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STAFF REPORT

Natural Gas Research and Development

2015 Annual Report

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California Energy Commission

Nicole Smith
Tiffany Solorio
Project Managers

Fernando Piña
Office Manager
ENERGY SYSTEMS RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

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Adrienne Kandel
Anish Gautam
Avtar Bining
Brad Meister
David Hungerford
David Stoms
Jackson Thach
Jeff Doll
Kevin Uy
Matt Fung
Michael Lozano
Rajesh Kapoor
Rizaldo Aldas
Robert Kennedy

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

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

Natural Gas Research and Development is the staff report for the 2015 Natural Gas Annual Report project conducted by the Energy Commission's Energy Research and Development Division. The information from this project contributes to the Energy Research and Development Division's Natural Gas Program.

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

ABSTRACT

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

The *Natural Gas Research and Development 2015 Annual Report* highlights project successes and benefits and covers completed projects and current research from July 1, 2014, through June 30, 2015. In fiscal year 2014-2015, the California Energy Commission administered \$24 million in natural gas research, development, and demonstration projects geared toward improving energy efficiency, renewable energy, advanced generation, and energy infrastructure in California.

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

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EXECUTIVE SUMMARY

Almost 40 years ago, California's serious air quality problems made natural gas the fuel of choice for electricity generation. Roughly 40 percent of the state's natural gas is used to generate electricity; the remainder is used in industrial processes or by the residential and commercial sectors for space and water heating and cooking. California's successful efficiency programs and its reliance on renewable energy sources for electricity have slowed the demand for natural gas. Competition for the state's imported supply, however, is increasing. Although the primary fuels for transportation are oil based, transportation technologies — such as natural gas-fueled vehicles — are adding to California's natural gas demand.

Natural gas-related energy research benefits California's economy, environment, and ratepayers by developing technologies, tools, and methods that increase energy efficiency, reduce pollution and greenhouse gas emissions, and increase public safety. Consistent with its statutory purpose, the California Energy Commission acts on behalf of the California Public Utilities Commission (CPUC) and the people of California when providing public interest energy research program funding to California researchers. These researchers include small businesses, universities, California-based national laboratories, utilities, energy companies, and private research organizations. By selecting and coordinating research among these organizations, the Energy Commission maximizes the effectiveness of the program.

Successes and benefits of Energy Commission natural gas research investments include tangible technology advancements and improvements that help California meet energy policy goals. For example, research provided the justification that led to pipe insulation requirements for the state's home energy standards. These standards, in effect January 1, 2014, will save California ratepayers an estimated 8.2 million therms per year over a six-year period and reduce ratepayer bills by nearly \$7.9 million every year. The Energy Commission is committed to being a responsible steward of its natural gas research and development investments. This stewardship is illustrated by the Energy Commission's adherence to both statutory direction and the state's energy policies. For example, energy efficiency research projects address several state policies and goals, including the California Public Utilities Commission's *Energy Efficiency Strategic Plan* and the California Energy Commission's *Integrated Energy Policy Report*, Governor Brown's *Clean Energy Jobs Plan*, and Assembly Bill 758 (Skinner, Chapter 470, Statutes of 2009), which increases energy efficiency in existing buildings.

Renewable energy research brings clean alternatives to conventional natural gas resources to commercialization. These research projects address several renewable energy generation and greenhouse gas reduction goals, including the Assembly Bill 32 – the Global Warming Solutions Act of 2006 (Núñez, Chapter 488, Statutes of 2006). California's Renewables Portfolio Standard (as mandated by Senate Bill 1078 [Sher, Chapter 516, Statutes of 2002] and Senate Bill 107 [Simitian, Chapter 464, Statutes of

2006]). These bills and the targets they establish are among the most progressive in the United States. These standards were expanded by Senate Bill X1-2 (Simitian, Chapter 1, Statutes of 2011, First Extraordinary Session), which targets 33 percent of electricity generation to be provided by renewable resources by 2020. The Clean Energy and Pollution Reduction Act of 2015, (De León, Statutes of 2015) will establish 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.

In this *Natural Gas Research and Development 2015 Annual Report*, the California Energy Commission addresses the priorities to support pipeline safety and research that support the Governor's Climate Change and Drought Executive Orders B-29-15 and B-30-15. As directed by CPUC Resolution G-3507, the Energy Commission submitted the *Draft Climate, Drought and Safety Natural Gas Budget Plan* on September 23, 2015, a supplement to the *Natural Gas Research, Development, and Demonstration Program, Proposed Program Plan and Funding Request for Fiscal Year 2015-2016*, discussing how to continue supporting efforts in the following research initiatives:

- Natural gas pipeline safety, building on current and proposed efforts
- Impacts from climate change, drought and natural gas infrastructure, such as the pipeline safety impacts of subsidence (ground shifting)¹ from the excessive use and loss of groundwater
- Long-term strategic view of using natural gas in a carbon-constrained, water-efficient environment.

Natural gas pipeline research supports improvements to safety, quantification and reducing fugitive emissions; operational cost-savings, planning for climate change, and biogas compatibility. Safety, however, is a primary focus with the majority of natural gas pipeline projects developing new tools to monitor and measure pipeline leaks. Early identification of defects to pipeline integrity can be assessed and monitored by advanced technologies, allowing remedial strategies to be determined before the structural damage leads to a failure.

Methane, a powerful greenhouse gas (GHG), is the primary component of natural gas, and fugitive methane emissions could significantly reduce the benefits of natural gas as a cleaner fuel for transportation, electricity, and other end uses. Assessing and addressing fugitive emissions are one of the most important issues associated with natural gas. These R&D efforts align with the recommended *IEPR* energy policies.

Moving California's transportation section from oil fueled vehicles to natural gas technologies primarily reduces criteria pollutants for better air quality and decreases

¹ *Subsidence* is the motion of the earth's surface as it shifts downward relative to sea level because of subsurface ground movement.

greenhouse gases. Natural gas transportation research also promotes advancements in renewable natural gas production to help California meet the Low Carbon Fuel Standard (LCFS) goal of reducing the carbon intensity of California's transportation fuel mix by 10 percent and the *State Alternative Fuels Plan*, which sets targets for alternative fuel use in the state.

Projects funded by the Energy Commission are consistent with the annual budget plans and policy objectives approved by the CPUC. Annual reports detailing the research, development and demonstration activities approved in the budget plans are submitted by October 31 for each fiscal year.

This *Natural Gas Research and Development 2015 Annual Report* describes the natural gas research, development and demonstration program and highlights projects from July 1, 2014, to June 30, 2015, as required by the CPUC Decision 04-08-010. All projects are listed in Appendix A.

CHAPTER 1:

Introduction and Program Overview

The Role of Natural Gas Research and Development

California relies on natural gas to meet many of its energy demands, including space and water heating, cooking, industrial processes, natural gas vehicles, and power plants. Roughly 90 percent of the natural gas supply in California comes from the southwestern United States, the Rocky Mountains, and Canada.² The remaining 10 percent is produced in state, both on- and offshore. The safe and efficient production, transportation, and use of this energy resource are critical to California's economy, social vitality, environment, and clean energy future.

Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) recognized natural gas as a vital energy resource for California and directed the California Public Utilities Commission to impose a surcharge on all natural gas consumed in California. This surcharge funds a range of public interest research and development (R&D) activities in the areas of energy efficiency, renewable energy and advanced generation, and energy infrastructure. These activities advance science and develop technologies to increase natural gas end-use efficiencies, improve reliability, or reduce environmental impacts that are not adequately addressed by competitive or regulated entities. The California Energy Commission has administered natural gas research and development in the public interest since 2005. The program was updated by Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006), changing how the natural gas research funds are encumbered and managed.

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

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

The *Natural Gas Research and Development 2015 Annual Report* is the tenth annual report submitted to the CPUC and covers fiscal year 2014-2015 (beginning on July 1, 2014, and ending June 30, 2015), to satisfy CPUC reporting requirements.³

² California Energy Commission.

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

Policy

Natural Gas Research Meets Policy Objectives

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

Research Guides State Energy Policy

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

The Energy Commission's funding decisions are designed to meet energy policy goals and standards without sacrificing safety or reliability (Table 1).

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

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

Policy or Standard	Goal
Governor Brown’s <i>Clean Energy Jobs Plan</i>	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).
California’s Loading Order, From the California <i>Energy Action Plan</i>	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.
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 greenhouse gas (GHG) emission reduction goals.
<i>Integrated Energy Policy Report</i>	The Energy Commission’s biennial energy forecasting and assessment report recommends policies to foster the development of energy efficiency, renewable energy, and more.
Assembly Bill 32 (2006) – The California Global Warming Solutions Act	Requires the state to reduce greenhouse gas emissions to or below 1990 levels by 2020.
<i>CPUC Energy Efficiency Strategic Plan</i>	Sets efficiency goals, including zero-net-energy goals for new homes by 2020 and for new commercial buildings by 2030.
Senate Bill X1 2 (2011) – The Renewables Portfolio Standard	Requires all electricity retailers to meet 33% of their retail sales with renewable energy by 2020.
Senate Bill 1250 (2006)	Provisions for specified entities to fund cost-effective energy efficiency and conservation activities and public interest research and development not adequately provided by the competitive and regulated markets.

Policy or Standard	Goal
<i>The State Alternative Fuels Plan</i>	Recommends actions to meet alternative fuel goals and sets a goal of 26% of the fuels coming from alternative sources by 2022.
Executive Order S-01-07 Low Carbon Fuel Standard (LCFS)	Sets goal to reduce carbon intensity of the state's fuels by 10% by 2020.
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	Sets greenhouse gas reduction target of 40 percent below 1990 levels by 2030.

