CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

STAFF REPORT

Natural Gas Research and Development Program

2019 Annual Report – Appendices

Gavin Newsom, Governor

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APPENDIX A: Select Natural Gas Policy Goals for California's Energy Future

Table A-1: Legislative Policy Goals and Standards

Legislation	Policy Goal or Standard
Assembly Bill 32 (2006)	AB 32 requires California to reduce its GHG emissions to 1990 levels by 2020 — a reduction of approximately 15 percent below emissions expected under a "business as usual" scenario. The full implementation of AB 32 will help mitigate risks associated with climate change, while improving energy efficiency, expanding the use of renewable energy resources, cleaner transportation, and reducing waste.
Assembly Bill 1613 (2007)	The Waste Heat and Carbon Emission Reduction Act mandates that California policies advance the efficiency of the state's use of natural gas by using excess waste heat through CHP technologies.
Assembly Bill 1900 (2012)	Develop standards for constituents in biogas to protect human health and pipeline integrity and safety
Assembly Bill 193 (2018)	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.
Assembly Bill 2006 (2018)	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.

Legislation	Policy Goal or Standard
Assembly Bill 2127 (2018)	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.
Assembly Bill 2195 (2018)	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.
Assembly Bill 2195 (2018)	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.
Assembly Bill 3232 (2018)	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.
Senate Bill 1250 (2006)	Provisions for specified entities to fund cost-effective energy efficiency and conservation activities and public interest research and development not adequately provided by the competitive and regulated markets.
Senate Bill X1 2 (2011)	The Renewables Portfolio Standard requires all electricity retailers to meet 33 percent of their retail sales with renewable energy by 2020.
Senate Bill 1371 (2014)	SB 1371, Leno. Natural Gas: Leakage Abatement—with priority given to safety, reliability, and affordability of service, the CPUC must determine whether existing practices are effective at reducing methane leaks and promoting public safety and whether alternative practices may be more effective.

Legislation	Policy Goal or Standard
Senate Bill 350 (2015)	The Clean Energy and Pollution Reduction Act of 2015 (De León, Statutes of 2015),—which establishes a California target to increase the percentage of the state's renewable electricity sources from one-third to 50 percent and achieve a doubling of statewide energy efficiency savings in electricity and natural gas for customers by 2030.
Senate Bill 32 (2016)	The California Global Warming Solutions Act requires the state to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030.
Senate Bill 887 (2016)	Natural Gas Storage Wells -This bill requires the operator of a gas storage well, before January 1, 2018, to have commenced a mechanical integrity testing regime specified by the division and would require the division to promulgate regulations that establish standards for all gas storage wells, as specified. (i) The standards for natural gas storage wells need to be improved in order to reflect 21st century technology, disclose and mitigate any risks associated with those wells, recognize that these facilities may be in locations near population centers, and ensure a disaster like the Aliso Canyon leak does not happen again.
Senate Bill 1383 (2016)	This bill requires the state board (CARB), no later than January 1, 2018, to approve and begin implementing that comprehensive strategy to reduce emissions of short-lived climate pollutants to achieve a reduction in methane by 40%, hydrofluorocarbon gases by 40%, and anthropogenic black carbon by 50% below 2013 levels by 2030, as specified. The bill also would establish specified targets for reducing organic waste in landfills.

Legislation	Policy Goal or Standard
Senate Bill 100 (2018)	SB 100, De León. California Renewables Portfolio Standard Program: emissions of greenhouse gases. The California Renewables Portfolio Standard Program requires the PUC to establish a renewables portfolio standard. The program additionally requires each local publicly owned electric utility, as defined, to procure a minimum quantity of electricity products from eligible renewable energy resources to achieve the procurement requirements established by the program. The Legislature has found and declared that its intent in implementing the program is to attain, among other targets for sale of eligible renewable resources, the target of 50% of total retail sales of electricity by December 31, 2030.
Senate Bill 1000 (2018)	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.
Senate Bill 1013 (2018)	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.
Senate Bill 1014 (2018)	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.

Legislation	Policy Goal or Standard
Senate Bill 1016 (2018)	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.
Senate Bill 1017 (2018)	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.
Senate Bill 1403 (2018)	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.
Senate Bill 1477 (2018)	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.

Table A-2: Policies and Standards

Policy/Standard	Description
Public Resources Code 25620	Public interest energy research, demonstration, and development projects should advance energy science or technologies of value to California citizens.
California's Loading Order, from the California *Energy Action Plan*	Prioritizes Energy Commission's research investments: 1) energy efficiency and demand response, 2) renewable energy and distributed generation, and 3) clean fossil fuel sources and infrastructure improvements.
Integrated Energy Policy Report	The Energy Commission's biennial energy forecasting and assessment report recommends policies to foster the development of energy efficiency, renewable energy, and more.
CPUC *Energy Efficiency Strategic Plan*	Sets efficiency goals, including zero-net-energy goals for new homes by 2020 and for new commercial buildings by 2030.
Bioenergy Action Plan to implement Executive Order S-06-06 (2006)	Outlines a set of target goals that would establish the increasing use, and production of biofuels and biopower for both electricity generation and substitution of natural gas and petroleum within the state of California.
Executive Order S-01-07 Low Carbon Fuel Standard (LCFS) (2007)	Sets goal to reduce carbon intensity of the state's fuels by 10 percent by 2020.
Governor Brown's *Clean Energy Jobs Plan* (2011)	California should produce 20,000 new megawatts (MW) of renewable electricity by 2020, 12,000 MW of distributed energy, 8,000 MW of large-scale renewables, and 6,500 MW from combined heat and power (CHP).
Executive Order B-18-12 Greening State Buildings	Calls for efficiency improvements in new or renovated state buildings larger than 10,000 square feet; sets zero-net-energy (ZNE) and GHG emission reduction goals.
Executive Order B-18-12 Greening State Buildings	Calls for efficiency improvements in new or renovated state buildings larger than 10,000 square feet; sets zero-net-energy (ZNE) and GHG emission reduction goals.

Policy/Standard	Description
Executive Order B-29-15	Established actions to save water, increase enforcement to prevent wasteful water use, streamline the state's drought response, and invest in new technologies that will make California more drought-resilient.
Executive Order B-30-15 GHG Reduction Target and Climate Adaptation and Senate Bill 32 (2016)	Sets a GHG reduction target of 40 percent below 1990 levels by 2030.
Executive Order B-32-15 Integrated Action Plan	Directs improvement of freight efficiency, transition to zero-emission technologies, and increase competitiveness of California's freight system.
Governor Brown's Aliso Canyon Gas Leak Proclamation (2016)	The order directs further action to protect public health and safety, ensure accountability and strengthen oversight of gas storage facilities.
Air Resources Board's *California's 2017 Climate Change Scoping Plan*	The strategy for achieving California's 2030 greenhouse gas target.

APPENDIX B:
FY 2018-19 Active, Completed, and Terminated Project List

Table B-1 lists all Fiscal Year 2018-19 active, completed and terminated (with funds spent) natural gas research agreements.

This project list does not include one project that was approved at an Energy Commission Business Meeting in 2018 but later terminated at the request of the Recipient, Efficient Drivetrains Inc. (PIR-17-016). No work was performed for this project and no funds were spent.

Table B-1: Fiscal Year 2018-19 Natural Gas Research Agreements

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
500-15-002	South Coast Air Quality Management District	On-Road, In-Use Emissions and Fuel Usage Assessment	$2,000,000	$1,250,000	12/9/2015	Active
500-15-005	The Regents of the University of California, Irvine	A Multi-Hazard Investigation of Climate Vulnerability of the Natural Gas Energy System in Southern California	$893,692	$0	6/14/2016	Active
500-15-006	University of California Merced	Solar Water Heating for the Residential, Commercial and Industrial Sectors	$999,806	$0	6/14/2016	Active
500-15-007	University of California, Santa Cruz	Investigate Climate-change-induced Vulnerability of the Northern California Natural Gas Energy System and Identify Resilience Options	$600,000	$0	6/14/2016	Active
500-17-003	San Francisco State University	Technical Assistance for the Energy Commission Food Processing Program	$249,947	$0	1/17/2018	Active
500-18-003	National Renewable Energy Laboratory	Developing Innovative Low Emission Natural Gas Engine and Vehicle Technology for Medium-and-Heavy-Duty Vehicles	$3,700,000	$6,025,000	6/12/2019	Active
PIR-14-024	Electric Power Research Institute (EPRI)	Development and Demonstration of a Cost Effective, Packaged Approach to Industrial Gas Efficiency Using Organic Rankine Cycle Technology	$999,889	$269,000	6/10/2015	Active
PIR-15-006	Institute of Gas Technology dba Gas Technology Institute	Demonstration of Advanced Aluminum Melting with High Efficiency and Low Emissions	$1,299,985	$325,500	3/9/2016	Active

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-15-006	Institute of Gas Technology dba Gas Technology Institute	Demonstration of Advanced Aluminum Melting with High Efficiency and Low Emissions	$1,299,985	$325,500	3/9/2016	Active
PIR-15-010	ergSol, Inc.	Integration of Advanced Solar Thermal Technology into Industrial Processes	$1,200,000	$300,000	3/9/2016	Active
PIR-15-013	Institute of Gas Technology dba Gas Technology Institute	Demonstration of Water Recovery from Hot, Humid Industrial Exhaust Gases	$1,294,032	$325,000	6/14/2016	Active
PIR-15-017	ICF Incorporated, L.L.C.	Characterization of Fugitive Methane Emissions from Commercial Buildings in California	$203,972	$0	6/14/2016	Active
PIR-16-001	Institute of Gas Technology dba Gas Technology Institute	Demonstrating Natural Gas Heat Pumps for Integrated Hot Water and Air-Conditioning in Restaurants	$864,294	$260,748	1/25/2017	Active
PIR-16-002	Institute of Gas Technology dba Gas Technology Institute	Demonstration of Advanced High-Efficiency, Low Capacity HVAC Systems	$750,000	$182,000	1/25/2017	Active
PIR-16-003	Institute of Gas Technology dba Gas Technology Institute	Demonstration and Assessment of Residential Gas Heat Pump Water Heaters in the Los Angeles Basin	$1,084,230	$310,500	1/25/2017	Active
PIR-16-004	Advanced Microgrid Solutions, Inc.	Advanced HVAC Technology Demonstration Project to Reduce Natural Gas Use in Hospitals	$1,216,707	$902,463	1/25/2017	Active
PIR-16-005	Energx Controls, Inc.	A Comprehensive, High Efficiency Solution for Water Heating in Multi-Family Buildings	$753,605	$192,840	1/25/2017	Active

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-16-007	The Regents of the University of California, Merced	A Novel Low-Cost, High-Efficiency Solar Powered Micro-CHP System for Electricity, Hot Water, and Space Heating	$816,659	$118,472	2/15/2017	Active
PIR-16-009	Element 16 Technologies, Inc.	Small-CCHP Packaged System with Innovative Quick-Response, Compact, and High-Temperature Thermal Energy Storage	$1,500,000	$150,000	2/15/2017	Active
PIR-16-010	All Power Labs, Inc.	Development and Demonstration of an Innovative Micro-scale Biomass Gasifier Combined Cooling, Heating, and Power System	$1,500,000	$326,272	2/15/2017	Active
PIR-16-011	Energy and Environmental Economics, Inc. (E3)	A Strategic Assessment of the Long-term Role of Natural Gas in a Carbon Constrained and Water-Efficient Future	$1,099,733	$362,750	3/8/2017	Active
PIR-16-012	Lawrence Berkeley National Laboratory	Effective Kitchen Ventilation for Healthy ZNE Homes with Natural Gas Appliances	$1,000,000	$200,000	3/8/2017	Active
PIR-16-013	The Regents University of California, Davis	Quantification of Methane from California's Plugged & Abandoned Gas Wells: Effects of Land Subsidence and Other Factors	$597,433	$0	3/8/2017	Active
PIR-16-014	Electric Power Research Institute (EPRI)	Multi-tiered Greenhouse Gas Emissions Measurements of California's Natural Gas-Powered Industrial and Fueling Infrastructure	$1,400,000	$259,362	3/8/2017	Active
PIR-16-015	Lawrence Berkeley National Laboratory	Characterize Actual and Future Impact of California's Drought on Three-component Ground Deformations and their Influence on the Natural Gas Infrastructure	$1,196,750	$145,000	3/8/2017	Active

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-16-016	Gladstein, Neandross & Associates, LLC	Development, Demonstration and Testing of Advanced Ultra-Low Emission Natural Gas Engines in Port Yard Trucks	$1,399,681	$49,001	4/12/2017	Active
PIR-16-017	The Regents of the University of California, Irvine Advanced Power and Energy Program	Using Renewable Natural Gas in Common Appliances and Implications on Emissions, Fuel Stability and Operational Performance	$250,000	$0	4/12/2017	Active
PIR-16-019	Terzo Power Systems, LLC.	CNG Hybrid Power System for Mobile Vehicles	$1,497,400	$5,150	4/12/2017	Active
PIR-16-021	Electric Power Research Institute (EPRI)	Data Driven Approaches to Understanding Occupant Natural Gas Use in Low-Income Multifamily Communities	$260,145	$78,712	4/27/2017	Active
PIR-16-024	Transient Plasma Systems, Inc.	Development and Demonstration of a Production-Intent Transient Plasma Ignition System for High Efficiency Natural Gas Engines	$899,139	$62,711	6/14/2017	Active
PIR-16-025	Southwest Research Institute	Research and Development of Natural Gas D-EGR Engine for Improved On-Highway Efficiency	$834,514	$250,000	6/14/2017	Active
PIR-16-027	Lawrence Berkeley National Laboratory	An Integrated Risk Management and Decision-Support System for Ensuring the Integrity of Underground Natural Gas Storage Infrastructure in California	$1,475,761	$0	6/14/2017	Active
PIR-16-028	DNV GL USA, Inc.	A Barrier-Based Quantitative Risk Management Approach for Underground Storage of Natural Gas	$2,398,939	$373,725	6/14/2017	Active

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-17-001	T2M Global LLC	High Efficiency Waste Heat to Osmotic Power	$1,299,109	$132,535	3/21/2018	Active
PIR-17-002	Altex Technologies Corporation	Advanced Thermo Electric Generator System (ATEGS)	$1,222,850	$167,885	3/21/2018	Active
PIR-17-003	Institute of Gas Technology dba Gas Technology Institute	Demonstration of 4.5 and 25 kW CARB-compliant Reciprocating Engine Micro-CHP Systems	$1,499,406	$167,600	3/21/2018	Active
PIR-17-004	Element 16 Technologies, Inc.	Low Temperature, Efficient Heat Capture to Reduce Natural Gas Consumption in the Chemical Industry	$1,500,000	$300,000	3/21/2018	Active
PIR-17-005	University of California, Riverside	Demonstration of Smart Combustion Technology Using Natural Gas Fuel Quality Sensors	$1,499,910	$193,900	3/21/2018	Active
PIR-17-006	EtaGen, Inc.	High-Efficiency and Ultra-Low Emissions Linear Generator Demonstration Project in Southern California	$995,659	$1,386,066	3/21/2018	Active
PIR-17-007	Lawrence Berkeley National Laboratory	Emerging Energy Efficiency Technologies in California's Chemicals and Allied Products Industry-Estimating Energy Efficiency Cost Curves and Identifying Technology R&D Needs and Gaps	$300,000	$0	3/21/2018	Active
PIR-17-008	Transportation Power, Inc.	Demonstration of a CNG-Hybrid Electric Super-Truck (CHEST)	$1,052,149	$259,926	4/11/2018	Active
PIR-17-009	Institute of Gas Technology dba Gas Technology Institute	Optimization and Demonstration of a Near-Zero, Heavy-Duty, Hybrid-Electric Truck	$1,499,381	$253,999	4/11/2018	Active
PIR-17-010	Lawrence Berkeley National Laboratory	Using Chemical and Isotopic Analyses to Improve Life-Cycle Assessments of the Natural Gas Consumed in California	$549,978	$53,633	5/9/2018	Active

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-17-011	The Regents of the University of California, Irvine	Developing a Methodology to Determine Chemical and Isotopic Composition of Natural Gas Consumed in California	$550,000	$84,989	4/11/2018	Active
PIR-17-012	The Regents of the University of California	Developing Next-generation Cal-Adapt Features to Support Natural Gas Sector Resilience	$1,000,000	$0	4/11/2018	Active
PIR-17-013	InfraTerra, Inc.	Development of an Integrated Methodology for Assessing Integrity of Levees Protecting Natural Gas Infrastructure	$549,500	$500	4/11/2018	Active
PIR-17-014	Eagle Rock Analytics	Developing Next-Generation Cal-Adapt Features to Support Natural Gas Sector Resilience	$200,000	$0	4/11/2018	Active
PIR-17-015	Lawrence Berkeley National Laboratory	SUper eMitters of Methane Detection Using Aircraft, Towers, and Intensive Observational Network (SUMMATION)	$2,600,000	$14,425,970	4/11/2018	Active
PIR-17-017	Institute of Gas Technology Institute	High Efficiency Process Heating	$1,405,947	$1,480,000	5/9/2018	Active
PIR-18-001	West Biofuels, LLC	Production of Pipeline Grade Renewable Natural Gas and Value-Added Chemicals from Forest Biomass Residue	$2,000,000	$560,000	5/15/2019	Active
PIR-18-002	Regents of the University of California, Los Angeles	Seismic Risk Assessment and Management of Natural Gas Storage and Pipeline Infrastructure in CA	$3,485,255	$410,411	5/15/2019	Active
PIR-18-003	The Regents of the University of California on behalf of the Berkeley campus	Performance Based Earthquake Engineering Assessment Tool for Gas Storage and Transmission Systems	$4,940,158	$254,294	5/15/2019	Active

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-18-004	Taylor Energy	Renewable Syngas Methanation	$1,999,695	$224,039	5/15/2019	Active
PIR-18-005	Gas Technology Institute	Improving the Performance of Wall Furnaces in California Homes	$1,000,000	$100,000	6/12/2019	Active
PIR-18-006	Lawrence Berkeley National Laboratory	Cost-Effective Technologies and Strategies to Improve Energy Efficiency and Reduce Emissions of Direct Heating Equipment in California with Health Benefits	$2,000,000	$86,899	6/12/2019	Active
PIR-18-007	Regents of University of California, Davis	Phase Change Material-Enhanced Insulation for Residential Exterior Wall Retrofits	$1,570,000	$165,870	6/12/2019	Active
500-13-006	California Air Resources Board	Identification and Evaluation of Constituents Found in Biogas in California	$400,000	$400,000	2/12/2014	Complete
500-14-004	CO2Nexus, Inc.	CO2 Cleaning Project	$900,300	$1,110,732	5/13/2015	Complete
500-15-004	The National Aeronautics and Space Administration	California Baseline Methane Survey: Identification of Large Fugitive Methane Emitters from the Natural Gas Sector	$600,000	$0	6/14/2016	Complete
500-16-002	South Coast Air Quality Management District	Low NOx 12-Liter Natural Gas Engine Development	$1,000,000	$3,375,915	9/14/2016	Complete
PIR-14-001	Gas Technology Institute	High Efficiency Indirect-Fired Rotary Dryer with Advanced Heat Pump for Bulk Foods Processing	$2,600,000	$700,000	7/22/2014	Complete
PIR-14-013	Institute of Gas Technology dba Gas Technology Institute	Advanced Fueling Method to Achieve Full Fill for Natural Gas Vehicles	$400,000	$300,000	4/8/2015	Complete

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-14-014	Institute of Gas Technology dba Gas Technology Institute	Pipeline Right of Way Monitoring and Notification System	$1,049,978	$0	5/13/2015	Complete
PIR-14-015	Acellent Technologies, Inc.	Rapid+ System for Natural Gas Pipeline Integrity Management	$1,633,093	$103,000	5/13/2015	Complete
PIR-14-017	Gas Technology Institute (GTI)	Demonstration of an Advanced Low NOx Ribbon Burner Combustion System for Industrial Bakeries	$950,000	$245,000	5/13/2015	Complete
PIR-14-019	Institute of Gas Technology dba Gas Technology Institute	Advancing Novel Biogas Cleanup Systems for the Production of Renewable Natural Gas	$1,000,000	$214,650	6/10/2015	Complete
PIR-14-020	Las Gallinas Valley Sanitary District	Las Gallinas Valley Biogas Energy Recovery System (BERS) Project	$61,779	$3,101,203	6/10/2015	Complete
PIR-14-021	Mosaic Materials, Inc.	Cost Reduction for Biogas Upgrading via a Low-Pressure Solid-State Amine Scrubber	$1,000,000	$200,000	6/10/2015	Complete
PIR-15-002	Regents of the University of California (University of California, Davis)	Understanding and Improving Solar Water Heater Effectiveness in California Households	$500,000	$40,000	11/12/2015	Complete
PIR-15-003	Institute of Gas Technology dba Gas Technology Institute	Assessment of Fugitive Emissions from the Natural Gas System-Commercial Buildings	$599,891	$0	11/12/2015	Complete
PIR-15-007	Gallo Cattle Company, LP dba Joseph Gallo Farms	Conversion of Low Value Waste Heat into High Value Energy Savings	$1,207,136	$402,379	3/9/2016	Complete
PIR-15-008	Institute of Gas Technology dba Gas Technology Institute	Development, Integration, and Demonstration of 6.7 Liter Natural Gas Engine in Medium Heavy-Duty Vehicles	$1,000,000	$1,641,643	3/9/2016	Complete

Agreement #	Recipient	Title	Agreement Amount	Match Amount	Agreement Approval	Project Status
PIR-15-009	Institute of Gas Technology dba Gas Technology Institute	Industrial Steam Boiler Heat Recovery for High Efficiency Water Heating	$585,300	$255,000	3/9/2016	Complete
PIR-15-012	Institute of Gas Technology dba Gas Technology Institute	Pipeline Safety and Integrity Monitoring Technologies Assessment	$1,006,812	$0	6/14/2016	Complete
PIR-15-014	Institute of Gas Technology dba Gas Technology Institute	High Accuracy Mapping for Excavation Damage Prevention and Emergency Response	$1,481,426	$0	6/14/2016	Complete
PIR-16-020	Gary Klein and Associates, Inc.	Code Changes and Implications of Residential Low Flow Hot Water Fixtures	$249,900	$40,400	4/27/2017	Complete
PIR-16-022	Lawrence Berkeley National Laboratory	Costs and Benefits of Community vs. Individual End-Use for Solar Water Heating	$250,000	$0	4/27/2017	Complete
PIR-16-023	The Regents of the University of California, Los Angeles	Evaluation of Community-Scale Solar Water Heating in Los Angeles County	$240,404	$0	4/27/2017	Complete
PIR-15-011	Institute of Gas Technology dba Gas Technology Institute	Performance Evaluation of an Industrial Waste Heat Recovery System	$500,000	$129,500	6/14/2016	Terminated w/funds spent

Source: California Energy Commission

APPENDIX C:
FY 2018-19 Natural Gas Active, Completed, and Terminated Project Highlights

Appendix C provides project highlights for the 78 active and completed agreements, including those that were terminated with funds spent, during Fiscal Year 2018-19.

