of the produced RNG is high. The leading cause of the high costs of the methanation process, as with many other fuel synthesis processes, is the deactivation of catalysts. While the effect of trace contaminants on catalysts is known, the detailed measurement and characterization of these trace contaminants is often not performed. This leads to inadequate gas cleanup and early catalyst deactivation.

### Project Description:
This project developed, through lab and pilot-scale testing, a novel bioenergy pathway to convert woody biomass into renewable natural gas (RNG) via fluidized bed methanation for cost-effective pipeline injection. A fast internally circulating fluidized bed (FICFB) gasifier was used to convert biomass to producer gas with high efficiency. Researchers developed and tested new methods for the measurement of trace contaminants in the product gas. New gas cleanup methods were tested on producer gas with contaminants measured before and after gas cleanup. The trace contaminants in the cleaned gas were evaluated to determine if they are suitable for methanation catalysts. The project then tested these catalysts in a fluidized bed methanation experiment. Finally, technical and economic analysis was performed for a full-scale (60 MW RNG) facility with the intent to scale-up for future projects.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Conversion of woody biomass to renewable natural gas is a first-of-its-kind demonstration in California and may prove to be a viable pathway to convert forest waste into renewable energy. Given unprecedented tree mortality rates in California, there is an urgent need to test and demonstrate forest waste-to-energy pathways. The project also demonstrated fluidized-bed methanation for the first time in the U.S., a process more efficient than conventional fixed-bed methanation.

### Applicable Metrics:
- **Lower Costs:**
  This project demonstrated a low-cost bioenergy pathway that converts woody biomass into RNG. Techno-economic analysis indicates that a full-scale facility would produce RNG at approximately $8/therm. Although this is two to three times the price of natural gas, it is competitive with RNG produced from other biogas sources, such as anaerobic digester gas.
- **Increase Safety:**
  This project demonstrated a bioenergy pathway that could ultimately harness the growing supply of dead trees. Dead trees present a large wildfire risk as they are dry and more prone to
catch fire. Utilizing these trees for bioenergy could aid in reducing wildfire risk, increasing safety for surrounding communities.

Environmental Benefits:
Results from this project can help design and commercialize a full-scale woody biomass to renewable natural gas facility. Such a facility would result in decreased impacts to climate change by decreasing dependence on fossil natural gas and by reducing harmful environmental emissions (namely black carbon) associated with wildfires.

Energy Security:
Successful commercialization of this technology will result in decreased dependence on fossil natural gas by introducing a new renewable natural gas pathway.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000,000</td>
</tr>
</tbody>
</table>

**Update:**
Numerous improvements to the fast internally-circulating fluidized bed gasifier were completed to allow for precise sampling of the producer gas. New producer gas cleanup methods, including a chilled biodiesel scrubber, were developed and implemented to remove water and tars from the producer gas; a critical step before methanation can occur. A methanation reactor was constructed and tested to prove that methane could be produced via the fluidized bed methanation method. Finally, a techno-economic analysis was performed showing significant cost reduction for producing RNG via fluidized-bed methanation compared to conventional fixed-bed methods. Key next steps for the technology include additional catalyst research to determine optimal methanation catalysts and a pilot-scale demonstration to prove the technology can be scaled-up while maintaining the same performance characteristics.

![Chilled biodiesel scrubber for removal of water and tars from the producer gas.](image)
**Project Name:**
Development and Demonstration of a Cost Effective, Packaged Approach to Industrial Gas Efficiency Using Organic Rankine Cycle Technology - [PIR-14-024]

**Recipient/Contractor:**
Electric Power Research Institute, Inc.

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/29/2015 to 12/31/2018</td>
</tr>
</tbody>
</table>

**Research Area:**
Renewable Energy and Advanced Generation

**Issue:**
Gas-fired industrial processes, including ovens, furnaces, dryers, and kilns, operate with relatively low efficiency, resulting in a large quantity of waste heat. The U.S. Department of Energy estimates that the U.S. industrial sector uses about one-third of the total U.S. energy consumption and up to 50% of this energy is lost as waste heat. Waste heat with temperatures below ~1000 degrees Fahrenheit is not often used for electricity generation due to barriers that include high cost, low efficiencies, and the lack of real world technical and economic performance data.

**Project Description:**
This project demonstrates application of the Organic Rankine Cycle (ORC) to generate electricity using waste heat from industrial ovens. An ORC process that can utilize medium or low temperature waste heat to directly produce electricity is applicable to a broad range of industrial operations.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
Some of the unique and innovative aspects of the technology being evaluated include: high efficiency working fluid; advanced turbine design that reduces irreversible losses; packaged solution that reduces installation costs and complexity; unique refrigerant management system to manage refrigerant charge (charge flexibility needed as operating temperatures vary); and, flexibility in heat exchangers both for evaporator and condenser, that allows the system to capture heat from a variety of industrial processes that use different heat rejection media (e.g. air, liquid).

**Applicable Metrics:**

**Lower Costs:**
This project demonstrates cost-effective generation from low-grade waste heat captured from an industrial process. The estimated simple payback period for the system is 6 years.

**Greater Reliability:**
This project demonstrates a viable strategy for peak demand reduction through coordinated onsite clean generation during periods of high demand. Industrial natural gas demand for 2015 was forecast to be 5,320 MM therms per year. The U.S. Department of Energy estimates that 20-50 percent of industrial energy use is lost as waste heat. Conservatively assuming 20 percent waste heat loss and one-half of this waste is available for recovery, the potential energy recovery is 532 MM therms per year. Conservatively assuming an ORC efficiency of 7 percent, this corresponds to about 1,000 GWh per year of electric generation that could be realized through this project.
<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$999,889</td>
</tr>
</tbody>
</table>

**Update:**
Several delays with demonstration sites and equipment manufacturers caused the project to fall behind schedule. As of August 2018, the Energy Commission stopped work on the project, but will consider continuing the project when the research team has satisfied certain requirements.
### Project Name:

### Recipient/Contractor:
The Regents of the University of California on behalf of the Davis campus

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>12/15/2015 to 12/14/2018</td>
</tr>
</tbody>
</table>

### Research Area:
Energy-Related Environmental Research

### Issue:
California invested substantially in encouraging adoption of solar water heating (SWH) technology to reduce residential GHG emissions. However, SWH has extremely low penetration in the marketplace despite environmental benefits and State investment. In 2010, the California Solar Initiative Thermal (CSI-T) program began providing subsidies to encourage cost-effective SWH. Authorizing legislation aimed for 200,000 new installations by 2017. Entering the final quarter of 2017, the CSI-T program has installed 5300 residential systems.

### Project Description:
This research aims to clarify technical and human factors that affect performance of solar water heating (SWH), delineate opportunities for improving performance, identify specific niches that could yield substantial benefits; and provide a basis for increasing environmental benefits from SWH in California's single family home sector. Research includes collecting information from those who use, have used, or have considered using SWH technologies in their homes, contractors who have sold and/or installed SWH, industry leaders who are or could be promoting the technology, and other stakeholders. Research draws on and analyzes multiple streams of data toward understanding; benefits and costs of SWH in practice; motivations and experience of adopters and non-adopters; and, what types of changes to the technology and selection - relative to conditions, policy, and industry practices - would improve the rate of adoption and SWH performance.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
Research will help deliver California's statutory energy goals by providing a clear picture of technology adoption issues and usage/behavior issues related to the performance of SWH. Addressing barriers to stronger performance and wider adoption requires a comprehensive and detailed understanding of the complex SWH market system, including a socially informed approach to shaping technology and system choices, as well as transcending conventional energy efficiency paradigms that have, to date, failed to deliver goals of SWH programs in the state.

### Applicable Metrics:

**Environmental Benefits:**
Research provides a basis for increasing environmental benefits from SWH in California's single family home sector by clarifying technical and human factors that affect performance of SWH, delineating opportunities for improving performance, and identifying specific niches that could yield substantial benefits.

### Natural Gas Funds Encumbered:
$500,000
Update:
Employing a range of qualitative and quantitative methodologies, the research team performed an analysis of solar water heating technologies installed in California. Methods and data used include the CSI-T database, case studies of successful solar water heating markets, analysis of contractors and installations in California, interviews with industry experts, surveys of householders with solar water heaters, and successfully securing utility data portraying energy consumption before and after installation of solar water heaters. An investigation of factors that are favorable to successful installation and use of solar water heating is ongoing, e.g., availability of skilled contractors, building codes, HOA rules, and historical design review processes. Quantitative analysis of system performance in light of weather conditions, technology choice, and other key parameters is ongoing.

Number of approved incentives for single-family and single-family low-income solar thermal water heating installations under the California Solar Initiative-Thermal (CSI-Thermal) program (data as of November 23, 2017). Researchers are investigating whether the constellation of technologies, contractors, consumer interest, and other factors may be favorable to specific niches for residential solar thermal in California.
### Project Name:
Assessment of Fugitive Emissions from the Natural Gas System-Commercial Buildings - [PIR-15-003]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan:
- Natural Gas Research

### Project Term:
1/4/2016 to 3/29/2019

### Research Area:
Energy-Related Environmental Research

### Issue:
California has initiated efforts for quantifying emissions for some sources of emissions, such as natural gas pipelines. However, experts recognize that emissions from other sources, such as commercial buildings, have not been well characterized. This project is essential to providing the necessary information to measure and quantify methane emissions from commercial buildings.

### Project Description:
The project is a small-scale field measurement program to develop and validate a field method to plan, conduct, and analyze measurements of fugitive methane leaks/emissions from commercial buildings in northern and southern California. The method measures post-metering methane leakage from appliances or system components and quantify total building emissions. The scope of work is designed to ensure a representative sample of building types and consider factors such as construction year, geographical distribution, and services provided. Study plans to sample about 20 to 30 buildings. The field data and statistical analysis are used as inputs into a Monte Carlo simulation. Ensuring the field data collected is a proper random sampling of use cases across the state of California allows the Monte Carlo simulation output to be used for scenario analysis to estimate expected emission reductions from future regulations.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Ambient measurements of methane from other studies suggest that there are sources of emissions from the natural gas system that are not included in the State greenhouse gas inventory. One of them could be commercial buildings. This project is designed to collect data to improve estimations of methane emissions from buildings, which is essential to ensuring that the State develops well informed emission reduction strategies.

### Applicable Metrics:

#### Environmental Benefits:
The project results will assist in quantification of after-the-meter methane leakages from commercial sectors. This information will help California's efforts to reduce greenhouse gases by inform the greenhouse gas inventory calculation managed by the California Air Resource Board.

#### Natural Gas Funds Encumbered:
$599,891
Update:
The Recipient (GTI) has subcontracted with the Lawrence Berkeley National Lab (LBNL) for measurement method development. LBNL has successfully conducted lab testing of the method. Using the method, GTI has collected methane emission measurements from twenty-two food services facilities and two healthcare facilities. GTI will also work with ICF International, the recipient of a parallel agreement (PIR-15-017) that will measure methane emissions from other building sectors, such as hotels and department stores. The field data and statistical analysis will be used as input into a Monte Carlo simulation. The simulation output will be used for scenario analysis to estimate expected emissions reduction from future regulations.

IMAGE

GTI field steam making leak measurement in the kitchen.
**Project Name:**
Investigate Climate Vulnerability of the Natural Gas System and Identify Resilience Options in the San Diego Area - [PIR-15-004]

**Recipient/Contractor:**
ICF Incorporated, L.L.C.

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
1/12/2016 to 5/30/2018

**Research Area:**
Energy-Related Environmental Research

**Issue:**
Energy infrastructure in California’s low-lying coastal zones and rugged inland terrain could be adversely impacted by permanent inundation from sea level rise, coastal flooding, or in inland zones vulnerable to landslides, wildfires, and inland flooding. However, detailed information on the threats is often insufficient to inform action, beyond resilience measures that would be undertaken for non-climate reasons. This project improves understanding of vulnerabilities and adaptation measures for natural gas infrastructure within the SDG&E territory so that appropriate policy and planning decisions can be made.

**Project Description:**
The goal of the project is to develop an understanding of climate-related hazard vulnerability and adaptation options in the San Diego Gas & Electric (SDG&E) territory at a level of detail appropriate for informing energy sector policy and planning. The recipient is partnering with SDG&E to conduct a detailed, robust climate change vulnerability assessment and identify and evaluate appropriate adaptation measures. Possible adaptation measures are determined using literature reviews, interviews with key experts, modeling, and workshop elicitation. Potential direct and indirect impacts and adaptation measures are evaluated at an asset-by-asset level, and through system wide assessment. This provides a suite of practical, actionable climate change adaptation measures optimized to SDG&E’s natural gas system and customer needs.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
SDG&E (a funding partner for this project) will use this research to identify feasible climate adaptation measures that will increase reliability and lower overall costs to the utility and its ratepayers. SDG&E is also sharing the results of this study with the U.S. Department of Energy via its Partnership for Energy Sector Climate Resilience, which is being coordinated with the California Public Utilities Commission/California Energy Commission Adaptation Working Group.

**Applicable Metrics:**
**Lower Costs:**
Cost savings to ratepayers will be realized by avoided costs of damage and service disruptions from climate change impacts, as well as avoided costs from over adapting.

**Greater Reliability:**
The conclusion from the study will assist SDG&E and other utilities with preparing adaptation plans to climate change, to improve reliability of natural gas service. SDG&E will be able to avoid some service interruption resulting from climate change impacts.
### Natural Gas Funds Encumbered:

$456,703

**Update:**

By analyzing potential climate change-driven impacts to the San Diego area gas system, the research team generated flexible adaptation pathways to help utilities adapt to climate change hazards while managing uncertainty. The results show many gas assets will potentially experience increased exposure to sea level rise-driven coastal hazards, wildfire, extreme heat, inland flooding, and landslides. Overall, natural gas assets and services are expected to experience limited impacts from the climate hazards investigated in this study. The team developed flexible adaptation pathways. The pathway is created to manage uncertainty by making and adjusting adaptation decisions as new information on climate and non-climate variables becomes available. The project is part of the California 4th climate assessment. The final report will be part of the assessment reports published in late 2018.

---

**IMAGE**

Aboveground regulators exposed to 100-year coastal wave flooding.
### Project Name:
Probabilistic Seasonal and Decadal Forecasting for the Natural Gas System - [PIR-15-005]

### Recipient/Contractor:
The Regents of the University of California, on behalf of the San Diego campus

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
11/18/2015 to 3/30/2018

### Research Area:
Energy-Related Environmental Research

### Issue:
Natural gas, used for both domestic and industrial applications, is a primary source of energy in California. Demand for natural gas varies because of several factors, including changing weather and climate and climate conditions. Because gas demand responds to these variations and changes, and thus can vary significantly from one year to the next and also over decades, better predictions of the weather and climate variation would be useful for State agencies and utility managers in various types of operations decisions and planning.

### Project Description:
This project develops weather and climate forecast models that provide seasonal predictions for temperature and precipitation of 0-9 months and decadal predictions of 10-20 years for selected meteorological stations in California. The average projected temperature and precipitation from 10 downscaled global climate models will be constructed to estimate the mean changes and spread of possible changes over the next 20 years. Hindcasts of temperature and precipitation, using the same methodology, will be compared with historical observed data to evaluate decadal forecast skill. These projections will form the basis of 10-20 year lead-time predictions of weather and climate fluctuations that will affect California. Preliminary results show that improved predictability is possible for only a few months in advance.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project provides information that can improve California’s natural gas operations through planning for those parts of the system that are impacted by weather/climate fluctuations.

### Applicable Metrics:
**Greater Reliability:**
Improved forecasting of short and long-term weather and climatic variability will improve operation of the natural gas system allowing utilities to anticipate periods of greater and lesser demand. Natural gas customers will benefit through the establishment of a more reliable, more efficient, and possibly less expensive supply.

**Energy Security:**
Improved forecasting of short and long-term weather and climatic variability will help ensure that adequate natural gas resources are available increasing energy security.

### Natural Gas Funds Encumbered:
$399,467
Update:
Significant progress was achieved, demonstrating good performance with probabilistic forecasts as far out as a few months in advance. Results show that improved predictability is possible for only a few months in advance. The team examined decadal forecasts from different research centers around the world and found relatively poor performance. The final report contributed to California's Fourth Climate Change Assessment.

Downscaling of Precipitation from a Global Climate Model to California.
**Project Name:**

**Recipient/Contractor:**
Institute of Gas Technology dba Gas Technology Institute

**Natural Gas Funding Plan:**
Natural Gas Research

<table>
<thead>
<tr>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/8/2016 to 3/31/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Industrial furnaces burn natural gas and vent the hot exhaust gas. Combustion systems, furnace designs, and insulation are designed to provide the highest possible efficiency, lowest emissions, and lowest cost. However, if heat is recovered from the exhaust gas and used to preheat combustion air, the efficiency increases but the oxides of nitrogen (NOx) emissions and the overall capital cost increase. Technology is needed that can address each of these issues cost effectively.

**Project Description:**
This project demonstrates a Radiative Recuperator with Secondary Emitters (RRSE) technology on an aluminum melter to reduce natural gas use. This advance technology will preheat the combustion air with heat from the exhaust gas. Ultra-low NOx burners will be installed and operated with air preheated to as high as 1200 degrees Fahrenheit in the RRSE. Further natural gas savings are anticipated by using the exhaust gas leaving the RRSE to preheat scrap on its way to the furnace.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This technology will recover heat from the exhaust gas and used to preheat combustion air without increasing the oxides of nitrogen (NOx) emissions and the overall capital cost. If this technology is successfully demonstrated, it could lower the cost of recovering heat from furnace exhaust gases, reduce NOx and greenhouse gas emissions and reduce the payback period to recover the cost of equipment and installation and would be applicable to other industrial operations.

**Applicable Metrics:**

<table>
<thead>
<tr>
<th>Lower Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>This technology could reduce natural gas use and costs. Up to 10% of industrial natural gas furnaces can benefit from this technology. For these furnaces, average gas savings are estimated at 25%. Assuming 10% market penetration, each year there is potential to annually save 2 billion cubic feet (2 trillion Btu) of gas, or about $10 million (based on $5 per million Btu for gas).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Benefits:</th>
</tr>
</thead>
<tbody>
<tr>
<td>This project could reduce NOx emission and CO2 emissions by 106,000 metric tons (assuming 10 percent market penetration of the technology).</td>
</tr>
</tbody>
</table>

**Natural Gas Funds Encumbered:**
$1,299,985
Update:
The recipient has executed an agreement with subcontractor, California Die Casting. Engineering design and modeling is completed for the recuperator to be installed at California Die Casting. Work continues on preparing the furnace for upgrades. This includes installation of refractory materials and preparations for installation of the combustion system. The burners have been received and will be ready when needed. The furnace outer shell work will be completed August 2018, and refractory installation is underway. The team is developing a timeline for completion of furnace rebuild.

IMAGE

Preliminary recuperator design with a stacker for scrap preheating.
**Project Name:**
Conversion of Low Value Waste Heat into High Value Energy Savings - [PIR-15-007]

**Recipient/Contractor:**
Gallo Cattle Company, LP dba Joseph Gallo Farms

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan</th>
<th>Project Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>4/1/2016 to 2/28/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Waste heat from biogas to electricity generators and steam processes from industrial facilities are usually exhausted into the air wasting potential energy. Instead of using this wasted energy, these industries will use electricity and natural gas to produce steam or heat for internal processing and cooling purposes. Cost effective methods of using waste heat in food processing is needed to maximize efficiency within the plant and reduce energy and operating costs.

**Project Description:**
This project demonstrates a new innovative absorption chiller system that extracts waste heat from biogas to electricity generators and uses the heat for heating and chilling purposes in a food processing facility.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The waste heat from the generators is normally exhausted into the atmosphere and the energy is lost. With this project, the heat is captured and re-used within a food processing facility to offset natural gas purchases for heating and chilling. Demonstration of the technology will show the energy savings and cost effectiveness of this waste heat recovery technology and application to others in the food processing industry.