Source: California Energy Commission

Natural Gas Research Budget Plan – Developing the Research Portfolio

The natural gas energy research funding plan and portfolio follows the state's "loading order" of energy resources, established in 2003 in the state's first *Energy Action Plan*.⁵ This loading order has been instrumental in California's leadership as a clean energy innovator. Energy efficiency is the least expensive, most reliable, and environmentally responsible strategy, and the loading order identifies energy efficiency and demand response systems as the preferred way to meet the state's growing energy demands. These are followed by renewable energy resources, distributed generation, combined heat and power applications, and, finally, by clean and efficient fossil-fired generation.

Authorized Budget

Budget Plan Summary

In March 2014, the Energy Commission submitted to the CPUC *the Natural Gas Research, Development, and Demonstration Proposed Program Plan and Funding Request for Fiscal Year 2014-15*. This proposed plan established the direction and budget for natural gas research and development. The CPUC approved the plan in June 2014 and authorized the Energy Commission to administer \$24 million for Natural Gas R&D projects during a two-year funding period. The Energy Commission expects to encumber all funds for new awards by June 30, 2016 (Table 2). Administration expenses for FY 2014-2015 were also allocated for program staffing and technical support. The Energy Commission has 14 staff positions funded with natural gas funds.

⁵ *State of California Energy Action Plan (May 2003)* http://www.energy.ca.gov/energy_action_plan/.

Table 2: FY 2014-15 Natural Gas R&D Budget Plan Summary

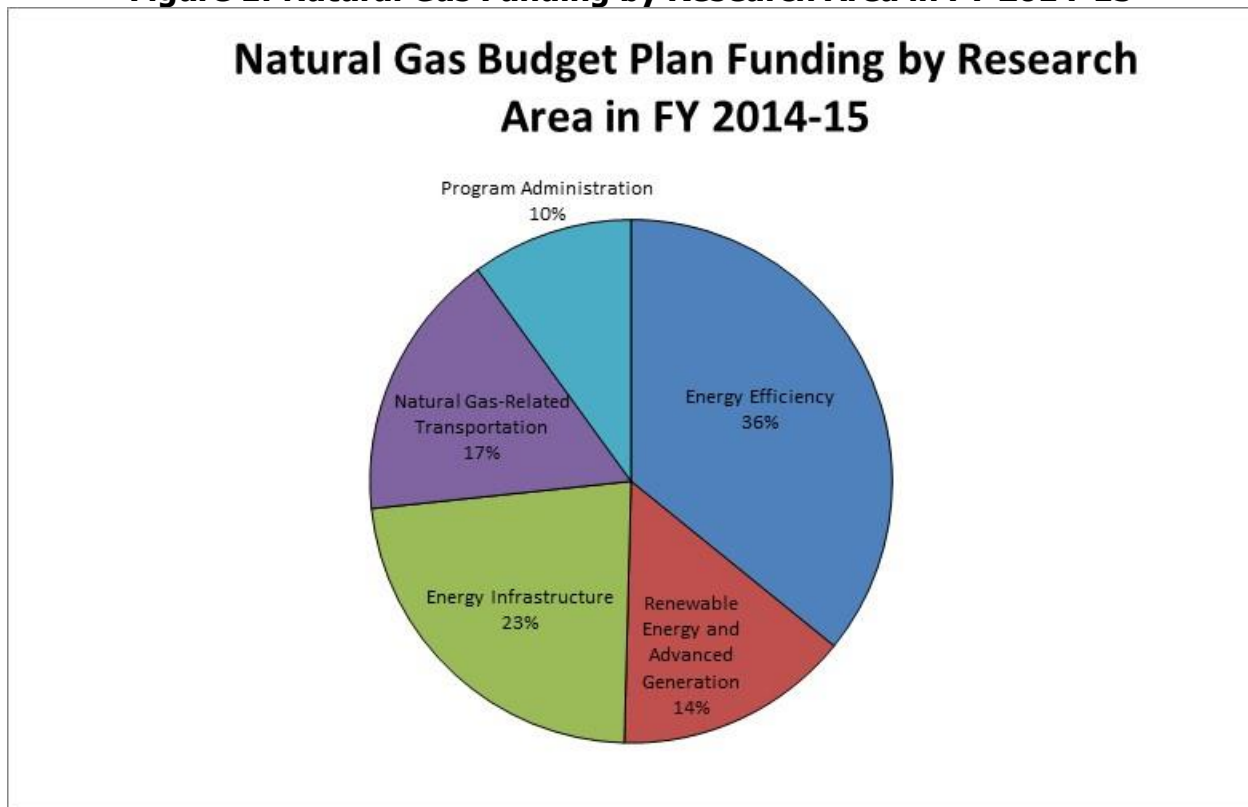
Program Areas	Approved Budget
Energy Efficiency	\$8,600,000
Buildings End-Use Energy Efficiency	\$4,300,000
Industrial, Agriculture, and Water Efficiency	\$4,300,000
Renewable Energy and Advanced Generation	\$3,500,000
Energy Infrastructure	\$5,500,000
Natural Gas Pipeline Integrity	\$2,500,000
Energy-Related Environmental Research	\$3,000,000
Natural Gas-Related Transportation	\$4,000,000
Technical Support	\$140,000
Program Administration	\$2,260,000
TOTAL	\$24,000,000

Source: California Energy Commission

Funding Areas

This section describes the major funding areas for the Natural Gas R&D Program and highlights Natural Gas R&D projects in fiscal year 2014-15 which are producing significant results to resolve California’s energy issues (Figure 1).

Figure 1: Natural Gas Funding by Research Area in FY 2014-15



Credit: California Energy Commission Staff

Energy Efficiency Research — These research projects improve the energy efficiency of homes, businesses, industrial processes, agricultural operations, water and wastewater systems, and data centers. Since California’s large population demands large amounts of energy, improving energy efficiencies is the state’s most important strategy to reduce energy use and cost, greenhouse gas emissions, and other harmful impacts by using energy inefficiently. California’s building efficiency standards are updated every three years, and building efficiencies continue to improve as technologies advance. Industries strive to keep operating costs low while maintaining environmentally clean and energy-efficient operations. Agricultural operations such as food processing plants continue to benefit from advanced processing techniques and heat recovery technologies.

- **Industrial, Agriculture, and Water Efficiency** — The industrial, agriculture, and water (IAW) sectors in California annually use 30 percent of all natural gas consumed in the state and rely heavily on an affordable, reliable, and sustained energy supply.⁶ This economic sector benefits from research that helps reduce

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

energy use and cost, meet environmental challenges, cope with increasing energy demand, and accelerate renewable resources use

- **Buildings End-Use Energy Efficiency** — The buildings end-use energy efficiency research program promotes reducing on-site natural gas use and addressing technology gaps that hinder improving efficiency and reducing natural gas use in buildings while addressing environmental challenges.

Renewable Energy and Advanced Generation Research — R&D promotes renewable energy and advanced generation technologies such as improvements in industrial heat recovery, customer-side solar thermal applications, renewable natural gas conversion technologies, and combined heat and power (CHP) systems.

Energy Infrastructure Research — The safety and security of the natural gas system infrastructure are important priorities for California.

- **Natural Gas Pipeline Integrity** —Infrastructure research projects demonstrate natural gas pipeline integrity monitoring and inspection technologies that are past the “proof-of-concept” stage and are ready for demonstration in a real-world utility setting.
- **Energy-Related Environmental Research** — R&D develops cost-effective approaches to evaluating and resolving environmental impacts of energy production, delivery, and use in California; explores how new energy applications and products can solve/mitigate environmental problems; identifies vulnerabilities of the energy system to climate change; and develops cost-effective approaches to ensure reliable energy services.
- **Natural Gas-Related Transportation** — Transportation research addresses several of the state’s policy goals to reduce petroleum consumption; increase alternative fuel use, and reduce GHG emissions in California. This research area supports natural gas engine development and other technology advancements to reduce tailpipe emissions from the transportation sector. Alternative transportation fuels, such as natural gas, have displaced roughly 2.14 billion gallons of gasoline and 77 million gasoline equivalents of diesel since implementing the 2011 Low Carbon Fuel Standard.⁷ This displacement is comparable to removing nearly 500,000 vehicles from California roads, or emission reductions equaling 2.8 million metric tons.

Response to CPUC Resolution G-3507

In the *Natural Gas Research, Development, and Demonstration Program, Proposed Program Plan and Funding Request for Fiscal Year 2015-2016*, the Energy Commission

⁷ Yeh, Sonia, Julie Witcover and Jeff Kessler. *Status Review of California's Low Carbon Fuel Standard Spring 2013*. Institute of Transportation Studies, University of California, Davis 2013.

identified \$3.6 million from awarded contracts over the last decade in which the contractors completed the research efforts but had unspent funds that were returned to the Energy Commission. On June 25, 2015, in support of actions defined in the Governor’s Executive Orders B-29-15 and B-30-15, CPUC Resolution G-3507 states, “Given the urgency of these recent climate change and drought directives and safety needs, we find it appropriate for the CEC to submit an additional plan for investing the unspent funds in these areas. Specifically, the plan should allocate unspent funding to new efforts to address:

- Natural gas pipeline safety, building upon current and proposed efforts,
- Impacts at the nexus of climate change, drought, and natural gas infrastructure, such as the pipeline safety impacts of subsidence from the excessive use and loss of ground water, and
- Long term strategic view of the use of natural gas in a carbon-constrained, water-efficient environment.”

The plan was submitted to the CPUC on September 23, 2015, and the Energy Commission is awaiting formal direction from the CPUC. Given the priorities identified in the CPUC Resolution G-3507, this program annual report highlights research projects addressing the priority areas in the resolution.

Program Updates

Applying Safety Policy Statement of the CPUC

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

The Energy Commission invests in research and technologies that support the implementation and practice of the CPUC’s guiding principles on health and safety. Examples of Natural Gas R&D projects that assess and reduce safety risk or support health and safety include Real-Time Active Pipeline Integrity Detection (RAPID), Healthy Homes – Exposure to Unvented Combustion Gases, and Innovative Air Cleaner for Improved Indoor Air Quality (IAQ) and Energy Savings. (Chapter 3).