Project Name: Identification and Evaluation of Constituents Found in Biogas in California - [500-13-006]

Recipient/Contractor: California Air Resources Board

Natural Gas Funding Plan: Natural Gas Research

Project Term: 3/26/2014 to 3/29/2019

Research Area: Energy-Related Environmental Research

Issue: Biogas is produced by converting biomass to a gaseous mixture of carbon dioxide, methane, and other components. 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 constituents of concern that may adversely impact public health, but little information has been available regarding these constituents.

Project Description: The researchers conducted a comprehensive set of measurements of biogas composition for thirteen different biogas/biomethane sample streams and a single natural gas stream. They derived sample streams from seven different production sources: two waste water treatment plants, two dry green waste and solid waste facilities, one wet green waste and solid waste facility, and two landfills.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: Prior to this project, only limited information was available regarding constituents of concern in biomethane produced from different feedstocks. This project identified and evaluated 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.

Applicable Metrics:

Public Health: The identification of hazardous constituents informs the 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.

Natural Gas Funds Encumbered: $400,000

Update: The project has been completed. The methane content of the raw biogas ranged from 35 to 70.5 percent. Biomethane from food waste digesters had methane contents above 90 percent. Other targeted constituents include ammonia, alkanes, sulfur compounds, VOCs, siloxanes, metals, bacteria, pesticides, and others. The composition of biogas and upgraded biomethane produced in California depends on the feedstock and the design of the anaerobic digester. The tests conducted to date

suggest that the composition of biogas produced at different facilities varies significantly. The findings have led to additional work supported by CARB to further investigate particular chemical compounds identified by this study.

Researcher explaining the sampling setup at a wastewater treatment plant

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 its assets and the Energy Commission has sold the equipment via the state auction process. Although the project was never completed, the former technology officer hoped to submit preliminary results from its testing during a portion of the agreement period. The final report was received in October 2019.

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 3/31/2020

Research Area: Natural Gas-Related Transportation

Issue: Results based on U.S Environmental Protection Agency (EPA) test procedures for heavy-duty on-road engines 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 deviations from certification tests, including 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 for a variety of vehicle classes and 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. The researchers recruited over 200 vehicles from a variety of California fleets to represent a pool of different vehicle technology types and routes. 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 real world route-based data to compare with previous tests. The results will be used to develop new drive cycles, develop deterioration factors, identify technology shortfalls and paths for improvement, prioritize resources to support advanced engine and aftertreatment technology research, 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. Comparisons with other technologies including diesel, hybrid, and electric will also be used to match vehicle technologies to vocations for which benefits can be maximized. This project will assist fleets in alternative fuel vehicle procurement planning and inform policymakers with real world vehicle emissions data that is highly valuable for the refinement of test cycles, emissions modeling tools and inventories (e.g., the CARB Emissions Factor -- EMFAC -- model), and standards development.

Applicable Metrics:

Lower Costs: The results assist in developing vocation-optimized drive cycles to maximize fuel efficiency. Deterioration effects will also be investigated through 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: As of May 2019, 100 percent of the test vehicles have been recruited with concurrent progress made in activity monitoring (95 percent complete), portable emissions testing (83 percent complete), chassis dynamometer testing (21 percent complete), and mobile emission laboratory testing (20 percent complete). SCAQMD requested a 9-month no-cost time extension to resolve delays caused by recruitment difficulties for specific vehicles, test equipment procurement, contracting issues, and personnel changes. The researchers are targeting December 2019 to complete all testing and data analysis.

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/11/2017 to 1/4/2019

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 such as the Air Resources Board (CARB) and natural gas facility operators, and it can serve as a baseline to enable potential future monitoring and verification of mitigation efforts by CARB.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project has provided new insights into California's methane inventory. Specifically, the research team has conducted the first systematic assessment of the relative contributions of methane point sources including their distribution by space, time, and sector. This work also highlights the potential for efficient point source monitoring techniques to directly enable mitigation of a broad class of methane super-emitters, representing a significant contribution to California's climate stabilization targets.

Applicable Metrics:

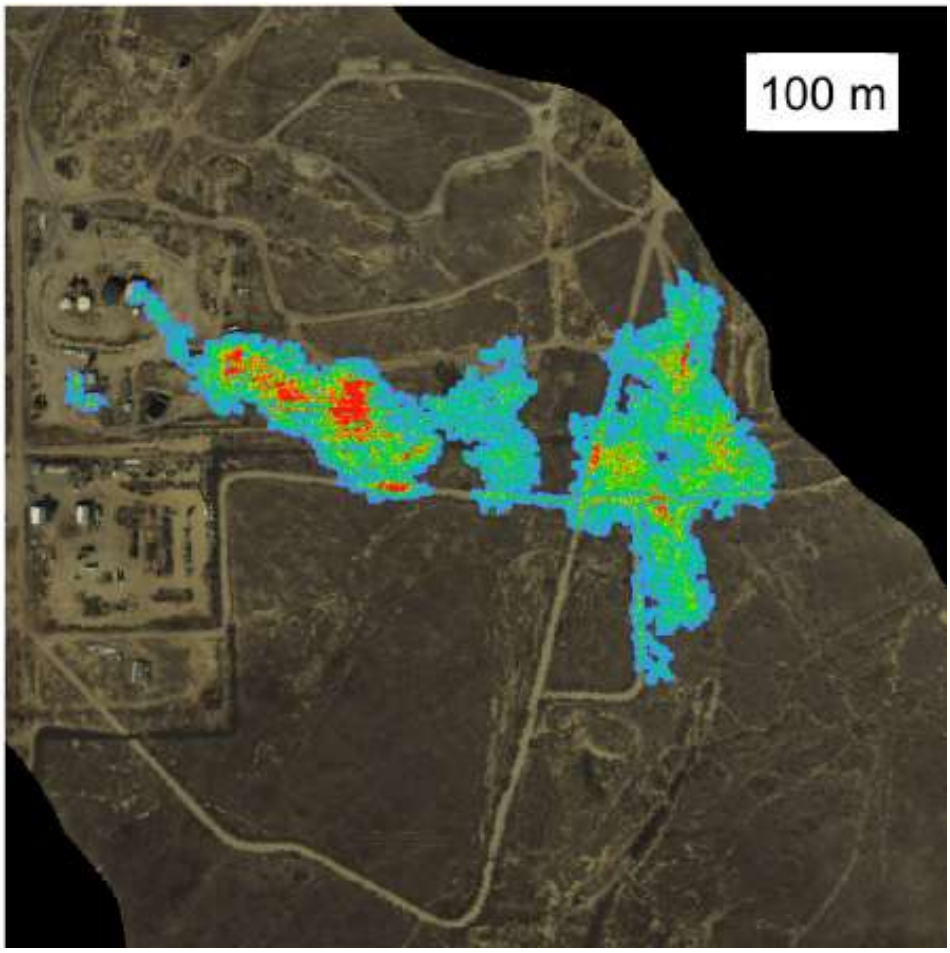
Environmental Benefits: The project provided an effective method to quickly identify large methane emitters from California's natural gas system. It also generated a database of emitting sources. The results help state and local agencies and stakeholders to prioritize mitigation efforts of the large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

Natural Gas Funds Encumbered: $600,000

Update: The final report is expected to be published in Fall 2019. The research team conducted a comprehensive survey of facilities and components in California using an

airborne imaging spectrometer capable of rapidly mapping methane plumes. The work spanned all sectors, resulting in the detection, geolocation, and quantification of 562 strong methane point sources. Estimated emissions from them contribute more than a 33% of the State's methane inventory for 2016. Super-emitter occurred in every surveyed sector. This work highlights the potential for point source monitoring to enable mitigation of a broad class of super-emitters, representing a significant contribution to California's climate stabilization targets, reduced natural gas product loss, and early warning of potentially hazardous leaks. CARB is using the findings to inform their oil & gas emission regulation and GHG inventory.

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: Natural Gas Research

Project Term: 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 coordinated assumptions and the selection of data sets with those used for California's Fourth Climate Change Assessment. 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 Assessment was released late in 2018. The team has met with SoCalGas to present preliminary results and is preparing the final report.

Proof of concept image for potential inundation

Project Name: Solar Water Heating for the Residential, Commercial and Industrial Sectors - [500-15-006]

Recipient/Contractor: University of California Merced

Natural Gas Funding Plan: Natural Gas Research

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

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. UC Merced researchers previously 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. In addition, copper mini-channel solar collectors, capable of producing low-grade steam for such uses as dry cleaning, steam cleaning, produce drying, sterilization, and blanching of vegetables, will be developed and lab tested at UC Merced. The research will determine if the copper mini-channels can produce steam required for use in such industries. 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:

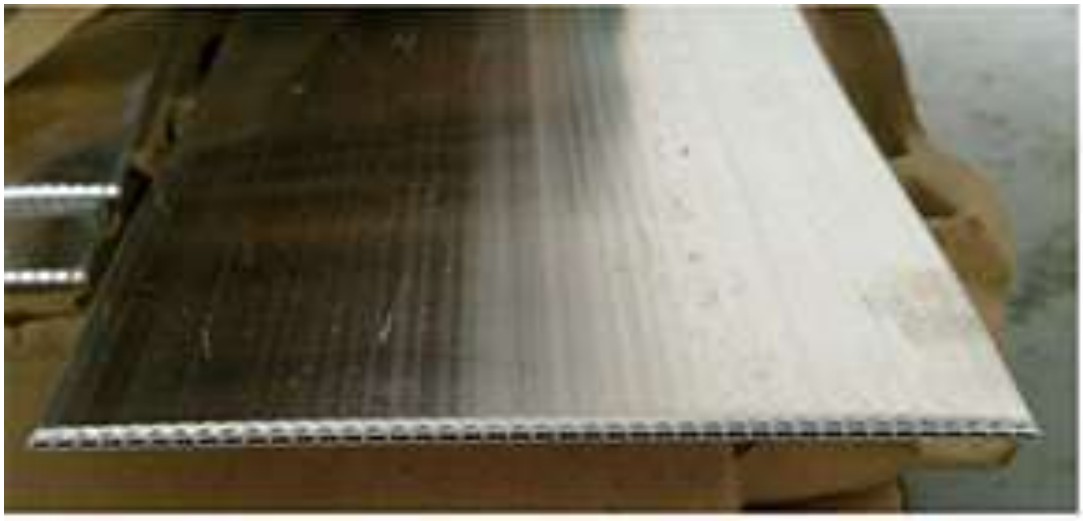
Lower Costs: This project aims to lower the upfront cost of solar thermal water heating systems by up to 30 percent by utilizing lower cost materials and increasing the efficiency of solar collectors utilizing aluminum in collector construction. The reduction in natural gas consumption will also lower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

Environmental Benefits: This project aims to improve air quality and reduce greenhouse gas emissions by reducing the consumption of natural gas for water heating.

Natural Gas Funds Encumbered: $999,806

Update: The aluminum mini-channel solar collectors for demonstration at a 25-unit apartment complex and a single-family home in Southern California have been fabricated and are ready for installation. The equipment will be installed and operating this summer.

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/30/2016 to 11/20/2019

Research Area: Energy-Related Environmental Research

Issue: Climate change-induced hazards are likely to increase the risks to 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 is developing 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:

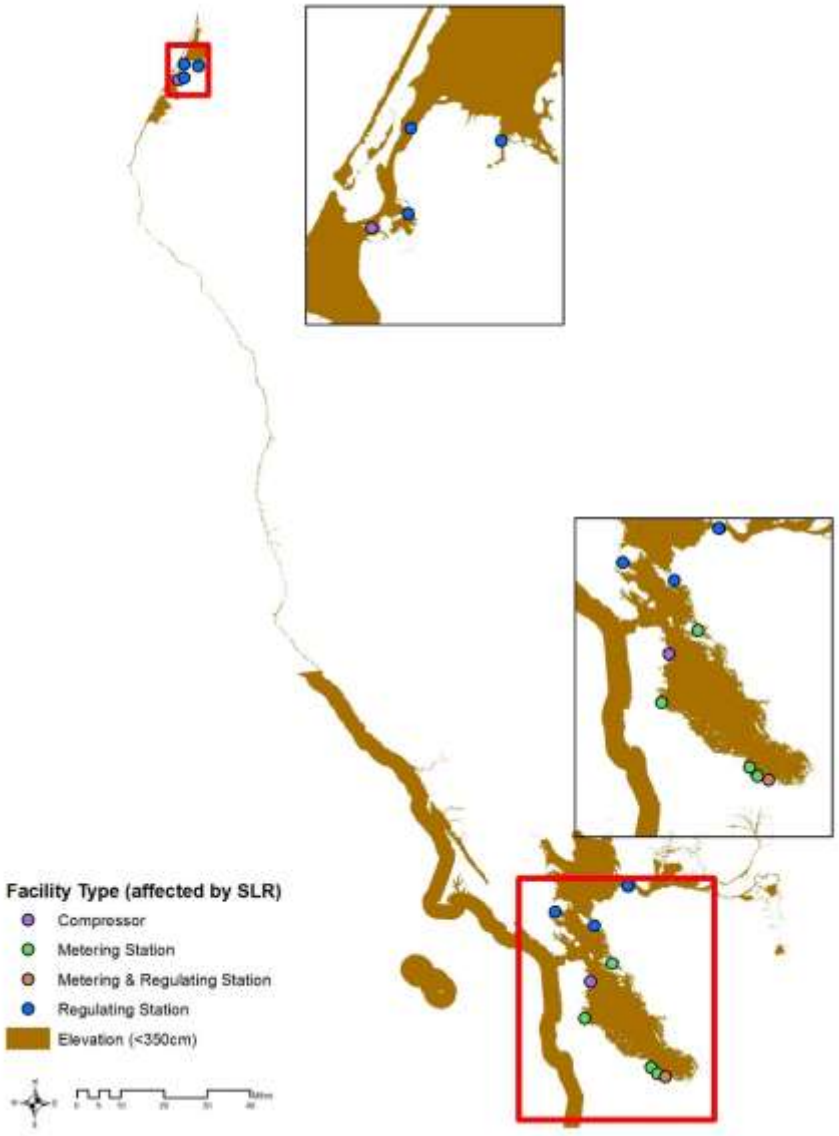
Greater Reliability: This project is developing a technical-economic model, in collaboration with PG&E, to identify system vulnerabilities related to infrastructure and operations.

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: The researchers have calculated sea-level-rise and wildfire risks under different climate change scenarios in Northern California have been completed, allowing calculation of the probability that natural gas facilities may be inundated at different water depths or the probability of the facility being burned. The researchers also developed a regional economic model to address the vulnerability of the Northern California natural gas system to climate-change induced weather events. This state-level model accounting for interactions among regions in order to quantify the effects of service disruption onto other sectors and regions. Understanding the regional and sector impacts of natural gas system disruption helps the government and the industry identify the key components of the infrastructure and choose the resilience options needed to face a changing climate.

Natural gas facilities in northern California exposed to the maximum sea level rise (350 cm)



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 is 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 developed and demonstrated 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.

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 also reduces NOx. The three-way catalyst after-treatment system simultaneously reduces carbon monoxide, hydrocarbon, and NOx emissions. Optimized engine controls maintains 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 2027 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 methane gas 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).

Natural Gas Funds Encumbered: $1,000,000

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 the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (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, even on low load port drayage cycles. The final project report is published.

MY2018 Cummins Westport ISX12N

Project Name: Technical Solutions for Food Processing Industry - [500-17-003]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 3/1/2018 to 12/31/2020

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 commercially available and advanced (emerging) technologies that could reduce GHG emissions and be implemented in the near term and the long term, such as by 2030 and beyond. Additionally, the recommendations 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 needs and research 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 result in the identification of 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: The contractor has compiled a listing of energy efficiency measures based on its past assessments of food processors in central and northern California and has developed methods for analysis of these measures to identify technologies with the most potential for the food processing Industry. In addition, the contractor has identified food processors for interviews, in order to identify the pain points for the application of these natural gas technologies for the food processing industry.

Project Name: Developing Innovative Low Emission Natural Gas Engine and Vehicle Technology for Medium- and Heavy-Duty Vehicles - [500-18-003]

Recipient/Contractor: U.S. Department of Energy (National Renewable Energy Laboratory)

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/31/2023

Research Area: Natural Gas-Related Transportation

Issue: The Natural Gas R&D Program has funded projects leading to the commercialization of near-zero emission natural gas engines in the heavy-duty vehicle market. The Sustainable Freight Action Plan and the Mobile Source Strategy both identify a need to adopt near-zero emission vehicles and renewable fuels to aggressively reduce criteria pollutant and greenhouse emissions from the heavy-duty transportation sector. Although near-zero emission natural gas vehicles are commercially available, there are still barriers preventing large-scale adoption of the technology in California. These barriers include engine availability, engine efficiency, and total cost of ownership compared to diesel vehicles.

Project Description: This agreement with NREL funds several competitively selected subcontracts with cost share from a consortium of agencies including the U.S. DOE and the South Coast Air Quality Management District (SCAQMD). Projects include:

1. US Hybrid: develop and demonstrate a fully integrated and optimized natural gas, plug-in hybrid truck using the L9N near zero engine, a commercial parallel hybrid powertrain, a liquid-cooled lithium-ion battery, and a GPS-based predictive geofencing control architecture.
2. Transient Plasma Systems: develop a production intent prototype of a transient plasma ignition system to enable stable ignition of natural gas at high-pressure, high exhaust gas recirculation (EGR) conditions.
3. Cummins, Inc: develop a 12-15 liter natural gas engine using a natural gas specific combustion design to achieve a 20 percent system cost reduction, 10 percent improvement in thermal efficiency, and near-zero NOx emissions.
4. Gas Technology Institute: develop and demonstrate a smart compressed natural gas (CNG) fueling station using sensors, an advanced full fill algorithm, and cost-effective pre-cooling using a near-isentropic free piston expander/compressor.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project will develop technologies that can improve the competitiveness of natural gas vehicles compared to diesel vehicles by reducing total cost of ownership, improving efficiency, and increasing engine availability. Commercialization of these technologies

will bolster deployment of near-zero emission natural gas vehicles and cost effectively reduce NOx and GHG emissions from the heavy-duty transportation sector.

Applicable Metrics:

Lower Costs: This project will focus on developing production-intent prototypes with cost reduction strategies that increase market adoption of natural gas vehicles. Strategies include engine redesigns to reduce system costs by 20 percent, a low maintenance advanced ignition system to reduce maintenance-related costs, hybridization to reduce fuel costs, and a low cost pre-cooling technology that can better enable CNG full fills.

Environmental Benefits: Transitioning from heavy-duty diesel vehicles to natural gas vehicles that use renewable natural gas as a transportation fuel will result in significant reductions in greenhouse gas emissions. Efficiency improvements achieved through this project using technologies such as optimized natural gas engine design, advanced ignition, and hybridization can also lead to reductions in greenhouse gas emissions.

Public Health: Improving the efficiency and performance of natural gas engines for heavy-duty vehicles will improve their competitiveness compared to diesel engines. Increased deployment of efficient, near-zero emission natural gas engines will result in reduced NOx, with a range of public health benefits.

Natural Gas Funds Encumbered: $3,700,000

Update: The project was approved at the June 2019 Energy Commission Business Meeting and is pending final agreement execution.

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 7/31/2014 to 3/31/2019

Research Area: Energy Efficiency

Issue: The drying of 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 uses waste heat/steam in the thermally driven heat pump. As to primary energy consumption, the demonstrated thermo-vacuum system differs from the state-of-the-art equipment by mostly pumping power that was 8-10 kW, while the off-shelf drying equipment requires 5-6 kW for recirculating pumps and over 20kW to power the air fans. Thus, the thermo-vacuum system demonstrated a reduction in primary energy consumption by at least 40 percent.

Applicable Metrics:

Lower Costs: The technology reduced natural gas consumption by 61-65 percent (from about 18,687 cubic feet per hour to 7,000 cubic feet per hour) and electric savings by at least 40 percent. Assuming 500,000 tons per year of dried products produced in California, annual natural gas savings would be about 2 billion cubic feet and electricity savings about 4 MWh along with the potential to recover 80 million gallons of water.

This technology could result in annual natural gas savings of $20 million and reduction of 200,000 metric tons greenhouse gas annually.

Natural Gas Funds Encumbered: $2,600,000

Update: Project was completed on time and under budget. The results from the project indicate that the technology requires only 6.7 MMBtu/hr for optimal ejector network operation and the thermo-vacuum system has the potential to reduce gas consumption by 61 to 65 percent for the same drying product throughput and electric savings by at least 40 percent. GTI hopes to further enhance the technology by optimizing product charge and discharge systems, mechanical systems and steam and heat harvesting. While the technology progressed from TRL 5 to TRL 7, the production costs have yet to be determined. Martin Feed is continuing to host the equipment, and expressed satisfaction with the preliminary results and feed quality. However, further development is needed before this technology is ready for market. GTI Plans to apply to the Gas Industry (via NFP Utilization Technology Development Program) for the follow-on pre-commercial engineering and design optimization for the selected market applications.