**Applicable Metrics:**

<table>
<thead>
<tr>
<th>Lower Costs</th>
<th>Environmental Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>This system has the potential of reducing energy costs by approximately 23% for natural gas and 38% for electricity for chilling and heating in food processing facilities. However, preliminary results have shown higher savings.</td>
<td>This system can lower natural gas use by 23.5% and thus reduce greenhouse gas emissions</td>
</tr>
</tbody>
</table>

**Natural Gas Funds Encumbered:**
$1,207,136

**Update:**
Measurement and verification is still underway but preliminary data show significant savings. The natural gas boiler has shown savings of 29% and the ProCream Dryer has shown natural gas savings of 25% compared to operation in 2016. The data collection has also shown electrical savings of 84% compared to operation in 2016.
The ThermoSorber with cooling tower stacked on top.
Project Name:
Development, Integration, and Demonstration of 6.7 Liter Natural Gas Engine in Medium Heavy-Duty Vehicles - [PIR-15-008]

Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

Natural Gas Funding Plan: Natural Gas Research
Project Term: 4/1/2016 to 3/31/2019

Research Area:
Natural Gas-Related Transportation

Issue:
The market demand for natural gas powered commercial vehicles has increased significantly in recent years. The lack of availability of certain matching engine sizes and performance ratings has constrained the expansion of natural gas vehicle penetration in the commercial vehicle markets that includes pickup and delivery trucks, utility trucks, school buses, shuttle buses, yard tractors, and specialized municipal works vehicles such as street sweepers.

Project Description:
The project is developing, integrating, and demonstrating an advanced version of Cummins Westport Inc. (CWI)'s 6.7-liter natural gas engine. The engine, dubbed the B6.7N, meets the California Air Resources Board's 2018 requirements for heavy-duty on-board diagnostics (HD-OBD) and the optional low NOx standard of 0.1 g/bhp-hr. HD-OBD ensures emissions are kept at the certified low NOx level throughout the life of the engine by running monitors on major parts and subsystems. The HD-OBD system detects engine issues when they occur, allowing operators to efficiently make the necessary repairs to maintain effective engine operation. This project lays the foundation for follow-on work to further reduce the NOx emissions of the engine to the 0.02 g/bhp-hr level. The project includes demonstrations of the engine in applications such as delivery trucks, shuttle buses, and yard trucks.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project will provide a natural gas engine option to a vehicle market segment that did not previously have access to natural gas engines that are capable of meeting performance and efficiency standards comparable to diesel. This project also supports efforts to reduce NOx significantly in heavy-duty vehicles such as school buses and street sweepers, resulting in emissions reductions in California communities where these vehicles operate daily.

Applicable Metrics:
Public Health:
The use of advanced natural gas engines in heavy-duty vehicles will reduce criteria pollutant emissions. The ISB6.7 G reduces NOx emissions by 50% compared to equivalent diesel or gasoline engines. HD-OBD ensures emissions are kept low throughout the life of the engine.

Consumer Appeal:
HD-OBD notifies the driver when an engine issue is detected, signaling the need for maintenance to keep emissions low. This early detection reduces the chances of subsequent progressive engine damage. HD-OBD also stores information about the issue to improve future troubleshooting and resolution procedures.
**Natural Gas Funds Encumbered:**

$1,000,000

**Update:**

The B6.7N entered commercial production in January 2018 after receiving all the necessary certifications from the U.S Environmental Protection Agency and CARB. The vehicle demonstrations are continuing to accumulate miles. The demonstration of two Tico yard trucks operated by the United Parcel Service in a freight transfer facility in Ontario experienced unexpected delays, but it is now on track with the trucks delivered in June.

![MY2018 Cummins Westport B6.7N Engine.](image-url)
### Project Name:

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan:  Project Term:
- Natural Gas Research
- 6/30/2016 to 6/29/2019

### Research Area:
Energy Efficiency

### Issue:
Industrial boilers lose an estimated 16% of the fuel energy as waste heat in the exhaust. Recovering this waste heat and using it to heat water that is normally heated with natural gas will increase overall system efficiency with proportional reductions in natural gas use, and greenhouse gas and oxides of nitrogen (NOx) emissions. Currently available heat recovery technologies are custom engineered and fabricated for each application site and/or process. This costly site-specific engineering and installation makes the economic payback unattractive to the majority of industrial customers that could benefit from recovering waste heat.

### Project Description:
This project demonstrates the benefits of an emerging heat recovery technology originally designed for hot water boilers. The heat recovery system called "SideKick", will be installed and tested in industrial steam boilers and offers the opportunity for substantial waste heat recovery resulting in increased fuel efficiency and greenhouse gas emission reductions. The "SideKick" is a boiler economizer that is custom sized to provide hot facility water rather than preheating boiler intake water. An economizer is a device that is attached to the boiler exhaust plumbing to heat water. This reduces application engineering and heat recovery hardware costs, leads to lower installation costs and greater potential for market adoption. This project will independently document the energy efficiency, energy cost reductions, performance and installation requirements for the heat recovery system. The demonstration is being installed at Mission Linen Supply in Oxnard.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
In conventional boiler exhaust heat recovery approaches for boiler feed water heating, the heat recovery unit configuration is standardized due to the proportional relationship between the water flow through the economizer to the boiler size. This setup leads to efficiency gains of 1-3% - but there is still significant energy lost through the high temperature exhaust stack which is due to the inability of standard economizers to achieve higher efficiency due in part to the low water flow rates for such applications. Under this project, the "SideKick" will be installed to recover heat from a conventional steam boiler exhaust by heating a separate process water stream in the facility. This will allow for recovery of sensible and latent heat content from the exhaust stack with estimated efficiency improvements of approximately 8% in most installations.

### Applicable Metrics:
**Lower Costs:**
Successful demonstration could reduce installation and energy costs--saving an estimated $207 million in energy cost savings across California's industrial markets over the expected 20-year lifetime of the technology.
Environmental Benefits:
By saving natural gas, this technology would reduce greenhouse gas (GHGs) and NOx emissions by 8% each.

Natural Gas Funds Encumbered:
$585,300

Update:
As of 6/29/2018 Mission Linen Supply, the host site for the demonstration and installation contractor, is working with the City of Oxnard on the permit approval for installation of the equipment on the roof of the laundry facility. The new insulated 1000 gallon hot water buffer tank, pumps, and system control components have been delivered to the site.

**IMAGE**

![Image of SideKick Heat Recovery Unit](attachment:image.png)

SideKick Heat Recovery Unit.
<table>
<thead>
<tr>
<th><strong>Project Name:</strong></th>
<th>Integration of Advanced Solar Thermal Technology into Industrial Processes - [PIR-15-010]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recipient/Contractor:</strong></td>
<td>ergSol, Inc.</td>
</tr>
<tr>
<td><strong>Natural Gas Funding Plan:</strong></td>
<td>Natural Gas Research</td>
</tr>
<tr>
<td><strong>Project Term:</strong></td>
<td>4/11/2016 to 12/31/2019</td>
</tr>
<tr>
<td><strong>Research Area:</strong></td>
<td>Energy Efficiency</td>
</tr>
<tr>
<td><strong>Issue:</strong></td>
<td>The industrial sector in California consumes approximately 5,254 million therms of natural gas per year. The vast majority of industrial processes occur in a temperature range between 100 to 300 degrees F. Solar thermal (ST) systems can meet a significant portion of heating requirements in many industrial and commercial settings but there are few ST industrial installations in California and the market place lacks data on economics, performance, and reliability.</td>
</tr>
<tr>
<td><strong>Project Description:</strong></td>
<td>The project demonstrates a high efficiency solar thermal evacuated tube system that will offset the use of natural gas steam boilers. The demonstration will take place at an industrial pharmaceutical manufacturing facility.</td>
</tr>
<tr>
<td><strong>How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:</strong></td>
<td>Solar Thermal system implemented by this project will harness the thermal energy from the sun using evacuated tube collectors (ETC) and utilize the energy in various heating processes ranging from 100 to 300 degrees Fahrenheit. The ETC, in the ergSol Solar Thermal systems, have greater heat retention than current Flat-Plate Collectors, which leads to higher efficiencies in varying weather conditions and higher operating temperatures. Furthermore, the Solar Thermal system provides higher energy density per square meter per day (4.039 kWh/m²--2/day) than what is currently out on the market. Solar thermal systems further California's clean energy goals by conserving resources, enhancing the state's economy, and protecting public health and safety.</td>
</tr>
</tbody>
</table>
| **Applicable Metrics:** | **Lower Costs:** This technology is anticipated to lower operational and maintenance costs when compared to conventional boiler systems and help extend the replacement intervals of conventional boilers by reducing the load on those boilers.  
**Environmental Benefits:** If successful, this technology will reduce natural gas use for process heat and therefore reduce greenhouse gas emissions. |
| **Natural Gas Funds Encumbered:** | $1,200,000 |
### Update:

As of 6/25/2018, the recipient has completed the design and is awaiting approval of the final design by the test site, Roche Laboratories. The location of the solar system on the roof had to be changed to another area near an air handler which resulted in a revision to the earlier design.

![Image](image-url)

**IMAGE**

Roof Installation of Solar Thermal Evacuated Tubes.
### Project Name:

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan:  Project Term:
| Natural Gas Research | 6/30/2016 to 3/31/2020 |

### Research Area:
Energy Efficiency

### Issue:
The U.S. Department of Energy estimates that 20 to 50 percent of industrial energy use is lost as waste heat. Lower temperature waste heat, such as heat extracted from cooling water from machines or condensers, is much more challenging to recapture cost-effectively within industrial applications therefore far fewer market participants have focused in this area. A low-cost, low-temperature waste heat recovery (WHR) system that is applicable to the industrial sector and does not require changes to ancillary equipment or void existing warranties could open up a new avenue for natural gas savings in California.

### Project Description:
This project hoped to replace an existing rooftop HVAC unit at a chemical industrial facility with a Waste Heat Recovery (WHR) roof top unit, along with a water storage tank and piping. The WHR unit was to remove heat from the occupied space and uses it to pre-heat process hot water.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project hoped to demonstrate a low-cost, low-temperature WHR system for use by the industrial sector.

### Applicable Metrics:
- **Lower Costs:**
  - This technology hoped to lower process hot water natural gas use by 25 percent.

### Natural Gas Funds Encumbered:
$500,000

### Update:
A Stop Work Order was issued on June 5, 2018 as a result of a Critical Project Review meeting on May 8, 2018. The Stop Work Order was issued because of several technology challenges faced by this project including: a) commercially available unit is not Title 24-2013 compliant; b) future uncertainty on the availability of the heat recovery unit; c) the technology is not a good fit for industrial facilities for several reasons, (such as, non-ideal location of rooftop units and water heating equipment; intermittent water use, lack of tank/tankless water heaters for process operations); and d) challenges integrating with existing heat recovery systems. As this technology cannot be used by the industrial sector, the agreement may be mutually terminated.
<table>
<thead>
<tr>
<th><strong>Project Name:</strong></th>
<th>Pipeline Safety and Integrity Monitoring Technologies Assessment - [PIR-15-012]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recipient/Contractor:</strong></td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
</tr>
<tr>
<td><strong>Natural Gas Funding Plan:</strong></td>
<td>Natural Gas Research</td>
</tr>
<tr>
<td><strong>Project Term:</strong></td>
<td>6/15/2016 to 1/11/2019</td>
</tr>
<tr>
<td><strong>Research Area:</strong></td>
<td>Natural Gas Infrastructure Safety and Integrity</td>
</tr>
<tr>
<td><strong>Issue:</strong></td>
<td>Inspection and monitoring of the natural gas pipeline system require advanced external and in-line inspection technologies to identify certain types of damage, such as cracks and weld damage. However, many of these technologies are limited to providing indications of damage without a comprehensive evaluation of combined pipe threats and risk assessment. Internal inspection technologies are currently limited in identifying cracks and weld damages in certain wall thicknesses and pipe sizes. Research is needed to explore and investigate new pipeline technologies to prevent incidents and provide early indications of damage and reduced operation costs.</td>
</tr>
<tr>
<td><strong>Project Description:</strong></td>
<td>This project involves an assessment of technologies for improving pipeline performance, predicting and monitoring threats, and reducing risks in the natural gas transmission and distribution pipeline systems. The assessment of these technologies is based on quantifiable scales consisting of evaluating their probabilities of leak detection, technology readiness level, and cost-to-market value. The research aims to identify various emerging pipeline safety and integrity management technologies, specify commercial and close-to-market equipment, sensors, systems and processes, and catalog the status and applicability of the available technologies in a web-based program and database for regulators and operators. This project is testing the selected technologies in pipeline and utility practices in real field applications and comparing the implementation and commercialization costs of the technologies with the anticipated benefits in a quantifiable scale.</td>
</tr>
<tr>
<td><strong>How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:</strong></td>
<td>The web-based database will benefit regulators and natural gas systems operators by providing the status and applicability of each technology, its operating parameters and scope, implementation gaps, and further development needs. A plan will be developed to implement these technologies in California's natural gas pipeline infrastructure.</td>
</tr>
<tr>
<td><strong>Applicable Metrics:</strong></td>
<td>Lower Costs: The project prioritizes the technical applicability of the identified technologies and their cost effectiveness based on a risk-to-value assessment and enables regulators and utilities to more readily identify new technologies. Increase Safety: The assessment will focus on performance-based technologies that reduce the risk of Right-of-Way (ROW) encroachments, pipe damages, natural forces, and other gas pipeline threats.</td>
</tr>
</tbody>
</table>
Public Health:
Public health and safety are addressed by supporting the implementation of technologies that minimize catastrophic failures, detect leaks, and reduce gas emissions to the environment.

**Natural Gas Funds Encumbered:**
$1,006,812

**Update:**
The Recipient completed the evaluation of research efforts on pipeline integrity and risk management technologies. A web-based program was developed to provide California natural gas operators with access to various commercial and close-to-market technologies. A technology workshop was performed with the Energy Commission, California natural gas utilities, and project stakeholders on July 7, 2017 and it further identified development needs and implementation gaps. Three technology areas of highest interest were identified at the workshop: (1) pipeline damage prevention, (2) damage mitigation and integrity management, and (3) pipeline risk and information systems. Four demonstrations of selected technologies in these areas were performed at PG&E and SoCal Gas, which are described in a draft final report submitted in August 2018.

Website screenshot for various commercial and close-to-market technologies at [http://gasapps.gastechnology.org/webroot/app/techindex/](http://gasapps.gastechnology.org/webroot/app/techindex/)
### Project Name:
Demonstration of Water Recovery from Hot, Humid Industrial Exhaust Gases - [PIR-15-013]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
6/30/2016 to 3/31/2020

### Research Area:
Energy Efficiency

### Issue:
Industrial and agricultural dryers, commercial cooking plants, and some chemical processes consume natural gas and approximately 5 billion gallons of water per year in California. Recovery and reuse of much of this water would help the State meet needed reductions in water demand while also reducing natural gas use. The barriers to recovering water have traditionally been the low cost of water and the high equipment and energy cost of water recovery. The need for energy efficient water recovery is becoming more acute as drought conditions persist.

### Project Description:
This project demonstrates an energy efficient method for water recovery from hot, humid exhaust gas at the United States Gypsum (USG) plant in Plaster City, CA. A demonstration scale Clean Liquid Water by Ejector-Assisted Recovery (CLEAR) unit will be attached to the humid exhaust gas and recover hot water from a portion of that exhaust gas, the recovered hot water will be reused on-site to reduce natural gas use.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
This project will validate the performance and cost benefits of the novel CLEAR water recovery and energy saving technology. The demonstration hopes to achieve high-performance while keeping costs low by employing a mass-customization design approach using predesigned modular CLEAR water recovery units. If successful, this technology can be used in other industrial and agricultural dryers, commercial cooking plants, and some chemical processes.

### Applicable Metrics:
**Lower Costs:**
Increase the efficiency of natural gas fired industrial dryers while also recovering water (25% of water in the exhaust gas) that could be used for on-site reuse and reducing energy costs from hot water recovery.

**Natural Gas Funds Encumbered:**
$1,294,032

### Update:
June 2018 - After a design review and comments period (April - May 2018) with the engineers from the demonstration host site - the project team has redesigned the system to minimize the needed ambient air flow rate and to reduce the size and power demands of the blowers. The project team is now engaged in beginning the detailed system design and putting together the equipment and materials list.
Proposed recovery system layout.
<table>
<thead>
<tr>
<th><strong>Project Name:</strong></th>
<th>High Accuracy Mapping for Excavation Damage Prevention and Emergency Response – [PIR-15-014]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recipient/Contractor:</strong></td>
<td>Institute of Gas Technology dba Gas Technology Institute</td>
</tr>
<tr>
<td><strong>Natural Gas Funding Plan:</strong></td>
<td>Natural Gas Research</td>
</tr>
<tr>
<td><strong>Project Term:</strong></td>
<td>6/15/2016 to 10/1/2018</td>
</tr>
<tr>
<td><strong>Research Area:</strong></td>
<td>Natural Gas Infrastructure Safety and Integrity</td>
</tr>
<tr>
<td><strong>Issue:</strong></td>
<td>Natural gas operators primarily use manual, paper-based methods to create asset maps and document asset properties and environmental conditions. These manual methods are time consuming, can lead to human data entry errors, and create delays in making asset and engineering information available to stakeholders. A more automated, mobile technology is needed to simplify the creation of asset maps and make data more readily available for sharing.</td>
</tr>
<tr>
<td><strong>Project Description:</strong></td>
<td>This project, which is complete, developed and demonstrated a prototype system to create and display high accuracy maps using recent advances in mobile, geographic information system (GIS), and global positioning system (GPS) technologies. The high accuracy mapping (HAM) technology offers a viable option to gas utilities to more accurately map their underground assets by deploying commercially available equipment together with advanced software, mobile tool configuration and measurement techniques. The HAM technology developed and deployed in this project has the potential to map over 90% of the underground assets with an accuracy within 6 inches. A web-based tool was developed in this project to provide real time information on underground distribution assets and excavation activity. It offers the utility a common operating picture at any point for more functional communications, planning and ultimately a more efficient and safe operation.</td>
</tr>
<tr>
<td><strong>How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:</strong></td>
<td>While there are traditional solutions to capture asset location information digitally (such as traditional GPS technology), there were no systems that truly automate data capture to create high accuracy maps with traceability data and allow the data to be accessed in near real-time. The high accuracy mapping tool developed by this project overcame the technological barriers and achieved these functionalities.</td>
</tr>
<tr>
<td><strong>Applicable Metrics:</strong></td>
<td><strong>Lower Costs:</strong> There are about 600 excavation damage events related to natural gas pipelines in California annually, with an average damage cost of $5000 per event. If fully deployed throughout California, this technology is estimated to reduce excavation damage by 50% annually, resulting in cost savings of $1.5 million.</td>
</tr>
<tr>
<td></td>
<td><strong>Greater Reliability:</strong> PG&amp;E estimated that the technology can reduce excavation damage events by 50%, or 300 annually throughout California, leading to increased reliability and security of natural gas infrastructure and supply.</td>
</tr>
</tbody>
</table>
Increase Safety:
Improves system integrity by reducing excavation damage and improves public safety by promoting situational awareness through the visualization of high accuracy maps and related information during emergencies.

Environmental Benefits:
With average gas release of around 40,000 standard cubic feet per excavation damage event, this technology is estimated to reduce natural gas emissions by 11,700 Mscf annually in California.

Natural Gas Funds Encumbered:
$1,481,426

Update:
The research team configured and deployed a total of 22 HAM units to 10 service locations throughout the PG&E service territory. PG&E service crews mapped a total of 37,951 feet of pipe and 3,475 point features (valves, fittings, etc.) with an average accuracy within 6 inches for 91.46% of collected assets. A survey of 16 gas utility companies demonstrated a 75% interest rate in applying the technology. GTI is working with a subcontractor on a commercialization strategy for the technology.

Mapping software being used in field.
### Project Name:
GPS Excavation Encroachment Notification System Implementation - [PIR-15-015]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/15/2016 to 3/30/2018</td>
</tr>
</tbody>
</table>

### Research Area:
Natural Gas Infrastructure Safety and Integrity

### Issue:
Accidental damage to pipelines by excavations such as digging, grading, trenching, and boring is a primary challenge to safe pipeline operations. The Pipeline and Hazardous Material Safety Administration reported that excavation damage is the root cause of about 26% of gas transmission pipeline incidents and 35% of serious gas distribution pipeline incidents in the last 10 years. Between 2015 and 2016, third-party excavation damages in California accounted for roughly 50% of their reported gas incidents, which often resulted from failure to follow one-call notification before digging, lack of accurate markings, or failure to follow standard excavation procedures around utility lines.