Commitment to Diversity

In 2014, the Energy Commission adopted a resolution strengthening its commitment to diversity in program funding and continues to encourage disadvantaged and underrepresented businesses and communities to engage in and benefit from its many programs.

To meet this commitment, Energy Commission staff conducts outreach efforts and activities to:

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

Out of the 98 California-based, active and completed Natural Gas projects in FY 2014-15, 22 have at least one site located within a disadvantaged community — defined as the 25 percent highest scoring census tracts in CalEnviroScreen 2.0. For more information on CalEnviroScreen, go to <http://www.calepa.ca.gov/EnvJustice/GHGInvest/>.

Stakeholder Outreach – Avoiding Research Duplication

When creating the budget plan and developing its research portfolio, the Energy Commission receives input from experts in energy research, including the state's investor-owned gas utilities, state and federal agencies, and other interested parties. Periodically, the Energy Commission, in conjunction with the CPUC, holds workshops to explore research initiatives across all natural gas technical subject areas considered for the next funding cycle. These workshops help avoid research duplication, generate new research ideas, create the best research industry practices and bring together utilities, researchers, manufacturers, end users, and policy makers from state and federal agencies, such as the California Air Resources Board.

For example, the Energy Commission initiated an informal partnership with the United States Department of Energy's (U.S. DOE) Advanced Research Projects Agency – Energy (ARPA-E) program to maximize coordination of funding opportunities. ARPA-E supports developing and deploying transformational energy technologies and systems.

The Energy Commission also supports and participates in the activities of the Emerging Technologies Coordinating Council (ETCC). The ETCC provides a forum for members to meet and exchange information on energy efficiency research and provides a path for promising technologies to the marketplace.

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

Contracts and Solicitation Updates: Enhancing Investments for California

Ensuring that most natural gas funds are spent in California, the Energy Commission continues expanding its efforts to contract with California-based entities,⁸ using competitive selection processes. These improvements responded to feedback from stakeholders and policy makers and increase the effectiveness of a program as a generator of California energy investments.

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

- Has its headquarters in California **and** manufactures the specific product in the state.
- Has an office in California to transact business and manufacture the product or perform the awarded research in California.

Natural Gas R&D funds are typically awarded competitively through grant solicitations. A competitive solicitation is a public request for proposals to provide services, provide a specified product, and/or solve a defined problem under an agreement. The Energy Commission uses grant funding opportunity (GFO) for grants and request for proposals (RFP) for contracts. The procedures for competitive solicitations follow the requirements under the *State Contracting Manual*, State Public Contracts Code, Public Resources Code, and other laws and regulations, such as civil service restrictions, prevailing wages, and the California Environmental Quality Act.

Energy Commission proposal scoring criteria favors proposals with low overhead and general and administrative costs.

Natural Gas Research Projects Awarded in FY 2014-15

In fiscal year 2014-15, \$23.1 million in natural gas funding was awarded to 27 research projects (Table 3).

⁸ Public Resources Code Section 25620.5 (h) and (i).

Table 3: Natural Gas R&D Program Projects Awarded in FY 2014-15

Agreement	Title	Award Recipient	Approved	Match Funding
500-14-001	High Resolution Measurement of Levee Subsidence Related to Natural Gas Infrastructure in the Sacramento-San Joaquin Delta	U.S. Geological Survey Earthquake Science Center	\$325,000	\$0
500-14-003	Visualizing Climate-Related Risks to the Natural Gas System Using Cal-Adapt	The Regents of the University of California on behalf of the Berkeley campus	\$300,000	\$0
500-14-004	CO2 Cleaning Project	CO2Nexus, Inc.	\$900,300	\$1,110,732
500-14-005	Weather Related Scenarios for the Natural Gas System: California's Fourth Climate Change Assessment	The Regents of the University of California, San Diego	\$600,000	\$0
PIR-14-001	High Efficiency Indirect-Fired Rotary Dryer with Advanced Heat Pump for Bulk Foods Processing	Gas Technology Institute	\$2,600,000	\$700,000
PIR-14-002	Research and development of natural draft ultra-low emissions burners for gas appliances	Lawrence Berkeley National Laboratory	\$400,000	\$0
PIR-14-003	Measurement and Control of Ventilation Rates in Commercial Buildings in California	Lawrence Berkeley National Laboratory	\$750,000	\$0
PIR-14-004	Demonstration of a Novel Ultra-Low NOx Boiler for Commercial Buildings	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$798,788	\$525,000
PIR-14-005	Near Zero NOx Burner	Altex Technologies Corporation	\$347,933	\$30,000
PIR-14-006	Demonstration of High-Efficiency Hot Water Systems in Commercial Foodservice	Fisher-Nickel, Inc.	\$889,036	\$371,449
PIR-14-007	Healthy and Efficient New Gas Homes	Lawrence Berkeley National Laboratory	\$1,250,000	\$400,995

Agreement	Title	Award Recipient	Approved	Match Funding
PIR-14-008	Demonstration of High-Efficiency Commercial Cooking Equipment and Kitchen Ventilation System	Fisher-Nickel, Inc.	\$909,515	\$352,500
PIR-14-009	Comparison of Advanced Ignition Systems for Near-Zero-Emission Heavy-Duty NG Trucks	North American Repower, LLC	\$750,000	\$1,138,726
PIR-14-010	High Frequency Corona Discharge Ignition System Demonstration	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$750,000	\$0
PIR-14-011	Advanced Plasma Ignition Systems for Class 3-8 Natural Gas Engines	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$749,868	\$300,699
PIR-14-012	Research of Advanced Spark Ignited Prechambers Utilizing Turbulent Jet Ignition	Olson-Ecologic Engine Testing Laboratories, LLC	\$750,000	\$984,700
PIR-14-013	Advanced Fueling Method to Achieve Full Fill for Natural Gas Vehicles	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$400,000	\$300,000
PIR-14-014	Pipeline Right of Way Monitoring and Notification System	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$1,049,978	\$0
PIR-14-015	Rapid+ System for Natural Gas Pipeline Integrity Management	Acellent Technologies, Inc.	\$1,633,093	\$103,000
PIR-14-017	Demonstration of an Advanced Low NOx Ribbon Burner Combustion System for Industrial Bakeries	Gas Technology Institute (GTI)	\$950,000	\$245,000
PIR-14-018	Showcase Field Demonstrations of a 25 kW Low-Emission Reciprocating Engine CHP System at the SoCal Gas Energy Resource Center	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$562,820	\$175,000

Agreement	Title	Award Recipient	Approved	Match Funding
PIR-14-019	Advancing Novel Biogas Cleanup Systems for the Production of Renewable Natural Gas	Institute of Gas Technology dba Gas Technology Institute (GTI)	\$1,000,000	\$214,650
PIR-14-020	Las Gallinas Valley Biogas Energy Recovery System (BERS) Project	Las Gallinas Valley Sanitary District	\$999,070	\$1,350,580
PIR-14-021	Cost Reduction for Biogas Upgrading via a Low-Pressure Solid-State Amine Scrubber	Mosaic Materials, Inc.	\$1,000,000	\$200,000
PIR-14-022	Improvements to biogas production using micronutrients, operational methodologies, and biogas processing equipment to enable pipeline injection of biomethane	Biogas Energy Inc.	\$415,000	\$112,100
PIR-14-023	Renewable Natural Gas Production from Woody Biomass via Gasification and Fluidized-Bed Methanation	The Regents of the University of California, San Diego	\$1,000,000	\$237,000
PIR-14-024	Development and Demonstration of a Cost Effective, Packaged Approach to Industrial Gas Efficiency Using Organic Rankine Cycle Technology	Electric Power Research Institute (EPRI)	\$999,889	\$0
TOTALS	27 Projects		\$23,080,290	\$8,852,131

Source: California Energy Commission Staff

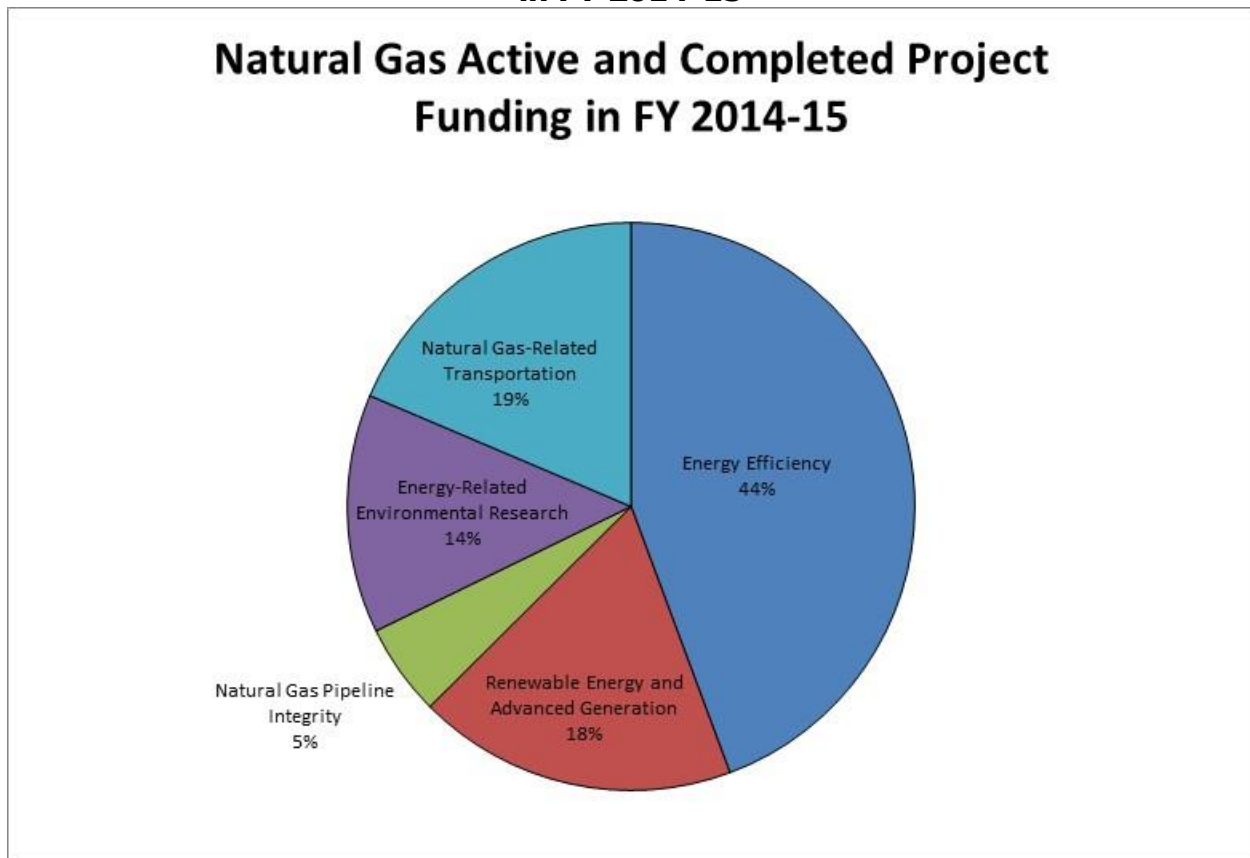
Active and Completed Research Projects in FY 2014-15