Rotary Drum Dryer

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. The shortcomings of this approach are a significant obstacle to optimizing vehicle range and ensuring the safety, reliability, and consistency of CNG dispensers.

Project Description: Gas Technology Institute (GTI) developed a gas characterization technique and fueling algorithm that uses communication between NGVs and CNG dispensers to identify tank volume, pressure, and temperature prior to filling. The algorithm improves consistency and safety of natural gas vehicle fueling by validating when the vehicle is near the full fill target. GTI also performed fueling simulations to evaluate current state-of-the-art fueling methods and improved fueling algorithms developed using the characterization technique. Using an environmental test chamber and a commercial heavy-duty CNG storage system, GTI tested the improved fueling algorithm and validated its benefits under a variety of real world conditions. GTI also investigated pre-cooling strategies that would be needed to achieve full fills at higher ambient temperatures. Addressing these issues and developing a solution that can be deployed across the NGV industry can improve the competitiveness of low emission, heavy-duty NGVs.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project addressed 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 (e.g., 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 the economics of natural gas vehicle fleet operations by maximizing vehicle range and reducing frequency of refueling. CNG on-board storage systems are typically oversized to compensate for under filling. The capital costs for on-board storage systems can be reduced by 10 percent ($5,000 per vehicle for some heavy-duty vehicles) if oversizing can be avoided without losing range.

Increase Safety: Real world testing of the fueling algorithm demonstrated termination of all fills at nearly 100 percent full, with only one case of slight overfill within the error of the pressure transmitter. Standardizing this fueling algorithm for the CNG industry can result in safer fills and a foundation for future pre-cooling technologies to assist in achieving full fills at high ambient temperatures.

Consumer Appeal: Heavy-duty natural gas vehicles with a 20 percent under-fill can result in a 30 gasoline gallon equivalent of underutilized fuel capacity, 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 advanced fueling algorithm combined with wireless communication of data between the vehicle and dispenser demonstrated termination of all fills at nearly 100 percent full in every thermodynamically possible case. Further development should be focused around packaging the algorithm with wireless data transmitting hardware in dispensers and vehicles. Pre-cooling is 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 develop low cost pre-cooling for CNG stations. The final project report was accepted in February 2019. GTI is using results from this project to work with CSA Group, a leading codes and standards organization for NGVs, to write a guidance document on developing new standards for safe full fills and fueling algorithms.

CNG Compressor and Station Storage Testing

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: Natural Gas Research

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

Research Area: Natural gas Infrastructure Safety and Integrity

Issue: The greatest threat to buried natural pipelines is the operation of non-utility company excavation equipment within the pipeline's legal right-of-way (ROW), resulting in accidental damage. Damage to the pipeline can have severe safety consequences, including fire, explosion, and loss of life. Pipeline damage can also lead to natural gas leaks thereby increasing greenhouse gas emissions, and disruption of natural gas delivery to customers. A system that could provide advanced notice of potentially damaging activities would benefit both gas utility operators as well as the public at large.

Project Description: This project designed, tested, and demonstrated a system that automatically monitors the pipeline's ROW and notifies gas utility operators of encroachment threats. The deployment of this system will allow utilities to mitigate risk to their pipelines by being better informed of where and when threats are occurring. The monitoring system had sensor stations placed along 4,000 feet of new pipeline at several discrete locations in the ROW. Mobile sensor packages were deployed on excavation equipment to alert operators when the equipment approached the pipeline ROW. Additionally, data communication links between the stationary sensors, mobile sensors, data loggers, web links, and user dashboard were established. A web hosted user interface was developed to display alarm conditions and send notifications to alert utility personnel. The system demonstrated that it was possible for a user to "see" a pipeline ROW, its surrounding environment, and the locations and status of the sensors in real-time.

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 advancement and breakthroughs to overcome barriers to the achievement of the State of California's statutory energy goals by preventing excavation damage to natural gas pipelines. By making it possible to retrofit the ROW monitor system one excavation at a time, it is practical and cost-effective for utility operators to deploy it.

Applicable Metrics:

Lower Costs: The extreme historical incidents of transmission pipeline in California have cost more than $600 million. The pipeline monitoring system can alert threats at early stage and significantly reduce the amount of extreme incidents. The reduction in extreme incidents of pipelines would further lower the overall cost.

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, gouges; defective welds; or other anomalies.

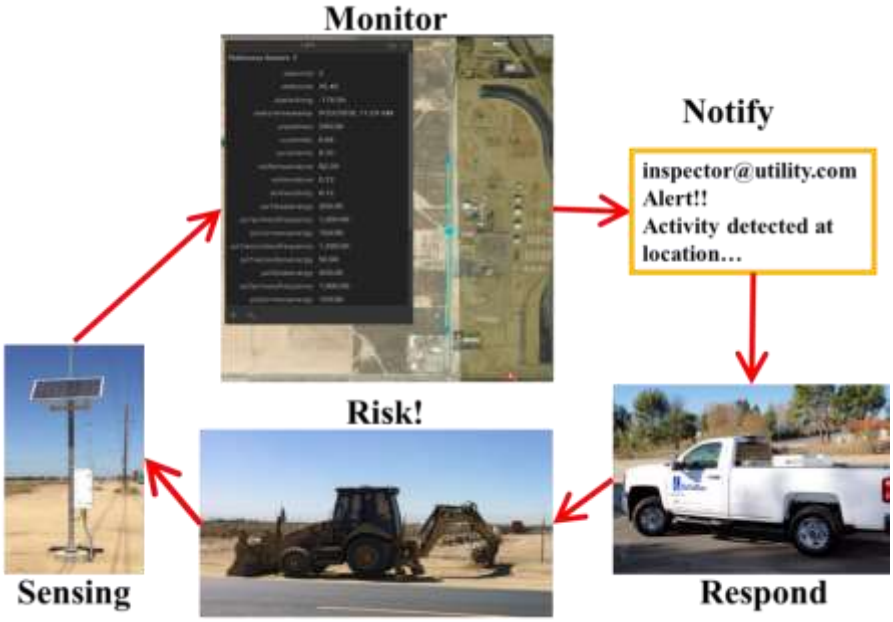
Increase Safety: The greatest benefit of ROW monitoring to California ratepayers is improved safety by reducing the risk of incidents from natural gas pipeline damage. This technology provides utility operators the ability to remotely monitor activity in the ROW and the activity of excavation machinery. This provides timely notification to utility operators and assists in the prevention of damage to gas pipelines.

Environmental Benefits: The monitoring system reduces incidents of damage that cause the release of methane, a potent greenhouse gas, to the atmosphere. Based on the transmission line incidents that resulted in the release of natural gas given in MCF from 2010 to the present (source: DOT PHMSA), the deployment of the monitoring system could annually lower the emissions by 29,516 MCF.

Natural Gas Funds Encumbered: $1,049,978

Update: The final report was received and the project completed in 2018. A natural gas pipeline ROW monitoring system was successfully designed, engineered, and tested on SoCalGas pipelines. Various types of sensors were deployed and tested, and the pipeline was hydro-tested during the installation period, allowing calibration data to be captured. A solar power option was successfully demonstrated for the sensors. Three sensor stations were installed over a length of roughly 4,000 feet of new pipeline. The system is currently running and providing sensor data with additional financial support from Operations Technology Development and Pipeline and the Hazardous Materials Safety Administration. Several non-California utilities have expressed interests in testing the technology.

Pipeline Right of Way Monitoring and Alerting System



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 and monitor pipeline degradation and encroachments to avoid pipeline accidents.

Project Description: This project developed and demonstrated the Real-time Active Pipeline Integrity Detection (RAPID+) system. The system detects degradation to the pipeline and its impacts due to external encroachments, which are the two most common causes of pipeline leaks. This system consists of a surface-mounted ultrasonic sensor array that can identify corrosion damage on or inside a pipe and detect encroachments that pose a threat. The project included 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 and monitor defects 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. It is estimated to save nearly $5,000,000 per mile over 25 years.

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

Update: The final report was received and the project was completed in 2018. This system was designed to detect degradation to the pipeline and its impacts due to

external encroachments, which are the two most common causes of pipeline leaks. The core technology of the acoustic ultrasonic sensors for detecting damage was modified and further improved in this project for the detection of soil movement and excavation equipment impacts to the natural gas pipelines. The field demonstration of the system also showed that the vibration sensors sensitivity needs to be increased to be more effective and further improvement of the sensors is needed before commercializing the technology.

Acellent's Encroachment Detection System helps 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: Natural Gas Research

Project Term: 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 demonstrated a technique for NOx mitigation in natural gas fired systems by reducing the temperature in the combustion zone. This project adjusted the ribbon burner design to enhance the combustion system and therefore reduced the process temperature, emissions and increase energy efficiency. This approach was based on modification of primary air composition by recirculation of carbon dioxide and other combustion products from the exhaust stream and 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 a minimum of 5% in industrial operations compared to standard ribbon burner combustion systems.

Environmental Benefits: The combustion technology has the potential to reduce NOx emissions by at least 50%.

Natural Gas Funds Encumbered: $950,000

Update: The project is complete. The project results are as follows: (1) NOx emission reduced by 50% in pilot testing and 25% in full technology demonstration; (2) Natural gas consumption yield 5% savings (based on 4pir-54 Btu/lb.) with potential for higher savings; (3) Carbon emissions reduced by 5%, and (4) =>$660,000 annual cost

savings. Preliminary discussions on the licensing of this technology have been initiated by GTI.

Combustion Oven during Installation process

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 4/30/2019

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 to remove water and carbon dioxide (stage 1), hydrogen sulfide, siloxanes, and oxygen (stage 2), and nitrogen (stage 3) from raw landfill gas to generate pipeline quality gas. The 100 standard cubic feet per minute (scfm) pilot scale cleanup system was deployed at the Coyote Canyon landfill in Newport Beach, CA for testing using actual landfill gas.

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 applications.

Applicable Metrics:

Lower Costs: This project set out to demonstrate a low-cost method of converting landfill derived biomass into RNG. The technology could be an alternative to existing multistep expensive state-of-the-art processes. This technology uses off-the-shelf, stable, more environmentally benign absorbent solutions.

Environmental Benefits: A number of tangible environmental benefits can be realized by injection of cleaned up RNG into the natural gas pipeline. By capturing and utilizing methane that would otherwise be flared, the transportation and power generation industries could use this renewable fuel to displace higher polluting fuels such as diesel.

Energy Security: Successful commercialization of this technology will result in decreased dependence on fossil natural gas by introducing a new renewable natural gas pathway. The renewable source would be available as a backup for solar and wind supplies during downtime or shortages at peak time.

Natural Gas Funds Encumbered: $1,000,000

Update: This project concluded in April 2019. Innovative aspects of the technology were sufficiently strong to attract an industrial energy company, RealEnergy, to re-deploy the equipment at another California landfill and to continue the evaluation of the technology. Some of the project goals associated with the demonstration of the gas cleanup technology and related data collection were not achieved during the project period due to a change of demonstration site and inadequate preparations for weather conditions at the landfill site.

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

Natural Gas Funding Plan: Natural Gas Research

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

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: This project installed and operated a pre-commercial biogas energy recovery system (BERS) that converted 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 converts 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 provides all biogas required to operate the BERS. By eliminating the need for external natural gas supplies, the project provides energy stability to the wastewater treatment plant and reduces 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.

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.

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: 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.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/29/2015 to 2/29/2020

Research Area: Renewable Energy and Advanced Generation

Issue: Gas-fired industrial equipment, 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 in a fabric dye and finishing facility. 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: The technology being evaluated consists of a complete packaged unit, which reduces installation costs and complexity. It uses high-speed kinetic turbines that are oil free and have no metal-to-metal contact, which minimizes wear. It was designed for high reliability and low maintenance. Although the technology is installed in other parts of the world, this demonstration shows that the small 20kW unit can be a cost effective option in California.

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.

Natural Gas Funds Encumbered: $877,739

Update: The Electric Power Research Institute (EPRI) and its subcontractors successfully installed the Organic Rankine Cycle (ORC) system at the demonstration site and it is generating electricity from waste heat. Data collection and analysis is ongoing.

Installation of the Organic Rankine Cycle (ORC) system

Project Name: Understanding and Improving Solar Water Heater Effectiveness in California Households -

[PIR-15-002]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 12/15/2015 to 12/14/2018

Research Area: Energy-Related Environmental Research

Issue: California has invested substantially in the adoption of solar water heating (SWH) to reduce residential GHG emissions. However, SWH has extremely low penetration 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 installations by 2017, but fewer than 10,000 applicants were filed as of June 2019. To meet energy and climate-related goals, it is imperative to understand the potential role of solar water heating in displacing natural gas consumption for residential hot water use.

Project Description: This research assessed the performance and potential of natural gas-displacing solar water heaters in single-family homes in California. This assessment considers the possible scale and scope of solar water heating in the context of low natural gas prices, high system costs, doubts about field performance, and perceived availability of better alternatives. The research documented diversity in user satisfaction and perceived system performance, and a qualified decrease in project costs to below $5000 per installation. The research also found clusters of low-income installations successfully fostered through community action agencies. These community agencies were key to reducing installation costs. The suitability of solar water heating for California households is not purely a matter of cost-effectiveness within a typical energy efficiency framework, but also of evolving perceptions and values in the context of ongoing energy transformation.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This research supports California's energy goals by providing a clear picture of technology adoption issues related to the performance of SWH and demonstrating holistic technology assessment, which will be crucial to a successful transition. Currently, single-family residential solar water heating is not positioned to play a large role in emission reduction policies. The research shows, however, that solar water heating could contribute to decarbonization efforts and benefit some households in its current form. Improvements are possible in further strengthening performance reliability, lowering installed cost (e.g., through simpler systems, workforce learning, etc.), pinpointing good candidates for solar water heating, and increasing awareness amongst

potential users. The research also demonstrates how holistic technology assessment can support California's clean energy transition.

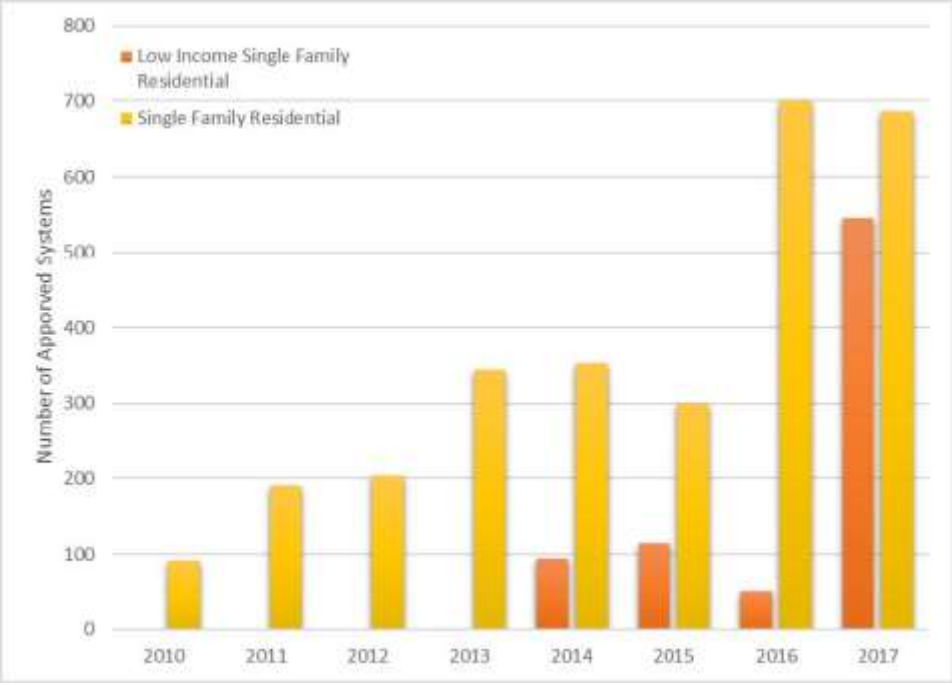
Applicable Metrics:

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 improved performance, and identifying specific application that could yield the greatest 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 households with solar water heaters, and successfully securing utility data of 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 has been completed along with knowledge transfer across diverse stakeholder groups that do not typically overlap. The final report is in publication.

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).



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: This project developed and validated a field method to measure after-meter methane leakage from natural gas-fired appliances and gas piping. The researchers took field measurements at 20 commercial food service sites and two inpatient healthcare facilities in California. Using data collected from these buildings, the project team performed a variety of statistical analyses to estimate the magnitude of methane emissions from the food service sector for several scenarios. These scenarios include cities and regions that have different numbers of food service sites with different sizes of operation.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project collected methane emission data from California's commercial building sector. This is the first time emissions from this sector have been systematically studied. The findings from this study were shared with the California Air Resources Board to improve estimations of methane emissions from buildings, which are essential to ensure that the State develops well-informed emission reduction strategies.

Applicable Metrics:

Environmental Benefits: The project results assist in quantification of after-the-meter methane leakages from commercial sectors. This information will help California's efforts to reduce greenhouse gases by informing the greenhouse gas inventory calculation managed by the California Air Resource Board. This project began the process of better estimating the impact of these sectors on total statewide emissions.

Natural Gas Funds Encumbered: $599,891

Update: The project is completed. The researchers developed measurement techniques for fugitive emissions from piping components and combustion equipment and validated them in the field for most of the commercial equipment encountered. The

majority of those fugitive emissions came from a relatively small number of appliance and piping component types. This suggests it may be possible to significantly reduce fugitive emissions from the commercial food service sector by identifying and repairing a relatively small number of problem areas. The results are shared with the California Air Resource Board (CARB). CARB is considering using the results from this study and other Energy Commission funded methane emission studies to improve its GHG inventory.

GTI field steam making leak measurement in the kitchen

Project Name: Demonstration of Advanced Aluminum Melting with High Efficiency and Low Emissions -

[PIR-15-006]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 4/8/2016 to 3/31/2020

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 recovers heat from the exhaust gas and uses it 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:

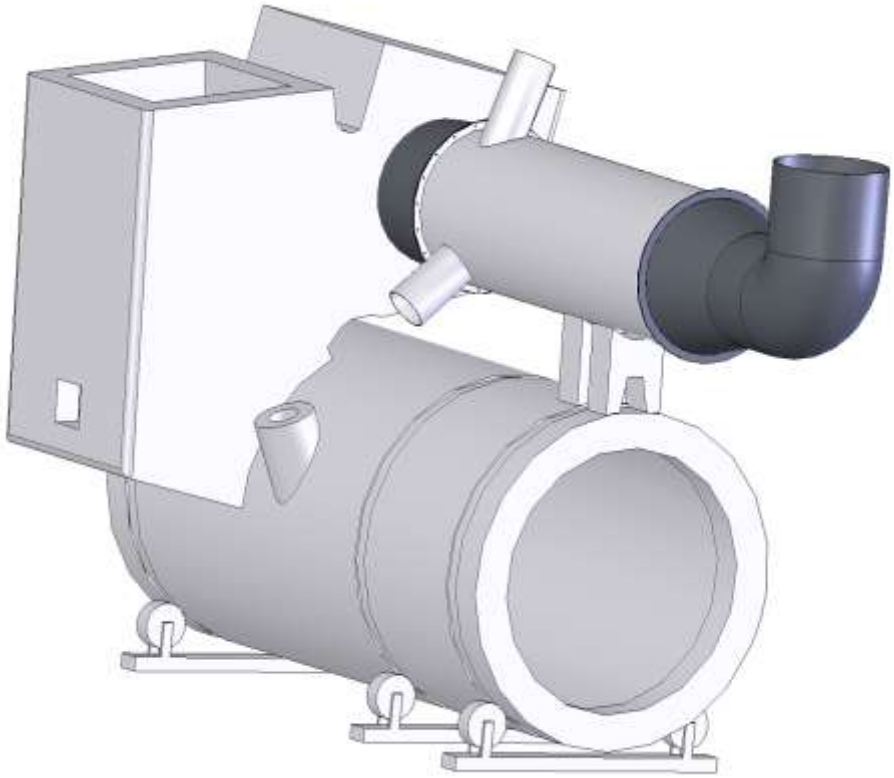
Lower Costs: This technology could reduce natural gas use and costs. Up to 10% of industrial natural gas furnaces can benefit from this technology. For these furnaces, average gas savings are estimated at 25%. Assuming 10% market penetration, each year there is potential to annually save 2 billion cubic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

Environmental Benefits: This project could reduce CO2 emissions by 0.12 million tons annually (assuming 10 percent market penetration of the technology).

Natural Gas Funds Encumbered: $1,299,985

Update: 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 furnace outer shell work is completed and refractory installation is underway. The team is developing a timeline for completion of furnace rebuild. The recipient has completed the furnace design work for modifying the furnace to allow operation with preheated air and prepared the demonstration site for these modifications

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 4/1/2016 to 2/28/2019

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 utilizing 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 demonstrated 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 engine generators is normally exhausted into the atmosphere and the energy is lost. This project captured the waste heat to offset natural gas purchases for heating and chilling. Demonstration of the technology showed the energy savings and cost effectiveness of this waste heat recovery technology and potential application to others in the food processing industry.

Applicable Metrics:

Lower Costs: This system has proven to reduce natural gas usage by approximately 19,500 MMBTUs (approximately 23% reduction) per year and electricity savings by approximately 1.38 GWh (approximately 38% reduction) per year.

Environmental Benefits: This system has demonstrated a GHG emission reduction of approximately 2,000 MTCO2e per year.

Natural Gas Funds Encumbered: $1,207,050

Update: The final report was completed and a copy was submitted to the technology provider for future applications of the technology.

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 delivery trucks, utility trucks, school buses, shuttle buses, yard tractors, and specialized municipal works vehicles such as street sweepers. The addition of a smaller, more optimized engine for lighter loads can better serve these vehicle applications.