### Project Description:
This project, which was completed this year, developed and demonstrated an advanced location awareness tool called the Global Positioning System Excavation Encroachment Notification System (GPS EENS). The system increases situational awareness of operating excavators and reduces the risk of third party damage on the utility natural gas pipeline infrastructure. Utilizing geographical information systems, the tool monitors excavator behavior during operations such as digging, idling, or moving across locations. Mobile deployment of the technology, integrated with existing utility first-response solutions, provides emergency responders with near real-time asset maps and communications necessary to take preventative measures. The increased situational awareness capabilities include accurate damage location, asset maps, and enhanced alerting and targeted informational communications to first responders, law enforcement, and other related responders.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The GPS EEN system utilizes a GPS technology along with a sensor array that includes accelerometers, gyroscopes, and other sensors to provide specific information about the behavior of the excavator. This project advances the technology used to determine the state of the excavator, such as idling, digging, backfilling, and traveling between project sites. The project provides enhanced situational awareness of excavators operating near or on utility infrastructure and significantly reduces the risk of pipeline excavation damage.

### Applicable Metrics:
**Lower Costs:**
The benefit of using the technology has already been initiated by installing about 150 units in the utility's own equipment, as well as in participating contractors’ excavators. Such deployment targeted 12% of the non-significant incidents in California which are caused by first- and second-party excavators and cost about $1,564,500 annually.
Increase Safety:
The implementation of the technology results in the ratepayer benefit of improved public safety and operational efficiency. The project provides enhanced situational awareness of excavators operating near or on utility infrastructure and significantly reduces the risk of pipeline excavation damage. The integrated system provides situational awareness of the excavator location, operating status, asset maps, and related right-of-way boundaries in real-time to operating utilities for effective monitoring and decision making.

Natural Gas Funds Encumbered:
$1,301,288

Update:
A total of 150 GPS ENNS devices were built and installed on excavators and backhoes operating in the Pacific Gas and Electric Company and Southern California Gas company service areas. GTI also configured and deployed operations dashboards and utilized the system architecture to enhance emergency response situational awareness. The development work and field demonstration of the system were complete in November 2017. This project was successfully completed in March 2018 and the final report was published in June 2018 and can be accessed here: http://www.energy.ca.gov/2018publications/CEC-500-2018-014/CEC-500-2018-014.pdf.

Field test installation of the Excavation Encroachment Notification (EEN) device.
### Project Name:
Demonstration of a Multi-Analytic Risk Visualization Tool for the California Pipeline Industry - [PIR-15-016]

### Recipient/Contractor:
DNV GL USA, Inc.

### Natural Gas Funding Plan: Project Term:
Natural Gas Research | 6/24/2016 to 3/30/2018

### Research Area:
Natural Gas Infrastructure Safety and Integrity

### Issue:
Pipelines are critical to delivering the fuels needed by consumers and industry in California. However, the pipeline network is extensive and operates in a diverse environment with both natural and man-made threats. Unanticipated failures continue to occur that threaten life, the environment, and the economy. Predicting and prioritizing the threats before they become factors is challenging. As a result, there was a need for a comprehensive risk management modeling tool to address the complex, interactive threats and help operators proactively manage the pipelines.

### Project Description:
This project, which was completed in March of 2018, developed and demonstrated a new risk assessment and management methodology for pipelines. This risk management methodology uses a Bayesian network (statistical probability) to enable more effective, systematic, and verifiable decision-making, utilizing all the knowledge and data available to the pipeline company and helping them make decisions when information is limited. This effort tailored the Recipient's Bayesian network threat modeling tool to fit California pipeline operators' requirements, successfully demonstrated the methodology on various pipelines, and transferred the knowledge gained to the pipeline companies.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
A smarter risk assessment model was created by the Recipient's use of Bayesian network methodology. DNV GL developed a network threat model for pipelines. The model integrates physics-based models and expert knowledge using cause-result relationships, including multiple interacting threat mechanisms to provide high probability threat assessments. These are then used by personnel in the field to limit possible hazards and perform any preventative maintenance actions identified.

### Applicable Metrics:
**Lower Costs:**
Using the model will reduce failures from third party damage and external corrosion of pipelines to decrease down time and associated costs. It will also help pipeline operators identify and prioritize risks to make mitigation actions more efficient and less costly.

**Greater Reliability:**
The model provides timely condition-based maintenance actions to increase the reliability of pipelines.

**Environmental Benefits:**
The model informs where conditioned based maintenance actions should be implemented that will lessen greenhouse gas emissions by reducing methane leaks.
Natural Gas Funds Encumbered:
$1,309,305

Update:
The project successfully ended on March 30th, 2018, and the final report was published on September 4th, 2018 at http://www.energy.ca.gov/2018publications/CEC-500-2018-023/CEC-500-2018-023.pdf. The model was successfully tested with pipeline operators who identified that the model helped them determine what data is most useful and answer questions such as "What data would reduce uncertainty of threats the most?", "What data should we gather first?" and "When do we have enough data?". SoCalGas, has had a number of discussions about obtaining the tool and using the model for other pipelines. The model is provided as a service, it is not sold as a commercial standalone software model.

Model output showing an identified incursion area.
### Project Name:
Characterization of Fugitive Methane Emissions from Commercial Buildings in California - [PIR-15-017]

### Recipient/Contractor:
ICF Incorporated, L.L.C.

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
7/18/2016 to 3/29/2019

### Research Area:
Energy-Related Environmental Research

### Issue:
Methane is a short lived climate pollutant. Previous research results suggest some fugitive methane emissions in the natural gas system take place once the gas enters buildings, after being metered. The current status of understanding fugitive natural gas emissions in commercial buildings is very limited. This agreement's goal is to better characterize fugitive methane emissions from specific appliances and system components downstream from the customer meter in commercial buildings in California, informing energy sector policy and planning, particularly related to natural gas systems.

### Project Description:
The research focuses on fugitive emissions in commercial buildings across northern and southern California. The researchers use a leak detection method developed by another Energy Commission funded project to determine where methane leaks are present and to what magnitude. The project is sampling about 75 commercial buildings, including hotels, offices, and department stores. A building characteristic survey will also be administered to collect building information. The project is driven by a detailed and robust statistical survey and analysis methodology. The end result from this project will be an estimate of fugitive methane emissions from appliances and system components, by commercial building type, for all commercial buildings in California.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Buildings are a potential source of methane emissions that have not been adequately characterized. Without at least an order of magnitude estimation of actual emissions via measurements, efforts to reduce greenhouse gas emissions will be ill informed. This project is designed to provide the California Air Resources Board with basic information about the order of magnitude emissions from buildings and their sources (e.g., meters, appliances) to allow the development of corrective measures, if necessary.

### Applicable Metrics:

#### Environmental Benefits:
This research will allow the State to identify potential mitigation plans to reduce methane emissions from commercial buildings. The California Air Resource Board will use this information to improve the greenhouse gas inventory.

#### Natural Gas Funds Encumbered:
$599,683
**Update:**

The project team is coordinating with Gas Technology Institute on a complementary study under a separate Energy Commission grant (PIR-15-003) to characterize methane emissions from a subset of commercial buildings (food service and healthcare) in California. The research team has finalized its subcontract with GTI to conduct the field work. The first two sites were sampled in early July 2018, and the field work is expected to be completed in fall 2018. The focus of the field work will be other building types beyond food service and healthcare, though some overlaps with PIR-15-003 are planned to get time-varying results. The research team will also send out the second round of building surveys to get more information on building characteristics.

**IMAGE**

Field measurement of Methane Leaks.
### Project Name:

Demonstrating Natural Gas Heat Pumps for Integrated Hot Water and Air-Conditioning in Restaurants - [PIR-16-001]

### Recipient/Contractor:

Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan:

Natural Gas Research

### Project Term:

2/16/2017 to 1/30/2020

### Research Area:

Energy Efficiency

### Issue:

Restaurants consume more natural gas than any other commercial building, with much of the onsite energy used to heat water. Most restaurants use gas water heaters. Common high efficiency gas water heaters use condensing combustion but these systems are more expensive and the cost savings are small due to the low cost of natural gas and the small efficiency gain (approximately 10 to 15%). A potential alternative is a gas-fired heat pump with operating COPs of 1.5 or greater and natural gas savings of 40% or more. However, gas-fired heat pumps are an emerging, innovative technology that needs to be tested in real world operating conditions to verify performance and savings.

### Project Description:

The project seeks to reduce natural gas consumption within the area affected by the Aliso Canyon natural gas leak in Southern California. This project demonstrates an innovative, low-cost gas-fired heat pump system. It will be installed at two full-service restaurants in Southern California, to reduce energy used for commercial hot water (CHW) and air conditioning. The commercial restaurant industry typically has large hot water loads, and greater internal heat gain from occupancy and kitchen equipment. The project seeks to demonstrate a 40% reduction in natural gas and offset 20% or more of the annual air conditioning cost.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:

This project demonstrates a low-cost integrated heating and cooling, gas fired heat pump system at two restaurants. The system is unique in its efficiency and low-cost. It provides hot water and A/C simultaneously for commercial kitchens with two different types of load. This demonstration provides understanding of the real-world operational characteristics critical to successful commercialization. For restaurants and other commercial applications, this type of system can replace both conventional gas fired water heating and reduce electric cooling load, resulting in reductions in greenhouse gas emissions and natural gas use.

### Applicable Metrics:

**Lower Costs:**

Natural gas heat pump water heaters integrated with air conditioning is expected to reduce natural gas use by 40% and electricity use by 20% in restaurant applications. To offset the energy cost expense of A/C, this technology will be deployed as an integrated system for hot water and supplemental A/C.

**Environmental Benefits:**

This gas heat pump emits less greenhouse gas (GHG) emissions compared to gas storage water heaters and free air conditioning is provided. It also uses a natural refrigerant/absorbent, ammonia-water, which has zero ozone depletion potential and zero global warming potential.
**Natural Gas Funds Encumbered:**

$864,294

**Update:**

New restaurant demonstration sites were approved in first quarter of 2018. Baseline monitoring will be performed over a 2- to 3-month period. This is followed by installation and commissioning of the GHP system for a 12-month monitoring period. The field prototypes of the heat pump systems are being custom built. One of the units is complete and has been tested, and packaged for shipment. The second unit has been assembled and is undergoing testing. (updated Aug 31, 2018).

**IMAGE**

Preliminary Rendering of GHP System Outdoor Skid.
### Project Name:
Demonstration of Advanced High-Efficiency, Low Capacity HVAC Systems - [PIR-16-002]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>3/1/2017 to 1/29/2021</td>
</tr>
</tbody>
</table>

### Research Area:
Energy Efficiency

### Issue:
Several factors have led to the improved energy performance of existing homes. These include the growth of the home performance community, and programmatic efforts of Energy Upgrade California, Regional Energy Networks, and utility rebates. To achieve a 20 percent reduction in statewide building energy use in 2030 compared to projected levels of usage, significant leaps forward in home energy efficiency will be needed. Thermal performance will be an important factor in creating zero-net energy homes.

### Project Description:
This project couples home performance improvements, such as air sealing and upgrading insulation, with advanced low-capacity heating, ventilation and air conditioning systems (HVAC) to capture energy saving at the system level. HVAC systems will be installed and tested in five high houses with two years of data collection of system performance. The technology tested will reduce natural gas use at the homes, resulting in less gas consumption in the area affected the Aliso Canyon gas leak. The data will be analyzed by comparing baseline home energy use to the performance of the installed HVAC configuration. The goal is to achieve energy savings 30 percent greater than that of a Title 24-compliant new home, or existing average home in the Los Angeles Basin with standard equipment.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project evaluates low capacity HVAC systems in existing residential buildings and in warm, Southern California climates characterized by low heating loads and moderate cooling loads. This project couples low capacity HVAC systems with selected home performance measures, and compares energy performance and comfort over an extended period of time. Natural gas reduction for heating is expected to be approximately 30 percent. Electricity benefits also result from lower cooling loads due to the selected home performance improvements.

### Applicable Metrics:

**Lower Costs:**
Natural gas reduction for space heating is estimated to be 30 percent per home, yielding utility bill savings.

**Environmental Benefits:**
Assuming an initial market penetration in 2020 of 2 percent and rising to 10 percent by 2025, this technology could reduce greenhouse gas emissions by 2.5 million metric tons from 2020 to 2030. Additionally this project estimates that NOx emissions will be reduced by approximately 48 percent based on a cumulative total of nearly 300,000 installations statewide by 2030 and assuming a new construction growth rate of 10 percent per year.
### Natural Gas Funds Encumbered:

$750,000

### Update:

Modeling and benchmarking of the demonstration homes began in Q3 2017, and was completed in spring 2018. The equipment manufacturer who was to provide the ultra-low NOx, energy efficient, low capacity HVAC units has chosen not to develop such a unit at this time. The recipient proposed an alternative low capacity HVAC unit. A stop work order was issued on July 31, 2018 while Energy Commission staff evaluates the options and whether the new alternative meets the statement of work and solicitation goals.

![Image of district-scale solar project incorporating solar-thermal and photovoltaic technologies](image_url)

Example of a district-scale solar project that incorporates solar-thermal as well as photovoltaic technologies (Drake Landing, AB, Canada). There is currently little understanding of how to deploy projects at community scales that cover the range between a single household and a full district.
**Project Name:**
Demonstration and Assessment of Residential Gas Heat Pump Water Heaters in the Los Angeles Basin - [PIR-16-003]

**Recipient/Contractor:**
Institute of Gas Technology dba Gas Technology Institute

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>2/27/2017 to 4/15/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Over 1.7 billion therms of natural gas are consumed each year for residential water heating in California investor-owned utility (IOU) territories. The majority of this consumption occurs in the 95% of homes with minimum efficiency storage water heaters. Yet the advancement of high efficiency water heating technology into the market has stalled. Faced with high first costs for advanced efficiency options, many consumers continue to select base efficiency models. At the same time, challenging total resource cost tests have led utilities to reduced incentive offerings for high efficiency gas water heaters.

**Project Description:**
This project aims to advance the commercialization of a residential gas-fired heat pump water heater (GHPWH) through field demonstration, extended-life laboratory testing, development of modeling tools, and stakeholder outreach events. The GHPWH integrates a small, gas-fired, single-effect, absorption heat pump with a hot water storage tank. Technology is being tested at homes in the Los Angeles Basin.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project supports the commercialization of residential gas fired heat pumps at a critical juncture in its development, with a focus on GHG emission reductions in the Los Angeles Basin. Previous generations of this pre-commercial technology have shown natural gas savings of 50%, and a 35-50% lower retrofit cost compared to other efficient gas water heaters. By installing natural gas heat pumps in residential homes using existing water heater gas piping and venting, the project has lower first costs and lower operating costs than other heat pump systems. Installation of the gas heat pump water heater systems supports the goals of AB 32, reducing GHG emissions by 50% annually when compared to baseline gas storage water heaters. Unlike other commercially available systems, the refrigerant and absorbent used by the gas-fired heat pumps has a global warming potential of zero.

**Applicable Metrics:**
Lower Costs:
With an equipment cost comparable to condensing storage water heaters, but with 50% energy savings, or greater, and a lower installation cost with reusing gas piping and with low-profile venting, the GHPWH has the lowest operating cost of all natural gas technology options and the lowest cost of ownership.

Environmental Benefits:
Considering the 1.7 billion therms consumed by residential water heating in 2015 in California, IOU territories, emitting 9.26 MMTCO2e per year through the combustion of natural gas, 100% deployment of GHPWH technology in California could yield GHG...
emission savings over 6 months of operation of 2.4 MMTCO2e, equal to the Air Resources Board’s estimated impact of the Aliso Canyon natural gas leak, resulting in substantial benefits to the Los Angeles Basin.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,084,230</td>
</tr>
</tbody>
</table>

**Update:**

Gas heat pump water heaters have been installed at 5 residential sites in the Los Angeles area. Approximately 6 to 8 weeks of data collection has occurred. A certification test report for the water heaters has been completed and submitted to the South Coast Air Quality Management District (SCAQMD). The test report shows positive early results. Once the SCAQMD review is complete, the equipment will be certified for operation in the homes.
**Project Name:**
Advanced HVAC Technology Demonstration Project to Reduce Natural Gas Use in Hospitals - [PIR-16-004]

**Recipient/Contractor:**
Advanced Microgrid Solutions, Inc.

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>3/1/2017 to 12/31/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Hospitals are among the most energy-intensive facilities in the U.S. and one of the highest end-users of natural gas in buildings in California. Hospitals rely on legacy ventilation protocols requiring a fixed number of air changes per hour, regardless of room use and occupancy. This results in over-ventilation of some rooms and under-ventilation of others. Natural gas is used to heat the air in the ventilation system, leading to wasted energy when the air is exchanged unnecessarily. Forty percent more natural gas is being used than is necessary to meet ventilation needs and indoor air quality standards for safety and occupant comfort.

**Project Description:**
This project demonstrates an efficient, advanced air-distribution approach to reduce energy waste in hospitals by using real-time indoor air quality sensors, advanced fault detection and diagnostic software, and monitoring-based commissioning. The project integrates a suite of advanced sensor technologies and diagnostic software in a pre-commercial energy management platform to improve operational efficiency of HVAC systems while significantly reducing natural gas use. ASHRAE Standard 62.1 applies to all commercial buildings in California except for hospitals. Standard 62.1 contains metrics for measuring environmental contaminants and ventilation rates based on occupancy and space contamination and provides three approaches to meet the standard: 1) ventilation rates; 2) natural ventilation; and 3) Indoor Air Quality Procedure (IAQP). This project focuses on using advanced sensors and software to validate and demonstrate that using IAQP can meet indoor air quality standards and result in a 30-50% reduction in on-site natural gas consumption. The IAQP method is currently not used by hospitals because of the complexities associated with the regulatory approval process.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project uses sensors and energy management equipment to conduct real-time monitoring of hospital HVAC systems, indoor air quality, and energy usage while measuring environmental contaminants and ventilation rates. The aim is to demonstrate that air exchanges in a hospital can be performed according to indoor air quality needs such as air contaminants and occupancy – rather than a fixed number of exchanges per hour depending on room type. The benefits of this approach are increased health and safety for patients, reduced energy use, longer HVAC equipment life, bill savings, and reduced GHG emissions. The Office of Statewide Health Planning and Development will consider code changes for California hospitals based on this research.
**Applicable Metrics:**

Lower Costs:
Hospitals are among the highest energy users, consuming more energy per square foot than many other buildings in other industrial and commercial sectors. Natural gas is the most used fuel in most large hospitals, primarily for space and water heating. This project has the potential to reduce natural gas use by 40 percent, with concurrent electricity savings of approximately 30 percent. Replicating this project throughout all 457 hospitals in California could save more than 127 million therms of natural gas annually. Assuming $1.00/therm equates to saving $127 million annually.

**Natural Gas Funds Encumbered:**
$1,216,707

**Update:**
On June 6, 2018, the Office of Statewide Health Planning and Development issued a building permit approving the installation of the indoor air quality (IAQ) sensors. As of July 12, 2018, the sensors have been installed. To implement the IAQ based ventilation, the integration of two data platforms is required. This integration was completed in July 2018.

**Demonstration Site--Kaiser Permanente South Bay Medical Center.**
### Project Name:
A Comprehensive, High Efficiency Solution for Water Heating in Multi-Family Buildings – [PIR-16-005]

### Recipient/Contractor:
Energx Controls, Inc.

### Natural Gas Funding Plan:  
Natural Gas Research

### Project Term:  
2/27/2017 to 12/31/2019

### Research Area:  
Energy Efficiency

### Issue:
There are over 10,000 apartment buildings in Los Angeles and Orange counties. The multifamily market has been slow in adopting emerging energy efficiency technologies due to lack of technologies in the marketplace and a lack of service providers. Common central water heating systems in multifamily apartments use approximately 200-250 therms/apartment/year, and most have never received energy efficiency retrofits.