In FY 2014-15 there were a total of 107 Natural Gas R&D active and completed projects with a total budget of \$98.6 million. This funding leveraged \$53.4 million in match funding procured or provided by award recipients. A small percentage of project funding came from the Public Interest Energy Research Electric (PIER-E) Program. The PIER Electric and Natural Gas R&D programs have historically provided joint funding for research projects that benefit electric and natural gas ratepayers simultaneously.

Energy efficiency, the top priority in the state's loading order, accounts for the largest share of Natural Gas R&D funds (44 percent), including research topics such as waste

heat recovery, building envelope systems, water heating, food service, and laundry (Figure 2). Renewable energy and advanced generation, second in loading order, accounts for 18 percent of FY 2014-15 funding. Topics researched in this area include combined heat and power, and biogas (recovery, upgrades, and cleanup). Energy infrastructure accounts for 38 percent program funding and addresses the safety and security of the natural gas system infrastructure, transportation, and environmental issues. Refer to Appendix A for a listing of research projects awarded over the last 10 years that are still active or completed in FY 2014-15.

Figure 2: Natural Gas Active and Completed Research Projects Topic Funding in FY 2014-15



Credit: California Energy Commission Staff

Planned Funding Opportunities

Natural Gas R&D Program’s Anticipated Funding Opportunities

The Energy Commission will continue to implement R&D consistent with the CPUC-approved budget plans for FY 2014-15 and 2015-16. Information about funding opportunities will be posted to <http://www.energy.ca.gov/contracts/pier.html> as it becomes available and is subject to change.

Table 4 provides upcoming Natural Gas R&D program funding opportunities for FY 2015-16. To receive an email when solicitations are released, interested parties can subscribe to the list server at <http://www.energy.ca.gov/research/>.

Table 4: Natural Gas R&D Funding Opportunities, FY 2015-16

Program Area	Natural Gas Funding Opportunities	Funding Amount	Status
Active Solicitations			Deadline to Submit Applications
Energy Infrastructure Transportation	Light Heavy-Duty to Medium Heavy-Duty Natural Gas Engine Integration and Demonstration	\$2 million	November 3, 2015
Energy Efficiency Industrial, Agriculture and Water Efficiency	2015 Industrial Natural Gas Energy Efficiency Grant Program	\$7.8 million	October 29, 2015
Anticipated Solicitations			Release Date
Energy Infrastructure Natural Gas Pipeline Integrity	Natural Gas Pipeline Safety, Integrity Management and Technology Assessment	\$2.9 million	Jan. 2016 – Mar. 2016
Energy Infrastructure Energy-Related Environmental Research	Solutions to Environmental Issues Associated With Natural Gas	\$2.6 million	Apr. 2016 – June 2016
Energy Efficiency Building Energy Efficiency	Building Natural Gas Technology Grant Program	\$6.1 million	Apr. 2016 – June 2016
Closed Solicitations			
Energy Infrastructure Natural Gas-Related Transportation	Advanced Natural Gas Engine Ignition Systems Research		\$2.25 million

Energy Infrastructure Natural Gas-Related Transportation	Infrastructure Improvement: Research for Natural Gas Fueling Stations	\$0.8 million
Energy Infrastructure Energy-Related Environmental Research	Regional Climate Impacts and Adaptation Studies for the Natural Gas System	\$1.9 million

Source: California Energy Commission Staff

Consideration of Program Funding Increases

As the Natural Gas Research Program proceeds into the future, the achievable research results will likely diminish due to the decreasing net value of the funds provided for the program. The program received the same funding level for the last eight years but inflation and commercial cost escalations have eroded the dollar value. To provide perspective, the Natural Gas research program was initiated in 2004 and in the first four years of the program, the amount of funding available for research was increased by 100 percent from \$12 million to \$24 million. The program funding amount has remained the same since 2008 even though the state has experienced major natural gas pipeline safety issues, historic droughts, increased impacts from climate change, and more aggressive policy attention on clean energy alternatives. This creates new stress and challenges for the state’s natural gas infrastructure. To adequately meet these ever growing and diverse research needs, the state needs to consider increasing the level of funding for natural gas R&D.

The working group that set the original recommended targets for PIER in 1996 noted that a socially optimum amount of research funding would be one percent of gross operating revenues, as industries requiring innovation typically have very high research budgets. As of 2013, the pharmaceutical industry invested 20 percent of revenues in R&D, information technology invested 10 percent, and the semiconductor industry invested 16 percent. In contrast, \$24 million is about one fifth of one percent of natural gas revenues in the state.

CHAPTER 2:

Projects

Project Overviews: Supporting State Policy and Program Directives

The California Energy Commission has already invested in research projects, implemented by previous budget plans authorized by the CPUC to investigate pipeline safety, climate, and drought issues. The following nine active or completed projects are examples supporting the goals of the Governor’s Climate Change and Drought Executive Orders B-29-15 and B-30-15.

As directed by CPUC Resolution G-3507, the Energy Commission submitted the *Draft Climate, Drought and Safety Natural Gas Budget Plan* on September 23, 2015, which was a supplement to the *Natural Gas Research, Development, and Demonstration Program, Proposed Program Plan and Funding Request for Fiscal Year 2015-2016*, discussing how the Energy Commission will continue to support efforts in the following research initiatives:

- Natural gas pipeline safety, building on current and proposed efforts
- Impacts from climate change, drought and natural gas infrastructure, such as the pipeline safety impacts of subsidence from the excessive use and loss of groundwater
- Long-term strategic view of using natural gas in a carbon-constrained, water-efficient environment.

Projects That Address State Priorities

The Energy Commission has invested in research projects, implemented through prior budget plans authorized by CPUC that investigate pipeline safety, climate, and drought issues. The following nine featured projects are examples of projects that supported these efforts for FY 2015-2016.

Project Name:

Forward Osmosis Desalination of Industrial Waste Water - [PIR-13-009]

Recipient/Contractor:

Trevi Systems Inc.

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/30/2014 to 3/31/2018

Program Area Initiative:

Energy Efficiency

Project Description:

Trevi Systems has partnered with the Orange County Water District (OCWD) on a demonstration project using its forward osmosis (FO) technology to meet their projected water demand without increasing natural gas demand. Trevi's FO system will be used to further concentrate the reverse osmosis (RO) brine wastewater to increase water yield, reducing brine volume (pumping energy) and using waste heat instead of natural gas to drive the FO process.

The uniqueness of Trevi System's FO desalting process is a simple and elegant method of purifying water while conserving energy. The process uses osmotic pressure as a "driving" force to pass water through a semi-permeable membrane, and then using thermal energy in the form of waste heat to produce pure water.

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

This process has the potential to reduce the energy cost at wastewater treatment plants while producing additional water from the RO system brine.

Applicable Metrics:

Lower Costs:

Forward Osmosis is more energy efficient than reverse osmosis. It uses waste heat as its energy source to concentrate the brine, and operates at low pressure, which reduces energy use and fouling of the membranes. Trevi Systems anticipates that its pilot FO process project at OCWD will annually save \$500,000 - \$900,000.

Natural Gas Funds Encumbered:

\$1,700,000

Match Funding:

\$600,000

Project Name:

Real-time Active Pipeline Integrity Detection (RAPID) - [PIR-12-013]

Recipient/Contractor:

Acellent Technologies, Inc.

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/30/2013 to 9/30/2015

Program Area Initiative:

Natural Gas Pipeline Integrity

Project Description:

Acellent developed and demonstrated a real-time active pipeline integrity detection system. Acellent's structural health monitoring (SHM) technology uses a network of distributed piezoelectric sensors/actuators to monitor and evaluate the condition of a pipeline Pacific Gas and Electric Company (PG&E) coordinated closely with the Acellent team to develop the necessary system requirements and demonstrated the RAPID system within the PG&E pipeline network. This project used SHM technology to provide an early indication of any physical damage to the pipeline so it can be assessed with minimal labor involvement prior to a potential structural failure. The SHM technology is a network of distributed piezoelectric sensors/actuators embedded on a thin dielectric film applied to new or existing pipelines.

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

The Acellent system was developed, tested and validated in the selected gas pipeline industry sector, PG&E in San Ramon, California. The system has been shown reliable and effective for early detection of pipeline damage, and the technology was deemed effective for in-field gas pipeline safety monitoring. This technology, if deployed, can potentially improve the safety and integrity of California's the gas pipelines.