Project Description: The project developed, integrated, and demonstrated 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 0.10 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 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 vehicle integration and demonstration in applications such as delivery trucks, shuttle buses, and yard tractors.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project provides a low NOx 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. Fleets using the engine developed through this project to replace diesel can reduce NOx emissions from their vehicles, resulting in improved air quality in California communities where their vehicles operate daily. School bus, shuttle bus, delivery truck, and yard tractor manufacturers currently offer the B6.7N.

Applicable Metrics:

Environmental Benefits: Natural gas engines can make use of renewable natural gas (RNG), a low carbon transportation fuel sourced from waste streams such as landfills and animal waste. Increased use of renewable natural gas in the transportation can

incentivize the capture of fugitive methane from these waste sources and displace fossil gas to achieve significant greenhouse gas reductions. Based on an estimate of 400 B6.7N engines deployed for school buses using RNG from anaerobic digesters, this can result in a reduction of over 93,000 short tons of CO2 equivalent emissions over the lifetime of the vehicles.

Public Health: The use of low NOx natural gas engines in heavy-duty vehicles will reduce criteria pollutant emissions. The B6.7N is certified to NOx levels 50 percent lower than equivalent diesel engines. HD OBD ensures emissions are kept low throughout the life of the engine. Based on an estimate of 400 B6.7N engines deployed for school buses, this can result in a reduction of over 250,000 pounds of NOx over the lifetime of the vehicles.

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 engine entered commercial production in January 2018 after receiving all the necessary certifications from the United States Environmental Protection Agency (U.S. EPA) and the California Air Resources Board (CARB). These certifications include meeting HD OBD compliance, U.S. EPA greenhouse gas emission standards, and the CARB Optional Low NOx standard of 0.10 g/bhp-hr. The vehicle demonstrations have completed with a combined 357,625 miles across three engineering units and eight commercial and transit fleet units. The University of California, Riverside completed chassis dynamometer testing of a yard tractor equipped with the B6.7N and confirmed its ability to maintain low emissions over real-world yard tractor and bus cycles. The final project report was accepted in April 2019.

MY2018 Cummins Westport B6.7N Engine

Project Name: Industrial Steam Boiler Heat Recovery for High Efficiency Water Heating - [PIR-15-009]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 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: The purpose of the project is to demonstrate the Heatsponge-Rainmaker technology coupled to an industrial steam boiler for generation of hot process water rather than its usual hydronic heating application that is advantageous to the host-site and to verify the performance, energy savings, and the emissions reduction benefits of the technology. In the very limited deployment of this technology for steam boiler and other non-standard applications thus far, energy savings and reduced emissions are realized according to the some end-users and the manufacturer. Independent verification of performance, energy savings and emissions benefits are needed to help potential end users to better understand the technology's benefits.

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" was installed to recover heat from a conventional steam boiler exhaust by heating a separate process water stream in the facility. This allowed for recovery of sensible and latent heat content from the exhaust stack with efficiency improvements of over 6% in most installations.

Applicable Metrics:

Lower Costs: The energy recovery obtained represents 6.2% savings of the yearly projected natural gas energy used by the facility boiler. Based on these results, the estimated payback is 23.6 years based upon the current single shift operation,

production rate, and $0.80/therm for natural gas. The system does provide some additional economic benefits not included in the calculation. This includes increase in available steam and hot water capabilities and avoided costs to increase the capacity of the boiler or hot water system. Based upon the operating data obtained, a three-shift operation would yield a simple payback of 7.8 years. The target metric was 10% energy efficiency improvement.

Environmental Benefits: The energy recovery obtained by the technology when demonstrated at Mission Linen Supply, Inc. represented 6.2% of the annual natural gas use by the facility's boiler. This savings resulted from an increased boiler operational efficiency from 82 to 88.6%. This increased efficiency represents a projected yearly savings of 6,889 therms of natural gas and a corresponding emissions reduction of 55.2 metric tons of carbon dioxide from the facility (Mission Linen in Oxnard California).

Natural Gas Funds Encumbered: $585,300

Update: Final report with results is complete. Operation at the project site has demonstrated an increase of boiler operational efficiency from 82% to 88.6% at the current production rate at the Oxnard facility. The hot water usage at the facility varies based upon the type of equipment needed to meet the production scheduled for a given day. Based upon the stated goal of the project of an 8% increase of efficiency the current application came up 1.8% short of this goal.

SideKick Heat Recovery Unit

Project Name: Integration of Advanced Solar Thermal Technology into Industrial Processes - [PIR-15-010]

Recipient/Contractor: ergSol, Inc.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 4/11/2016 to 12/31/2019

Research Area: Energy Efficiency

Issue: 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 Fahrenheit. 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.

Project Description: This project demonstrates the feasibility and viability of solar thermal evacuated tube collectors (ETC) in an industrial application. ETCs are a highly efficient subset of solar thermal systems with the capability to meet the thermal requirements of various industrial processes. For this project, the solar thermal ETC system will be installed at a wine bottling facility to provide heated water for storage in an expansion tank and to their 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 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 this project 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 technology used in this project provides higher energy density per square meter per day (4.039 kWh/m--2/day) than those currently out on the market. Solar thermal systems further California's clean energy goals by reducing natural gas use for process loads.

Applicable Metrics:

Lower Costs: This technology is anticipated to lower operational costs by about $12,000 annually, 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 by 70 metric tons of CO2 equivalent annually.

Natural Gas Funds Encumbered: $1,200,000

Update: The Recipient has received the required permits. The project is currently being installed and commissioned. Several deliverables have provided an overview of the system operating parameters, maintenance, control scheme, and benefits to ratepayers. Preliminary analysis shows that the system will be able to meet at least 40 percent of the facility's natural gas consumption annually. A critical project review, with the Recipient, site owners, and system installers, will be conducted in summer 2019 to determine a construction timeline and identify any potential delays to system commissioning. Since the CPR meeting a construction company, timeline, and budget have been approved.

Roof Installation of Solar Thermal Evacuated Tubes

Project Name: Performance Evaluation of an Industrial Waste Heat Recovery System - [PIR-15-011]

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: 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 was mutually terminated.

Project Name: Pipeline Safety and Integrity Monitoring Technologies Assessment - [PIR-15-012]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/15/2016 to 1/11/2019

Research Area: Natural gas Infrastructure Safety and Integrity

Issue: California's natural gas transmission system consists of approximately 11,000 miles of high-pressure pipelines. This system feeds more than 105,000 miles of gas distribution mains and more than 8.7 million services. Safe and secure operation of this system is an ongoing public interest requiring research and applying new and emerging technologies to reduce pipeline threats. Given the number of different technologies and tools available, the Energy Commission identified the need to research existing, new, and emerging technologies so that gas operators are more aware of the available technologies that can address specific threats, site conditions and operational requirements.

Project Description: This project provides an assessment of technologies for improving pipeline performance, predicting and monitoring threats, and reducing risks in the natural gas transmission and distribution pipeline systems. This technology assessment is based on quantifiable scales consisting of evaluating their performance, technology readiness level, and cost-to-market value. The proposed approach addresses a broad area of pipeline technologies and the various causes of pipeline incidents. The technologies include, but are not limited to, damage prevention, threat monitoring, integrity management, and risk assessment. The research identified various emerging technologies, specify commercial and close-to-market equipment, sensors, systems and processes, and catalogued the status and applicability of the available technologies in a web-based program and database for regulators and operators. This project also included field demonstration of the selected technologies in pipeline and utility practices with the California gas utilities to assist in their operation.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project identified technologies that provide the most benefit to California's natural gas pipeline integrity management practices. The web-based database provides operators with the information for selecting the best technologies to use for their specific threats, site conditions, and operation requirements. The field demonstrations enabled the operators to interact with the manufacturers to address utilities specific requirements and further develop the technologies to meet utility specifications as well as identify further research needs.

Applicable Metrics:

Lower Costs: The demonstrated cross-bore detection technology addressed safety of the infrastructure system against reported cross-bore incidents associated with horizontal directional drilling in urban environments. The technology helps avoid the costs of open trenching installation, which requires traffic management, transport of hard-core material, and re-instatement of road surface, and significantly reduce noise and disruption to businesses and the public.

Increase Safety: The field demonstration of meter breakaway fitting was performed to shut off the gas when a vehicular hit occurs. Reported incidents by CPUC show that 33% of the incidents caused by natural and external forces on the gas pipeline system in California in 2015 to 2017 resulted from vehicular hits to gas meters. The device was successful in shutting off the gas line in 75% of the tests when the vehicle had direct hits to the riser-side of the meter setup.

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. The developed EMAT technology is to detect corrosion metal loss and dents resulting from mechanical damage. The benefit of using the technology is specific to the incidents in pipes with diameters smaller than 12 inches. A total number of 17 incidents occurred in these pipe sizes between 2010 and 2016, which could have been addressed with the implementation of this technology. These incidents resulted in the release of about 303,600 Mcf of natural gas and had a total cost of $4,791,730.

Natural Gas Funds Encumbered: $1,006,812

Update: The final report was received and this project completed in January 2019. The research demonstrated several emerging and close-to-market technologies including obstacle detection during horizontal directional drilling, meter breakaway fitting for vehicle collision, and electromagnetic acoustic transducer for small-diameter, unpiggable gas pipelines for detecting cracks and weld defects. These demonstrations helped the utilities assess the applicability of each technology based on specific threats, site conditions, and operational requirements. For example, both obstacle detection technology and breakaway device are currently being evaluated by California gas utilities for further field demonstrations and implementation at their service areas

Website screenshot for various commercial and close-to-market technologies at 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 (to produce heated drywall slurry).

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project validates 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.

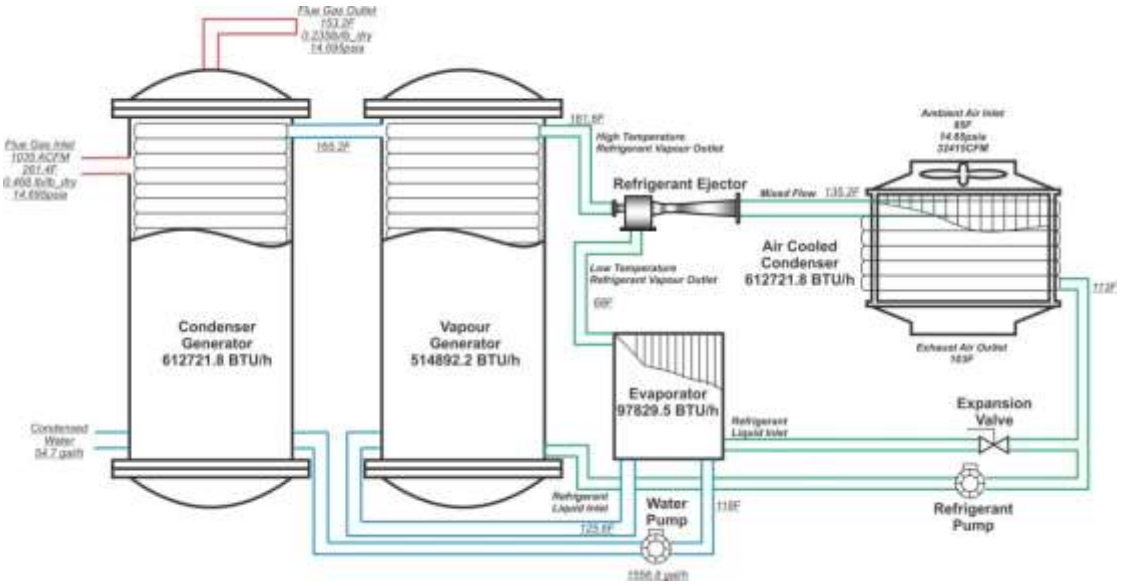
Applicable Metrics:

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 reduce energy costs from hot water recovery.

Natural Gas Funds Encumbered: $1,294,032

Update: Design was finalized along with the process and instrumentation diagram. The redesign will allow the system to be built on-site (instead of off-site fabrication and transport). The recipient has ordered off the shelf parts and is working on the heat exchanger fabrication. System is scheduled to be operational by August and on schedule for 6 months of M&V operational data.

Proposed recovery system layout



Project Name: High Accuracy Mapping for Excavation Damage Prevention and Emergency Response -

[PIR-15-014]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/15/2016 to 10/1/2018

Research Area: Natural gas Infrastructure Safety and Integrity

Issue: 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.

Project Description: 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, 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 for more functional communications and ultimately more efficient and safe operations.

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

Applicable Metrics:

Lower Costs: There are about 600 excavation damage events related to natural gas pipelines in California annually, with an average damage cost of $5,000 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.

Greater Reliability: PG&E estimated that the technology could reduce excavation damage events by 50%, or 300 annually throughout California, leading to increased reliability and security of natural gas infrastructure and supply.

Increase Safety: This technology improves system integrity by reducing excavation damage and increases 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 in California, by 11,700 Mscf annually.

Natural Gas Funds Encumbered: $1,481,426

Update: The final report was received and the project completed in 2018. The research team configured and deployed 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. A survey of natural gas stakeholders demonstrated great interests from gas utilities 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: 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 1/30/2020

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. The goal of this project 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 are using 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 is also being administered to homeowners 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. This is the first attempt to understand emissions from this sector and may lead to additional studies if necessary.

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. This project is designed to provide an improved understanding of emissions from commercial buildings. The results will be shared with the California Air Resources Board to allow the development of corrective measures, as 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. By the end of June 2019, about 100 buildings were measured. Building types include hotels, warehouses, offices, food services, and more. The research team will analyze measurement results in the summer and provide final findings in the fall of 2019.

The research team conducting methane measurement from exhaust vent of top of an office building.

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 2/1/2021

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. Most of these 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%). 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: This project demonstrates an innovative, low-cost gas-fired heat pump system (GAHP) with high efficiency and ultra-low NOx emissions. It is being pilot tested at two full-service restaurants in Southern California, to reduce energy used for commercial hot water (CHW). The commercial restaurant industry typically has large hot water loads, and greater internal heat gain from occupancy and kitchen equipment. Restaurants commonly have large internal load from cooking and air conditioning (A/C) load is often significant. The GAHP system also can offer the option of free space cooling. This project seeks to demonstrate a 40% reduction in natural gas and offset 20% or more of the annual air conditioning cost. The projects hope to reduce natural gas consumption within the area affected by the Aliso Canyon natural gas leak in Southern California.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project demonstrates a new high efficiency, ultra-low emissions commercial water heating and space cooling technology. The heat pump is expected to yield 40% or more natural gas savings to provide commercial hot water (CHW), and can supplement space cooling simultaneously. For restaurants and other commercial applications, this system can replace both conventional gas fired water heating. It has an estimated Annual Fuel Utilization Efficiency of 140% or greater and can reduce greenhouse gas emissions (GHG) by 40% or more compared to gas storage water heaters and 20% lower GHGs from electricity generation due to displacement of air conditioning.

Applicable Metrics:

Lower Costs: The technology is expected to reduce natural gas use by up to 45%, and electricity by up to 20% in restaurant applications. The system can also provide free air

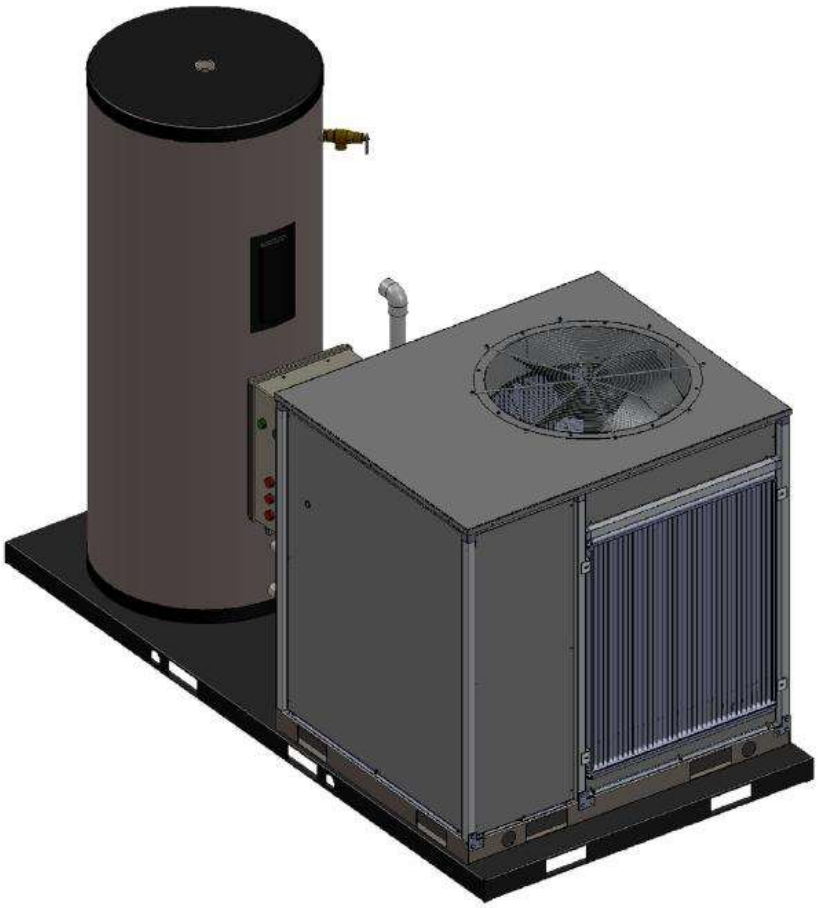
conditioning to cool the kitchen. This technology can provide energy savings, lower operating costs, and reduced greenhouse gas emissions for hospitality facility operators.

Environmental Benefits: Unlike other electrically driven heat pump systems that use environmentally damaging hydrofluorocarbons, the new heat pump uses a natural refrigerant/absorbent, ammonia-water, which has zero ozone depletion potential and zero global warming The NOx and GHG emissions are decreased by up to half and all combustion occurs outdoors.

Natural Gas Funds Encumbered: $864,294

Update: Recipient continues monitoring incoming data streams to ensure the hardware and software are functioning properly. The Integrated System Design report was received September 2019. All activities are on track for a timely completion. A Critical Project Review Meeting was held October 11, 2019. Recipient aims to submit the draft Baseline Field Demonstration Monitoring Report by late 2019.

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 3/1/2017 to 1/29/2021

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 insulation upgrades, with advanced, low-capacity heating, ventilation and air conditioning (HVAC) to capture energy savings at the system level. Low capacity HVAC systems will be installed and tested in five homes. The tested technology will reduce natural gas use at the homes, resulting in less gas consumption in the area affected by the Aliso Canyon gas leak. The newly installed HVAC configuration will be compared against baseline home energy use performance. The goal is to achieve 30 percent greater energy savings relative to 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: While most manufacturers now offer lower-capacity furnaces below 40,000 Btuh/hr, the technology is not widely deployed in California. This is due to contractor tendency to replace older, oversized systems with similar capacity, and oversize for new construction due to the perception that it is preferred. Ultra-Low NOx technology is just coming to market in the South Coast Air Quality Management District. This project will demonstrate one of the first commercially available ultra-low NOx and low capacity products. This project couples low capacity HVAC systems with home performance upgrades, and evaluates energy performance and comfort over an extended period of time. There is an anticipated 30 percent natural gas savings for heating.

Applicable Metrics:

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

Environmental Benefits: The proposed demonstration will occur in Southern California but low-capacity furnaces (with a capacity less than 40,000 BTU/hr) are applicable for

homes up to 2700 sq. ft. or more in mild California climates. The primary market segments in California are single-family, new-construction above code houses, and single-family existing homes where home performance techniques can be applied. Statewide benefits for these segments include: 1.1 Tera-Btu NG savings (2025); 125 GWh electricity savings (2025); 294,000 metric tons CO2e avoided (2020-2025); and 82 metric tons NOx avoided (2020-2025).

Natural Gas Funds Encumbered: $750,000

Update: On July 31, 2018, a Stop Work Order was issued on this project after GTI notified the CEC that their technology provider, Dettson, would no longer provide their ultra-low NOx, high efficiency, low capacity HVAC system, due to a lack of market potential in Southern California. The stop work order was lifted on January 31, 2019 after GTI partnered with Lennox to provide a suitable replacement, low capacity HVAC technology. Since then, the project has focused on getting the project on track such as getting new quotes, amending subcontracts, and updating field test agreements for the five demonstration homes. Selection of the air conditioner and coil have been finalized in order to complete the HVAC system specifications. Home performance upgrades, HVAC system installation, and initial data collection with the new HVAC systems, will be completed Summer 2019.

A newly installed, low capacity, Lennox furnace at Costa Mesa demonstration home

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 2/27/2017 to 10/15/2020

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.

Natural Gas Funds Encumbered: $1,084,230

Update: Gas heat pump water heaters have been installed at 5 residential sites in the Los Angeles area and data collection is nearing completion. Extended life testing continues, most recently the third of a set of 24-hour tests to assess the effect of removing the lid on the heat pump has on the Uniform Energy Factor. Model development and Title 24 analysis will begin soon. A TAC meeting was held on 1/9/19 and the project team received kudos from the TAC members.

GHPWH installed in one of the test sites

Project Name: Advanced HVAC Technology Demonstration Project to Reduce Natural Gas Use in Hospitals -

[PIR-16-004]

Recipient/Contractor: Advanced Microgrid Solutions, Inc.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 3/1/2017 to 12/31/2019

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.