### Project Description:
This project demonstrates an innovative high efficiency hot water design for a multifamily building, pairing a domestic hot water heat pump run on natural gas with a solar thermal evacuated tube collector and hot water controls. The configuration results in 75% reduction in hot water related energy use at an existing apartment building in Los Angeles County. By reducing building natural gas use and lowering emissions, the project demonstrates a mitigation approach to the Aliso Canyon gas leak. The research team is conducting a performance evaluation and cost analyses to assess energy savings and GHG reductions of the integrated system.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
This project addresses barriers to widespread adoption of gas engine heat pump and solar thermal evacuated tube collector technologies by demonstrating and validating energy savings, cost-effectiveness and performance indicators of these systems operating together and separately. Market barriers to be addressed include: lack of consumer and installer awareness/demand; lack of high-quality field performance data; small trained installer base; under-developed supply chain; challenges in optimizing the sizes for both technologies to maximize energy savings at the lowest cost, energy savings calculations, controls strategies, installation/commissioning; and uncertainties of system performance.

### Applicable Metrics:
- **Lower Costs:** Estimate reducing total natural gas used for water heating by more than 75% compared to conventional water heating.
- **Public Health:** Estimate significant reductions in greenhouse gas and NOx emissions due to deep natural gas energy savings.

### Natural Gas Funds Encumbered:
$753,605
Update:
The project is in the pre-install monitoring and verification phase. The team has completed final designs for pre-install monitoring and piping modifications necessary to install sensors, meters, and the monitoring platform. Monitoring of the existing site energy use began on May 23, 2018. The recipient has begun designing the system.

Integration of solar thermal evacuated tube collector and natural gas engine heat pump at Park West Apartments.
### Project Name:
A Novel Low-Cost, High-Efficiency Solar Powered Micro-CHP System for Electricity, Hot Water, and Space Heating - [PIR-16-007]

### Recipient/Contractor:
The Regents of the University of California on behalf of the Merced Campus

### Natural Gas Funding Plan:  Project Term:
Natural Gas Research  
4/4/2017 to 10/3/2019

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
Solar combined heat and power systems (CHP) offer the potential to reduce natural gas consumption by providing sufficient thermal energy to meet building hot water and space heating needs, while also providing distributed electricity generation. However, current commercially-available solar CHP systems combine traditional photovoltaic (PV) panel architectures with traditional thermal collector models, making them just as expensive per square meter as side-by-side installations of PV panels and thermal collectors.

### Project Description:
This project develops a novel, low-cost, high-efficiency solar combined heat and power (CHP) system capable of producing electricity for building loads and heat for hot water and space heating. The solar CHP system will utilize non-imaging optics for solar concentration, aluminum mini-channels for thermal collection, and commercially-available solar cells for electricity production and will be packaged in a glass tube.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The unique solar cell/mini-channel interface allows for the collection of thermal energy, while simultaneously cooling the solar cells and enhancing their efficiency. Additionally, the use of various types and efficiencies of solar cells enables the development of arrays that can be tuned for optimal performance in all of California’s 16 building climate zones.

### Applicable Metrics:
**Lower Costs:**
The solar CHP technology would generate the same amount of electricity (per unit area) as a standalone rooftop PV panel, and also generate a comparable amount of thermal energy as a standalone rooftop thermal panel, while being cost-competitive with either. This would require half the roof space to collect the same amount of energy, significantly reduce installation time and cost, and substantially increase system affordability. Each installed square meter of the novel solar CHP technology would reduce natural gas consumption by approximately 40 therms annually in a typical California building zone.

**Greater Reliability:**
Increased deployment of solar CHP systems would increase local generation and bolster local system reliability.

**Increase Safety:**
Increased deployment of solar CHP systems would improve safety by decreasing natural gas consumption, reducing the amount of natural gas transmitted and stored and the associated risks.
Environmental Benefits:
Each installed square meter of the novel solar CHP technology would offset 0.28 metric tons of carbon dioxide annually.

Natural Gas Funds Encumbered:
$816,659

Update:
The Recipient procured the needed components for assembling multiple prototypes for initial outdoor testing. Components include solar cells, mini-channels and mini-channel heat pipes. The first two complete prototype assembled tubes were tested. The novel manifold design for thermal performance was also tested. The next step is to complete the ongoing testing and begin fabrication of the initial five collector tubes. After a thorough evaluation, the Recipient managed to procure some vital components at a much lower cost than projected, and also managed to complete necessary design work without involving outside consultants. The work completed using in-house experts and resources eliminated two outside subcontracts and enabled significant reduction in a third one, with a total cost reduction of $125,722, which can be reallocated.

Diagram of the channel system that will collect thermal energy from the sun.
APPENDIX D: FY 2017-18 NATURAL GAS ACTIVE AND COMPLETED PROJECT WRITE-UPS

<table>
<thead>
<tr>
<th>Project Name:</th>
<th>A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California - [PIR-16-008]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipient/Contractor:</td>
<td>ICF Incorporated, L.L.C.</td>
</tr>
<tr>
<td>Natural Gas Funding Plan:</td>
<td>Natural Gas Research</td>
</tr>
<tr>
<td>Project Term:</td>
<td>3/1/2017 to 6/29/2018</td>
</tr>
<tr>
<td>Research Area:</td>
<td>Renewable Energy and Advanced Generation</td>
</tr>
</tbody>
</table>

**Issue:**
The majority of combined heat and power (CHP) systems in California are installed at commercial and industrial sites with relatively large on-site electric and thermal demands, due to favorable economics and mature product availability. However, smaller capacity CHP technologies have been commercialized and new products are emerging which could significantly impact the California market. There is a need to develop a better understanding of small and micro-scale CHP products and to examine their potential to penetrate the California market.

**Project Description:**
The purpose of this project was to perform a comprehensive assessment of small and micro-scale CHP technical and market potential in California. The assessment focuses on residential, commercial, and light industrial markets which have a peak electrical demand less than 5 megawatts. The project also identified barriers to the increased adoption of small and micro-scale CHP systems and discuss potential solutions to these barriers.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
CHP studies conducted over the years usually focus on multi-megawatt systems at large industrial or commercial facilities. This assessment builds on past CHP studies and expands the scope to include very small CHP systems down to 1 kilowatt scale. This assessment considers important recent technology and policy developments – such as advancements in distributed energy resources (i.e. solar PV, energy storage, microgrid configurations, etc.) and zero net energy building goals – and how they affect the role of small CHP systems in a modern California grid. Through its assessment of available technologies and applications, this study identified technology research gaps that need to be addressed in order for small CHP systems to take advantage of the highest potential applications.

**Applicable Metrics:**
Lower Costs:
The assessment serves as an information resource, providing estimates of CHP potential by size and sector. Facility owners may use this resource as a preliminary feasibility assessment when determining whether or not to install a CHP system, potentially offsetting consulting fees.

Economic Development:
The assessment highlighted the highest potential growth areas for small CHP systems, including applications where CHP is not typically adopted such as commercial office buildings and multifamily residential buildings. These results may help both small CHP manufacturers to find target markets and potential buyers to adopt a CHP system.
Natural Gas Funds Encumbered:
$200,000

Update:
The project performed an assessment of commercially available small CHP technologies, including technical and economic characteristics. Assessments of technical and market potential were also performed which estimated that California has 11.6 GW of technical potential and 1.9 GW of expected market adoption. The project also performed an analysis of barriers preventing additional market adoption and provided recommendations for how to address these barriers. Finally, the project conducted two stakeholder workshops during the project (August 2018 and March 2018) in order to vet the project results. Interested stakeholders can use these results for policy planning, insights on market opportunities, and recommendations to advance the state of technology. The final report can be found at the following link:

### Project Name:
Small-CCHP Packaged System with Innovative Quick-Response, Compact, and High-Temperature Thermal Energy Storage - [PIR-16-009]

### Recipient/Contractor:
Element 16 Technologies, Inc.

### Natural Gas Funding Plan: Project Term:
Natural Gas Research 4/3/2017 to 4/3/2020

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
In California, approximately 30% of natural gas is used for residential and commercial applications and is a significant source of greenhouse gas emissions; meanwhile at least 30% of summer peak electricity load in California is due to residential and commercial air conditioning. High peak electrical use for building cooling systems is costly to ratepayers, but often unavoidable due to the high summer temperatures in California.

### Project Description:
The purpose of this project is to develop and demonstrate a low-cost, quick response, small footprint, and highly flexible sulfur-based thermal energy storage (SuTES) technology for integration with traditional combined cooling, heating, and power (CCHP). This project will benefit California natural gas independently owned utility ratepayers by demonstrating that thermal energy storage retrofits to existing buildings can be economical, reduce peak demand, and improve integrated system efficiency. This project aims to expand applications for CCHP systems at many more residential and commercial buildings and improve project economics at smaller scales.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project will benefit California natural gas IOU ratepayers by demonstrating that thermal energy storage retrofits to existing buildings can be economical, reduce peak demand, and improve integrated system efficiency.

### Applicable Metrics:

**Lower Costs:**
The SuTES system utilizes low-cost storage media (sulfur) and containment materials to store and deliver CCHP system waste heat at a dramatically reduced cost compared to standalone electric or natural gas-fueled heaters. Initial estimates of savings compared to conventional power and HVAC systems are at least 10 percent per year.

**Greater Reliability:**
If successful, the SuTES system will enable increased deployment of small CCHP systems, reducing local system loads and increasing local generation capacity which will lead to greater reliability.

**Environmental Benefits:**
Due to more efficient natural gas usage, small CCHP systems have the potential to significantly reduce GHG emissions compared to standalone power and heating systems.
### Natural Gas Funds Encumbered:

$1,500,000

### Update:

The project has completed initial assessments of the technical and market potential for the SuTES technology in Southern California and has identified commercial buildings, healthcare facilities, colleges, and universities as potential early markets for the technology. The team is currently preparing for the on-site technology demonstration which will utilize a 540 kW-hr SuTES thermal battery, an absorption chiller, and a generator to create an integrated CCHP system. The key component, the SuTES thermal battery, has been designed, fabricated, and is undergoing testing in preparation for the demonstration which will take place in early 2019.

---

**IMAGE**

Schematic of system components and how the SuTES system will be charged and discharged.
### Project Name:
Development and Demonstration of an Innovative Micro-scale Biomass Gasifier Combined Cooling, Heating, and Power System - [PIR-16-010]

### Recipient/Contractor:
All Power Labs, Inc.

### Natural Gas Funding Plan: Project Term:
Natural Gas Research 4/3/2017 to 7/31/2019

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
Markets that have considerable potential for CCHP utilization are underserved due to technological and economic barriers to adoption associated with existing natural gas (NG) infrastructure and distribution systems. Many residential, commercial, and industrial buildings have easy access to a NG supply and use heating and cooling technologies that are designed for NG. An economical and bankable biomass CCHP can integrate its electrical, heating, and cooling outputs in industrial and commercial building applications thereby avoiding a substantial amount of NG and electricity usage, especially in markets that often shut down during peak electricity hours to remain economically viable.

### Project Description:
This project develops a cost-effective micro-scale (<50 kW) combined cooling, heating, and power (CCHP) system integrated with and powered by a biomass gasification waste-to-energy system known as the Power Pallet. This innovative Power Pallet CCHP system integrates its electrical, heating, and cooling outputs with light industrial and commercial building applications, avoiding a substantial amount of natural gas and electricity usage. The goals of the project are to reduce natural gas consumption, mitigate greenhouse gas emissions, and provide tangible benefits to disadvantaged communities.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project develops a cost-effective, bankable, 20kWe packaged CCHP system with absorption cooling, powered by a biomass gasification waste-to-energy platform. The technology produces renewable energy, undertakes innovation over current CHP technology with a system efficiency greater than 80 percent and a power-to-heat ratio greater than 0.4:1, reduce the amount of waste going into landfills, and it has the potential to create clean energy jobs.

### Applicable Metrics:
**Lower Costs:**
This biomass-fueled CCHP system will reduce natural gas consumption both through the use of its CHP output and through the use of waste biomass as alternative energy source. The cost of the alternative fuel is $6.3/MMBTU lower than the cost of natural gas fuel. This competitive technology has a benefit-cost ratio of 1.3 which implies potential economic benefits for the distributed energy sector. The reduction in natural gas demand also puts less of a strain on the capacity of the natural gas transportation, storage, and retail delivery infrastructure, with positive impacts on reliability and safety.
### Environmental Benefits:

This innovative CCHP system seeks to meet or exceed current emissions standards for stationary generators, targeting 26.6 CO @ 15% O2 [ppm] and 1.1 NOx @ 15% O2 [ppm]. The end-of-pipe GHG emissions aim to be less than 769.9 grams/kWh. Furthermore, the diversion of the biomass waste stream from landfills for use as feedstock to the Power Pallet avoids the methane emissions associated with the biomass decomposition.

### Natural Gas Funds Encumbered:

$1,500,000

### Update:

The focus has been on the assembly and operation of the combined cooling, heating and power (CCHP) Power Pallet (PP) prototypes PP1095 and PP1096 for the engineering validation testing (EVT). Assembly of the two CCHP PP units for the demonstration activities is in process at the APL facility. Preliminary results show that the overall system efficiency was equal to 80 percent and passed the evaluation conducted for the EVT. CO2 emissions were 45 percent higher than the target 769.9 grams/kWh. To meet the emission target, the project team will be focused on increasing the overall system efficiency thru improvement of the gasification performance.

---

**Image**

Distributed Renewable Energy Combined Cooling, Heating and Power system.
**Project Name:**
A Strategic Assessment of the Long-term Role of Natural Gas in a Carbon Constrained and Water-Efficient Future - [PIR-16-011]

**Recipient/Contractor:**
Energy and Environmental Economics, Inc. (E3)

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan</th>
<th>Project Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>4/3/2017 to 3/30/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy-Related Environmental Research

**Issue:**
As California develops plans to reach its greenhouse gas (GHG) emissions targets, there is uncertainty about the role of the natural gas industry and whether it can be sustained in the long-term. Natural gas is a fossil fuel and is the source of approximately 40 percent of statewide greenhouse gas emissions from fuel combustion overall. Without significantly reducing GHG emissions from natural gas use, the state will not be able to meet its 2050 emissions target of 80 percent below 1990 levels. Meanwhile, the natural gas system reflects a significant $27 billion infrastructure investment in the state and provides a low cost fuel that powers a significant share of California's energy system.

**Project Description:**
This project develops scenarios of the future of the natural gas system taking into account future natural gas use, operational factors, direct and indirect impacts from climate, technology development, and regulatory treatment and pricing in the natural gas industry. The scenarios will be evaluated as an integrated part of the energy system that can accommodate intermittent power from wind and solar resources, can accommodate biomethane from various waste and biomass streams, and can convert electrical power to gas as storage and for use in transportation and other sectors. The research team will use various tools to evaluate future natural gas scenarios against an all-electric future and investigate the cost differences by sector, risk differences, technology development potential, regional air quality and other factors important to the future of California.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The project uses its California PATHWAYS tool to develop scenarios (up to 2050) for the natural gas system that can achieve the State’s long-term greenhouse gas (GHG) reduction goals. For the first time, the study will model promising but still unavailable technologies/methods to decarbonize natural gas, such as the use of advanced hydrogen production technologies. The hydrogen would be available to the natural gas system in the PATHWAYS model. Direct and ancillary benefits of decarbonization of the natural gas system will be investigated, such as the feasibility of storing energy using a natural gas system with a very low carbon footprint. Finally, the direct and indirect consequences to ratepayers and natural gas utilities will be investigated.

**Applicable Metrics:**

- **Lower Costs:**
  Using the natural gas system to deliver low-carbon fuels has the potential to reduce the total system costs of GHG reductions, and a long-term view of the future will allow the industry to avoid potentially stranded assets in the gas system.
**Greater Reliability:**
The results of the study will provide more information on the future operations of the gas system, including a response to integrating more electric renewable generation and other changing energy demands due to a changing climate. Improved visibility into future demands can help the natural gas utilities improve reliability.

**Environmental Benefits:**
The results of the study will provide estimates of air quality statewide at a (4km x 4km) resolution for all future scenarios; this allows assessment of the co-benefits of improved air quality along with the GHG reductions and other benefits.

**Public Health:**
Identifying scenarios that can provide cleaner air will improve public health. In particular, disadvantaged communities with a greater pollution burden are a focus of the study.

**Energy Security:**
This study investigates the use of natural gas to displace imported oil used primarily in the transportation sector, leading to greater US energy security.

**Natural Gas Funds Encumbered:**
$1,099,733

**Update:**
The second meeting of the Technical Advisory Committee took place on August 10, 2018 in Sacramento. The research team presented preliminary results including technology options to decarbonize natural gas, a revised framework using the PATHWAYS model to estimate the potential penetration of different decarbonization options, and a method to estimate potential rate impacts.

![IMAGE](image.png)

**Building Blocks of the Study.** Blue areas represent existing tools that are being updated while the grey areas are new analytical tools being developed as part of this study.
### Project Name:
Effective Kitchen Ventilation for Healthy ZNE Homes with Natural Gas Appliances - [PIR-16-012]

### Recipient/Contractor:
Lawrence Berkeley National Laboratory

### Natural Gas Funding Plan:  Project Term:
Natural Gas Research  11/16/2017 to 3/31/2020

### Research Area:
Energy Efficiency

### Issue:
California's Title 24 building code requires installation of a venting range hood or other kitchen exhaust ventilation that meets specific airflow and sound requirements. However, many people report that they do not regularly use the kitchen ventilation in their homes. In addition, for many range hoods, operation at the minimum code-required airflow capacity removes no more than half of the pollutants emitted from front burners. There is a need to investigate the relationship between air flow rates and pollutant capture efficiency for kitchen exhaust ventilation systems.

### Project Description:
The objective of this project is to determine the efficiency of current code and potential code changes with field, laboratory, and simulation research to inform developers of residential building codes and standards, such as the Energy Commission's Energy Efficiency Division, how to protect indoor air quality and health in California zero-net energy (ZNE) homes with natural gas. The research team is collecting data on usage and performance of kitchen ventilation to mitigate pollutant exposures in recently constructed, ZNE multifamily buildings. The team is conducting simulations to determine the exposure and risk reduction benefits resulting from varying levels of a range hood capture efficiency requirements. The project is also evaluating performance of over-the-range microwave exhaust fans that are not currently compliant with the Title 24 building code but are nevertheless installed in homes to satisfy customer preferences.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
The innovation of this project is in combining initial measurements of installed equipment performance, in-use performance (the degree to which pollutant concentrations are controlled), controlled laboratory study (of microwave exhaust fans), data analysis, and simulations to estimate the distribution of exposure and risk across the population. This project will inform stakeholders such as the Energy Commission's Energy Efficiency Division of the advantages and disadvantages to adding pollutant capture efficiency into the criteria of codes and standards development.

### Applicable Metrics:
**Public Health:**
The project will result in ratepayer benefits by informing codes and standards, developed by the Energy Commission's Efficiency Division and others, to protect occupants of ZNE new homes from elevated exposures to air pollutants from natural gas stove top burners and combustion associated with cooking food.

### Natural Gas Funds Encumbered:
$1,000,000
**Update:**

The project kicked off in late 2017. The research team has completed review of previous studies and drafted a field study data collection plan. The team conducted a Technical Advisory Committee (TAC) meeting and shared the field study data collection plan with the TAC members. Currently, the team is reviewing the feedback provided by the TAC members and finalizing the subcontract with the subcontractor that will conduct the field study. The field work is expected to start by the end of 2018.

**Imagenote:**

Microwave ventilation above cooking stove.
### Project Name:
Quantification of Methane from California’s Plugged & Abandoned Gas Wells: Effects of Land Subsidence and Other Factors - [PIR-16-013]

### Recipient/Contractor:
University of California, Davis

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
8/17/2017 to 3/30/2020

### Research Area:
Energy-Related Environmental Research

### Issue:
Initial work has shown that methane (CH4) emissions from abandoned and plugged wells are a potential but poorly understood source of greenhouse gas emissions in California. During the recent drought, groundwater pumping induced land subsidence in California. This subsidence may be a factor in exacerbating methane leakage from abandoned and plugged wells if they are located in the same area.