Applicable Metrics:

- Lower Costs: Early damage detection using low cost technology will lower costs of gas pipeline operations and management.
- Greater Reliability: Early and timely damage detection will improve reliability of gas pipelines in California.
- Increase Safety: Early and timely damage detection and adequate measures to prevent pipeline failure will improve safety of gas pipelines in California.

Natural Gas Funds Encumbered:

\$622,622

Match Funding:

\$0

Project Name:

Commercialization of ILI Technology Which Accurately Detects, Locates, and Measures Pipeline Girth Weld Defects - [PIR-12-009]

Recipient/Contractor:

Diakont Advanced Technologies, Inc.

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/30/2013 to 4/1/2015

Program Research Area:

Natural Gas Pipeline Integrity

Project Description:

Diakont demonstrated its multichannel scanning electromagnetic acoustic transducer (MS-EMAT) fitted on a robotic crawler to perform comprehensive, remote in-line inspection of gas pipeline girth welds without excavating the pipeline. The MS-EMAT sensor technology inspects for hidden defects from construction and operational flaws, such as cracks caused by ground movement. All of these types of defects worsen over time and reduce pipeline safety. The sensor provides operators with accurate data and valuable information on the infrastructure integrity of California's pipeline network.

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

The MS-EMAT technology can potentially replace current best practices for validating the integrity of pipeline girth welds. The MS-EMAT sensor will allow operators to accurately assess pipeline girth welds without putting the pipeline integrity at risk.

Applicable Metrics:

- Lower Costs: Relative to hydrostatic testing, this technology can perform in-line inspection to detect girth weld defects faster and without excavation costs.
- Greater Reliability: Early and timely damage detection using in-line inspection technology will improve reliability of gas pipelines in California.
- Increase Safety: Early and timely damage detection and adequate measures to prevent pipeline failure will improve safety of gas pipelines in California.

Natural Gas Funds Encumbered:

\$1,000,000

Match Funding:

\$1,600,000

Project Name:

Evaluation of Opportunities to Mitigate Fugitive Methane Emissions From the California Natural Gas System - [500-11-027]

Recipient/Contractor:

DOE- Lawrence Berkeley National Laboratory

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/29/2012 to 3/31/2016

Program Area Initiative:

Energy-Related Environmental Research

Project Description:

This project is investigating sources of emission leaks from the natural gas system and exploring mitigation opportunities. During the project, the researchers discovered a significant discrepancy between different methods used to estimate emissions. As a result, more work is being conducted on characterizing emissions and work on examining mitigation prospects is delayed. Exploring options to reduce emissions is proceeding.

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

Research findings indicate that methane emission assessments are underestimated and that measures must be implemented to reduce methane emissions leaks from the natural gas system. Some of these results are being reported in the analysis AB 1257 Natural Gas Act Report.

Applicable Metrics:

- Environmental Benefits: Accurate and comprehensive accounting of methane emissions from the natural gas sector is essential to understand the climate benefits of natural gas as a fuel source. The research team is also planning to identify cost effective mitigation measures.

Natural Gas Funds Encumbered:

\$1,100,000

Match Funding:

\$0

Project Name:

Top-Down Quantification of Methane Emissions From California's Natural Gas System - [500-12-006]

Recipient/Contractor:

The Regents of the University of California, Davis

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/30/2013 to 6/30/2016

Program Area Imitative:

Energy-Related Environmental Research

Project Description:

This project is quantitatively surveying methane emissions from key subsectors of the natural gas system, including production, processing, transmission and distribution, and end uses in homes. Four field campaigns are planned for this project, and the first took place in November 2013. The field campaigns included a research aircraft, a mobile platform, and other measurement techniques.

Top-down quantification of methane emissions refers to using ambient measurements of methane to infer emissions for a given source. For example, ambient methane measurements upwind and downwind of a facility using a research aircraft can estimate emissions for a relevant facility (e.g., natural gas basin). Top-down measurements capture overall emissions. Measurements of methane emissions from individual components in a facility may miss emissions from unknown sources or from the lack of complete sampling of every component in a given facility. Top-down measurements, therefore, are usually higher than bottom-up measurements (measuring emissions from the different components in a facility and adding all the measurement to estimate total emissions).

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

Researchers have reported that actual methane emissions from the natural gas system may be much higher than expected. However, emission estimates from the natural gas system are highly uncertain. This research will help provide a more accurate and comprehensive accounting of methane emissions from the natural gas sector.

Applicable Metrics:

- Environmental Benefits: Identifying the main sources of methane emissions from the natural gas system will allow developing cost effective mitigation measures to reduce the impacts of climate change.

Natural Gas Funds Encumbered:

\$900,000

Match Funding:

\$0

Project Name:

Improving an Airborne Natural Gas Leak-Detection System - [500-13-005]

Recipient/Contractor:

The Regents of the University of California, Davis

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

3/17/2014 to 6/17/2016

Program Area Initiative:

Energy-Related Environmental Research

Project Description:

The research team is using an aircraft instrumented to measure methane and ethane. The researchers are conducting flights over known leaks to determine the probability of detection from a single flight pass and to estimate the number of passes required for any given confidence level. They are also identifying atmospheric conditions suitable for surveys using this technology. Finally, this project will quantify the magnitude of the detected leaks under different meteorological conditions. Ethane is measured to distinguish methane from natural gas from other sources of emissions such as landfills.

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

Detecting leaks from transmission pipelines is important because these leaks increase costs to ratepayers, reduce the climate benefits of natural gas, and may be associated with public safety issues. The *ARB Scoping Plan* under AB 32 mandates methane emission reductions from the natural gas sector, and SB 1371 requires the CPUC to implement strategies to reduce emissions from transmission lines. This research will guide these efforts.

Applicable Metrics:

- Environmental Benefits: A cost-effective method to detect leaks from natural gas transmission pipelines should allow a timely elimination of these leaks of this potent greenhouse gas resulting in immediate climate benefits.

Natural Gas Funds Encumbered:

\$300,000

Match Funding:

\$0

Project Name:

Combined Heat and Power with Thermal Storage for Modern Greenhouses [PIR-11-023]

Recipient/Contractor:

Southern California Gas Company

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/29/2012 to 3/31/2015

Program Area Initiative:

Renewable Energy and Advanced Generation

Project Description:

This project demonstrated the economical operation of a combined heat and power (CHP) system with thermal energy storage (TES) for modern greenhouses. TES allows the engine's heat to be stored as hot water, providing the greenhouse operator more flexibility to run the engine when electricity or carbon dioxide (CO₂) is required. When the greenhouse grow lights are off and the engine is running to supply heat or CO₂, the operator can sell excess power to the electric utility. The greenhouse operating strategy depends on the value of this surplus power. For CHP projects, a special feed-in tariff applies to exported power. The rate paid by utilities varies by the time of day (peak, mid-peak, off-peak, or super-off-peak) and the season of the year (summer or winter months). Also, the various utility charges that can be avoided by powering the grow lights onsite can significantly improve CHP economics.

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

The market potential for CHP and TES technology in California greenhouses could exceed 2.2 gigawatts for four major crops: cucumbers, lettuce, bell peppers, and tomatoes.

Applicable Metrics:

- Lower Costs: CHP and TES provide significant cost savings for four necessary energy streams necessary to run a greenhouse: power, heat, hot water, and carbon dioxide.
- Economic Development: More CHP systems for greenhouses creates jobs for those installing and operating the CHP systems, and also makes greenhouses more economically viable, spurring growth in both industries.
- Environmental Benefits: In addition to the typical CHP benefits of higher overall efficiency, greenhouse application provides nearly 100% carbon capture and sequestration from the engine-generator system waste stream.

Natural Gas Funds Encumbered:

\$1,502,699

Match Funding:

\$3,901,080

Project Name:

Advanced Envelope Systems for Factory Built Homes - [PIR-12-028]

Recipient/Contractor:

The Levy Partnership, Inc.

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

6/30/2013 to 9/30/2016

Program Area Initiative:

Energy Efficiency

Project Description:

This research project will focus on increasing the energy performance of factory-built homes by developing and commercializing the next generation of cost-effective wall and roof envelope designs that, from an energy perspective, are high-performance, cost-effective, and add minimally to first costs. This project will apply a combination of innovative design, concurrent engineering in the design-development process, and leverage the advantages afforded by factory production and rapid commercialization.

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

Innovative new designs for wall and roof construction assemblies that significantly increase insulation values from R-13 to R-23 for walls and from R-19 to R-49 for attic ceilings. Although manufactured homes are not subject to Title 24, Part 6, these new designs will make significant progress towards making manufactured homes more efficient providing for greater energy security and reliability through less electrical load on the grid.

Applicable Metrics:

- Lower Costs: Potential benefits include an estimated 1500 kWh per year savings for cooling and fan use and 140 therms per year for heating cost compared to current construction. These savings are a statewide average for manufactured housing over six climate zones. Savings should be on the order of 15 percent electric and 22 percent natural gas over total energy of baseline homes. Base house is 1,680 square feet.
- Environmental Benefits: Less energy use translates to less CO2 and less water consumption associated with generating power.

Natural Gas Funds Encumbered:

\$1,304,261 (These projects also have PIER-E funding because the project has a natural gas and electric element that benefits the natural gas and electric ratepayer.

Match Funding:

\$299,781

Project Name:

Improve Energy Efficiency of Hot Water Distribution Systems in Multifamily Buildings - [PIR-12-030]

Recipient/Contractor:

Enovative Group, Inc.