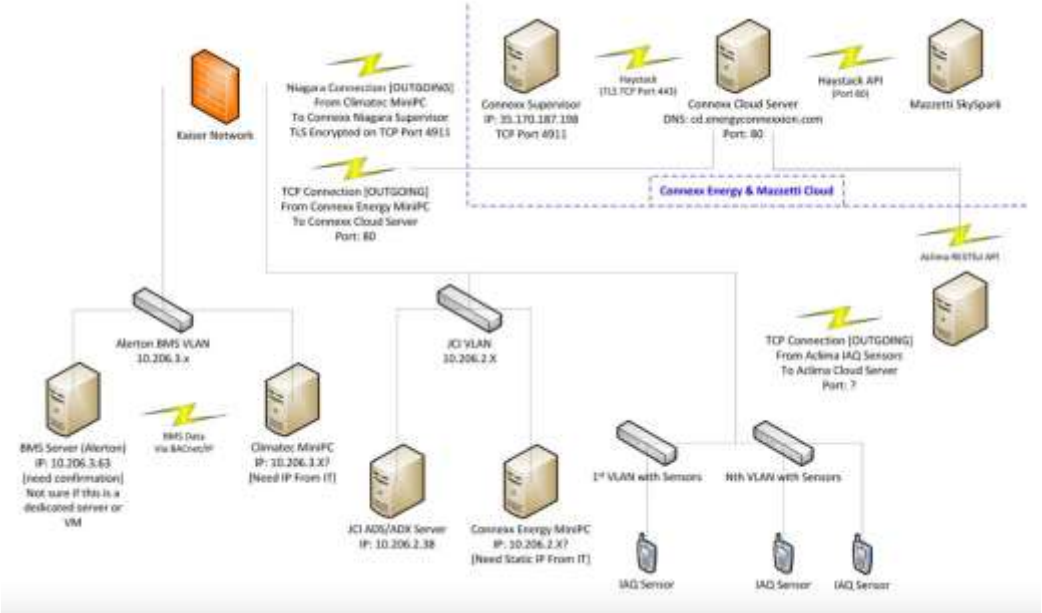
Applicable Metrics:

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: The Office of Statewide Health Planning and Development has approved two of three incremental permits required for this project. Construction of Increment 1 was completed in July 2018 and involved the installation of 76 indoor air quality (IAQ) sensors and one outdoor air quality sensor. In October 2018, the air quality sensor data and building management system data was integrated into one advanced platform. With the two platforms integrated, the air quality sensors can inform and modulate HVAC system ventilation rates. Increment 2 involves the conversion of constant air volume air-handling units to variable air volume and was completed in June 2019. Increment 3 involves reprogramming the ventilation rates and implementing IAQ-based ventilation and is expected to be completed in October 2019.

Building Management System Indoor Air Quality Sensor Integration Architecture



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 has the potential to reduce natural gas use by 75% 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:

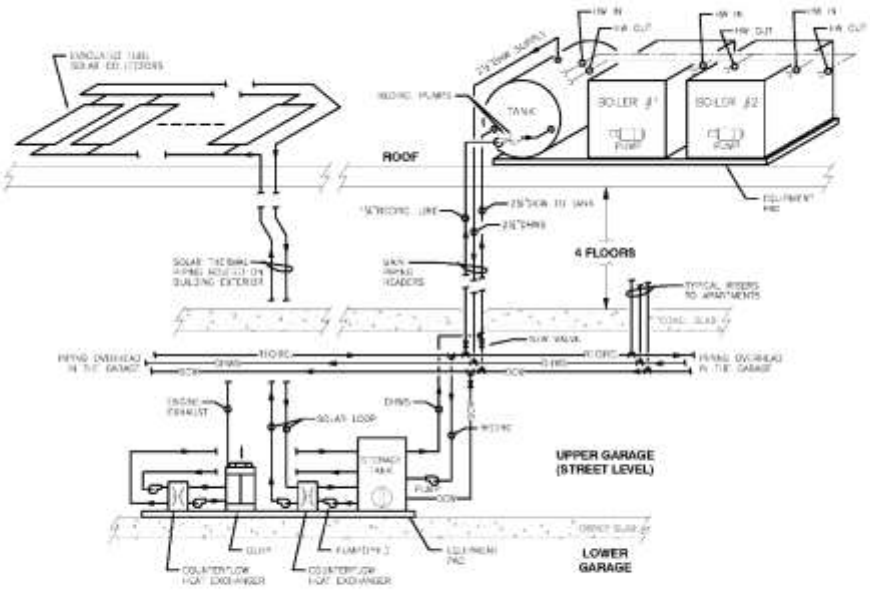
Lower Costs: Potential to reduce total natural gas used for water heating by 75% compared to conventional water heating.

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 solar collectors and the gas engine heat pump have been delivered to the project site. Construction is underway.

Integration of solar thermal evacuated tube collector and natural gas engine heat pump at Park West Apartments



PARK WEST APARTMENTS, LOS ANGELES
NEW DOMESTIC HOT WATER SYSTEM SCHEMATIC

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: Natural Gas Research

Project Term: 4/4/2017 to 10/3/2019

Research Area: Renewable Energy and Advanced Generation

Issue: California is faced with the challenge of reducing natural gas consumption to increase safety, reduce greenhouse gas emissions, and enable zero net energy buildings. Solar combined heat and power (CHP) offers the potential to reduce natural gas consumption by providing 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 PV panel architectures with traditional thermal collector models, limiting cost competitiveness.

Project Description: This project developed 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 CHP collector is a modular solar collector, which simultaneously generates both heat and electricity at efficiencies comparable to standalone PV and solar thermal systems. The system is packaged in a glass tube and utilizes non-imaging optics for solar concentration, aluminum mini-channels for thermal collection, and commercially available solar cells for electricity production. This reduces the required collector footprint and reduces installation costs, thus providing significant cost savings over existing systems installed side-by-side.

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 lowering natural gas consumption and 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 project has successfully demonstrated and verified the technical performance of a twenty-tube array solar CHP collector. The system generates 150 W of electricity and 400 W of thermal heat per square meter. Once commercialized, the technology will reduce natural gas consumption, increase safety and electricity reliability in residential, commercial and industrial building sectors.

UC Merced Solar-CHP Collector Testing Set-up

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: Natural Gas Research

Project Term: 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 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.

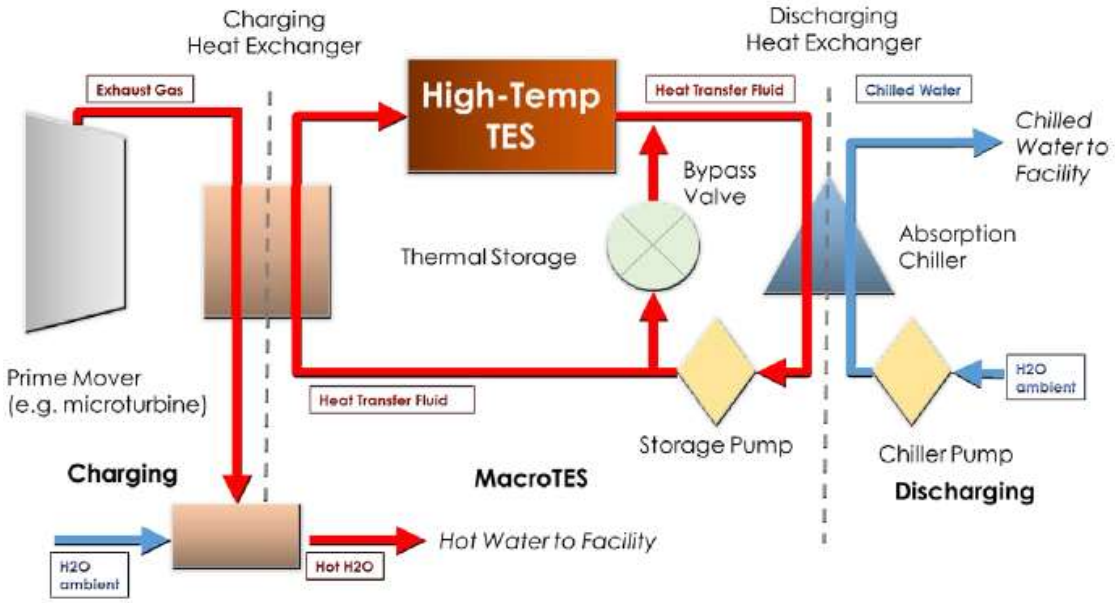
Greater Reliability: If successful, the SuTES system will enable increased deployment of small CCHP systems, reducing local system loads and increasing local generation capacity, which will lead to greater reliability.

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 team 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 and fabricated. The team has identified several modifications that are required before deployment, which is scheduled to begin in the second half of 2019.

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: Natural Gas Research

Project Term: 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 developed a cost-effective micro-scale (less than 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, communities, and commercial building applications, avoiding a substantial amount of natural gas and electricity usage.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project developed a cost-effective, bankable, 25kWe packaged CCHP system with absorption cooling, powered by a biomass gasification waste-to-energy platform. The technology produces renewable energy; drives improved efficiency over current CHP technology, with a system efficiency greater than 80 percent and a power-to-heat ratio greater than 0.4:1; reduces the amount of waste going into landfills; and has the potential to create clean energy jobs.

Applicable Metrics:

Lower Costs: This biomass-fueled CCHP system reduces natural gas consumption both through the use of its CHP output and through the use of waste biomass as an 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 meets current emissions standards for stationary generators, targeting 26.6 CO at 15% O2 [ppm] and 1.1 NOx at 15% O2 [ppm]. The end-of-pipe GHG emissions are 1,330 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. Additionally, one CCHP unit avoids approximately 81 tonnes of CO2e emissions in California. For the 180 MWh of electricity offset from the generation and avoided air conditioning load provided by the CCHP system, this equates to 43 tonnes of avoided CO2e per year per CCHP unit.

Natural Gas Funds Encumbered: $1,500,000

Update: The research team is focused on pilot demonstration activities of two combined cooling, heating and power (CCHP) Power Pallet (PP) prototypes. The pilot testing incorporated a rigorous evaluation of the CCHP PP through engineering validation testing to ensure a safe, robust, and efficient design. Results showed that the system efficiency is equal to 80% in converting producer gas to electricity and thermal load, and 44% from biomass to electricity, heat, cooling, and biochar. The gasifier CCHP system converted 28 kg biomass/hr into 89 kW of producer gas used to generate a net electrical output of 22 kW and recovered 48 kW of heat, of which 23 kW were used for a heating load and cooling applications. In 2018, CalFire awarded funds to Mendocino County to deploy 10 CCHP Power Pallet units to process wood waste and reduce wildfire risk, reflecting the market readiness of the technology.

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)

Natural Gas Funding Plan: Natural Gas Research

Project Term: 4/3/2017 to 3/30/2020

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 mid-century emissions goals. 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 with an emphasis in the distribution network, taking into account future natural gas use, operational factors, impacts from climate, technology development, and regulatory treatment and pricing in the natural gas industry. The natural gas system scenarios will be evaluated as an integrated part of the energy system that can accommodate intermittent power from wind and solar resources, and can accommodate renewable natural gas such as biomethane. The study is evaluating the impacts to customers and options to transition the natural gas distribution system to one compatible with the required deep reductions of greenhouse gas emissions by 2030 and 2050.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: The research team is using their PATHWAYS model to develop scenarios (up to 2050) for the natural gas system that can achieve the State's long-term greenhouse gas (GHG) reduction goals. The study is investigating how to best decarbonize buildings taking into account the potential competition between renewable natural gas and electricity. The preliminary final findings suggest that electrification is the best option to decarbonize buildings. This has enormous implications for ratepayers and for the natural gas industry in general. The research team investigated alternative approaches to minimize impacts to ratepayers, the state economy, and the natural gas industry. Finally, the study is finding that electrification will also improve air quality conditions.

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.

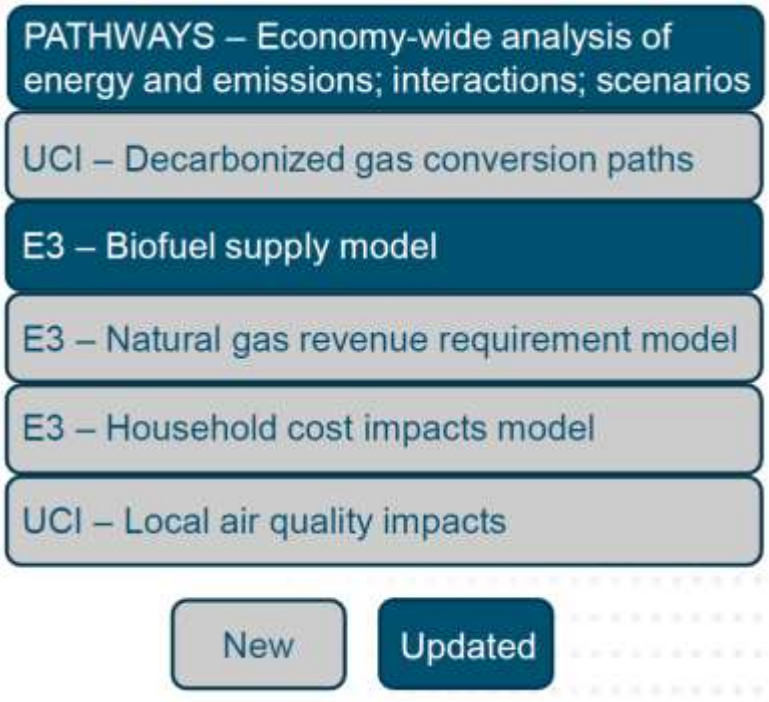
Environmental Benefits: The results of the study will provide estimates of air quality statewide at a (4km x 4km) resolution for all future scenarios; this allows assessment of the co-benefits of improved air quality along with the GHG reductions and other benefits.

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.

Natural Gas Funds Encumbered: $1,099,733

Update: The last meeting of the Technical Advisory Committee took place in May 2019. CEC Staff also organized a public workshop on June 6, 2019 to present preliminary final results and to receive public comments. A draft final report will be available late in August 2019 and will be reviewed by the TAC and the public. A final report is expected to be published in late 2019.

Building Blocks of the Study. Blue areas represent existing tools that are being updated while the grey areas are new analytical tools being developed by E3 and UC Irvine 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: Natural Gas Research

Project Term: 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 in residential homes. However, the code currently requires airflow rates instead of pollutant removal efficiency. For many range hoods, operation at the minimum code-required airflow capacity removes no more than half of the pollutants emitted from front burners of the cooking stove. In addition, the pollution impact in multi-family homes, and the effectiveness of microwave ventilation systems, are not well understood.

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, on 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 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 exposure to air pollutants from natural gas stovetop burners and combustion associated with cooking food.

Natural Gas Funds Encumbered: $1,000,000

Update: 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. The team completed the field study plan based on feedback provided by the TAC members and finalized the agreement with the subcontractor conducting the field study. The fieldwork started in the spring of 2019.

Microwave ventilation above a 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 natural gas wells are a potential but poorly understood source of greenhouse gas emissions in California. During the recent drought, groundwater pumping induced land subsidence in parts of California. This subsidence may be a factor in exacerbating methane leakage from abandoned and plugged natural gas wells if the gas wells 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 due to pumping of ground water during drought. 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 from these natural gas wells in subsidence areas.

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 and 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 abandoned and plugged gas wells in California.

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 inventory. The mitigation effort then can be better informed to reduce methane emissions in the state.

Natural Gas Funds Encumbered: $597,433

Update: The research team obtained well database information from the California Department of Conservation and the map of subsidence from the United States Geological Survey (USGS) and the 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 team has measured about 100 abandoned and plugged gas wells. Only a few of these wells were found to be emitting. The research team is working to gain access to wells in the subsidence area.

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.

Increase Safety: 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 and 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.

Environmental Benefits: 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 state GHG reduction goals.

Natural Gas Funds Encumbered: $1,400,000

Update: The project is well underway and the research team has successfully planned and completed three intensive measurement campaigns at a natural gas combined cycle power plant, at a large food processing facility, and at CNG vehicle fueling stations in Southern California. Data and preliminary results from the first measurement campaign were presented and discussed in the Interim Measurement Results – Region 1 Report, which was submitted in October 2018. Preliminary results from the second and third intensive measurement campaigns were presented in the Interim Measurement Results – Region 2 Report in April 2019. Currently, the project team is finalizing site access agreements for the fourth measurement campaign at the natural gas combined cycle power plant.

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 4/12/2017 to 3/30/2020

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, natural gas investor-owned utilities (IOUs), and scientists. The proposed research will consider all three components (two horizontal and one 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 are 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 natural gas IOUs. A more accurate predictive capability will enable drought-related subsidence to 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.

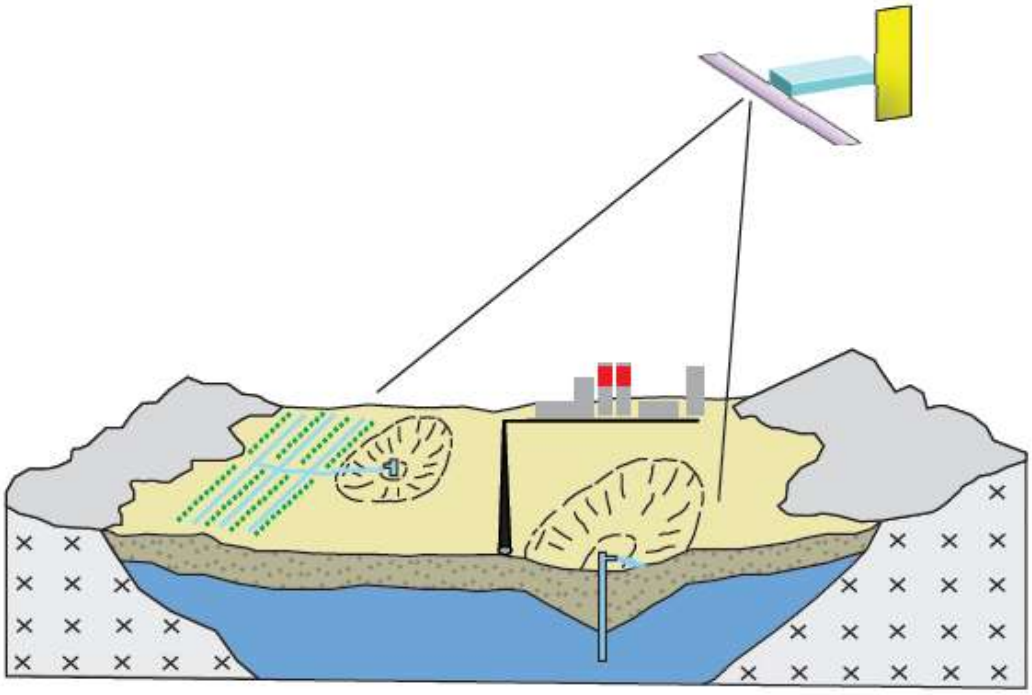
Increase Safety: The project will develop a capability that could provide early warning of growing subsidence bowls that approach vital natural gas infrastructure. This can inform risk-based decisions on preventative engineering actions to protect the infrastructure before it experiences damaging surface 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.

Natural Gas Funds Encumbered: $1,599,584

Update: The project team acquired GPS data at the Corcoda site and compared data to the 3D displacement field, which was evaluated from Interferometric Synthetic Aperture Radar (InSAR) data. These data indicate vertical displacement magnitude far exceeding the horizontal displacement magnitude. Researchers completed initial coupled pumping and subsidence numerical modeling of the El Nido area and calculated vertical and horizontal displacement that could inform the pipeline analysis. InfraTerra, a major project sub-contractor, has acquired data on the pipeline network from PG&E. The research team published a paper in the Journal of Hydrology: "Role of agricultural activity on land subsidence in the San Joaquin Valley, California." Through December 2019, the research team will improve the site-specific numerical modeling of the El Nido area.

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 larger 8.9-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 port 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 engines 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: Gladstein, Neandross & Associates (GNA) worked with Capacity Trucks to complete integration of the 6.7-liter engine into two yard trucks. At the Advanced Clean Transportation Expo in April 2019, GNA showcased the first unit as an example of a low emission alternative for ports as they transition away from higher emitting technologies. The yard trucks will be demonstrated at Cal Cartage before moving to the Everport terminal to complete at least six months of commercial operation. In preparation, GNA submitted a test plan that includes activity data logging and operator surveys and conducted liquefied natural gas safety demonstration to inform operators on how to safely handle the fuel. The University of California, Riverside upgraded the initial gas sensor design by resolving uncertainties caused by the speed of sound and thermal conductivity sensors.

Preparation of liquefied natural gas yard tractors for commercial demonstration

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, Irvine

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/12/2017 to 11/30/2019

Research Area: Energy Efficiency

Issue: Biogas fuels are generated from a variety of sources such as anaerobic digestion processes at water treatment plants and dairies and biodegradation of materials in landfills. Using biogas fuels 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 is increased, the reductions in CO2e emission will increase correspondingly.

Natural Gas Funds Encumbered: $250,000

Update: This project will complete in November 2019 and the project's final report has been received. The Recipient conducted burner testing of four different appliance burners and run simulations on nine. The results from these tests and simulations were presented in final individual reports, which are included as appendices to the final report. The Recipient has also authored several journal papers that are available online and has presented at several conferences and stakeholder meetings.

Results from this study show that, generally, high percentage of either CO2 or H2 in natural gas causes ignition failure, CO2 addition into natural gas tends to increase CO and UHC emissions but decrease NOx emissions of appliances, and H2 addition into natural gas does not influence the emission performance of these appliances, especially when the percentage added is low.

Cooktop Flames

Project Name: CNG Hybrid Power System for Mobile Vehicles - [PIR-16-019]

Recipient/Contractor: Terzo Power Systems, LLC.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/1/2017 to 12/6/2019

Research Area: Natural Gas-Related Transportation

Issue: The agricultural sector is responsible for a significant portion of pollutant 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. The project aims to achieve a 60 percent reduction in carbon dioxide emissions and a 20 percent reduction in noise compared to a diesel baseline.

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: The researchers submitted interim deliverables detailing the individual subsystems, integration strategy, and controls overview for the experimental CNG hybrid-electric vehicle. Due to supplier delays for key components such as the battery pack, the researchers could not conduct the demonstration in the 2018 harvest season. A press event was held in December 2018 to showcase the experimental vehicle alongside a baseline diesel vehicle to interested stakeholders. The researchers are continuing to troubleshoot and establish finalized safety features in preparation for the 2019 harvest season.

Hybrid almond harvester vehicle at a demonstration event

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.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: The project resulted in recommendations for code changes to improve hot water distribution systems. If new homes were built incorporating the results several benefits would accrue to the State. First-year savings from one home with distribution improvements would be 11-19 therms, 1750-3180 gallons of water, and $1500 to the builder. The higher savings includes distribution improvements with lower-flow fixtures. On average about 100,000 new single-family homes are built in California annually. Cumulative savings in ten years from distribution improvements would be 59-107 million therms and 9.6 to 17.5 billion gallons of water. This translates to about 310,000-565,000 metric tons of CO2e reduced.