### Project Description:
This project includes field campaigns to measure methane leakage from abandoned and plugged natural gas wells in the areas where land subsidence has occurred. After collecting information from the field, the team conducts analyses to determine the significance of subsidence and other factors in explaining variations in methane emissions.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The methane emissions from abandoned/plugged natural gas wells are not well understood in California. The results from this project will provide the first insight on the quantity and characteristics of leakage from the wells. The knowledge gained will help focus the State's greenhouse gas mitigation efforts.

### Applicable Metrics:
**Increase Safety:**
This agreement will provide information to the Division of Oil, Gas, and Geothermal Resources to prioritize technical review and maintenance of abandoned natural gas wells in the areas where land subsidence has occurred. The agreement will also provide a better understanding of methane emissions from California's natural gas system.

**Environmental Benefits:**
This project will provide new data to the Air Resource Board on methane emissions from the natural gas system by quantifying and characterizing emissions from abandoned wells, which is a sector that is not currently included in California's methane emissions profile. The mitigation effort then can be planned to reduce methane emissions in the state.

### Natural Gas Funds Encumbered:
$597,433
Update:
The research team downloaded Division of Oil, Gas, and Geothermal Resources (DOGGR) lists of oil and gas wells in California and mapped all abandoned and plugged wells. The team also obtained maps of subsidence from the United States Geological Survey (USGS) and Jet Propulsion Laboratory (JPL). Based on this information, the team identified thousands of potential wells in four areas for field measurements: Sacramento Valley, Sacramento River Delta, San Joaquin Valley near El Nido, and the foothills of southern San Joaquin Valley. The field work has started in the Sacramento Valley.

Soil chambers used for soil gas methane flux measurements and gas sampling for isotopic analysis.
### Project Name:
Multi-tiered Greenhouse Gas Emissions Measurements of California's Natural Gas-Powered Industrial and Fueling Infrastructure - [PIR-16-014]

### Recipient/Contractor:
Electric Power Research Institute, Inc.

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
4/6/2017 to 6/2/2020

### Research Area:
Energy-Related Environmental Research

### Issue:
Despite a number of intensive measurement campaigns in recent years to locate and mitigate greenhouse gas (GHG) emissions, significant uncertainty still exists in the estimates of methane (CH4), carbon dioxide (CO2), and nitrous oxide (N2O) from natural gas and petroleum infrastructure. The estimates resulting from different measurement approaches, such as 'top-down' and 'bottom-up', show discrepancies that suggest missing or underestimated sources in state inventories. These data gaps can limit California's ability to meet regulatory requirements; thus, a new approach to detection and quantification of these emissions is needed.

### Project Description:
This project includes a series of multi-tiered measurement campaigns for fugitive methane (CH4) and stack nitrous oxide (N2O) emissions behind-the-meter at a variety of natural gas infrastructure sites, including multiple power plants, industrial facilities, and compressed natural gas fueling infrastructure sites. New and previously collected data from aircraft are used to identify geographical areas of high GHG emissions that can be further investigated on the ground. Ground measurements are made at the site or facility system and subsystem levels with screening tools, such as infrared cameras, to locate specific leaks. Follow-up measurements with quantitative tools (such as Hi Flow devices, quantitative camera technology, tracer release, and mobile plume integration) are used to estimate emission rates. N2O stack measurements at gas-fired power plants and industrial boilers are made to understand the potential impact on GHG emissions.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
Ambient measurements of methane suggest that actual methane leaks are much higher than what California Air Resources Board (CARB) reports in the State GHG Inventory. This project will help determine whether industrial facilities are significant sources of underestimated emissions. New GHG measurements focused on previously under-sampled sources will lead to improved emissions estimates for a number of source categories, and will identify leaks that have previously been unknown. This will provide information for mitigation actions by CARB and power plants in support of SB 32, SB 1371, and other GHG mitigation and safety regulations.

### Applicable Metrics:
**Lower Costs:**
Early identification and mitigation of methane leaks will result in the ratepayer benefits of reduced net cost of natural gas due to reduced losses of natural gas.
<table>
<thead>
<tr>
<th>Increase Safety:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing leaks increases the overall safety for workers and the public that live near gas delivery infrastructure due to avoided emissions and reduced risk of fire/explosion. The information collected from this project may subsequently improve workforce training and inform operations of natural gas plants, refineries, and natural gas fueling stations.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Benefits:</th>
</tr>
</thead>
<tbody>
<tr>
<td>As CH4 and N2O have high global warming potential, mitigation of these emissions on a broad scale could have significant environmental benefits. Identification and quantification of methane leaks in natural gas infrastructure system will allow for CH4 leak mitigation, as required by SB 1371 and help to address ambitious GHG reduction goals set by SB 32.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,400,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Update:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The project was kicked off on July 20, 2017. First Technical Advisory Committee meeting was held on February 16, 2018, and was attended by representatives from CARB, PG&amp;E, SoCalGas, LBNL, Montrose Air Quality Management Services, GTI, and Scientific Aviation. During the TAC meeting, the measurement strategies and instruments to be deployed at selected facilities during intensive and non-intensive measurement campaigns were discussed. The first intensive measurement campaign took place during the week of June 18-22. Measurements were conducted by staff from EPRI, LBNL, Montrose Air Quality Management Services, GTI, and Scientific Aviation. During the next months, the research team will perform QA/QC on raw data collected during the first intensive measurement campaign to facilitate initial analysis of GHG emissions at the host site.</td>
</tr>
</tbody>
</table>
**Appendix D-138**

**Project Name:**
Characterize Actual and Future Impact of California’s Drought on Three-component Ground Deformations and their Influence on the Natural Gas Infrastructure - [PIR-16-015]

**Recipient/Contractor:**
Lawrence Berkeley National Laboratory

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>4/12/2017 to 3/30/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy-Related Environmental Research

**Issue:**
The recent drought in California led to increased groundwater pumping in the Central Valley that, in turn, has resulted in land subsidence. Vertical and lateral ground movements unequally affect natural gas infrastructure. The lateral component poses the greatest risk to the pipelines. Currently, only the vertical-component of land deformation field is considered in subsidence monitoring and modeling efforts led by Department of Water Resources, NG IOUs, and scientists. The proposed research will consider all three components (2 horizontal+1 vertical) of ground subsidence to inform risk-based decision making.

**Project Description:**
This study characterizes the impact of California’s drought related subsidence on natural gas infrastructure. The goal of this research project is to develop and demonstrate a new methodology to more accurately identify areas with relatively high risk of potential natural gas infrastructure damage due to subsidence and the identification of potential remedial actions. The main innovation and advantages within this project is the combination of large-scale state-of-the-art remote sensing surveys linked with advanced modeling and inverse analysis of three-component (one vertical and two horizontal) ground deformation. Specifically, the study involves ground deformation monitoring, infrastructure damage evaluation, water pumping and geologic data evaluation, and coupled groundwater flow and geomechanical modeling to enable natural gas utilities to predict areas of potential future drought related subsidence and estimate risk of damage to the infrastructure.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The project will result in a technology that allows for more accurate predictions of the impact of subsidence on natural gas infrastructure through analysis of three-component ground deformations imaged by satellite-based land surface monitoring. This technology could be adopted by NG IOUs. A more accurate predictive capability implies that future drought related subsidence can be forecasted with greater confidence leading to increased safety, lower costs, and environmental benefits.

**Applicable Metrics:**
Lower Costs:
The quantitative predictive methodology developed by the proposed project will enable natural gas IOUs to take early preventative engineering measures to prevent failure, thus lowering mitigation costs and benefiting natural gas ratepayers.
Increase Safety:
The project will provide a capability that could provide early warning of growing subsidence bowls that approach vital natural gas infrastructure. This can inform risk-based decisions on preventative engineering actions to protect the infrastructure before it experiences damaging surface strains, therefore providing safeguarding against abrupt failure and gas leaks.

Environmental Benefits:
Methane ranks amongst most potent greenhouse gases (GHG) due to its high global warming potential that is 21 times that of carbon dioxide. Early prevention of natural gas infrastructure failure will help to minimize methane leaks and reduce associated GHG emissions.

<table>
<thead>
<tr>
<th><strong>Natural Gas Funds Encumbered:</strong></th>
<th>$1,599,584</th>
</tr>
</thead>
</table>

**Update:**
The project team finalized subcontracting activities, acquired Interferometric Synthetic Aperture Radar (InSAR) data from JPL and extracted the range changes (ground surface displacement) for 2015-2017, and obtained subsurface geological interfaces for the study area and the base of the freshwater reservoir. Using collected data, researchers set up a preliminary model and ran a test inversion for volume change for 2015-2017. Over the next few months, the team will develop a 3D textural model and construct a numerical grid for fluid flow and geomechanical simulations to identify the causes of different subsidence bowls in this region. PG&E has been involved in discussions related to selection of sites for field measurements.

**IMAGE**

3-D monitoring of land surface deformations that pose risk to the natural gas infrastructure.
**Project Name:**
Development, Demonstration and Testing of Advanced Ultra-Low Emission Natural Gas Engines in Port Yard Trucks - [PIR-16-016]

**Recipient/Contractor:**
Gladstein, Neandross & Associates, LLC

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
6/1/2017 to 6/5/2020

**Research Area:**
Natural Gas-Related Transportation

**Issue:**
Heavy-duty yard trucks are a leading source of criteria pollutant and greenhouse gas emissions in port cargo handling operations. Demonstrations of advanced low emission natural gas engines in yard truck applications have been limited to those in the 9-liter class. These engines are larger than diesel engines normally specified for the application and may not provide the optimal benefits. There is an increasing need to operate low emission natural gas vehicles on renewable natural gas (RNG) to realize greenhouse gas (GHG) benefits, especially in high-priority areas like the San Pedro Bay ports. However, increased fuel quality variation of RNG could negatively affect engine operation.

**Project Description:**
This project demonstrates two natural gas-fueled yard trucks equipped with 6.7-liter engines certified to the California Air Resources Board's optional low oxides of nitrogen (NOx) standard in cargo handling operations at the Port of Los Angeles. The project will include a side-by-side performance comparison between 1) the yard trucks powered by the 6.7-liter natural gas engine, 2) a yard truck powered by a 9-liter natural gas engine, 3) a typical diesel yard truck, and 4) a battery-electric yard truck. Emissions and performance testing will be performed on UC Riverside's chassis dynamometer under controlled conditions.

The project is also developing an advanced gas sensor that can monitor fuel quality in real time, enabling engines to adapt to differences in fuel composition to optimize engine efficiency. The natural gas fuel quality sensor will be integrated into the natural gas yard truck to validate sensor response and utility when operated on several sources of RNG with varying fuel compositions.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:**
This project introduces a right-sized 6.7-liter low NOx natural gas engine for yard truck applications. Comparisons of this technology to other alternatives can help guide clean transportation investments for freight sustainability. The advanced gas sensor technology has potential to significantly improve the emissions and performance of natural gas yard trucks (and eventually other on-road or off-road natural gas vehicles) that operate on varying compositions and qualities of RNG.

**Applicable Metrics:**
**Environmental Benefits:**
The advanced gas sensor technology can enable wider use of RNG in the transportation sector. RNG is a low carbon fuel derived from waste streams such as landfills, wastewater treatment plants, and dairies. On average, RNG has 50 percent lower carbon intensity than...
fossil gas. Direct fueling of RNG without pipeline injection results in even lower carbon intensity by avoiding the carbon impact related to pipeline leakage. By allowing engines to automatically adjust to a large range of fuel quality variations, the gas sensor allows for direct RNG use without compromising engine performance.

Public Health:
In the transportation sector, mobile off-road equipment is the second largest contributor to NOx emissions in the San Joaquin and South Coast Air Basins. Low NOx natural gas engine technology results in 50 to 90 percent lower NOx emissions when compared to conventional diesel engines. Increased adoption of these engines in yard truck applications will help improve air quality in disadvantaged communities surrounding high-traffic freight corridors such as the San Pedro Bay ports.

Natural Gas Funds Encumbered:
$1,399,681

Update:
A technical advisory committee meeting was called in December 2017 to discuss unexpected project delays related to the procurement of the two yard trucks powered by the 6.7-liter engine. A follow-up meeting was held in January 2018 with project stakeholders and the yard truck manufacturer to resolve the pertinent issues. The quote for the two yard trucks was secured in March 2018 with an expected delivery date of December 2018. The vehicle demonstration test plan and prototyping of the advanced gas sensor are under development.

Port Yard Truck in Operation.
## Project Name:
Using Renewable Natural Gas in Common Appliances and Implications on Emissions, Fuel Stability and Operational Performance - [PIR-16-017]

## Recipient/Contractor:
The Regents of the University of California, on behalf of the Irvine campus

## Natural Gas Funding Plan:
Natural Gas Research

## Project Term:
5/12/2017 to 11/30/2019

## Research Area:
Energy Efficiency

## Issue:
Using biogas fuels, which are generated from a variety of sources such as anaerobic digestion processes at water treatment plants and dairies, and from biodegradation of materials in landfills can help the State of California meet its goal to increase the adoption of renewable energy, yet many potential end use appliances are undeveloped for use of this fuel as an alternative to natural gas.

## Project Description:
This project evaluates the stability, operational, and emissions implications of operating dual fuel appliances in homes and businesses that can use both pipeline quality natural gas and biogas. An overview of the market availability of these appliances will be provided along with a summary of existing test results and procedures used to evaluate these devices. Existing data, and new test data from a representative list of appliances collected in this study will provide information on stability, performance and emissions using various fuel mixture ratios and fuel intensities. Recommendations for burner design modifications will be made to enable use of larger amounts of biogas.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Under previous CEC projects 500-08-034 and 500-12-004, UCI developed simulation methodologies that accurately predict stability and emissions as a function of fuel composition. This project will apply these validated methodologies to household appliances, which were not studied in the prior projects. The project's results on burner stability, mixture limits, and pollutant emission impacts will evaluate the implications of using more biogas in appliances and the impact on resultant air quality, equipment performance, and safety. The results can guide operational modifications to existing equipment. Results will be shared with policymakers to facilitate increased adoption of renewable fuels which supports California’s Renewable Portfolio Standard.

## Applicable Metrics:
### Environmental Benefits:
Residential/commercial gas appliances consumed approximately 53% of the ~13 billion therms of natural gas provided by Investor Owned Utilities in California in 2013. If one percent of this natural gas could be displaced with biogas, this could reduce CO2e emissions by more than 350,000 metric tons annually (assuming 0.00531 mt/therm). As the percentage of biogas increases, the reductions in CO2e emission will increase correspondingly.

### Natural Gas Funds Encumbered:
$250,000
Update:
The project has identified appliance burner configurations and fuel composition ranges. Residential natural gas stovetop burners were procured and tested with CO2/natural gas mixtures to evaluate emissions, ignition performance and flame characteristics. A pre-test was conducted on a low NOx storage water heater. Hydrogen/natural gas mixture testing was done with stovetop burners to document emissions, ignition performance, combustion noise etc.; results were shared with Southern California Gas.
**Project Name:**
Research, Development and Demonstration of Low-Emission CNG Engines for Construction Vehicles - [PIR-16-018]

**Recipient/Contractor:**
Olson-Ecologic Engine Testing Laboratories, LLC

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/15/2017 to 6/5/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Natural Gas-Related Transportation

**Issue:**
Construction equipment is one of the largest category of off-road emissions in the South Coast Air Basin, accounting for about one third of the off-road NOx and PM 2.5 emissions. Both pollutants contribute to the region's serious air quality problems. Despite improvements in air quality over the last forty years, the South Coast Air Basin has suffered an uptick in the number of unhealthy smog days in 2016. For most off-road equipment categories running on diesel, PM 2.5 component is a particulate matter of concern and is classified as toxic.

**Project Description:**
This project is being terminated (see project update). Its original intention was to acquire, test, develop research, and demonstrate two engines in two different off-road construction vehicle applications. One off-road 18-liter engine will be converted from diesel to compressed natural gas (CNG) for use in a Caterpillar scraper. The second engine that will be acquired and demonstrated for off-road use is the newest and cleanest CNG from Cummins Westport Inc., an 8.9-liter engine for use in a Caterpillar loader. California State University Fullerton will address opportunities to improve fuel efficiency when compared to conventional fueled engines operating in similar duty-cycles. This research will identify the various sources of energy losses. The analytical and simulation models will assess potential areas for improvement and these will be implemented where practicable.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project targets a high-emitting vehicle market that has not yet been addressed. Due to the size and life-span of the large construction vehicles, research has been limited, but this research aims to look at effective strategies to integrate the use of natural gas in these vehicles in order to reduce emissions.

**Applicable Metrics:**

**Public Health:**
Introducing natural gas into this high-emitting niche market has the potential to reduce emissions. Construction vehicles can be found in operation daily throughout California, therefore finding strategies and technologies that can address the emission issues in the off-road market is critical for air-quality improvement and achieving ambient air quality attainment in the most severely polluted regions of California.

**Natural Gas Funds Encumbered:**
$1,500,000
Update:

In August 2017, a Critical Project Review was conducted to review significant project changes and issues presented at the kick-off meeting, which affected the project's ability to meet the solicitation requirements. Issues included loss of OEM participation, changes in the proposed engine, subcontractor changes, and data collection approach. Staff assessed the proposed changes and issued a Stop Work Order (SWO) in September 2017 with conditions to lift the SWO. In November 2017, Olson Ecologic notified the Energy Commission that they were unable to meet the conditions of the SWO and requested a 60-day extension to present an alternative. Following the submittal of the proposed alternative in January 2018, the Energy Commission and Olson Ecologic agreed to a mutual termination, as the alternative project changes presented did not adequately meet the requirements of the solicitation.
### Project Name:
CNG Hybrid Power System for Mobile Vehicles - [PIR-16-019]

### Recipient/Contractor:
Terzo Power Systems, LLC.

### Natural Gas Funding Plan: Project Term:
Natural Gas Research
6/1/2017 to 12/6/2019

### Research Area:
Natural Gas-Related Transportation

### Issue:
The agricultural sector is responsible for a significant portion of mobile source emissions in the San Joaquin Valley Air Basin. Cleaner alternatives to conventional diesel powered off-road agricultural vehicles will be necessary to reduce criteria pollutant and greenhouse gas emissions. Powering off-road vehicles with a non-diesel engine presents unique challenges due to torque requirements, vehicle control constraints, highly varied application-specific work functions, and hydraulic power integration. No cost-effective diesel alternatives currently exist for powering these high-torque off-road vehicles in the agricultural sector.

### Project Description:
This project is developing an easy to integrate, cost effective, natural gas hybrid-electric power system that can replace diesel power systems on mobile agricultural equipment. The hybrid power system uses an integrated battery system that allows the engine to be decoupled from the electrified propulsion and hydraulic systems. The hybrid power system improves system efficiency, reduces emissions, creates healthier working environments, and provides a transitional platform to zero emission vehicles in the future. The system will be integrated on an almond harvester and demonstrated in real world operation at an orchard in Madera.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project is developing a natural gas hybrid power system that can achieve the same performance as diesel engines while reducing emissions and improving efficiency when integrated with heavy-duty off-road vehicles. The system is designed to be modular and adaptable to a wide variety of off-road applications. The system can also serve as a transitional platform for zero emission off-road vehicles that will become more feasible as battery technology improves.

### Applicable Metrics:
**Environmental Benefits:**
The hybrid-electric power system enables two primary efficiency benefits: 1) the natural gas engine is de-coupled from the propulsion and hydraulics, allowing it to operate at its preferred high efficiency conditions, and 2) the electro-hydraulic system is more efficient than conventional diesel power take-off systems.

**Public Health:**
Mobile farm equipment and other off-road equipment produce around 140 tons of oxides of nitrogen (NOx) per day and account for around 20 percent of toxic PM2.5 emissions from mobile sources in the San Joaquin Valley Air Basin. The hybrid natural gas agricultural...
vehicle will aim to provide a cleaner Tier 4 or higher option to displace diesel vehicles, reducing the NOx and particulate matter emissions from the agricultural sector.