Natural Gas Funding Plan:

Natural Gas Research

Project Term:

7/15/2013 to 6/30/2017

Program Area Initiative:

Energy Efficiency

Project Description:

This research project will quantify the energy and water impacts of crossover and unbalanced recirculation loops in domestic hot water systems associated with multifamily buildings and identify best practices and tools for identifying and pinpointing these issues. The data on the magnitude of energy waste, how to identify it, and how to correct it will result in design standards that enhance existing building codes and standards.

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

Energy and costs savings are expected due to elimination of cross over; water savings due to minimizing dilution of hot water with cold water; sewage savings due to less wasted water to treat. Preventing, identifying and repairing crossover issues can provide many avenues for reducing energy, water and other waste (less wasted water going down the drain) in central hot water systems. Benefits to residents include receiving hot water sooner at the fixture and landlords can benefit by lower costs.

Applicable Metrics:

- Lower Costs: Energy and cost savings due to elimination of crossover; water savings due to minimizing dilution of hot water with cold water; Contractor projects 15-30% gas savings and, in some cases, up to 40% water savings.
- Greater Reliability: Existing systems that experience crossover can be cost effectively retrofitted. Water savings can be very beneficial in communities that are facing water shortages and may not have a reliable water source.
- Environmental Benefits: Significant Energy and water savings and elimination of water waste. Contractor projects 15-30% gas savings and, in some cases, upwards of 30% water savings.
- Consumer Appeal: Identifying and correcting crossover results in greater customer/tenant satisfaction since they will receive hot water sooner.

Natural Gas Funds Encumbered:

\$1,061,800

Match Funding: \$12,000

Case Study: Natural Gas Pipeline Safety Activities and Integrity Management

The Value of Natural Gas Pipeline Safety Research

The safety and security of California's vast natural gas pipeline infrastructure are priorities for California. Many catastrophic gas pipeline failures, however, have happened in California during the past five years, such as the San Bruno pipeline failure in September 2010 and Fresno pipeline damage and fire in April 2015. The loss of human life and property from the San Bruno event is estimated in the billions of dollars, in addition to damage to the environment. Another major threat to California's natural gas pipelines safety and operation is impacts from the long-term drought, causing groundwater depletion leading to ground shifting or subsidence. All these risks to the pipeline network are yet to be quantified and fully understood. The California natural gas transmission and distribution infrastructure are vulnerable to damage by many natural and non-natural disasters and threats. Furthermore, current natural gas pipeline safety and integrity management technologies and operational practices have limitations and are insufficient to ensure the safety, security, and integrity of the natural gas pipelines. Research is necessary to develop more reliable and cost-effective technologies and tools to ensure pipeline infrastructure integrity.

Natural Gas Pipeline Research

California Energy Commission's Natural Gas Pipeline Safety and Integrity research area has funded research projects for many years. This program sponsors research and development projects focused on providing near-term solutions improving safety, reducing environmental impacts, and enhancing the reliability of California's natural gas pipelines.

One such research project assessed using pipeline inspection technologies nationwide and performed a gap analysis to identify those technologies not used by California pipeline operators. Emerging technologies were also assessed to identify those that can provide the most benefits to current integrity management and inspection practices in California.

Addressing heightened public concerns regarding pipeline safety, funded projects are developing and demonstrating low-cost, long-life reliable sensors for both inspection and continuous monitoring of pipelines, as well as detection and prevention of right-of-way (ROW) violations – a major cause of pipeline damage and failure. Still, there remains a need for improving the accuracy, durability, and reliability of tools available to pipeline operators that provide advanced information on, and control over, California's pipeline network. There is a demand for better ROW monitoring technologies and advanced risk analysis and assessment techniques, methods, and models. Also, tools must be researched and developed. Analyzing risks and providing operators with early notification of potential external threats can reduce failures in

California's natural gas pipeline network, improving the infrastructure safety and integrity.

Many such efforts are also underway in other states and at the federal level by the U.S. Department of Transportation (DOT). In particular, DOT's Pipeline Safety and Hazardous Materials Safety Administration (PHMSA) supported research projects on a variety of pipeline safety and integrity aspects during the past 20 years. Similarly, natural gas utilities, natural gas associations, universities, national laboratories, private research companies, and many others are conducting and sponsoring natural gas pipeline safety research. The Energy Commission continues to leverage natural gas research results through public workshops.

Natural Gas Pipeline Safety and Integrity Management Workshop

On July 16, 2015, Energy Commission staff conducted a workshop to discuss the current research and future requirements and opportunities for research on natural gas pipeline safety and integrity management technologies, tools, practices, and risk assessments. Staff provided an overview of the natural gas pipeline safety and integrity management research program at the Energy Commission followed by presentations from natural gas pipeline safety program funded research project principals, natural gas utilities, CPUC, Gas Technology Institute, Pipeline and Hazardous Materials Safety Administration, and Pipeline Research Council International. At the workshop, Energy Commission staff also hosted a discussion of potential research initiatives to address natural gas pipeline safety and integrity management issues, research gaps, and future research needs and opportunities. Advanced risk assessment methods and tools must be further researched and developed, as well as low-cost and highly durable and reliable sensors that can monitor threats and determine damage. This discussion was valuable to plan the future research program and develop the scope of work for the upcoming solicitation. More information about the workshop is at http://www.energy.ca.gov/research/notices/2015-07-16_workshop/presentations/.

CHAPTER 3:

Benefits Assessment

This chapter provides a progress report on the ratepayer benefits of the Natural Gas R&D program for the nine featured projects that support state policy and program directives, as discussed in Chapter 2, and introduces Appendix B — benefits for completed projects in FY 2014-15.

Benefits Overview of Nine Featured Projects

In consideration of Governor's Executive Orders B-29-15 and B-30-15, the CPUC's Resolution G-3507 prioritizes Energy Commission research investments in natural gas pipeline safety, drought, and climate change. In addition to this chapter's focus on the nine featured projects from Chapter 2, additional projects are included for their topical relevance and impressive results, all demonstrating current and ongoing activities in these areas:

- Pipeline and distribution safety
- Water conservation
- Climate/greenhouse gas reductions

Pipeline Safety

Natural gas pipelines run throughout California, including underneath high population areas. Nearly half of California's gas transmission pipelines are more than 50 years old, installed before 1960⁹ when no state or federal agency regulated pipeline safety.¹⁰ Many are susceptible to failure.

From 1994 to 2013, 788 pipeline accidents were recorded in California, killing 27 people, injuring 113, and causing \$626.5 million in property damage.¹¹ In addition, pipeline leaks release methane gas, a potent global warming gas. In 2011, the Energy Commission funded the Gas Technology Institute to study the top causes of pipeline

⁹ Calculated using 2009." United States Department of Transportation: Pipeline and Hazardous Materials Safety Administration data as reported in Pipeline Safety Trust. "*Age of Transmission Pipelines - PG&E Compared to Southern California Gas*," n.d. <http://pstrust.org/docs/AgesCompared.pdf>.

¹⁰ Johnson, Steve, Pete Carey, Paul Rogers and Joshua Melvin. "*Investigators Slam PG&E over San Bruno Explosion*." *San Jose Mercury News*, August 30, 2011. and Lana Groeger. "Pipelines Explained: How Safe are America's 2.5 Million Miles of Pipelines?" *ProPublica*, Nov 15, 2012.

¹¹ "*All Reported Pipeline Incidents*." United States Department of Transportation: Pipeline and Hazardous Materials Safety Administration. Pipeline Safety Stakeholder Communications. 2013. <https://hip.phmsa.dot.gov/analyticsSOAP/saw.dll?Portalpages>.

tragedies and where research money should go to prevent them. Failure to detect pipeline defects or even ruptures was prominent causes, along with poor historical records on individual pipelines. The report also reviewed the status of fault detection technology and what could be improved.¹²

With guidance from that report, and through public workshops, the Energy Commission funded research aimed at detecting or avoiding pipeline faults with four projects active during FY 2014-15. The research includes University of California research on innovative monitoring technologies; University of California assessment of the vulnerability of Bay Area gas pipelines to sea water intrusion; developing and demonstrating a sophisticated pipeline weld inspection tool by Diakont Advanced Technologies, Inc.; and development and demonstration by Acellent, Inc. of an inspection tool using sensors able to sit on pipelines 24/7 and report on above-ground damage to pipelines. A new project underway will advance Acellent's technology to enable reporting on aboveground and underground damage to pipelines. Also, GTI is beginning demonstration to avert pipeline ruptures during excavations by establishing a pipeline right of way monitoring and notification system. GTI estimates that 4,000 leaks annually can be attributed to excavation, most of them insignificant but nonetheless emitting methane into the atmosphere.

Using Robots to Inspect Pipeline Welds

Defective pipeline girth welds contributed to the September 9, 2010, San Bruno explosion that took eight lives and destroyed dozens of homes¹³ as over pressurized natural gas, in the words of one expert, "popped through the welds".¹⁴ Girth welds are joints that connect major natural gas pipelines and are located roughly every 20 feet along the pipes. Many are half a century old and require immediate inspection; however, this inspection process is expensive, long, and arduous.

With natural gas funding of \$1 million and match funding of \$1.6 million, San Diego based Diakont Advanced Technologies, Inc. developed and demonstrated a sophisticated scanning tool to detect faulty girth welds in natural gas pipelines as its remotely operated diagnostic inspection system (RODIS) robot (Figure 3) crawls

¹² Gas Technology Institute. *California Natural Gas Pipeline Assessment: Improving Safety by Enhancing Assessment and Monitoring Technology Implementation*. California Energy Commission, December 2013. <http://www.energy.ca.gov/2014publications/CEC-500-2014-024/CEC-500-2014-024.pdf>.

¹³ National Transportation Safety Board, Pipeline & Hazardous Materials. *Pacific Gas and Electric Company Natural Gas Transmission Pipeline Rupture and Fire, San Bruno, California, September 9, 2010*. 2010. <http://www.sanbruno.ca.gov/PDFs/NTSB - PipelineSanBruno992010.pdf>.