Applicable Metrics:

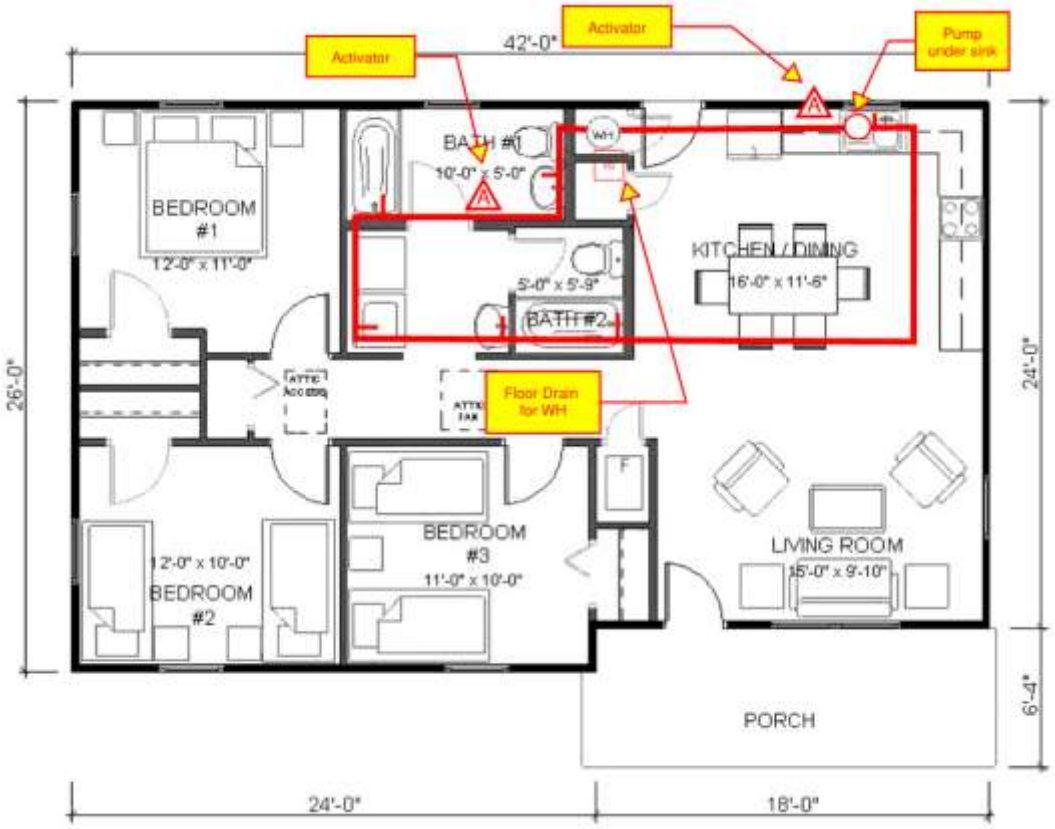
Lower Costs: Following adoption of distribution improvement code changes developed by this project, new Title 24 compliant homes would on save 11-19 therms of natural gas and 1750-3180 gallons of water annually along with reductions in building cost to the builder due to compact designs. Assuming average cost of residential natural gas of $1.50/therm and $1.50 per 100 cubic feet of water, annual cost savings per home will be approximately $367 to $666.

Environmental Benefits: The associated cumulative emission reductions in ten years is between 310,000 metric tons of CO2e and 565,000 metric tons of CO2e.

Natural Gas Funds Encumbered: $249,900

Update: The final report is undergoing review and includes strategies to improve hot water distribution in single-family homes to achieve deep reductions of distribution energy and water waste and hot water delivery quality improvement. These strategies include improvements to distribution systems, pipe layout optimization, use of two water heaters, moving the water heater closer to the fixtures, pipe size reduction, compact architectural design, and lower-flow fixtures. Based on laboratory test results, a distribution performance model was developed to simulate transient hot water delivery operation in complicated distribution networks, with realistic hot water use schedules. Based on performance assessment results, the research estimates that with improved distribution designs, distribution losses can be reduced by more than 50% and system energy water consumption by more than 25%.

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: 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 the low-income sector.

Applicable Metrics:

Lower Costs: Understanding natural gas usage patterns can help identify strategies to reduce energy used for heating. This directly results in less money spent on energy by low-income residents. 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 the installation of data acquisition instruments and is currently collecting and analyzing energy use and behavioral data in two low-

income apartment complexes located in Lancaster and San Diego. The recipient will use the energy use and behavioral information to identify behavioral factors that increase gas use, and will recommend effective behavioral strategies to reduce gas usage.

Water Heater Controller

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/12/2017 to 6/28/2019

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:

Environmental Benefits: 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.

Natural Gas Funds Encumbered: $250,000

Update: In June 2019, Lawrence Berkeley National Laboratory completed their final report and had their final project meeting. In the proposal for this project LBNL hypothesized that there may exist an optimal scale at which the system delivers maximum benefit to the users. The results show that this is indeed the case, with a scale of 8 households providing maximum benefits (minimum life cycle cost) for single-family detached household, and 32 households for single-family attached and multi-family.

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/12/2017 to 12/28/2018

Research Area: Energy Efficiency

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 investigated the electric, natural gas, and GHG emission savings of community-scale solar water heating. The team also assessed 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 produced 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 defined the needs for a community scale SWH system, identified current technologies and configurations, described the trade-offs with other clean energy technologies for cost-effectiveness and feasibility, and evaluated land use requirements. The data from the reports and case study provided 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:

Lower Costs: 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.

Natural Gas Funds Encumbered: $240,404

Update: The recipient submitted the final report and the project is complete. The report conclusions indicate that community scale solar water heating may be viable, under the right conditions, including adequate roof top space and residential density. Costs may also vary widely because a retrofit depends on the condition and configuration of a building's plumbing, and whether the natural gas heaters that are

currently installed can be used as auxiliary heaters. Qualification for incentives is also essential for any solar water heating project to be economically and practically feasible. If all conditions are favorable, community scale solar water heating could reduce the water heating load by up to 50%. The results of this research may inform policy makers and community developers about the viability of community scale solar water heating and whether or not it should be pursued.

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.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/30/2017 to 3/31/2020

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 developed 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 was tested at Argonne National Laboratory across the full operating range of a commercially available near-zero emission natural gas engine: the Cummins Westport ISX12N. The researchers evaluated the test results 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 15 percent, reduce NOx 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

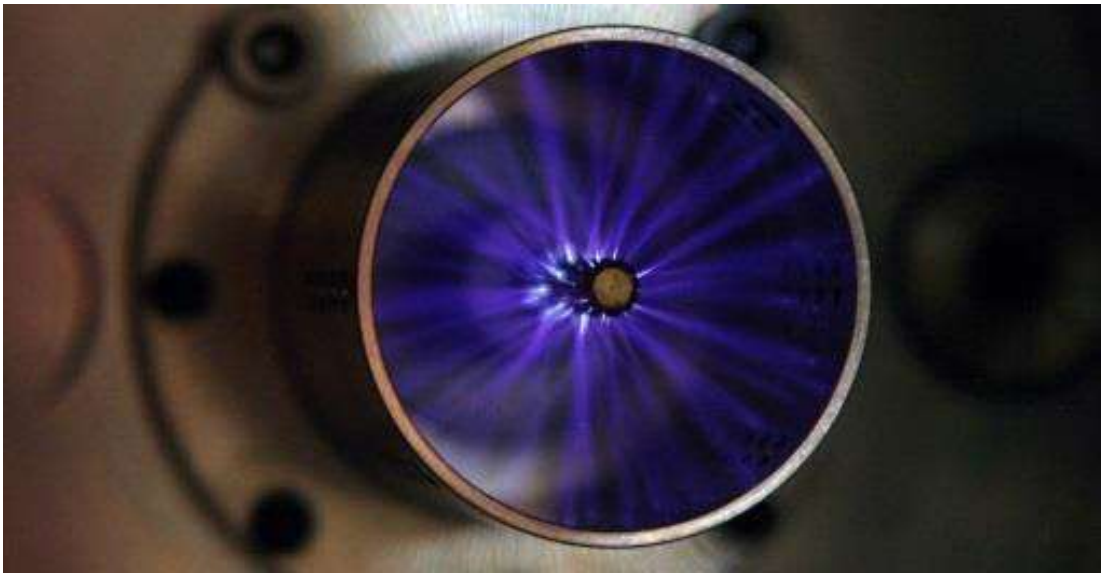
erosion of conventional spark plugs. By reducing maintenance needs, transient plasma ignition can increase the reliability of natural gas engines.

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.

Natural Gas Funds Encumbered: $899,139

Update: The researchers improved on their initial design by increasing the frequency of pulses. Single cylinder test results showed higher stability at high dilution conditions, suggesting potential to improve flame kernel development. The multi cylinder prototype was designed and underwent system level testing before being sent to Argonne National Laboratory. Baseline testing of the ISX12N was completed. System level testing required to validate the system delayed engine testing at Argonne National Laboratory from February 2019 to June 2019. The testing demonstrated stable operation, improved brake thermal efficiency, reduced carbon monoxide and NOx emissions, and extension of dilution tolerance. Test results will be shared with engine manufacturers and Tier 1 suppliers. Next steps include miniaturizing the system so it can be readily integrated into vehicles.

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. This project will help determine an optimal hardware configuration for a D-EGR natural gas engine to maximize benefits.

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.

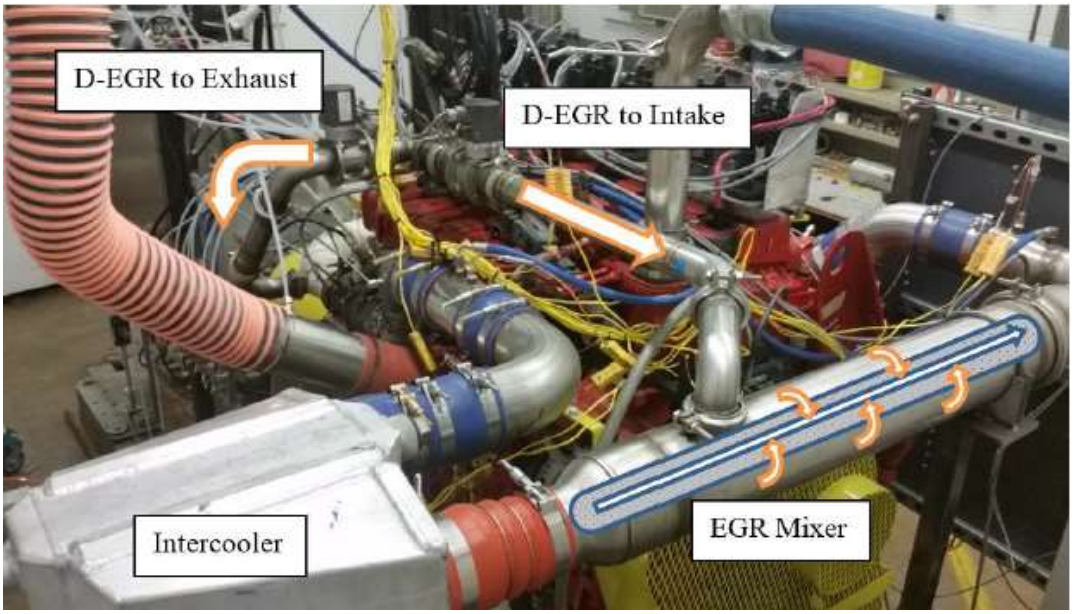
Environmental Benefits: Increased adoption of natural gas as a transportation fuel for heavy-duty vehicles with high efficiency, near-zero emission natural gas engines will reduce criteria pollutant and greenhouse gas emissions. This project aims to demonstrate a 10 percent increase in engine efficiency, 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: The researchers successfully converted the 12-liter test engine to a D-EGR configuration. A GT power model was calibrated to predict the performance of the D-EGR engine, identifying its ability to achieve a 10 percent relative improvement in brake thermal efficiency. The advanced ignition system was identified as a key component and must sufficiently extend the enrichment limit of the dedicated cylinders to reduce incomplete combustion. The project experienced several schedule challenges related to the high compression ratio piston supplier and some test equipment failures. However, the team still expects to complete the project on time with testing of the optimal engine configuration in August 2019.

D-EGR Natural Gas Engine in Instrumented Test Cell



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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/30/2017 to 12/31/2020

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 Management and Decision Support System (IRMDSS) 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 will improve the reliability of the gas supply by predicting the potential occurrence of gas leaks with advanced monitoring and process-based modeling, recommending preventive and corrective measures that can be taken

before leaks happen, and informing decisions on mitigation measures when low-level, or large leaks occur.

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.

Natural Gas Funds Encumbered: $2,975,761

Update: This project is on schedule and all deliverables are up to date. Lawrence Berkeley National Laboratory developed several models for wellbores and reservoirs and adapted the models for optimal performance. The team has obtained preliminary results using InSAR monitoring technology and presented the results to the Energy Commission. The initial study is promising. The Recipient is currently working on a field demonstration. A storage well at SoCalGas was identified as a test site and monitoring devices are being installed. The team will then present their results to the utility and obtain feedback. Lastly, a report will be prepared detailing the demonstration, outcomes and lessons learned.

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 is a critical element of the natural gas infrastructure, since it helps balance the supply and demand for end users. Underground gas storage assets presents unique challenges to risk assessment compared to other systems such as pipelines and power plants as the surface components and sub-surface components are closely interconnected and the failure modes of one could affect the other. Utilities are already using risk management approaches. However, factors, such as the aging of the storage system, the range of gas qualities that are coming into the pipeline, and the greater demand on gas have necessitated the need for a renewed look at the risk management methods.

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 by combining two models, the bowtie and Bayesian network models, that could be used separately or in combination. This will be a first of its kind risk assessment approach in which 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 for use 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: The project team performed a gap analysis and identified the current industry approaches to risk assessment and areas for improvement. A Hazard Identification (HAZID) workshop was conducted on April 4 and 5, 2018 with utility partners, industry members, and Energy Commission staff. The HAZID workshop identified the threats along with relevant preventive barriers, and the results were incorporated into a bowtie model 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. A workshop was held December 13, 2018 with TAC and industry subject matter experts to go over the Bayesian network model. The integrated bowtie and Bayesian network model has been completed, and is now undergoing validation. An operational guide and webinar is planned to train stakeholders.

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: The project team successfully built a lab-scale, Waste Heat to Osmotic Power system and is in the process of evaluating its performance and characteristics of key components. The project team is currently focused on resolving technical challenges in system development before proceeding with remaining technical tasks.

Lab Scale System

Project Name: Advanced Thermo Electric Generator System (ATEGS) - [PIR-17-002]

Recipient/Contractor: Altex Technologies Corporation

Natural Gas Funding Plan: Natural Gas Research

Project Term: 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 combines 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 ratepayers $72 million per year.

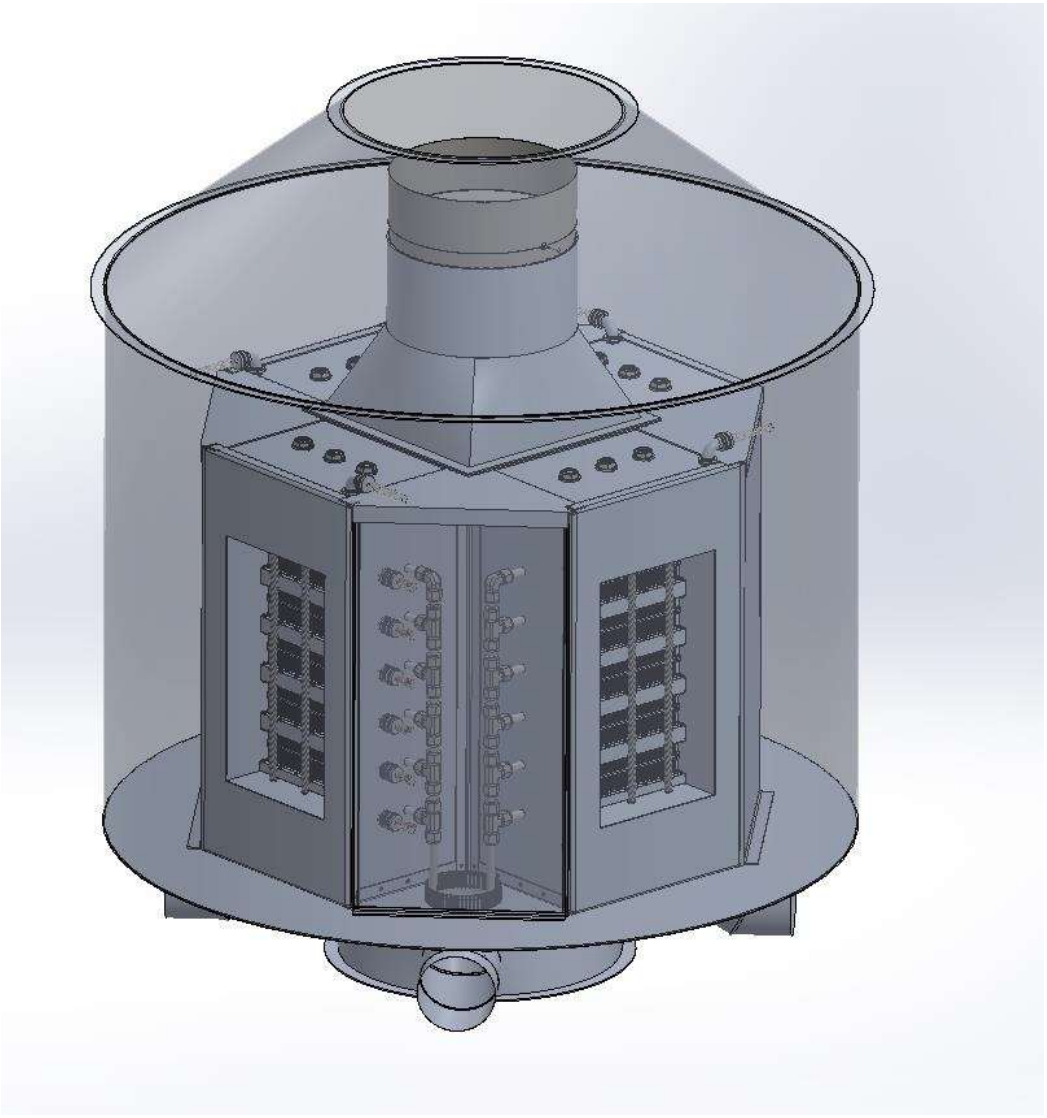
Economic Development: It is projected that during the first five years after commercialization, up to 20% of the market will be captured. If 20% of the market were penetrated, that would provide a cumulative sale value of $251million.

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: The project team has completed the design of the 250 W and 2 kW thermoelectric generator systems that target two different temperature ranges. The team is currently in the process of completing fabrication of the two systems and then will proceed to validate their performance.

2 kW ATEGS Assembly Drawing



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: Natural Gas Research

Project Term: 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 a 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 benefits.

Applicable Metrics:

Lower Costs: Conservatively assuming a 10-year life, the cost of the electricity produced by the CHP system is about 25% of the cost of grid electricity in California, delivering cost savings to facility owners.

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 team conducted laboratory performance and emissions testing of the micro-CHP system. Technical issues with the emissions control catalyst where uncovered during baseline testing. The project team is in the process of making design updates to address the identified issues before continuing with baseline testing.

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).

Project Name: 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: Natural Gas Research

Project Term: 4/25/2018 to 3/31/2022

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 demonstrates 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 at 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: The recipient 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:

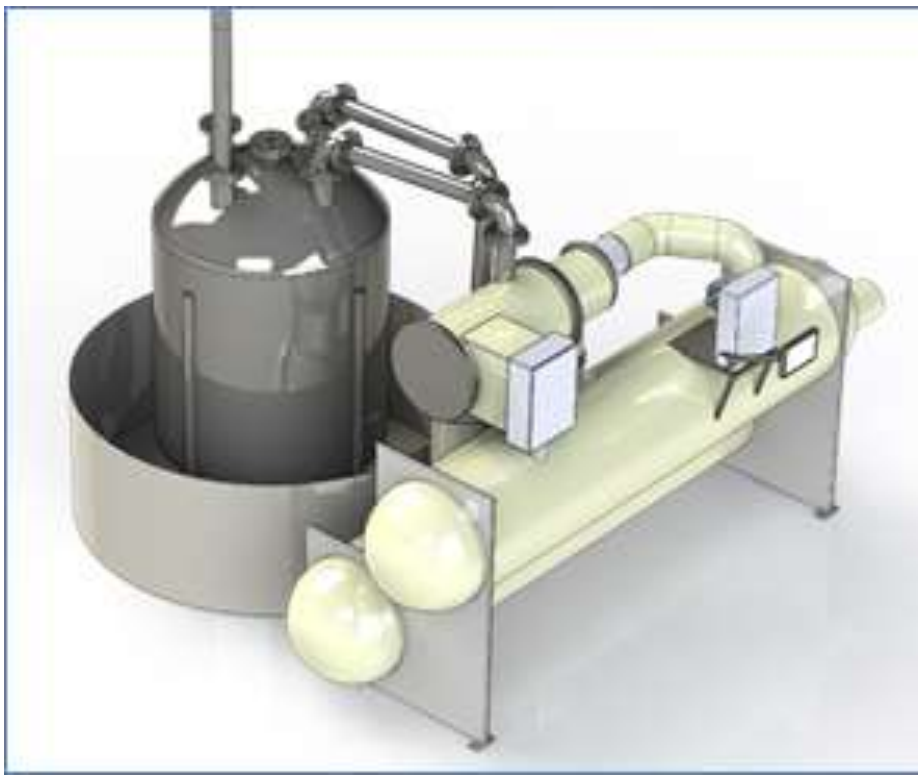
Lower Costs: The heat capture system has the potential to recover useful heat from low-temperature waste heat streams and deliver it for process heating applications to

reduce on-site natural gas demand and cost at industrial facilities. For the project host-site, the project has potential to reduce sodium borate dryer natural gas use by 15%.