Natural Gas Funds Encumbered:
$1,497,400

Update:
Energy Commission staff conducted a site visit and critical project review meeting in January 2018 to evaluate project progress and verify large equipment purchases. The various major subsystems are being tested prior to chassis integration. Staff conducted another site visit in July 2018 to ensure the project is on track for demonstration testing during the harvest season.

IMAGE

Almond harvester chassis with global vehicle motors in the foreground.
**Project Name:**
Code Changes and Implications of Residential Low Flow Hot Water Fixtures - [PIR-16-020]

**Recipient/Contractor:**
Gary Klein and Associates, Inc.

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
5/15/2017 to 12/31/2018

**Research Area:**
Energy Efficiency

**Issue:**
Appliance standards have been steadily reducing the maximum allowed flow rates for hot water fixtures. However, with little change in distribution system designs, building occupants using low flow fixtures will experience longer waiting time for hot water and lower delivered hot water temperature. There has not been any study that systematically addresses these issues and the impact of low flow fixtures on hot water system performance. Without carefully addressing these issues, low flow fixtures may not be able to achieve the intended energy and water savings, and market adoption of low flow fixtures could be hampered.

**Project Description:**
This research analyzes and recommends future code changes to hot water distribution systems for improvements to piping design in new construction and existing buildings. The research provides solutions to overcome market adoption barriers, identifies distribution improvement strategies, and demonstrates how to apply the identified strategies to a range of building designs. The recipient is assessing hot water delivery speed using a custom model calibrated with laboratory test results -- in addition to measuring energy and water efficiency. Results will support future code changes and provide guidance to industry practitioners.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
If warranted, the results of this study will likely inform changes in Title 24 Energy Code requirements on single-family new construction. There may also be recommendations to make changes to Title 20 Appliance Standards and perhaps the California Plumbing Code. Following adoption of code changes developed by this project, new Title 24 compliant houses built from 2020 to 2030 may collectively save their occupants 7 million gallons of wasted hot water annually by 2030. This translates into collective annual savings of 4.6 million therms of natural gas or $4.6 million. The associated annual emission reductions are 24.5 metric tons of CO2e and 5.6 kg of NOx.

**Applicable Metrics:**

- **Lower Costs:**
  Following adoption of code changes developed by this project, new Title 24 compliant houses built from 2020 to 2030 may collectively save their occupants 7 million gallons of wasted hot water annually by 2030. This translates into collective annual savings of 4.6 million therms or $4.6 million.

- **Environmental Benefits:**
The associated annual emission reductions are 24.5 metric tons of CO2e and 5.6 kg of NOx.
Natural Gas Funds Encumbered:
$249,900

Update:
The hot water distribution modeling tool has been developed and used to prepare the draft Report on Feasibility of Hot Water Distribution System Improvement Strategies. Two technical advisory committee meetings are planned for the remainder of the agreement to obtain stakeholder input on hot water distribution system improvement strategies.

Plumbing Schematic for Hot Water Distribution System.
## Project Name:
Data Driven Approaches to Understanding Occupant Natural Gas Use in Low-Income Multifamily Communities - [PIR-16-021]

## Recipient/Contractor:
Electric Power Research Institute, Inc.

## Natural Gas Funding Plan:
- Natural Gas Research

## Project Term:
5/19/2017 to 12/30/2019

## Research Area:
Energy Efficiency

## Issue:
Low-income households spend a disproportionate share of their monthly income on energy. In instances where gas and electricity are master-metered, the energy costs are often part of the monthly rent, resulting in high utility costs for low-income households. While advanced technologies can contribute to energy use reductions for these communities, behavior change is a significant under-tapped source of energy savings.

## Project Description:
The goal of this project is to understand low-income occupant behavior with respect to natural gas use. This research identifies behavioral factors that increase gas use, recommends effective behavioral strategies to reduce gas usage, and tests behavioral interventions. The project provides information on the water heating, space heating, and cooking loads of two low-income, apartment complexes in Los Angeles and San Diego Counties.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
To understand how natural gas is used in low-income homes, this project integrates data from smart thermostats, new advanced gas sub-metering technology, and advanced metering infrastructure (AMI) data. The data will provide information on the impact of temperature set-points, hot water usage, and cooking behavior, while AMI data will be used to determine historical baseline usage and to correlate whole home performance and impact at the individual device level. The collected data will increase knowledge of natural gas use and occupant behavior and can identify intervention strategies and customized solutions, including use of advanced energy technologies, that can potentially lead to lower natural gas use for this sector.

## Applicable Metrics:
**Lower Costs:**
Reduced energy used for heating directly results in less money spent on energy. This is especially important in low-income communities where a bigger portion of their income is attributed to energy costs.

**Natural Gas Funds Encumbered:**
$260,145

## Update:
The recipient has completed assembly of the data loggers for the Los Angeles and San Diego apartment complexes and is coordinating with LINC housing to allow installation access to place the loggers in the apartments. The recipient is finalizing a Behavior Intervention Plan which will include the list of measures to be installed in each unit.
Data Acquisition Box.
**Project Name:**
Costs and Benefits of Community vs. Individual End-Use for Solar Water Heating - [PIR-16-022]

**Recipient/Contractor:**
DOE- Lawrence Berkeley National Laboratory

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/12/2017 to 6/28/2019</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Solar Water Heating (SWH) still requires significant institutional support within California to reach a point where growing market share produces the cost reductions that lead to self-sustaining expansion of the market. It is clear that improving consumer information and raising incentive levels should help increase SWH system market share. The remaining questions for SWH are: 1) What is the optimal level of investment of public resources, and 2) How can investment be more targeted to maximize the chances of successful uptake of SWH projects? The objective of this project is to provide data that will be useful in guiding decisions about SWH program design and deployment.

**Project Description:**
This project evaluates different solar water heating (SWH) technologies, installation types, and financing mechanisms. The team is developing a model to address cost, payback, and how investments can maximize uptake of SWH. This project assesses factors affecting the scale of solar water heating (SWH) installations, such as system cost, performance, and reliability and scale. These factors impact whether a project is undertaken at the individual or community level. The team is also quantifying state-level energy and natural gas emissions reductions from SWH installations.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The resulting study creates a detailed cost/benefit modeling framework, that does not currently exist, to evaluate utilization of SWH systems at different scales and whether there is an optimal scale, e.g. individual-level versus community-level. This modeling framework and supporting data advances California’s statutory energy goals by helping improve uptake and scale of SWH projects in California. It also informs market transformation programs such as the California Solar Initiative - Thermal.

**Applicable Metrics:**

<table>
<thead>
<tr>
<th>Environmental Benefits:</th>
</tr>
</thead>
<tbody>
<tr>
<td>If 1% of the market adopted SWH, it could avoid natural gas consumption by 1.6 million therms annually. The associated annual emissions reductions are approximately 8500 metric tons of CO2, 2.4 short tons of NOx, 2.9 short tons of CO, 0.4 short tons of volatile organic compounds and 0.2 short tons of methane.</td>
</tr>
</tbody>
</table>

**Natural Gas Funds Encumbered:**
$250,000
**Update:**

In May 2018, Lawrence Berkeley National Laboratory completed the analytical framework model. The model uses solar water heater system performance and consumer data to show how to maximize installation of solar water heaters in California.

<table>
<thead>
<tr>
<th>IMAGE</th>
</tr>
</thead>
</table>

Example of a district-scale solar project that incorporates solar-thermal as well as photovoltaic technologies (Drake Landing, AB, Canada). There is currently little understanding of how to deploy projects at community scales that cover the range between a single household and a full district.
**Project Name:**
Evaluation of Community-Scale Solar Water Heating in Los Angeles County - [PIR-16-023]

**Recipient/Contractor:**
The Regents of the University of California, on behalf of the Los Angeles Campus

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/12/2017 to 12/28/2018</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Area:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Efficiency</td>
</tr>
</tbody>
</table>

**Issue:**
While Solar Water Heating (SWH) systems have been implemented across California, community scale SWH has not yet been widely adopted. It is not yet clear what the ideal SWH configuration is for a community scale system, or how the geographic and building type characteristics inform the best configuration for a given site.

**Project Description:**
This project investigates the electric, natural gas, and GHG emission savings of community-scale solar water heating. The team is also assessing the cost-effectiveness of highly efficient advanced energy systems for community scale water heating.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project will produce a series of reports and case studies to understand the environmental and cost benefits of community solar water heating (SWH) to replace conventional building-level hot water systems. The research will define the needs for a community scale SWH system, identify current technologies and configurations, describe the trade-offs with other clean energy technologies for cost-effectiveness and feasibility, and evaluate land use requirements. The data from the reports and case study will provide information on the GHG reductions associated with reduced natural gas use from community scale SWH systems. Replacing conventional gas water heating at multi-family buildings with solar will help California meet its AB32 goals and targets for zero net energy buildings and communities.

**Applicable Metrics:**

<table>
<thead>
<tr>
<th>Lower Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community scale solar water heating may reduce natural gas and electricity consumption by replacing building hot water systems. Reductions in energy consumption will reduce energy cost of building owners.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$240,404</td>
</tr>
</tbody>
</table>
Update:
The team has submitted the Solar Water Heating Report, which describes and reviews existing solar water heating technologies and the industry standards for selecting solar water heating systems for different community sites. The Methodology Report has been completed and includes descriptions of the modeling methods used to determine the solar potential of a land site, the expected hot water output of a solar water heating system, and the assumptions used to determine the energy draw of conventional hot water systems for different building types. The second Technical Advisory Committee meeting was recently held to gain feedback on the upcoming Case Study Site Selection Report, which will contain a description and illustration of the community site chosen, its selection methodology, and a breakdown of building facility characteristics and aggregated energy consumption profiles.
### Project Name:
Development and Demonstration of a Production-Intent Transient Plasma Ignition System for High Efficiency Natural Gas Engines - [PIR-16-024]

### Recipient/Contractor:
Transient Plasma Systems, Inc.

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2017 to 6/30/2019</td>
</tr>
</tbody>
</table>

### Research Area:
Natural Gas-Related Transportation

### Issue:
Spark-ignited natural gas engines are a promising alternative transportation technology to diesel engines that leverage an abundant, domestic, and cleaner burning fuel. Natural gas is difficult to ignite with traditional thermal spark ignition systems. High levels of exhaust gas recirculation and high pressure can lead to lower emissions and higher efficiency, but these conditions make it more difficult to consistently ignite natural gas. Advanced ignition systems are potential enabling technologies for improving the thermal efficiency of natural gas engines.

### Project Description:
This project is developing a production intent prototype of a non-thermal plasma ignition system that can reduce maintenance requirements, improve engine efficiency, and reduce emissions of heavy-duty on-road natural gas engines. The project builds on previous research work that validated the benefits of this technology in single cylinder test engines by focusing on developing a multi-cylinder system. The prototype will be tested at Argonne National Laboratory across the full operating range of a commercially available near-zero emission natural gas engine: the Cummins Westport ISX12N. Test results will be evaluated to determine immediate benefits as well as further opportunities to optimize the engine using the plasma ignition system.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The non-thermal plasma ignition system uses multiple short nanosecond pulses of energy to ignite natural gas in an internal combustion engine. Unlike traditional spark plugs, this technology does not rely on a sustained high energy spark to ignite the fuel. The transient plasma ignition system has the potential to improve fuel efficiency by over 20 percent, reduce emissions by more than 50 percent, and increase spark plug lifetime compared to a conventional energy arc-spark system. The ignition system is intended as a drop-in replacement for standard ignition coil modules, allowing for simple engine integration and greater opportunities for near-term commercialization.

### Applicable Metrics:
Greater Reliability:
Current heavy-duty natural gas engines undergo shorter maintenance intervals than diesel engines due to the need to replace spark plugs. Transient plasma ignition does not rely on high-energy thermal ignition that leads to the erosion of conventional spark plugs. By reducing maintenance needs, transient plasma ignition can increase the reliability of natural gas engines.
Public Health:
Exposure to ambient fine particulate matter, generally from vehicle traffic and diesel engines, is associated with a significantly higher risk of stroke and cancer. Oxides of nitrogen (NOx) are precursors to tropospheric ozone and smog. The non-thermal plasma ignition technology is expected to significantly reduce particulate matter from heavy-duty engines by extending dilute-burn capability, which can also reduce NOx production by more than 50 percent.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$899,139</td>
</tr>
</tbody>
</table>

**Update:**
Energy Commission staff conducted a site visit and critical project review meeting in May 2018. Transient Plasma Systems is developing a new ignition system architecture with higher pulse repetition rates than previous designs (100 kHz). High voltage transmission gates have been validated to enable multi-cylinder operation. The final design of the six-cylinder system is underway with plans to integrate it with the ISX12N for engine testing by late 2018.

**IMAGE**

Non-thermal plasma formed by nanosecond pulsed power technology.
**Project Name:**
Research and Development of Natural Gas D-EGR Engine for Improved On-Highway Efficiency - PIR-16-025

**Recipient/Contractor:**
Southwest Research Institute

**Natural Gas Funding Plan:**  
Natural Gas Research

**Project Term:**  
6/30/2017 to 12/31/2019

**Research Area:**  
Natural Gas-Related Transportation

**Issue:**
Natural gas is an attractive alternative transportation fuel due to its abundance, low cost, and lower emissions compared to diesel. However, diesel engines have higher thermal efficiency than current stoichiometric natural gas engines. This efficiency deficit erodes some of the greenhouse gas benefits of natural gas over diesel. It also reduces the competitiveness of natural gas vehicles. Recently, ultra-low emission natural gas engines have entered the heavy-duty on-road vehicle market. Efficiency improvements without compromising emissions must be made to increase adoption rates of low emission natural gas vehicles.

**Project Description:**
This project is developing and demonstrating dedicated exhaust gas recirculation (D-EGR) on a 12-liter heavy-duty on-road natural gas engine. D-EGR dedicates two cylinders of the six-cylinder test engine to produce the entirety of the exhaust gas used in the EGR system, taking advantage of internal syngas production with exothermic partial oxidation to extend dilution limits for stable combustion in the remaining cylinders. Southwest Research Institute is evaluating up to four advanced ignition systems to extend the rich burn limitations of the dedicated cylinders. Other engine optimization tasks include improving the combustion system and optimizing the turbocharger. The fuel efficiency and emissions benefits of this advanced engine concept will be tested on typical heavy-duty engine test cycles used for certification.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The efficiency gap between current stoichiometric natural gas engines and comparable diesel engines is a primary barrier to wider adoption of natural gas vehicles. D-EGR is an innovative engine design concept that maintains the emissions benefits of stoichiometric engines while improving efficiency through reduced pumping work. Further optimization of the engine around the D-EGR concept can help close the efficiency gap.

**Applicable Metrics:**

**Lower Costs:**
In 2015, the US Energy Information Agency estimated that California used 17.1 trillion BTUs of natural gas in transportation applications. Roughly 96 percent of the fuel used was used by trucks. A 10 percent increase in efficiency resulting from the D-EGR system potentially equates to $32 million to $42 million in fuel savings per year.

**Environmental Benefits:**
Increased adoption of natural gas as a transportation fuel for heavy-duty vehicles with high efficiency, near-zero emission natural gas engines will reduce criteria pollutant and...
greenhouse gas emissions. This project aims to demonstrate a 10 percent increase in engine efficiency, which translates to reduced fuel consumption and carbon emissions.

Public Health:
High levels of EGR enabled by the D-EGR configuration can reduce in-cylinder temperatures, reducing NOx emissions. This project aims to demonstrate near-zero NOx emissions below the 0.02 g/bhp-hr level, which is 90 percent below the current emissions standard.

Natural Gas Funds Encumbered:
$891,580

Update:
A critical project review meeting was held in June 2018 to evaluate project progress. Although the project was initially delayed due to test cell upgrades, the technical progress is back on track. Baseline tests have been completed showing an initial brake thermal efficiency of 37 percent. The engine has been converted to the D-EGR configuration. Four advanced ignition systems have been selected for the test program: dual coil offset, pre-chamber turbulent jet ignition, non-thermal plasma ignition, and microwave ignition. The research team is preparing for combustion visualization testing, modifying the exhaust system with the optimized turbocharger, and re-turning the engine model with data from the converted D-EGR engine.
### Project Name:
Development of Advanced Heavy Duty Class 8 CNG Engine Technology to Increase Efficiency - [PIR-16-026]

### Recipient/Contractor:
North American Repower, LLC

### Natural Gas Funding Plan: Project Term:
Natural Gas Research
7/28/2017 to 6/30/2020

### Research Area:
Natural Gas-Related Transportation

### Issue:
Stoichiometric spark-ignited natural gas engines are less efficient than equivalent diesel engines, resulting in fuel efficiency penalties in heavy-duty vehicle operation that may range between 10 to 20 percent depending on the application and duty cycle. In particular, spark-ignited natural gas engines experience losses in efficiency due to throttling. Heavy-duty natural gas vehicles require additional efficiency improvements to increase their competitiveness compared to diesel vehicles.

### Project Description:
This project was terminated in June 2018. The project's aim was to convert a 13-liter diesel engine to an advanced natural gas engine. The engine uses highly dilute lean burn combustion to achieve high efficiency and selective catalytic reduction to achieve ultra-low oxides of nitrogen (NOx) emissions. High energy ignition systems and advanced air handling enable the engine to reliably operate at highly dilute lean burn conditions. The project involves modeling and testing several major subsystems including the combustion system, air intake and exhaust, and control systems. The engine design uses the most effective parametric arrangement of these subsystems to maximize engine efficiency and NOx emission reductions. Early in the project, the recipient unexpectedly lost some key personnel, resulting in major staffing needs to complete the combustion modeling and engine dynamometer testing tasks.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
Continued efficiency, performance, and emission improvements to natural gas engines are necessary to support California’s efforts to improve air quality and reduce greenhouse gas emissions. The need for these advances is primarily driven by California’s clean transportation energy policies and initiatives such as the Sustainable Freight Action Plan and the increasing need to reduce emissions of NOx to attain to health-based ambient air quality standards in California’s severely polluted South Coast and San Joaquin Valley air basins.

### Applicable Metrics:

#### Public Health:
The technology developed under this research aims to achieve 10 to 16 percent increased thermal efficiency compared to stoichiometric spark-ignited natural gas engines. This technology also aims to achieve a near zero NOx level of 0.02 g/bhp-hr, which is 90 percent below the current emissions standard.

#### Consumer Appeal:
A natural gas engine that operates more efficiently will be more competitive with their diesel counterparts and a more viable option for fleets in California.
### Natural Gas Funds Encumbered:

| $900,000 |

### Update:

In January 2018, the recipient requested termination due to their inability to complete the project considering their loss of major personnel and internal business conditions. The project was mutually terminated in June 2018 without any funds spent.
**Project Name:**
An Integrated Risk Management and Decision-Support System for Ensuring the Integrity of Underground Natural Gas Storage Infrastructure in California - [PIR-16-027]

**Recipient/Contractor:**
DOE- Lawrence Berkeley National Laboratory

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan</th>
<th>Project Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/30/2017 to 12/31/2020</td>
</tr>
</tbody>
</table>

**Research Area:**
Natural Gas Infrastructure Safety and Integrity

**Issue:**
A large amount of natural gas is stored deep underground at high pressure in California. Many of the wells used currently for natural gas storage were designed decades ago for oil and gas production and the stresses they encounter today when used for natural gas injection/withdrawal were not considered during the original well design process. Rigorous monitoring programs and surface leakage surveys at regular intervals are needed based on age and/or history of integrity-monitoring results. There is an urgent need for a risk management system that is thorough, robust, and reliable to help guide early damage detection and leak prevention.

**Project Description:**
The project is to develop an integrated risk assessment and decision support system (IRMDSS) methodology and framework to improve underground natural gas storage security. The IRMDSS will be designed for: a) real-time warning of imminent risks, b) long-term assessment of evolving risks, and c) early leakage/damage detection. The IRMDSS will build its model based on existing site characteristics and data to predict potential risks. The risk assessment framework models will be created to predict reservoir pressures (to be compared to maximum or minimum allowed pressure), predict risk of leakage, and evaluate wellbore leakages if there is leakage detected.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:**
Unlike traditional asset and risk management approaches, the IRMDSS will merge process models with continuous reevaluation and assessment to provide indicators of potential threats. The IRMDSS will demonstrate a scheme to update its risk models based on real-time data collected in the field. Therefore, gas operators will be able to update the risk levels frequently for more accurate prediction. This will provide greater reliability, lower costs, and increased safety for the gas supply system.