¹⁴ Robert Curry, environmental geologist at U.C. Santa Cruz, quoted in "Upton, John. "Bad Welds Faulted in San Bruno Blast." *The Bay Citizen*, January 21, 2011. <https://www.baycitizen.org/news/san-bruno-explosion/bad-welds-faulted-san-bruno-blast/>.

through the pipelines. Because girth welds are grainy, signals such as ultrasound bounce off them poorly and haphazardly, making accurate detection of faults a challenge.

Diakont solved this difficult problem by developing a scanning tool to resolve the graininess by using ultrasound signals of multiple frequencies and wave angles from both sides of each girth weld, and developing sophisticated software to turn the resulting reflected waves into meaningful scans and fault analysis.

Figure 3: MS-EMAT Sensor Mounted on Pipeline Crawler



Credit: Diakont Advanced Technologies, Inc.

The tool can detect poorly fused girth welds, contaminants in the welds, cracks, wear, excessive reinforcement, porosity defects, and lack of penetration. Diakont completed its natural gas-funded development and testing in May 2015.

The RODIS robot can be used in all types of pipelines, carrying the scanning tool forward and backward, up and down, around corners, through T-joints, and through changes in pipe size. Technicians viewing camera output in real time can send the camera back to revisit problem segments. In contrast, the next best in-pipe inspection technology, the *smart pig*¹⁵ is passive, flows downstream, and detects only magnetic field distortions, providing a far less accurate picture of girth problems than the Diakont scanning system provides. Because smart pigs flow one way, a second look at areas of concern requires a second run of the smart pig, at additional expense. Smart pigs also require the installation of special entry and exit points and cannot be applied

¹⁵ A smart pig is a large piece of machinery inserted into a pipeline to flow downstream and inspect the pipeline as it passes, using highly tuned sensors. The term originated as an acronym for Pipeline Inspection Gauge.

everywhere because they cannot flow through some common pipeline layouts including sharp bends, vertical sections, T-joints, and diameter changes.

Given these limitations, the current best practice for covering large areas comprehensively is hydro testing, filling the pipe with pressurized water in the hopes that all faulty pipes will leak detectably or burst. But that promotes corrosion and sometimes damages the pipelines and cannot detect faults before they become critical, including many girth weld defects.

Direct examination of every weld by a technician holding an ultrasonic thickness testing device outside the pipe can detect faults effectively, at considerable cost, in those areas that can be excavated and where pipelines are not encased. Pipeline coating must be removed for testing to be accurate; however, and the coating is what protects against future corrosion

Diakont's system is the most effective to inspect all pipeline areas, and the least expensive.

Benefits

Diakont reports that a typically sized direct inspection would be \$500,000 to \$1 million in excavation costs for the examination, then another \$50,000 to \$100,000 for technicians' work and analysis. A smart pig run would cost \$500,000, more if the smart pig is resent down the pipe.

In contrast, Diakont's RODIS crawler requires only a small excavation every 2,800 feet (or 140 girth welds), at a cost of around \$50,000. An additional \$100,000 is required for the expert analysis of the project. In total, a typical RODIS inspection costs \$150,000, compared to a best alternative estimate of \$500,000 to \$1.1 million, for a savings of more than \$350,000 to \$950,000. More importantly, the Diakont system will detect faults while preserving pipeline strength and coatings, potentially saving lives and property. A video explaining the technology can be viewed at https://www.youtube.com/watch?v=uGxz-iSp_JU.

Diakont estimates by 2019, pipeline operators will choose Diakont's system to inspect thousands of feet of pipeline each year, saving more than \$5 million in inspection-related costs. These price savings should be passed on to the ratepayer; however, the biggest benefit will be in lives saved and injuries avoided.

PG&E plans to use RODIS to aid its inspection of 7,000 miles of large transmission pipeline in Northern and Central California in an inspection process started in 2011. In 2014, PG&E spokesman Nick Stimmel told NBC Bay Area News that RODIS will expedite inspections, reducing job times from days to hours, and save hundreds of thousands of dollars.¹⁶ "I can say this is a significant improvement as far as cost, time, and

¹⁶ October 2014. Video at https://www.youtube.com/watch?v=uGxz-iSp_JU.

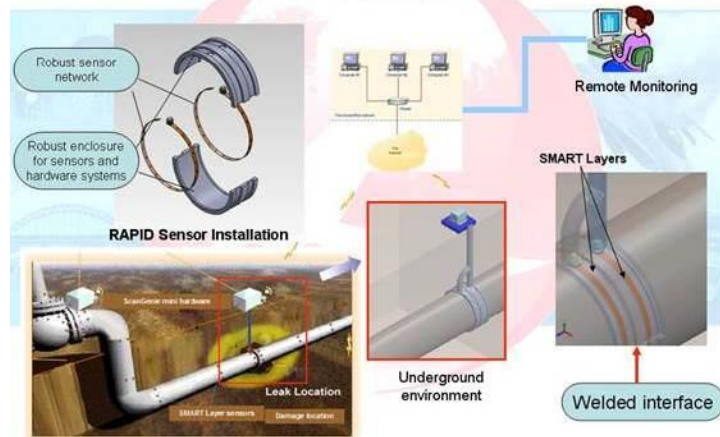
disruptions to our customers. Customers will see the benefit of safer, more reliable service and they'll also see less disruption to their communities. We're not digging in any ground above the pipe." In addition, the robot can be sent out quickly to check for damage after earthquakes.

Pipeline Monitoring 24/7

Sunnyvale-based Acellent Technology Company received a \$1,633,093 grant to demonstrate its real-time active pipeline integrity detection (RAPID) system, to monitor pipeline structural health 24/7. Small piezoelectric (vibration-activated) sensors/actuators are embedded in a thin dielectric film that is applied onto pipelines to monitor and evaluate the vibrations caused by the flow of natural gas, since abnormal vibrations can indicate pipeline damage or problems (Figure 4). The sensors/actuators scan the pipelines regularly and send results to an Acellent computer, which identifies unusual measurements then hones in on and reports damage. Acellent developed and successfully demonstrated a prototype at PG&E facilities in San Ramon and, under a new project just beginning, will implement it in the field.

The newer system will scan for encroachments on pipelines in addition to detecting degradation of pipelines above and below ground.

Figure 4: Schematic of Acellant's RAPID System



Acellent Technologies, Inc. installed its RAPID system on a test pipeline at the PG&E Advanced Technology Services facility to demonstrate the abilities of the technology for remote corrosion monitoring.

Credit: Acellent Technologies, Inc.

Benefits

Early and timely damage detection will allow for repairs that prevent pipeline failures. This increases safety, lowers the costs of gas pipeline management, improves reliability of natural gas delivery, and helps prevent global-warming methane leaks.

Acellent is already manufacturing 500 RAPID units per year and intends to produce 10,000 a year within two to three years. If the RAPID system is deployed over only one-eighth of PG&E's and SoCal Gas 8,000+ km (5,000+ miles) of natural gas transmission and distribution pipelines, Acellent estimates ratepayers would save \$3.5 billion dollars over the 25-year system life while paying just under \$1 billion in hardware and especially installation costs. This equates to annual benefits of \$61 million, after applying a discount rate of 6.06 percent to account for the costs of raising capital.¹⁷ Achieving just one-tenth of that goal would save \$6.1 million a year.

Applying Aerosol Spray Designed for Home Envelop Sealing to Natural Gas Pipelines

In a \$200,000 project funded by the Energy Commission in December 2014, the University of California, Davis, Western Cooling Energy Center (WCEC) applied aerosol spray duct sealing techniques to new building envelopes (Agreement 500-08-042, Project 3). Meanwhile, under a \$141,000 Energy Commission Natural Gas Energy Innovations Small Grant, WCEC extended the practice to sealing natural gas pipelines (Agreements 500-08-042 and 500-98-014, Project 449, respectively). In these techniques, an adhesive mist is sprayed into the pipeline or other target area. The aerosol naturally heads toward leaks where the blown air leaves the pipeline and settles, plugging the leak. The Energy Commission funded the nozzle part of the research.

Researchers demonstrated sealants and nozzles that could inexpensively seal leaks in new building envelopes, thereby saving energy. Under the Energy Innovations Small Grant, the grantees continue to develop and test sealants and sealing techniques for natural gas pipelines. Pipelines are more challenging because sealant could clog valves and other mechanisms. Researchers are testing sealants for both wide 14" diameter pipes and thin 1.6" diameter gas lines. Preliminary research suggests smaller aerosol particles might be needed than used in building envelope and duct applications. The product is probably three to five years from commercialization.

¹⁷ One nominal utility cost of capital is 8.06 percent, arrived at for PG&E in a 2013 CPUC proceeding. Subtracting average inflation of 2 percent, the real cost of capital is 6.06 percent. Using this discount rate, the net benefits would be \$1.8 billion in present value, or equivalently an annual benefit to ratepayers of \$61 million. Present and annual benefits account for the time value of money, the fact that raising money to install has costs, an interest rate paid to loans or a return paid to equity (stock) investors, and the fact that money earned in 10 years is less valuable than the same amount earned today because today's money can be invested and grow.

Benefits

In a benefit analysis performed for the Energy Commission, KEMA estimates that if this sealant is successful and applied to 30 percent of California natural gas pipelines, aerosol pipeline sealing could save more than 100 million therms of natural gas per year from leaks, worth more than \$130 million a year,¹⁸ protecting health and the climate. The cost of sealing pipelines would be less than hand repairs that require excavation.

In addition, the building envelope sealing component of the project was successful and may by 2024 offer annual savings of 10.4 million therms and 72.7 million kWh,¹⁹ worth \$15.2 million a year while saving 60,000 metric tons of carbon dioxide equivalent (CO₂eq) emissions annually.