Natural Gas Funds Encumbered: $1,500,000

Update: The recipient has entered into an agreement with the project host-site, Searles Valley Minerals (SVM). The recipient has installed natural gas flow meters and control valves to collect moisture and natural gas flow rates as part of the M&V baseline.

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), the ratio of a fuels 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 develops a "smart combustion technology" which advances 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 tons/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 could 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 annual natural gas savings at the installation site is estimated to be from $8,000 to $13,000.

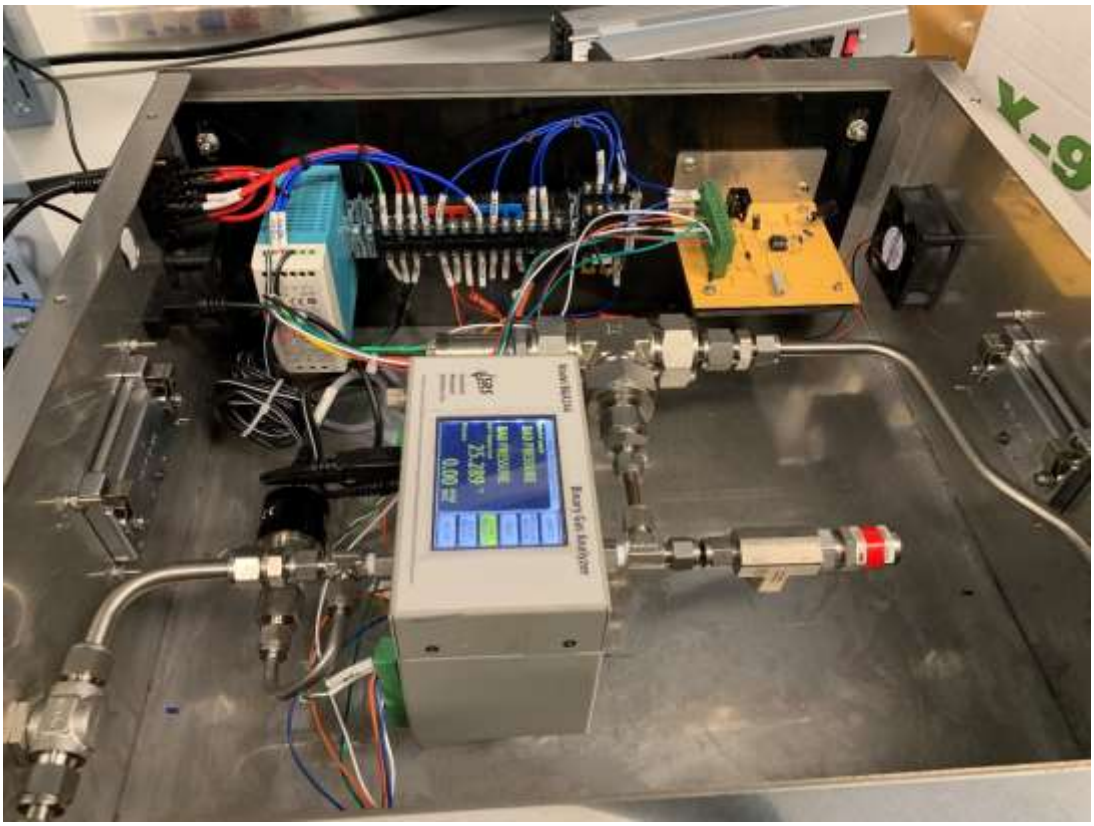
Environmental Benefits: One of the project goals is to achieve a 30 percent reduction in NOx emissions via a 10 percent increase in natural gas combustion efficiency enabled by the SCS technology.

Natural Gas Funds Encumbered: $1,499,910

Update: The Recipient has completed building an initial version of the natural gas database, and analysis of the predictive algorithm for the natural gas quality estimation. The natural gas simulator design was completed and installed, and an initial version of the sensor prototype fabrication was completed. Iterative improvement of the database by machine learning has started and the Recipient will continue further refinement of the natural gas database and predictive algorithm. The Recipient has started testing the sensor in a controlled environment, with typical gas pressures and temperature combinations as experienced by industrial boilers. Sonic velocity sensor was replaced to improve accuracy of readings.

Recipient is planning to start development of the extended natural gas blender with data acquisition system.

Sensor prototype for the integrated Smart Combustion System



Project Name: High-Efficiency and Ultra-Low Emissions Linear Generator Demonstration Project in Southern California - [PIR-17-006]

Recipient/Contractor: EtaGen, Inc.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/1/2018 to 12/31/2021

Research Area: Renewable Energy and Advanced Generation

Issue: Existing CHP solutions generally provide the highest economic and environmental returns when the end-use facility has large and steady thermal and electricity loads. Commercial and light industrial facilities, however, typically have smaller and variable thermal loads in comparison to their electricity loads, which makes it difficult for CHP solutions that use existing prime movers (engines and microturbines) and costly fuel cells to provide sufficient economic and environmental returns in the 5 MW and under-size range to warrant the investment.

Project Description: EtaGen is designing, building, and demonstrating an advanced linear generator with compelling economic, environmental, and operational attributes. The demonstration unit will be hosted by a major U.S. communications company. The EtaGen technology, with high electric and high overall efficiencies in the CHP mode, will better fit the energy load characteristics of most commercial and light industrial applications. Intrinsic ultra-low air criteria pollutant emissions coupled with a high-efficiency drive and small greenhouse gas (GHG) footprint on natural gas make EtaGen's technology environmentally attractive. Capital cost and operating cost projections will be on the low side of the DG and CHP technology spectrum.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals:
Breakthrough enhancements include high electrical efficiency through direct conversion of linear motion into electricity generation; very low emissions through low-temperature combustion without spark, flame or oil; variable compression/expansion allowing for fuel flexibility; standard materials and manufacturing processes to keep capital costs low; and, only two moving parts, no spark plugs and oil-less operation result in low maintenance costs.

Applicable Metrics:

Lower Costs: EtaGen's linear generator technology combines high electrical efficiency (>45%) with low installed cost (<2,500/kW). In terms of efficiency, it is similar to CHP-capable fuel cell technologies while pricewise it will be similar to standard internal combustion engines.

Natural Gas Funds Encumbered: $995,659

Update: EtaGen is currently working on contracting with the demonstration host site and securing air permits from SCAQMD for the demonstration, which is expected to begin in March 2020. They have also ordered parts for the commercial unit, which are to be assembled and tested in the fall and winter of 2019.

Rendering of EtaGen's 250 kW linear generator product.

Project Name: Emerging Energy Efficiency Technologies in California's Chemicals and Allied Products Industry-Estimating Energy Efficiency Cost Curves and Identifying Technology R&D Needs and Gaps - [PIR-17-007]

Recipient/Contractor: Lawrence Berkeley National Laboratory

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/29/2018 to 6/30/2020

Research Area: Energy Efficiency

Issue: California's chemicals and allied products manufacturing industry produces a wide array of products and is a major user of natural gas and electricity. Information is lacking on the major natural gas using systems in this sector and the potential energy efficiency research and development needs, emerging technologies that are most beneficial and associated costs and barriers that prevent implementation.

Project Description: The project provides a technical assessment of the chemical and allied products manufacturing industry in California and provides information on the energy use trends, energy efficiency opportunities and prioritized research needs and associated costs and barriers. The prioritized research needs will be categorized by Technology Readiness Levels (TRL) with a focus on TRL 7 through 9.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project identifies potential research that could help the chemical and allied products industry reduce energy use and costs, as well as greenhouse gas and other emissions, and increase their operational competitiveness. The focus is to guide future research on technologies with a TRL 7-9, since they have the highest likelihood of deployment by the industry in the next 3-5 years. As the chemical and allied products industry is one of the major users of natural gas, focusing on research with the highest potential for implementation in the near term will help the industry meet the state's energy efficiency and greenhouse reduction goals.

Applicable Metrics:

Lower Costs: This project will result in a technical assessment that will identify technologies that could be implemented in the next 3-5 years by the chemical and allied products industry. If these technologies are implemented it could reduce energy and costs, greenhouse gas emissions and associated criteria pollutants.

Natural Gas Funds Encumbered: $300,000

Update: The recipient obtained the energy use information for chemical and allied products manufacturing industry in California. LBNL could not get data from utilities so LBNL analyzed the natural gas and energy use information from value of shipments

(VOS) and value added (VA) estimated from US Census Annual Survey of Manufacturing (ASM2017). With this information the Energy Data Overview and Analysis report for California's Chemical Industry was developed.

Project Name: Demonstration of a CNG-Hybrid Electric Super-Truck (CHEST) - [PIR-17-008]

Recipient/Contractor: Transportation Power, Inc.

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/7/2018 to 6/30/2021

Research Area: Natural Gas-Related Transportation

Issue: Battery-electric trucks may require upwards of a megawatt-hour 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 hybrid 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.

Public Health: 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

Natural Gas Funds Encumbered: $1,500,000

Update: The researchers worked with the technical advisory committee to secure a match contribution from Cummins Westport to provide a B6.7N engine for the hybrid truck. The researchers are collecting engine layout information to inform vehicle integration tasks. Simulation tools are informing design decisions by estimating energy consumption and performance based on heavy-duty vehicle drive cycles. The researchers have placed orders for long lead-time items such as the battery modules and electric axles.

Innovative electric axle drive system

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/7/2018 to 6/30/2021

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 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 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 greenhouse gas (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 to disadvantaged or low-income communities or specific corridors such as the I-710.

Natural Gas Funds Encumbered: $1,499,381

Update: The research team is 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. The project is experiencing delays due to subcontracting issues and concerns about intellectual property protection related to the hybrid powertrain components and controls. A path forward has been identified that addresses IP concerns of all the project partners and avoids adjustments to the project scope.

Natural gas hybrid-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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/15/2018 to 3/31/2022

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 is developing a new technique helping to identify the origin of natural gas consumed in California and is offering a breakthrough methodology for estimating total life-cycle greenhouse gas 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 led by 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. Sample collection for this project began in the spring of 2019.

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: Natural Gas Research

Project Term: 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 and heavy hydrogen 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 identifying the origin of natural gas and offer a breakthrough technique for estimation of total lifecycle greenhouse gas emissions for natural gas used within the state of California that could be used by the California Air Resources Board. In addition, a 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 lifecycle 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 and California Department of Health, in illuminating the public health impacts of large natural gas leaks.

Natural Gas Funds Encumbered: $550,000

Update: The joint kick-off meeting for this project and agreement PIR-17-010 with LBNL was held in September 2018. The two projects are pursuing complementary methodologies to enhance abilities to estimate emissions from different natural gas basins. Sample collection will begin in November 2019.

Conditioned canisters ready for natural gas sample collection.

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, Berkeley

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/7/2018 to 3/31/2022

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 entire natural gas system. Cal-Adapt is a website and platform that provides natural gas system stakeholders with actionable information through interactive, compelling, and useful visualizations and tools. These tools can help users 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-effect 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:

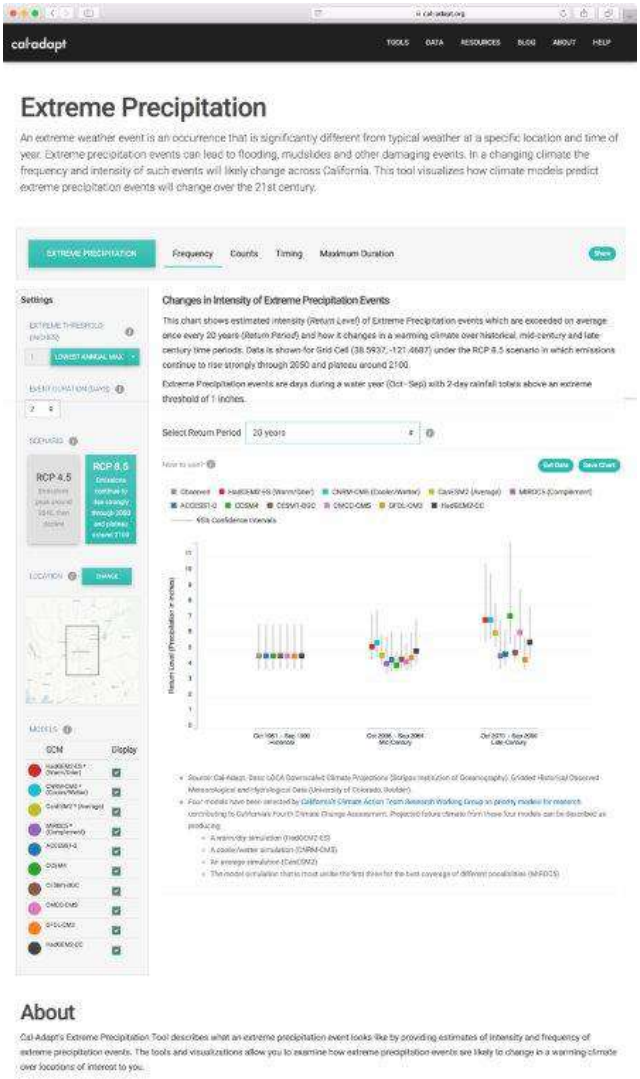
Greater Reliability: This project supports natural gas sector planning, management, and adaptation to climate change. Climate change is expected to impact California's natural gas and energy infrastructure through projected increased temperatures, sea level risk, wildfire risk, and severe droughts. Preserving 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: 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 (particularly natural gas utilities) will be better prepared to safeguard vulnerable populations and ratepayers.

Natural Gas Funds Encumbered: $1,000,000

Update: GIF has acquired, pre-processed, and uploaded datasets developed through California's Fourth Climate Change Assessment to the Cal-Adapt Climate Data Server. With this data, GIF has completed the development of the Extreme Precipitation Tool and the Data Download Tool. The Sea Level Rise Tool is being developed, and the development of the Enhanced Wildfire Tool will start soon. The project has held various webinars to a large group of interested stakeholders: one was specifically to introduce the Extreme Precipitation Tool and one to present the Data Download Tool. The purpose of the webinars was also to gather feedback and suggestions for additional features that might be helpful to users. Additionally, the project has been awarded web service research credits to build distributed cloud computing into Cal-Adapt, which enhances the Cal-Adapt site hosting and data services.

The Extreme Precipitation Tool on Cal-Adapt allows users to investigate what extreme events are projected to look like in the future



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 is identifying areas of high risk to natural gas infrastructure in the Delta and testing a minimum of four geophysical methods for assessing levee integrity. This testing is being conducted at several Delta sites and includes seismic surface-wave surveying, electrical resistivity, ground penetrating radar, and electromagnetic surveying. The research team is also conducting 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 natural gas investor owned utilities to (1) prioritize mitigation locations, and (2) allocate economic and work force resources where needed.

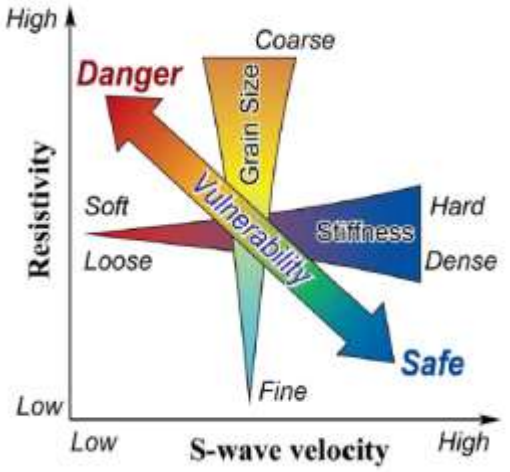
Applicable Metrics:

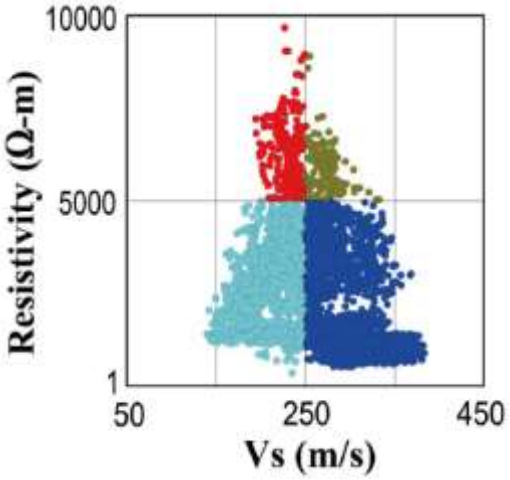
Greater Reliability: The study is using non-invasive geotechnical technology to develop a methodology for assessing the structural stability of levees protecting the Delta. Failure of these levees may affect natural gas pipelines and storage facilities that are a critical component of the state's natural gas infrastructure, so improving our understanding of the levees' integrity will help prevent potential disruptions from levee failures and ensure greater reliability and safety.

Natural Gas Funds Encumbered: $549,500

Update: The research team has been conducting a geotechnical assessment of levee conditions. Initially, the research began using the Rocscience software package RS3 to develop a three-dimensional model to properly capture soil-structure interaction effects around buried pipelines. The soil was modeled using a Mohr-Coulomb type failure surface with a constant cohesion and zero friction angle to simulate undrained loading conditions. The cohesion was modeled as uniform rather than as a spatially correlated random field. The simulations are still in the preliminary stages. The research team anticipates using the modeling to relate levee crest displacement to demands on the pipeline, and potentially to calibrate a two-dimensional model for a more detailed parameter study.

Concept of vulnerability assessment using the relationship between electrical resistivity and S-wave velocity (left), and classification into quadrants on a crossplot of data (right) extracted from a levee vulnerability assessment dataset. Inazaki, T., & Hayashi, K. (2011, January). Utilization of integrated geophysical surveying for the safety assessment of levee systems. In Symposium on the Application of Geophysics to Engineering and Environmental Problems 2011 (pp. 370-378). Society of Exploration Geophysicists.





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 the impacts of climate change 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 and with natural gas sector stakeholders 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 scientific and analytical guidance to the host of Cal-Adapt.

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 natural gas consumption.

Applicable Metrics:

Greater Reliability:

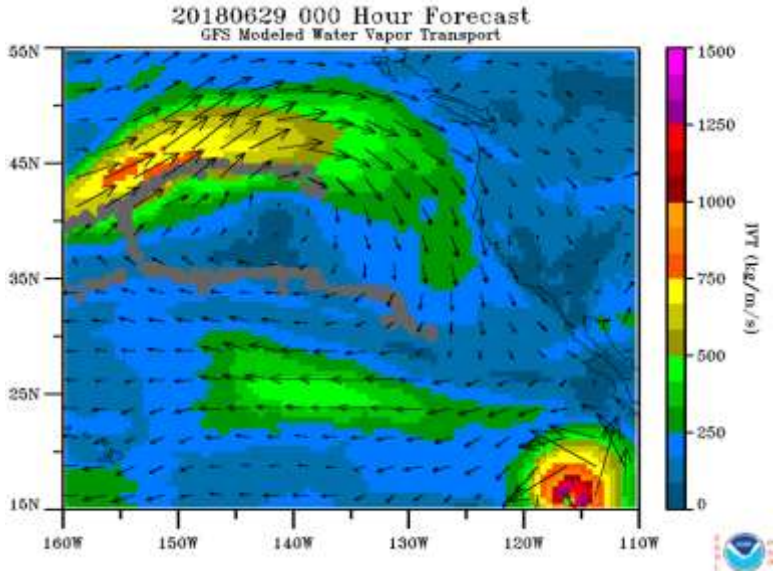
This project will result in the ratepayer benefits of greater natural gas reliability and increased safety by enabling investor owned utilities (IOUs) to understand natural gas infrastructure vulnerability in the context of risk from wildfire, sea-level rise, or extreme climate events. Informed decision-making around infrastructure management 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 kicked off in August 2018, whereafter the lead scientist worked with the host of Cal-Adapt to explore issues related to representation of variability and uncertainty, potential new tools of interest to the natural gas sector, and specific issues related to extreme precipitation. The lead scientist developed and provided an analytically rigorous approach to the representation of extreme precipitation events in terms of parameters of interest to managers of infrastructure. The lead scientist also led successful submission, with Energy Commission as co-convener, of a session entitled "Actionable Climate Tools and Data" at the American Geophysical Union's (AGU) Fall 2019 Meeting. This session will foster knowledge transfer and support both near-term and long-term planning for Cal-Adapt to meet the evolving needs of the natural gas sector.

Machine learning techniques could be used to identify the location and/or existence of atmospheric rivers, helping to understand and visualize certain heavy precipitation events.



Project Name: SUper eMitters of Methane Detection Using Aircraft, Towers, and Intensive Observational Network (SUMMATION) - [PIR-17-015]

Recipient/Contractor: Lawrence Berkeley National Laboratory

Natural Gas Funding Plan: Natural Gas Research

Project Term: 5/17/2018 to 3/31/2022

Research Area: Energy-Related Environmental Research

Issue: Multiple atmospheric studies have identified a significant underestimation of methane emissions reported by greenhouse gas inventories. These regional and local uncertainties present barriers to accurate methane accounting and cost-effective mitigation. Other studies show that the methane footprints of the natural gas supply chain are dominated by a small number of super-emitters; in many cases, 1-10 percent of potential sources contribute more than half the emissions. Existing measurement systems in the southern San Joaquin Valley cannot apportion emissions between sectors or provide information with the space-time resolution and timeliness needed for mitigation guidance for super-emitters.

Project Description: The project SUMMATION establishes persistent regional-scale methane (CH4) emissions monitoring, conducts high spatial resolution remote sensing of point source detection and quantification, organizes intensive field campaigns including low-cost sensors assessment, and brings together and analyzes a large data set for the southern San Joaquin Valley.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project is directly responsive to the directive in Assembly Bill 1496 to improve the monitoring and measurement of CH4 emissions, particularly high-emission CH4 hot spots, using the best available and cost-effective methods. Facilitating an end-to-end multi-scale and scalable approach for CH4 monitoring can identify cost-effective investments in natural gas infrastructure and in natural gas IOUs' monitoring programs. This will effectively lower the cost and risk for maintenance crews, in addition to sheltering ratepayers from unnecessary monitoring and measurement costs, resource losses, and damages from associated smog forming compounds, hazardous air pollutants, and climate impacts from greenhouse gas emissions.