**Applicable Metrics:**
- **Lower Costs:**
  The quantitative predictive methodology developed by the project will enable change of operations or early preventative engineering measures to prevent failure or damage, thus lowering mitigation costs through condition-based maintenance.

- **Greater Reliability:**
  The IRMDSS can help predict the potential occurrence of gas leaks by advanced monitoring and process-based modeling, recommend preventive and corrective measures that can be taken before leaks happen, and inform decisions on mitigation measures when low-level, or large leaks occur. These will improve the reliability of the gas supply.
Increase Safety:
The IRMDSS will help reduce the probability of and even prevent catastrophic and low-level gas leaks, and thus increase safety.

Environmental Benefits:
Early prevention and detection of failure will minimize methane leaks and thereby reduce emissions of greenhouse gases.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2,975,761</td>
</tr>
</tbody>
</table>

Update:
The project kicked-off in February 2018. LBNL has initiated development of use cases to guide the integration of the risk assessment framework models. LBNL worked with SoCalGas and selected a test well to install instruments with advanced monitoring equipment. This is necessary because it is not possible to know all the details of the rock properties underground within the well. The advanced monitoring equipment allows for continuously monitored data that allows for more frequent model property updates and more accurate risk assessment. The LBNL modeling team started to build a reservoir and a geomechanical model based on data from SoCalGas.
**Project Name:**
A Barrier-Based Quantitative Risk Management Approach for Underground Storage of Natural Gas - [PIR-16-028]

**Recipient/Contractor:**
DNV GL USA, Inc.

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
6/30/2017 to 12/31/2019

**Research Area:**
Natural Gas Infrastructure Safety and Integrity

**Issue:**
Underground gas storage (UGS) is a critical element of the overall natural gas infrastructure, since it helps balance the supply and demand of gas for end users. The natural gas consumption in California is projected to remain high for the next several years. The concentrations of impurities in the gas (also called gas quality) may change with time due to the mix of natural gas sources being accepted into the system. Some of the impurities are corrosive to the equipment injecting and extracting gas from the storage wells. With many of the storage sites aging, risk management is a major focus. The project objective is to develop a flexible risk assessment approach.

**Project Description:**
The project will advance risk assessment by combining two complementary modeling methodologies, the bowtie and the Bayesian network methods, into an effective tool for holistic risk management of the natural gas storage systems. The bowtie approach will systematically identify all the hazards and the nature of the various safety barriers that mitigate these hazards. The Bayesian network model will help quantify the likelihood of degradation of the safety barriers that prevent hazardous events from occurring. If an operator already has these safety barriers defined, they can still utilize the Bayesian model separately to calculate the probability of failure for identified threats. Safety barriers can range from passive hardware such as well tubing or well casing to hardware that requires human intervention such as a safety valve. The Bayesian network method accounts for the interactions between various factors leading to the degradation of safety barriers and identifies leading indicators for the performance of these safety barriers so that timely mitigative actions can be taken. The project will validate the proposed methods using case studies and make a best practice document.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The project will advance risk assessment approaches by identifying all the hazards and the various safety barriers that mitigate these hazards. The project will validate the proposed risk assessment methods using case studies from industry partners. The result of the project will be bowtie and Bayesian network models that could be used separately or in combination. The bowtie network model will be utilized as an operational risk management tool and the Bayesian network model will quantify the likelihood of degradation of the safety barriers to prevent hazardous events from occurring. The project will also develop a guidance document to be used as a best practice document for the risk assessment methods.
### Applicable Metrics:

**Greater Reliability:**
California users will benefit through avoidance of gas delivery disruptions. Improved risk management practices applied systematically may be able to reduce the implementation of extremely conservative measures that may reduce or disrupt energy delivery during high demand periods.

**Increase Safety:**
Improved understanding of threat mechanisms will help decision makers reduce the probability of failure by providing the operators with a risk-informed decision support tool.

**Environmental Benefits:**
Reduced release of natural gas to the atmosphere and aquifer is an intrinsic value for California's ecosystems, water supply, aesthetics, and other resources.

### Natural Gas Funds Encumbered:

$2,398,939

### Update:

This project began in September 2017. The project team performed a gap analysis to identify the current industry approaches to risk assessment, areas for improvement, and pathways to achieve these improvements. A Hazard Identification (HAZID) workshop was conducted, with participation from California utility partners, other industry members, and CEC staff. The purpose of the HAZID workshop was to identify the threats along with relevant preventive barriers. A HAZID report was developed. The HAZID workshop results were then converted in a manner suitable for incorporation into a bowtie model. The bowtie model was then used as a template to model the likelihood of failures of the well head and down hole components. A Bayesian network framework was developed to incorporate failure modes arising from corrosion and damage.
### Project Name:
High Efficiency Waste Heat to Osmotic Power - [PIR-17-001]

### Recipient/Contractor:
T2M Global LLC

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
4/20/2018 to 6/30/2021

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
An estimated 5 quadrillion Btu/yr of waste heat energy remains unutilized in California. A large portion of this waste heat is in the low-temperature range, which can be defined as waste heat below 400 degrees Fahrenheit. Low-temperature waste heat is difficult to recover and reuse economically. The various technologies currently being investigated have relatively low efficiency and high capital costs when used to generate power from low-temperature waste heat sources. The unutilized waste heat generated from natural gas combustion sources contribute to harmful emissions such as NOx and SOx, without providing any value.

### Project Description:
The goal of this project is to develop and demonstrate an innovative Waste Heat to Osmotic Power (WHOP) system. New CO2-philic polymeric draw solutions with high osmotic pressures, along with newly available high-flux Forward Osmosis (FO) membrane systems will pull large amounts of water across semi-permeable membranes in a process called Pressure Retarded Forward Osmosis (PRFO). The resulting pressurized water will run a turbo-generator to produce electrical power. The spent polymeric solution is regenerated by use of CO2 and waste heat, and restored as an osmotic draw solution for the next cycle of the PRFO process. The WHOP process promises efficiency greater than 15%, at an installed cost of less than $1,500/kW when in full production.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This Agreement will lead to technological advancement and breakthroughs to overcome barriers to the achievement of the State of California’s statutory energy goals through the development and demonstration of an engineering-scale 25 kW WHOP system for power generation from low-temperature waste heat. The success of this project will lead to innovative applications and practices for power generation in the PRFO process, and the creation of a more efficient techno-economic package at lower costs than current heat-engine based systems or solid-state devices. The successful demonstration of the WHOP technology will open a new economic pathway for currently wasted heat from industrial and other operations.

### Applicable Metrics:
**Lower Costs:**
Development and demonstration of a low cost waste heat to power system will lead to a cost savings to customers. The WHOP system is estimated to have an installed cost of less than $1,500/kW and a simple payback period of 1.5 years, when in full production.

**Economic Development:**
Assuming 1% per year penetration rate of the target waste heat market (1 quad), the WHOP system penetration would be 880 GWh per year. This translates to a 100-200 MW in additional capacity and a $1-3 billion per year market in California.
### Environmental Benefits:
The WHOP system will produce power without generating any new emissions of NOx, SOx, CO, CO2, PM, etc.

### Natural Gas Funds Encumbered:
$1,299,109

### Update:
Lab testing is underway to evaluate the different components of the WHOP system. Osmotic measurements are being performed to evaluate the selected polymers. Properties of the selected FO membrane modules are being investigated.
## Project Name:
Advanced Thermo Electric Generator System (ATEGS) - [PIR-17-002]

## Recipient/Contractor:
Altex Technologies Corporation

## Natural Gas Funding Plan: Project Term:
Natural Gas Research
4/20/2018 to 12/31/2021

## Research Area:
Renewable Energy and Advanced Generation

## Issue:
California has a vast amount of waste heat available that could be used to produce electricity, but there are relatively few installations of waste heat to power systems. Innovations are needed to more cost effectively utilize this waste heat energy. One technology to convert waste heat to power is thermoelectric generators (TEG). Current TEG power system competitiveness is limited by low efficiency and low net power output. In addition, the efficiency of single type TEG modules is lower when applied to broad waste heat temperature markets, thereby reducing the available markets that can be competitively addressed.

## Project Description:
This project is developing and demonstrating an advanced thermoelectric generator system (ATEGS) to produce electricity from waste heat. The recipient will use innovative, low-cost, durable, and very high heat flux Altex heat exchangers integrated with innovative high and low temperature Hi-Z TEG modules. They can be optimally aligned with the waste heat gas temperature profile to maximize efficiency and minimize cost. By matching TEG modules to the waste heat gas temperatures of interest and applying superior heat exchangers, a cost-competitive ATEGS can be manufactured for applications that cover almost all of the waste heat markets in California.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This Agreement combine state-of-the-art TEG modules with cutting-edge heat exchangers to create ATEGS configurations that will optimally address multiple waste heat markets at a competitive payback of less than 5 years. Electric power will be the primary output, with some applications also producing hot water in a retrofit package.

## Applicable Metrics:
**Lower Costs:**
California is estimated to have a 483 MWe waste heat to power market. If ATEGS penetrated 20% of that market, it would save the rate payers $72 million a year.

**Economic Development:**
It is projected that during the first five years after commercialization, 20% of the market will be captured. That will provide an accumulative sale value of $251 million.

**Environmental Benefits:**
If ATEGS penetrated 20% of the market, it would reduce the CO2 and criteria pollutants by 222,297 tons/year and 64 tons/year, respectively.
### Natural Gas Funds Encumbered:
$1,222,850

### Update:
Waste heat applications of interest have been defined and assessed. The design of the advanced thermoelectric generator system is in progress.
### Project Name:
Demonstration of 4.5 and 25 kW CARB-compliant Reciprocating Engine Micro-CHP Systems - [PIR-17-003 ]

### Recipient/Contractor:
Institute of Gas Technology dba Gas Technology Institute

### Natural Gas Funding Plan: Project Term:
Natural Gas Research
4/1/2018 to 9/30/2021

### Research Area:
Renewable Energy and Advanced Generation

### Issue:
Deployment of combined heat and power (CHP) systems have the potential to reduce primary energy consumption, decrease transmission and distribution losses, increase local reliability, and contribute to California's ambitious greenhouse gas reduction goals. Micro-CHP (CHP below 50 kW) has the potential to bring these benefits to a number of smaller markets including commercial office buildings, retail services, schools, and multi-family homes. However, the technology faces two key barriers: high cost and high emissions of criteria pollutants.

### Project Description:
This project is developing and demonstrating two cost-effective, near-zero NOx emission, reciprocating engine-based, micro-combined heat and power (CHP) systems in Southern California. The systems, sized at 4.5 kW and 25 kW, will first undergo laboratory testing in order to verify compliance with California Air Resources Board (CARB) Distributed Generation (DG) emissions standards and obtain CARB DG certification. If successful, they will be the only systems in their size range to be CARB DG certified, a significant step towards commercialization. The 4.5 kW and 25 kW systems will then be demonstrated at a commercial building and fitness center, respectively, in order to generate real-world operational data. The data will then be analyzed to produce summaries of system performance and cost-benefit estimates.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
If commercialized, the CHP systems would be the first available reciprocating engine-based, micro-CHP products available in California. This would allow access into an underserved market with approximately 3000 MW of potential according to a recent ICF study. Adoption of these systems would lead to lower cost, greater reliability, and public health related benefits.

### Applicable Metrics:
#### Lower Costs:
Conservatively assuming a 10-year life, the cost of the electricity produced by the CHP system would have been about 25% of the cost of grid electricity in California. The system would have yielded economic savings to facility owners who installed it.

#### Greater Reliability:
Distributed CHP systems increase both local and regional electric reliability. This is because they generate electricity for the local users while reducing transmission and distribution congestion regionally.
Public Health:
The CHP system far exceeded California ARB requirements for criteria pollutant emissions. In particular, laboratory tests showed NOx emission levels from the CHP system of 0.006 lb/MW-h compared to the California ARB DG Regulation of 0.07 lb/MW-h which corresponds to an order of magnitude reduction.

Natural Gas Funds Encumbered:
$1,499,406

Update:
The project completed lab testing in 2016 to verify that the CHP system is in compliance with 2007 California ARB standards. Testing results were promising – the system demonstrated a good electric efficiency of 28% (at full load, higher heating value basis) and excellent criteria pollutant emissions of 0.006 lb/MW-h (compared to the standard of 0.07 lb/MW-h). However, due to undisclosed reasons, the CHP technology manufacturer (and match funding provider) EC Power decided to suspend development of the CHP system in the US. Without their support, the demonstration could not continue as originally planned and the project was ended.

In spring 2018, a new project (agreement no. PIR-17-003) began which will test the same CHP technology and demonstrate it at a fitness center. EC Power has partnered with Lochnivar, a well-known US boiler manufacturer, to launch the product for the US market.

Computer render of the EC Power XRGi 15|20 combined heat and power unit, the Q-Heat Distributor, and the iQ-Control Panel shown above (left to right).
## Low Temperature, Efficient Heat Capture to Reduce Natural Gas Consumption in the Chemical Industry - [PIR-17-004]

### Recipient/Contractor:
Element 16 Technologies, Inc.

### Natural Gas Funding Plan:
<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>4/25/2018 to 3/31/2022</td>
</tr>
</tbody>
</table>

### Research Area:
Energy Efficiency

### Issue:
The chemicals industry is the second largest user of primary energy in the United States, after only the petroleum industry, representing almost a fifth of all manufacturing energy consumption. In California, this sector is likely to be affected by the cap-and-trade program, especially for those that emit more than 25,000 metric tons of CO2e annually. These industries will be required to reduce their emissions or purchase allowances. Finding methods to reduce the energy consumed and associated GHG emissions in the manufacturing of chemicals has the potential to impact their ability to be competitive in the global market.

### Project Description:
This project will demonstrate the first economically viable, low temperature industrial heat capture system with energy storage. The project's goal is to demonstrate a 15% natural gas usage reduction in a chemical processing plant in Southern California. This project will be the first large-industrial scale demonstration of Element 16's sulfur and pressurized water product. Successful operation of this technology would indicate to chemical industry that the heat capture systems (HCS) can reliably improve plant economics. One novel feature of the proposed HCS is heat energy storage with quick-charging and discharging. By demonstrating how inexpensive and economically advantageous this feature can be, this project would establish a viable use for intermittent low grade waste heat.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
Element 16 invented a heat capture system (HCS), which uses pressurized superheated water and elemental sulfur to inexpensively store and transport low temperature waste heat. A unique advantage of the HCS is sulfur's solid-liquid phase change at low temperature, reducing the footprint and cost to capture and store megawatt-hours of heat. The HCS uses modular tank heat exchangers with low-cost containment materials to extract heat from an intermittent waste heat stream. The key advantages of this heat capture system are its ability to capture heat from steam, low cost (<$15/kWh), small footprint, ability to store an intermittent waste heat source, and ability to deliver a continuous or on-demand heat supply.

### Applicable Metrics:
**Lower Costs:**
Element 16's heat capture system has the potential to recover useful heat from low-temperature waste heat streams and deliver it for process heating applications to reduce on-site natural gas demand at industrial facilities.
### Natural Gas Funds Encumbered:
$1,500,000

### Update:
The team held the project kick off meeting on April 26, 2018. The research team has begun the system design and cost modeling for the heat capture system.

Modular heat capture system with sulfur and superheated water tanks.
### Project Name:
Demonstration of Smart Combustion Technology Using Natural Gas Fuel Quality Sensors - [PIR-17-005]

### Recipient/Contractor:
The Regents of the University of California on behalf of the Riverside campus

### Natural Gas Funding Plan:
Natural Gas Research

### Project Term:
6/1/2018 to 9/30/2021

### Research Area:
Energy Efficiency

### Issue:
One of the major issues for industries is the variation in natural gas fuel quality. Variation in fuel quality affects the efficiency of the fuel combustion process. The Wobbe Index (WI), is the ratio of a fuel's calorific value to the square root of its specific gravity, is a well-known, critical factor to measure fuel quality and can be used to minimize the impact of variations in a fuel gas quality and thus improve combustion efficiency. However, WI is currently measured using bulky, complex, and expensive analyzers and this prevents their use in a small or medium scale industries.

### Project Description:
This project develops and demonstrates a Smart Combustion System (SCS) that uses an intelligent controller that includes natural gas fuel quality sensors. The sensor system uses artificial intelligence to predict the fuel quality of natural gas feedstock based on the Wobbe Index. The system is expected to improve the fuel efficiency and emissions profile of natural gas fired boilers.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project will develop a “smart combustion technology” which requires advancing multiple emerging technologies including intuitive fuel quality sensor technology, Artificial Intelligence, and Internet of Things. For the installation site, the technology is estimated to save approximately 8,000 to 13,000 therms/year, with GHG emission reductions of up to 186 metric ton/year. NOx reduction is estimated to be up to 157 kg/year, which is 19-28 percent reduction from current levels. Hence, widespread adoption of this technology by the California Industrial sector will reduce natural gas use and lower the GHG emissions and criteria pollutants.

### Applicable Metrics:
**Lower Costs:**
Increasing the efficiency of the natural gas combustion process will reduce the consumption of natural gas and result in lower natural gas costs. The yearly net saving of natural gas in the installation site is estimated from $8,000 to $13,000.

**Environmental Benefits:**
One of the project goals is to achieve a 30 percent reduction in NOx emissions via a 10 percent increase in natural gas combustion efficiency enabled by the SCS technology.
Natural Gas Funds Encumbered:
$1,499,910

Update:
The selection of a seed composition of natural gas was finalized and include four standard compositions from Rocky Mountain pipeline, Peruvian LNG, associated high ethane, associated high propane, and methane (for reference) have been selected. The Recipient has begun building the database, and licenses for Chemkin and ASPEN tool were secured and installed. The natural gas simulator design was completed and ordered. The estimated delivery for this critical equipment for sensor development is 10/2018.

Flow diagram of integrated Smart Combustion System.
**Project Name:**
Demonstration of a CNG-Hybrid Electric Super-Truck (CHEST) - [PIR-17-008]

**Recipient/Contractor:**
Transportation Power, Inc.

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan</th>
<th>Project Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/7/2018 to 6/30/2021</td>
</tr>
</tbody>
</table>

**Research Area:**
Natural Gas-Related Transportation

**Issue:**
Battery-electric trucks may require upwards of a megawatt-hour (MWh) of battery capacity to achieve operating ranges of 300 to 500 miles for large Class 8 trucks weighing up to 80,000 pounds. The charging infrastructure required to support large numbers of these trucks may take many years to establish. It is unclear how practical these trucks will be when considering the size of the battery pack and the power demands for charging within acceptable time intervals. Natural gas-driven range extenders are a potential solution. However, previous efforts have shown that improper optimization of the hybrid system can lead to reduced performance and high emissions.

**Project Description:**
This project is developing and demonstrating a plug-in, compressed natural gas (CNG), hybrid-electric drayage truck with a series hybrid design that uses a heavily downsized natural gas engine to significantly extend the operating range. The project aims to maintain 70 miles of all electric range with a smaller battery pack that does not require extraordinarily high charge rates. This project will result in the advancement of the state’s energy goals by expanding the use of low carbon natural gas as a transportation fuel in an advanced hybrid-electric configuration to reduce greenhouse gas and pollutant emissions from the goods movement sector.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The project integrates several innovations to achieve the truck’s performance goals: 1) improved CNG engine controls to achieve greater emission reductions under hybrid operating conditions, 2) high energy batteries in modular configurations to reduce weight, 3) innovative electric axle drive configuration to further reduce weight, cost, and parts count.

**Applicable Metrics:**
Greater Reliability:
Range extended hybrid trucks can use smaller battery packs without compromising operating range. Charging smaller battery packs does not require extremely high charge rates that can impact grid reliability at large scales.

Environmental Benefits:
The series-hybrid configuration can reduce greenhouse gas emissions by allowing the CNG engine to constantly operate at high efficiency conditions when recharging the battery. The electric drive system also enables high efficiency propulsion and regenerative braking.
APPENDIX D: FY 2017-18 NATURAL GAS ACTIVE AND COMPLETED PROJECT WRITE-UPS

<table>
<thead>
<tr>
<th>Public Health:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 8 drayage trucks tend to operate in and around major freight corridors surrounded by disadvantaged communities, such as the neighborhoods surrounding California ports and inland distribution centers. Developing a hybrid truck with the ability to operate in all electric mode can reduce the public health impacts of freight transportation to these sensitive communities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,500,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Update:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The kickoff meeting for this project was conducted in May 2018. The research team is working on the selection of the natural gas engine to be used as the range extender for the hybrid truck.</td>
</tr>
</tbody>
</table>

**IMAGE**

![Innovative electric axle drive system.](image-url)
**Project Name:**
Optimization and Demonstration of a Near-Zero, Heavy-Duty, Hybrid-Electric Truck - [PIR-17-009]

**Recipient/Contractor:**
Institute of Gas Technology dba Gas Technology Institute

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/7/2018 to 6/30/2021</td>
</tr>
</tbody>
</table>

**Research Area:**
Natural Gas-Related Transportation

**Issue:**
Real world testing of heavy-duty hybrid vehicles performed by UC Riverside, the California Air Resources Board, the National Renewable Energy Laboratory, and others have shown that they are consistently not meeting performance targets and are often increasing NOx emissions. This is largely because most hybrid controls in the Class 8 sector have not matured to have an integrated vehicle propulsion energy management solution. Current hybrid technologies are evolving from traditional internal combustion engine (ICE) only architectures. Most hybrid systems in Class 8 trucks do not efficiently use the driver demand coordination for efficient energy management between electrical and ICE power.

**Project Description:**
This project is developing and demonstrating a fully integrated and optimized liquefied natural gas, plug-in, hybrid-electric drayage truck. The project aims to develop a hybrid truck that can exceed the performance of conventional drayage trucks, while dramatically reducing emissions and maximizing fuel economy. The truck can also operate in all electric mode for zero emission operation and utilize engine start-stop technology to minimize extensive idling that is typical for certain port drayage duty cycles. The truck will also be equipped with the Cummins Westport L9N, an advanced natural gas engine certified to oxide of nitrogen (NOx) emission levels that are 90 percent below the standard. With the assistance of simulation models, advanced controllers for the major subsystems and optimized electrical components will be designed specifically to optimize vehicle performance and drivability for drayage applications.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This proposed project is developing and validating tools to facilitate technology transfer that can enable proper integration and optimization of natural gas engines with electric motors for a variety of vehicle drivetrains. This work advances the current state-of-the-art in matching and packaging of the natural gas engine and the electric subsystems at lower incremental capital cost, with better fuel economy, improved service and drivability, while lowering greenhouse gas and criteria pollutant emissions. Adoption of optimized natural gas hybrid-electric vehicles will increase freight efficiency, improve air quality, and assist California in achieving its sustainable transportation goals.

**Applicable Metrics:**
Environmental Benefits:
Improved fuel efficiency leads to reduced fuel use and GHG emissions. The project aims to double fuel efficiency compared to previous iterations of hybrid-electric drayage trucks, which translates to a 50 percent reduction in GHG emissions.
Public Health:
NOx is a major precursor to smog formation. The project aims to maintain the 0.02 g/bhp-hr NOx level of the L9N engine when operating in hybrid mode. Zero emission driving is also possible to further reduce air quality impacts.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,499,381</td>
</tr>
</tbody>
</table>

**Update:**
A kick-off meeting was held in May 2018. The research team is working on analyzing the vehicle system and associated duty cycles to determine high-level system specifications and baseline performance. This information will guide the development of the multi-level control system.

**Image**

Hybrid Natural Gas-Plug In Electric Heavy Duty Test Truck.
**Project Name:**
Using Chemical and Isotopic Analyses to Improve Life-Cycle Assessments of the Natural Gas Consumed in California - [PIR-17-010]

**Recipient/Contractor:**
Lawrence Berkeley National Laboratory

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/15/2018 to 3/31/2022</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy-Related Environmental Research

**Issue:**
California Assembly Bill 1496 (AB 1496) states that there is a need for much better information on the life-cycle emissions resulting from California's imports of natural gas and that there is an urgent need to improve the monitoring and measurement of methane emissions from major sources in California. The chemical and isotopic fingerprinting of natural gas from different sources presents a highly promising tool for quantifying specific sources of natural gas used in the state and calculating their associated emissions.

**Project Description:**
This project develops a methodology to enable the differentiation between sources of natural gas using chemical and isotopic analysis of natural gas constituents and investigates the relationship between the origin of natural gas and the concentration of methane molecules with two or more heavy isotopes.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
This project will develop a new technique helping to identify the origin of natural gas consumed in California and offer a breakthrough methodology for estimation of total life-cycle GHG emissions for natural gas used in California, providing support to the California Air Resources Board.

**Applicable Metrics:**
**Environmental Benefits:**
This project will develop a method to enable a better life-cycle assessment of the natural gas consumed in California, thus enabling procurement from lower-emitting source basins and reducing the overall emissions intensity of natural gas use in the state.

**Natural Gas Funds Encumbered:**
$549,978

**Update:**
In September 2018, a joint kick-off meeting took place with the team from agreement PIR-17-011 - UC Irvine. These two projects will develop a methodology for "chemical fingerprinting" of natural gas samples using different analytical approaches and will leverage available resources.
## Project Name:
Developing a Methodology to Determine Chemical and Isotopic Composition of Natural Gas Consumed in California - [PIR-17-011]

## Recipient/Contractor:
The Regents of the University of California, Irvine Campus

## Natural Gas Funding Plan: Project Term:
Natural Gas Research  
5/30/2018 to 12/30/2021

## Research Area:
Energy-Related Environmental Research

## Issue:
California relies on natural gas for electricity generation, heating, residential/commercial/industrial use, and, increasingly, transportation. Fugitive emissions from the natural gas supply chain are one of the largest methane sources regionally and nationally, and studies have shown that some natural gas production basins have higher rates of methane emissions than others. Because most natural gas consumed in California is imported from outside the state, and because the provenance of that gas is largely unknown, it is difficult to calculate the full life-cycle greenhouse gas emissions of natural gas, as required by California Assembly Bill 1496.

## Project Description:
The project includes measurements of the chemical (~80 volatile organic compounds) and isotopic composition (concentration of heavy carbon (13C) and heavy hydrogen (D) in methane) of natural gas in 25 basins across the United States. The team is compiling an online database of natural gas composition to show which constituents are unique to each basin. These data are then used to determine the contributions of natural gas from various basins to the natural gas procured in markets around California. The project team is performing a preliminary assessment of the greenhouse gas footprint of natural gas imported to California from different basins, using fugitive emissions rate estimates from previously published studies.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
The project results will provide a new method for identification of the origin of natural gas and offer a breakthrough technique for estimation of total life-cycle GHG emissions for natural gas used within the state of California that could be used by the California Air Resources Board. In addition, a developed database of natural gas composition, including toxic components could be used for better predicting health impacts from natural gas leaks.

## Applicable Metrics:
Environmental Benefits:  
This project will provide the framework for calculating total supply chain methane emissions of natural gas imported to and used in California. This will fulfill the requirements of Assembly Bill 1496 to carry out life-cycle greenhouse gas emission analysis of natural gas produced and imported into the state using the best available and cost-effective scientific and technical methods.
Public Health:
The database of the level of hazardous air pollutants in natural gas imported to California from each production basin in the United States, such as benzene, toluene, ethylbenzene, and many others, will be useful for state agencies, such as California Air Resources Board, Department of Health, in predicting the public health impacts of any future large natural gas leaks.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$550,000</td>
</tr>
</tbody>
</table>

Update:
The joint kick-off meeting for this project and agreement PIR-17-010 with LBNL will be held in September 2018. The two projects are pursuing complementary methodologies to enhance abilities to estimate emissions from different natural gas basins.
### Project Name:
Developing Next-generation Cal-Adapt Features to Support Natural Gas Sector Resilience - [PIR-17-012]

### Recipient/Contractor:
The Regents of the University of California

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/7/2018 to 3/31/2022</td>
</tr>
</tbody>
</table>

### Research Area:
Energy-Related Environmental Research

### Issue:
Energy sector operations, management, and planning require best available and peer-reviewed information on projected climate and weather-related risks to maintain safe, reliable, and affordable energy. California’s energy infrastructure, including facilities and pipelines that store, transmit, and distribute natural gas, is vulnerable to extreme weather events that may differ significantly from historical records as a result of changes in our climate.

### Project Description:
With funding and oversight from the Energy Commission, UC Berkeley’s Geospatial Innovation Facility (GIF) is developing Cal-Adapt to provide new visualizations of locally relevant climate-related risks to the natural gas system. Cal-Adapt provides natural gas system stakeholders with actionable information through interactive, compelling, and useful visualizations. These tools can identify vulnerable populations and infrastructure locations that are at risk from climate-related factors, thereby helping to secure California’s energy future.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project will provide crucial actionable information on climate-related risks to natural gas storage and distribution infrastructure. California is a global leader in addressing climate change and in developing energy policies that strive to conserve resources, protect the environment, and protect public health and safety while also providing reliable and cost-effective energy to ratepayers. The enhancements to Cal-Adapt described here can help the energy sector to meet its important climate, energy, air quality, and other environmental goals while also maintaining safe, reliable, and affordable energy for California.

### Applicable Metrics:
**Greater Reliability:**
This project will result in the ratepayer benefits of greater energy reliability by supporting natural gas sector planning, management, and adaptation to climate change. Climate change is expected to impact California’s natural gas and energy infrastructure through projected increased temperatures, sea level risk, wildfire risk, and severe droughts. Preserving reliable, safe, and cost-effective operations in the face of a changing climate requires integration of projected climate and weather-related parameters into decision making.
Energy Security:
California’s populations, both now and in the future, benefit from safe and reliable natural gas supplies. A critical facet of the energy sector is the ability to protect ratepayers from service interruptions and from larger service failures that may occur from climate-related events (such as heat waves or sea-level rise). By being able to identify locations that may be at risk from sea-level rise or extreme events, the energy sector will be better prepared to safeguard vulnerable populations and ratepayers.

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Update:</th>
</tr>
</thead>
<tbody>
<tr>
<td>This project was approved at the April 2018 Business Meeting.</td>
</tr>
</tbody>
</table>
**Project Name:**
Development of an Integrated Methodology for Assessing Integrity of Levees Protecting Natural Gas Infrastructure - [PIR-17-013]

**Recipient/Contractor:**
InfraTerra, Inc.

**Natural Gas Funding Plan:**
Natural Gas Research

**Project Term:**
5/31/2018 to 3/31/2022

**Research Area:**
Energy-Related Environmental Research

**Issue:**
Levees in the Sacramento-San Joaquin Delta were built as simple peat dikes resting on marsh soils and are therefore highly vulnerable to damage from floods, wave action, seepage, subsidence, burrowing animals, earthquakes, and sea level rise. The structural integrity of levees in the Sacramento-San Joaquin Delta (Delta) has for decades been a subject of investigations and continues to be a source of concern. This study will leverage the wealth of information from previous studies and optimize non-invasive geophysical data acquisition technologies to identify potential vulnerabilities of the natural gas infrastructure to levee failures in the Delta.

**Project Description:**
The Recipient is developing a comprehensive Geographical Information System (GIS) database that includes three major data sets: geohazards, levee condition, and natural gas infrastructure. These data sets are being combined to develop a map that delineates the Delta area into distinct regions with similar cumulative susceptibility for detailed geophysical data acquisition. Interferometric Synthetic Aperture Radar (InSAR) data is used to identify and characterize the distribution of geohazards in conjunction with the database. Geophysical investigations are performed for these levees with four geophysical survey techniques to obtain complete subsurface and structural levee profiles and to develop an understanding of the most effective method(s) for identifying natural gas infrastructure vulnerabilities from the Delta levees and environment. The results of the geophysical investigation will also be validated by the GIS database and existing soil boreholes made by the Department of Water Resources. Pipeline performance modeling will be conducted to understand the vulnerabilities of the natural gas infrastructure within the Delta system.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
The project will identify areas of high risk to natural gas infrastructure in the Delta and test a minimum of four geophysical methods for assessing levee integrity. This testing will be conducted at several Delta sites and will include seismic surface wave surveying, electrical resistivity, ground penetrating radar, and electromagnetic surveying. The research team will also conduct pipeline performance modeling to understand which potential levee breaches or geohazard impacts may cause pipeline failure. Understanding the thresholds where pipelines may perform well or fail is essential for (1) prioritization of mitigation locations, and (2) allocating economic and work force resources where needed.
**Applicable Metrics:**

Greater Reliability:
The study will use non-invasive geotechnical technology to develop a methodology for assessing the structural stability of levees protecting the Delta. Failure of these levees may affect natural gas pipelines and storage facilities that are a critical component of the state's natural gas infrastructure, so improving our understanding of the levees' integrity will help prevent potential disruptions from levee failures and ensure greater reliability.

**Natural Gas Funds Encumbered:**

$549,500

**Update:**

This agreement was executed in July 2018, and the kick-off meeting was held in September 2018.
## Project Name:
Developing Next-Generation Cal-Adapt Features to Support Natural Gas Sector Resilience - [PIR-17-014]

## Recipient/Contractor:
Eagle Rock Analytics

## Natural Gas Funding Plan:
Natural Gas Research

## Project Term:
5/7/2018 to 3/31/2022

## Research Area:
Energy-Related Environmental Research

## Issue:
California’s natural gas system is increasingly vulnerable to extreme weather as the climate warms. Cal-Adapt is growing rapidly in the scope and complexity of the data it hosts. Concurrently the needs of natural gas stakeholders are evolving and becoming more technical as climate change’s impacts on California become better understood. Cal-Adapt requires additional scientific and technological guidance and support to accommodate the increasing complexity of data and tools. Moreover, the field of climate modeling is developing quickly, and Cal-Adapt needs scientific expertise and guidance to identify opportunities to improve resilience of the natural gas system to climate change.

## Project Description:
The researcher will serve as scientific lead of Cal-Adapt, working closely with the host of Cal-Adapt to support development of tools and visualizations that successfully incorporate scientifically and statistically sound methods and more clearly convey uncertainty and range of data. The researcher will represent Cal-Adapt in the scientific community, identify opportunities to improve Cal-Adapt to meet the needs of natural gas sector stakeholders, and provide guidance and direction to the host of Cal-Adapt to ensure the cloud computing architecture is reflective of high-level best practices.

## How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project provides climate informatics to natural gas IOUs, governmental stakeholders, elected officials and energy sector stakeholders. Such informatics can be used to understand natural gas infrastructure vulnerability in the context of risk from wildfire, sea-level rise or extreme climate events. Informed deployment of infrastructure will increase reliability through reductions of damage, decrease costs through reduced losses, and increase safety of the delivery system. Data and algorithms to be hosted on Cal-Adapt will be used to understand shifts and changes in peak natural gas consumption.

## Applicable Metrics:
**Greater Reliability:**
This project will result in the ratepayer benefits of greater natural gas reliability and increased safety by enabling Investor-owned utilities (IOUs) to understand natural gas infrastructure vulnerability in the context of risk from wildfire, sea-level rise or extreme climate events. Informed deployment of infrastructure will increase reliability through reductions of damage, decrease costs through reduced losses and increase safety of the system delivery.
Natural Gas Funds Encumbered:
$200,000

Update:
This project was approved at the April Business Meeting.

Machine learning techniques could be used to identify the location and/or existence of an atmospheric river during pre-processing. This would allow Cal-Adapt to employ threshold independent proxies to visualize heavy precipitation events associated with atmospheric rivers.
### Project Name:
Near-Zero Emission Heavy-Duty Natural Gas Plug-In Hybrid-Electric Truck - [PIR-17-016]

### Recipient/Contractor:
Efficient Drivetrains Inc.

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>5/14/2018 to 12/31/2020</td>
</tr>
</tbody>
</table>

### Research Area:
Natural Gas-Related Transportation

### Issue:
Natural gas hybrid-electric vehicles represent a potential bridge between near-zero emission natural gas engine technology and zero emission electric vehicle technology. However, inadequate optimization of control systems and vehicle integration can lead to poor performance and increased emissions. Previous development efforts have not addressed this problem because they focused only on developing and demonstrating the hybrid-electric vehicle system, ignoring the complex interactions occurring between the natural gas engine and the after-treatment system. In addition, the hybrid-electric technologies must be developed with a clear path to market.

### Project Description:
This project is developing and demonstrating a heavy-duty, natural gas, hybrid-electric vehicle system. The research team is using a comprehensive and iterative testing and validation process to optimize the system controls with the goal of reducing oxides of nitrogen (NOx) emissions and improving fuel economy. The project involves a redesign of the hybrid system to reduce weight, complexity, and installation costs. The project will also test geofencing capabilities to limit noise and/or emissions while operating in sensitive areas such as disadvantaged communities. The test truck will be demonstrated with a Southern California fleet over 6 months.

### How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:
This project will integrate a hybrid-electric system with a production-ready natural gas engine that will greatly reduce air pollution and greenhouse gas emissions and be able to meet the requirements of California Air Resources Board's newly adopted Innovative Technology Regulation (ITR). The project will accelerate the path to market of natural gas hybrid-electric vehicle systems by reducing costs, increasing fuel savings, and validating the benefits of these systems over a prolonged fleet demonstration.

### Applicable Metrics:

**Economic Development:**
This project will establish a strategic partnership between two California-based companies specializing in clean transportation technologies that can create high-quality manufacturing jobs in the state.

**Environmental Benefits:**
This project aims to achieve a 30% increase in fuel economy in hybrid mode. The vehicle can also plug in to charge its batteries. These benefits translate to greenhouse gas emission reductions compared to conventional vehicles.
Public Health:
This project aims to reduce NOx emissions by 50% in hybrid mode. This project will also demonstrate the potential benefits of zero emission geofencing where hybrid vehicles can operate in all-electric mode in disadvantaged communities to limit engine noise and emissions.

**Natural Gas Funds Encumbered:**
$1,087,237

**Update:**
The kickoff meeting was held in June 2018. The research team is working on designing the next generation hybrid system with the goal of reducing weight, complexity, and installation costs to improve the technology's market feasibility.
**Project Name:**
High Efficiency Process Heating - [PIR-17-017]

**Recipient/Contractor:**
Institute of Gas Technology Institute

<table>
<thead>
<tr>
<th>Natural Gas Funding Plan:</th>
<th>Project Term:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Research</td>
<td>6/29/2018 to 3/31/2022</td>
</tr>
</tbody>
</table>

**Research Area:**
Energy Efficiency

**Issue:**
Current technologies for reducing natural gas use in industrial processes involve reducing heat losses and/or recovering and recycling heat that would be otherwise lost. A wide range of technologies are available, but many provide only modest gains in energy efficiency and long payback periods, and some may adversely affect the process. Solar thermal for process heating is attractive but current technologies are either limited to low temperature applications, not distributable or not economical.

**Project Description:**
This project will demonstrate the integration of high temperature solar thermal energy with an industrial process to significantly reduce its natural gas use. The system will be tested initially to address issues and acquire performance data prior to integration with an industrial process at a demonstration site. The project will assess the assumption that the Solar Thermal System (STS) technology can be seamlessly integrated into existing infrastructure and controls, allowing for a straight-forward installation and reliable operation, while providing high more than 20% natural gas reduction with a simple payback of less than 5 years. The STS can either preheat the feed material or add heat directly to the product.

**How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State’s Statutory Energy Goals:**
If the high temperature STS technology can deliver cost-effective and on-demand, high temperature process heat it will greatly expand the industrial market for solar thermal which will have a major impact of reducing greenhouse gas emissions for the industrial sector.

**Applicable Metrics:**

<table>
<thead>
<tr>
<th>Lower Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The STS technology is estimated to have a simple payback of less than 5 years, which make this technology cost effective for industries looking for alternatives to fossil fuel combustion.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Natural Gas Funds Encumbered:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,405,947</td>
</tr>
</tbody>
</table>

**Update:**
The agreement was approved at the 6/29/2018 business meeting and a kick off meeting took place in August 2018.