Applicable Metrics:

Greater Reliability: Identifying methane super-emitters will shorten the time needed to mitigate and fix the leaks and result in the improved resilience of California's natural gas system.

Increase Safety: Early detection and mitigation of methane emissions could reduce risk of catastrophic events such as pipeline explosions.

Environmental Benefits: Early detection of methane fugitive emissions will shorten time needed to fix the largest leaks and, hence, reduce the total amount of greenhouse gas emissions.

Public Health: Detection and mitigation of methane emissions will protect the public from long-term exposure to gases and odorants contained in natural gas delivered by California's Investor Owned Utilities.

Energy Security: Early detection of gas leakage could prevent potential disruptions to California's natural gas system caused by pipeline shutdowns, and hence interruptions of natural gas fired electricity plants.

Natural Gas Funds Encumbered: $6,000,000

Update: This project kicked off in June 2019 and was attended by multiple stakeholders, including representatives from California Air Resources Board, Environmental Protection Agency, Department of Energy, and the Environmental Defense Fund.

The research team installed methane detection tools on one out of three planned tower locations and started data collection. Preliminary results suggest well above average emissions northeast of Bakersfield - an area with many oil and gas well heads.

The team also engaged with multiple methane survey tools manufacturers and is working towards completion of a list of cost-effective technologies that will be tested during the field campaign in summer.

Project Name: High Efficiency Process Heating - [PIR-17-017]

Recipient/Contractor: Institute of Gas Technology Institute

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/29/2018 to 3/31/2022

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 demonstrates 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 technology can be seamlessly integrated into existing infrastructure and controls, allowing for a straight-forward installation and reliable operation, while providing more than 20% natural gas reduction with a simple payback of less than 5 years.

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:

Lower Costs: 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.

Natural Gas Funds Encumbered: $1,405,947

Update: Estimated delivery time for equipment has been delayed by three-months. Recipient continues to work on a 12-meter long prototype collector, the matched particle thermal fluid loop with storage. Continued work on the equipment and materials list generated from the Process and Instrumentation Diagram for the particle thermal storage skid. The lock hoppers were revisited to support a request for pressure vessels from the host site. The fabricator was able to accommodate the change to pressure rating. Locations were adapted for mounts, penetrations and hopper heads.

Project Name: Production of Pipeline Grade Renewable Natural Gas and Value-Added Chemicals from Forest Biomass Residue - [PIR-18-001]

Recipient/Contractor: West Biofuels LLC

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/31/2023

Research Area: Renewable Energy and Advanced Generation

Issue: The low cost of fossil natural gas and high levels of risk associated with new technologies challenge the commercial production of renewable gas (RG) from forest residues. In the past, several large-scale cellulosic biomass-to-biofuels projects have failed, increasing the rigor needed to demonstrate technical viability to stakeholders interested in financing projects. In addition, limited opportunities have been presented that create multiple value-added products, which could help reduce the financial risk of a new project. The current project will demonstrate at a pilot-scale, a complete system to convert forest fuels from high hazard zone regions to RG and value-added mixed alcohol by-products.

Project Description: The purpose of this agreement is to fund the development of technology that produces renewable gas (RG) from forest residue sources from high hazard zone (HHZ) regions. Some project goals include the demonstration and verification of a gasification pilot-scale system that can convert high quality RG that can meet natural gas standard in California investor owned utility territories, while achieving a wholesale cost of RG of $12/MMBTU or lower. This project will lead in the ratepayer benefits of increased natural gas reliability, lower costs, job creation, air emission reductions, and improved forest management and watershed protection. UC San Diego, National Renewable Energy Laboratory (NREL), Placer County Air Pollution Control District among many other companies and agencies will assist in the completion of the project.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project will contribute to future ratepayer benefits, including increased natural gas reliability, lower energy costs, job creation, air emission reductions, and improved forest management and watershed protection.

Applicable Metrics:

Lower Costs: The project seeks to validate a process that can generate multiple products to reduce the cost of RG and ultimately the cost of renewable gas to the consumer. One of the project objectives is to achieve a wholesale cost of RG of $12/MMBtu or lower.

Greater Reliability: The proposed technology will demonstrate a promising new technology that will allow for the in-state production of RG. Diversification of natural gas and RG will help support the reliability and resiliency of the gas system. Additionally, numerous critical natural gas distribution and transmission lines run through the forested landscape. Projects that support sustainable forest management will reduce the risk of infrastructure damage from wildfire.

Economic Development: A commercial facility would almost certainly be located in an IOU territory to connect to the IOU pipeline. Such a project would bring both long-term operations and short-term construction jobs to IOU ratepayers.

Environmental Benefits: The Sierra Nevada region supplies more than 60% of the state's fresh water supply. The health of the forested landscape is critical to reducing the risk of catastrophic wildfires that damage watersheds, soil retention and stability, and water hold capacity. The proposed project is expected to produce RG with a carbon intensity of 75% below that of fossil natural gas. Additionally, the project is expected to support the reduction of short-lived climate pollutants through the reduction of open-pile burning.

Natural Gas Funds Encumbered: $2,000,000

Update: The project successfully kicked off on July 2, 2019. The project team is in the process of initiating the project and developing more detailed project implementation plans, including an initial parameter test plan.

West Biofuel's existing catalytic synthesis reactor to be scaled up for the current project.

Project Name: Seismic Risk Assessment and Management of Natural Gas Storage and Pipeline Infrastructure in CA - [PIR-18-002]

Recipient/Contractor: The Regents of the University of California, on behalf of the Los Angeles Campus

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/14/2019 to 6/30/2022

Research Area: Natural gas Infrastructure Safety and Integrity

Issue: The United States Geological Survey predicts that "California has more a than 99% chance of having a magnitude 6.7 or larger earthquake within the next 30 years". Natural gas storage and pipeline infrastructure may be affected by such a seismic event. Assessing seismic risks of gas infrastructures is difficult because: the data used to quantify seismic hazards has significant uncertainties; the standard risk assessments are either quantitative using Finite Element Analysis software, which can be slow in development and costly or simple models, which are subjective; and it is difficult to take into account the correlation with other non-seismic hazards (e.g. corrosion).

Project Description: The project will develop an open-source seismic risk quantification methodology and software tool for natural gas storage and pipeline infrastructure by addressing earthquake hazards (i.e., ground shaking and displacement from surface faulting, landslides, and liquefaction) and their effects on California gas infrastructure. This tool will identify, prioritize, and mitigate earthquake impacts to natural gas infrastructure both before and after a seismic event is detected.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This open source seismic risk assessment software tool will capture knowledge from multiple domains of expertise and combining it into one simple risk assessment software. This project will combine expertise from multiple research teams to capture all geotechnical threats to gas pipeline and gas storage systems (i.e., earthquake ground motion, fault rupture displacement, landslide and liquefactions). The model created will be able to outperform the speed of current detailed analyses tools and outperform the quality of simple qualification tools. In addition, the open source software tool will integrate real time seismic activity and therefore will be able to perform predictions (before earthquake) and failure analysis (after earthquake).

Applicable Metrics:

Increase Safety: This open source seismic assessment software tool will help identify the most likely threats and enable decision makers to focus on the most seismically hazardous gas pipelines and underground gas storage systems for mitigation measures.

Natural Gas Funds Encumbered: $3,485,255

Update: This project is currently in the signature phase of agreement development, and is expected to start in early September.

Project Name: Performance Based Earthquake Engineering Assessment Tool for Gas Storage and Transmission Systems - [PIR-18-003]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/30/2022

Research Area: Natural gas Infrastructure Safety and Integrity

Issue: Current risk studies performed by gas utilities are derived from risk scoring that is highly subjective and qualitative, and they do not provide the necessary framework for proper incorporation of uncertainties in seismic demand and in fragility of natural gas infrastructure. For sound risk-informed decision making, the reliability of the risk assessments needs improvement through reducing uncertainties with quantitative data for seismic demand and the fragility of natural gas system and its components. A new seismic risk assessment tool is required to prioritize reliably the most impactful seismic retrofits for the natural gas infrastructure in California.

Project Description: The project will develop an open-source seismic risk assessment software package called OpenSRA to provide regulators and utilities with a tool to analyze seismic risk to gas infrastructure in California. The tool will utilize recent advances in seismic hazard analysis, and result in quantitative, more accurate and more reliable assessment of seismic risks. A suite of earthquake scenarios with associated rates of occurrence will be studied, including ground motion, fault rupture, liquefaction and landslide ground deformation. The scenario-based seismic parameter maps will be overlaid on the gas infrastructure system, and the seismic loading will be combined with infrastructure capacities to calculate the seismic performance of the natural gas system. The recipient will perform mechanical shake table tests of subsystem/component response to earthquake events, and the tool will be validated and demonstrated at two storage facilities and two pipeline systems by partnering with PG&E and SoCalGas. The software package will help IOUs identify the most impactful risk factors and areas of high risks, prioritize mitigation measures, and prevent failures of vulnerable system components.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: The new seismic risk assessment tool would result in more reliable estimates of risk, thereby enabling regulators and owners to fully assess seismic risk and to direct mitigation efforts to the most vulnerable components. The tool thus supports prioritization of implementing appropriate mitigation efforts. Remediation and risk-based construction can increase safety by reducing vulnerabilities in the highest risk areas. This will lower costs and minimize gas release by preventing failures. The increased safety, cost

savings, and environmental benefits will be evaluated at the demonstration sites through application of the tool. Consequently, the safety and integrity of natural gas storage, piping, and infrastructure systems would be improved. Resources for mitigation, operation, and maintenance programs would be efficiently and effectively disbursed.

Applicable Metrics:

Lower Costs: The quantitative risk methodology developed by the proposed project will enable early preventative engineering measures to be taken to prevent failure, thus lowering mitigation costs. Identification and remediation of high-risk existing infrastructure will reduce the cost of replacing and repairing infrastructure that fails. Providing the software tool OpenSRA freely to the public will enable system operators and their consultants to perform seismic analyses more economically and the results of the analyses will be amenable to efficient scrutiny by regulators and peer reviewers.

Increase Safety: When areas of high risk are identified, IOUs can prioritize mitigation measures for existing infrastructure and better plan to reduce the risk of failures in future infrastructure. Remediation and risk-based construction can increase safety by reducing the risk in the highest risk areas and the system as a whole.

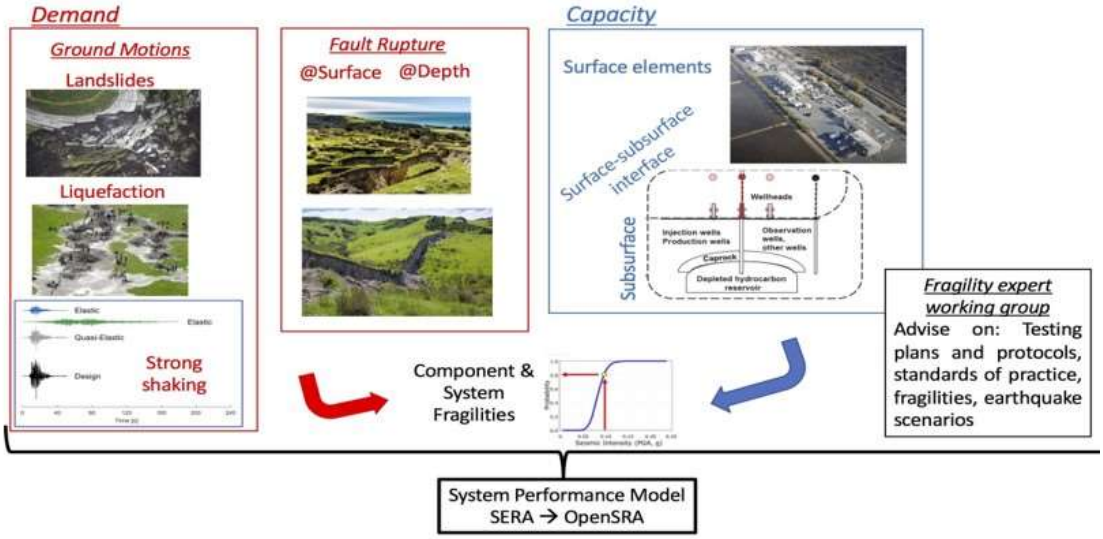
Energy Security:

Energy security is achieved through enhanced seismic risk management. The vulnerable components of natural gas systems can be identified and fixed at early stage, thus minimizing the interruption of gas delivery. The storage and transmission of natural gas in California is more secure when the system is strengthened productively against potentially disruptive earthquake effects.

Natural Gas Funds Encumbered: $4,940,158

Update: The project has not started yet due to the recent updates of UC agreement by DGS. This resulted in a set of new agreement forms and caused delay in agreement package sign-off.

Proposed seismic risk methodology



Project Name: Renewable Syngas Methanation - [PIR-18-004]

Recipient/Contractor: Taylor Energy

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/31/2023

Research Area: Renewable Energy and Advanced Generation

Issue: Currently, natural gas derived from fossil fuel plays a major role in the state's current energy consumption and represents a significant contributor to greenhouse gas emissions. Additionally, the state currently depends largely on out-of-state supplies of fossil natural gas, with 90% of the gas consumed in California imported via pipeline from out of state. To help address these issues, a large portion of readily available forest biomass could be economically converted into energy in the form of ultra-clean pipeline-quality renewable gas via thermo-chemical gasification.

Project Description: Taylor Energy is developing entrained-flow gasification technology for community-scale fuels and biopower generation, using pulse-detonation-burners to intensify the gasification process. The project advances the pilot-scale development of autothermal-gasification with reforming of bio-tar-vapors to form crude syngas, followed by a sour-gas shift and cryogenic deep-cleaning, then methanation to make pipeline-quality renewable gas. Forest biomass will be converted into syngas at 5-ton/day scale.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: The project team is developing gasification technology for community-scale fuels and biopower generation that can utilize available forest biomass, helping reduce out-of-state fossil natural gas use and cut greenhouse gas emissions in the energy sector.

Applicable Metrics:

Greater Reliability: The project is demonstrating the production of pipeline-quality gas suitable for injection into natural gas pipelines, increasing supplies of renewable natural gas.

Economic Development:

The project will contribute to fuel cost savings for ratepayers as well as economic development in rural areas.

Environmental Benefits: The environmental benefits of the project include reduced fire risk through the sustainable utilization of forest biomass as well as lower greenhouse gas emissions through the use of renewable natural gas.

Natural Gas Funds Encumbered: $1,999,695

Update: The project kicked off in July 2019. Deliverables for the first quarter include a site readiness verification and draft fabrication report.

Project Name: Improving the Performance of Wall Furnaces in California Homes - [PIR-18-005]

Recipient/Contractor: Gas Technology Institute

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/30/2023

Research Area: Energy Efficiency

Issue: Property owners bear the cost of energy upgrades, and tenants bear monthly energy costs, heating equipment purchases are primarily driven by low equipment costs. Therefore, low-cost, ductless natural-gas powered gravity wall furnaces and floor furnaces are common as simple, inexpensive methods to heat small apartments, and even single-family homes. These devices typically have standing pilot lights and lack fans, requiring only a gas line and an exhaust vent. They are atmospherically vented, drawing in combustion air from conditioned space and expelling combustion by-products through the exhaust.

Project Description: This project will determine the prevalence of wall and floor furnaces in California homes, and characterize baseline emissions and energy efficiency. The project develops and demonstrates retrofit packages for wall furnaces in existing homes, with payback on incremental costs over the life of the technology. The research includes market outreach and technology transfer with property owners, installers, manufacturers, and utilities to accelerate the adoption of more efficient wall furnace retrofit options in California.

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: This project will overcome barriers for wall-furnace retrofits by demonstrating two different solutions that increase efficiency while reducing installation costs: The solutions include: 1) A self-powered drop-in replacement for existing unpowered gravity furnaces, offering improved efficiency up to 75-80% AFUE, without requiring electrical service, and 2) A direct vent solution with an efficiency of up to 90% AFUE, but requiring electrical service and building modifications.

Applicable Metrics:

Lower Costs: A self-powered drop-in replacement for existing unpowered gravity furnaces, will offer improved efficiency up to 75-80% AFUE, without requiring electrical service. The increased efficiency will reduce natural gas use and costs.

Natural Gas Funds Encumbered: $1,000,000

Update: The project kicked off in August 2019. The first site visit took place in September 2019, and the team also had a meeting with the management team for the Los Angeles site. The team is getting ready to order the monitoring equipment so baseline monitoring can begin in 2019.

Project Name: Cost-Effective Technologies and Strategies to Improve Energy Efficiency and Reduce Emissions of Direct Heating Equipment in California with Health Benefits - [PIR-18-006]

Recipient/Contractor: DOE- Lawrence Berkeley National Laboratory

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/30/2023

Research Area: Energy Efficiency

Issue: Inadequate installation of natural gas, ductless, inefficient direct heating equipment (DHE) has adverse energy, economic, environmental, and health implications. Inefficient heaters cause increased energy costs and greenhouse gas (GHG) emissions. They pose safety and health risks by using combustion air directly from the living space with inadequate ventilation of combustion products. An estimated 9% of California households rely on DHE for heating needs. The installation, performance, and operational characteristics of DHE remains poorly understood. This is a barrier for the design of targeted policies that avoids the adverse impacts of this equipment.

Project Description: This project develops cost-effective strategies to reduce natural gas use, environmental impacts, and safety and health risks of direct heating equipment (DHE) in California. These strategies will be based on market assessment of this equipment in the state, laboratory and field evaluations, as well as policy and program modeling and analysis

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: The project hopes to develop cost-effective strategies to increase the adoption of higher-efficiency DHE in the state and contribute to reducing natural gas use and GHG emissions to meet the state's carbon and efficiency goals.

Applicable Metrics:

Lower Costs: Improvements in the energy efficiency of DHEs will result in lower energy costs. This will benefit households in low-income and disadvantaged communities where a large fraction of DHE is installed.

Increase Safety: There is potential to reduced safety risks posed by old and inefficient DHE models currently operating in California.

Natural Gas Funds Encumbered: $2,000,000

Update: The agreement was approved at the June 2019 business meeting and the project will have its kick-off meeting in the fourth quarter of 2019.

Project Name: Phase Change Material-Enhanced Insulation for Residential Exterior Wall Retrofits -

[PIR-18-007]

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

Natural Gas Funding Plan: Natural Gas Research

Project Term: 6/28/2019 to 3/31/2023

Research Area: Energy Efficiency

Issue: Single-family homes built before the 1978 building codes have uninsulated exterior wall cavities that contribute to unwanted thermal losses/gains and air leakage, wasting energy and introducing outdoor air pollutants. This results in excessive natural gas consumption for heating and high utility bills. Existing insulation solutions are either expensive (spray foam) or do not address leakage (blown-in insulation). The cost effective retrofit wall insulation strategies can only achieve limited improvements in thermal comfort and limited reductions in heating natural gas consumption and utility bills.

Project Description: This project develops and tests a PCM-enhanced insulation solution for existing homes that have little or no wall insulation, with the goal of showing sufficient cost savings and other benefits to recover the cost within 10 years when compared to existing uninsulated walls. Through modeling and selected laboratory testing, the most cost-effective applications of PCMs for wall retrofit-wall assembly in a range of California climate zones will be identified. This will include analyzing PCMs melting point, amount, and installation location (mixed blown-in insulation or applied to the interior wall surface. The project also tests and evaluates the process for aerosol sealing wall cavities in retrofit applications prior to installing cellulose or fiberglass insulation. Finally, the project will evaluate an optimized PCM-enhanced insulation solution for homes in three climate zones (Bay Area coastal (CZ3), Central Valley (CZ12), and Southern California coastal (CZ9)).

How the Project Leads to Technological Advancement or Breakthroughs to Overcome Barriers to Achieving the State's Statutory Energy Goals: PCMs are designed to store and release thermal energy at specific temperatures by melting and freezing. Adding PCM has the potential to reduce total heating energy requirements at reasonable cost if designed with the correct melt point, amount, and location in the wall. Aerosealing of wall cavities, prior to blowing in insulation, can greatly reduce wall air leakage and enhance the performance of lower cost cellulose and fiberglass insulation. It is estimated that the PCM-enhanced insulation could reduce emission by 30 million metric tons of CO2eq emissions and reduce criteria pollutant emissions by reducing natural gas and electricity usage for heating and cooling. The cost

effectiveness of PCM-enhanced insulation will drive adoption of the retrofit due to improved economic perform

Applicable Metrics:

Lower Costs: It is estimated that the PCM-enhanced insulation could save 5.0 billion therms of natural gas over the next 30 years due to reduce heating loads. This will reduce utility bills for ratepayers while also improving thermal comfort in their home. The timeframe of 30 years for energy saving was determined by the expected durability of the PCM insulation system. PCM is expected to have a lifetime similar to, or longer, than blown-in fiberglass or cellulose insulation, though this cannot be verified within the project timeline. The International Association of Home Inspectors states the lifetime of insulation materials is 50-100 years, and Insolcorp warranties their PCM products for 25 years.

Environmental Benefits: It is estimated that the PCM-enhanced insulation could reduce emission by 30 million metric tons of CO2eq emissions as well as reduce criteria pollutant emissions through reduction in natural gas and electricity usage for heating and cooling over the next 30 years.

Public Health: The PCM-enhanced insulation will reduce air leakage into the residence, which can improve indoor air quality. The reduction in natural gas usage provided by the PCM-enhanced insulation will also reduce emissions of criteria pollutants harmful to human health (carbon monoxide, PM 2.5, NOx, etc.).

Natural Gas Funds Encumbered: $1,570,000

Update: The project kick-off meeting was held and the research work is in progress.

Overall project vision for PCM-enhanced insulation solution for retrofitting uninsulated walls. PCM may be applied to the interior wall surface or mixed with blown-in insulation.