Water-Related Projects

Faced with four years of drought, shrinking water supplies and a record low snowpack due at least in part to climate change, Governor Brown on April 1, 2015, issued Executive Order B-29-15 to save water. The order creates a mix of restrictions, incentives, and enforcement activities to reduce water use, and establishes roles for the Energy Commission in water efficiency standards and in deploying innovative water solutions. Prior to this order, in FY 2014-15, the Energy Commission's Natural Gas R&D program was already funding research and saving both natural gas and water.

Water conservation, reuse, and desalination are particularly crucial to California's natural gas system because water shortages are motivating farmers and others to pump ever more groundwater, causing land subsidence that threatens pipeline integrity. "Groundwater levels are reaching record lows – up to 100 feet (30 meters) lower than previous records," noted Department of Water Resources (DWR) Director Mark Cowin in a NASA/DWR press release. San Joaquin Valley land is sinking at a rate of 2 feet per year.²⁰ Land sinks unevenly, with fine clay soils getting irreversibly compacted and falling more than coarser silts, for example. This changes the topography, stressing natural gas pipelines that were laid before subsidence, and stresses bridges, roads, and the California Aqueduct. Some pipelines have been

¹⁸ They estimated 108 million therms saved under the following under this scenario: natural leakage from gas pipelines is 2.5 percent, the midpoint of U.S. EPA's range of estimates (1.9 to 3.1 percent), and aerosol is conservatively able only to seal 60 percent of leaks, less than the 87 percent success it has with ducts. Low- and high-value scenarios vary that success rate as well as natural leakage and market adoption rates to achieve estimates of \$29 million therms and \$225 million therms, respectively. KEMA, Inc. *Aerosol Sealing Technology for Building Envelopes: A Cost Benefit Assessment for Ratepayers*. draft consultant report for California Energy Commission, 2015.

¹⁹ Ibid. These projections suppose that by 2020 10 percent of new buildings use aerosol envelope sealing.

²⁰ NASA Jet Propulsion Laboratory. NASA "California Drought Causing Valley Land to Sink." August 19, 2015. <http://www.jpl.nasa.gov/news/news.php?feature=4693>

exhumed, and some studies suggest that subsidence is degrading plugged wells in the Central Valley and may release methane that will find paths into the atmosphere.²¹

Forward Osmosis Desalination

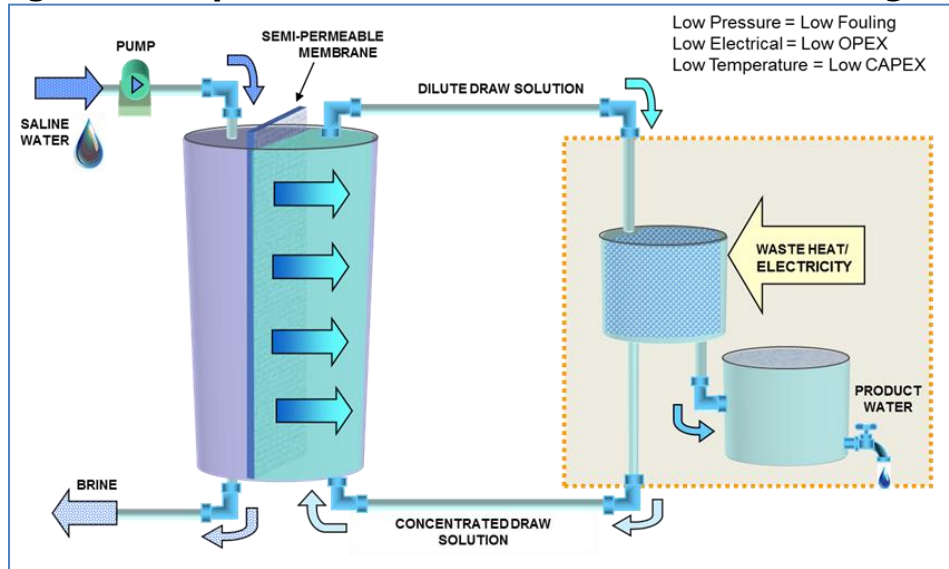
Using \$1.7 million in Energy Commission funding, Petaluma-based Trevi Systems will supplement an existing reverse osmosis (RO) groundwater replenishment system plant by partnering with the Orange County Water District to use Trevi's forward (not reverse) osmosis technology on brine waste of the RO system. In reverse osmosis, electric pumps apply pressure to overcome osmotic pressure and force pure water through filters that block contaminants and salts.²² In forward osmosis, osmotic pressure pushes water in the desired direction, with the help of a draw solution that is then separated from the water using heat. Trevi's system saves natural gas by using waste heat for that separation. Because RO cannot effectively force 100 percent of the water in brine through a membrane cost-effectively, the forward osmosis (FO) technology will increase potable water yield, while reducing brine volume and the energy required disposing of it (Figure 5).

Trevi's innovation is finding a draw solution that works and that is easily separated from the cleaned water using heat of a moderate temperature, which can be waste heat from a cogeneration unit, or geothermal sources that are not hot enough to create steam or industrial processes, or heat from the sun. In the worldwide research effort on FO systems, Trevi's system is the first to verifiably desalinate ocean water to drinking quality standards, and at the same time, save energy compared to RO.

²¹ Chilingar, G.V. and B. Endres. "Environmental Hazards Posed by the Los Angeles Basin Urban Oilfields: An Historical Perspective of Lessons Learned." *Env. Geol.* 2005, 47(2):302-317.

²² Salts and other solutes (dissolved particles) will spread evenly throughout a liquid unless blocked by a filter or semipermeable membrane. In that case, osmosis occurs as, for example, pure water moves naturally across a filter into salty water, trying to equalize the saltiness of both sides. In reverse osmosis, electric energy is used to reverse that flow, pushing salty water against osmotic pressure and through the filter, which blocks the salt. In forward osmosis, osmotic pressure works for rather than against the desalination because a "draw" solution is introduced on the pure water side; the water concentration in the draw solution is lower than in the brine or salt water, so the water wants to join the draw solution.

Figure 5: Simplified Trevi Forward Osmosis Process Diagram



Credit: Trevi Systems, Inc.

In addition to saving energy while recharging the water supply, the FO process is less vulnerable to scaling than RO, which clogs up the filter. FO allows scales to be dislodged using mechanical means, such as osmotic back-flush, rather than applying harsh chemicals, such as sulfuric acid.

The pilot plant will be able to process 26,000 gallons of water per day, with a post-pilot goal of increasing Orange County ocean water treatment by 20 million gallons per day, or 20 percent compared to the current RO system. This is water the RO system cannot purify.

Trevi estimates its FO process to be four times more energy-efficient than RO.²³ Before widespread use and the economies of scale seen in RO systems, Trevi expects its FO system to have a marginally higher first cost than RO and be paid back within two years, based on energy savings. The first customers after the Orange County demonstration might be California industrial users facing limits in the wastewater they can discharge, because the FO system can clean wastewater, not just seawater. By 2018, Trevi expects to build a large-scale 2.6 million gallons per day desalination plant. Because the energy savings quickly pay back the small increase in first costs, Trevi's system will provide opportunities for increased drinking water production and groundwater recharge, from seawater and wastewater, in California and worldwide.

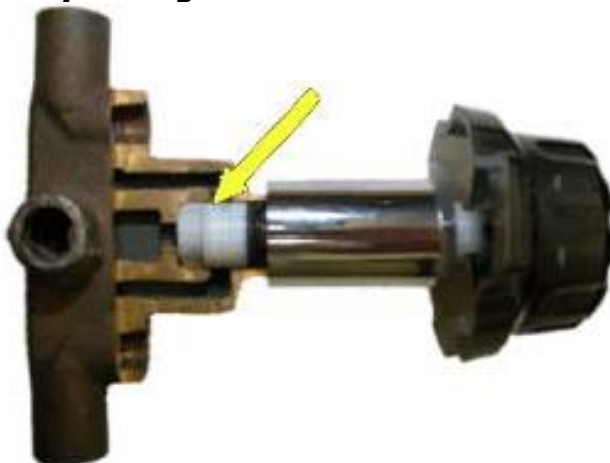
²³ In a typical brine concentration, RO requires 1.3 kWh per cubic meter of water treated (4.92 kWh per thousand gallons), while FO requires 0.3 kWh per cubic meter (1.14 kWh per thousand gallons). With a 33 percent renewable portfolio, the natural gas saved by not generating that electricity is 0,215 kWh per thousand gallons.

Fixing Hot Water Distribution Inefficiencies in Multifamily Buildings

Multifamily homes in California investor-owned utility service areas use 160 million therms of natural gas and 580 million kWh of electricity per year to heat water and distribute it to residents.²⁴ In 2011, it was estimated that one-third of the energy input in multifamily building central water heating systems was being lost in the recirculation loop and distribution branch lines.²⁵ The 2013 Title 24 updates will address this concern; however, two big issues remain: crossover and unbalanced recirculation loops. The extent of the problem is unknown but appears considerable. For example, a 2007 natural gas study monitoring three multifamily buildings found two of them had crossover.²⁶

Crossover occurs when cold water crosses over to the hot water lines through places where hot and cold water mix, for example, if the mixing valve to a faucet or showerhead is faulty (Figure 6). To compensate, landlords may set temperature set points higher and recirculate water continuously, using unneeded energy. In addition, tenants may run their shower or tap longer to get the water as hot as they desire, sending water down the drain.

Figure 6: A Faulty Mixing Valve in a Faucet Can Cause Crossover



Credit: Enovative Group, Inc.

²⁴ California Energy Commission Demand Analysis Office projections for 2015 prepared in August 2014.

²⁵ California Utilities Statewide Codes and Standards Team, *Multifamily Central DHW and Solar Water Heating*, October 2011.

²⁶ Howlett, Owen and Nehemiah Stone, "Improving Hot Water Delivery in Multifamily Buildings," *Home Energy Magazine*, 2007.

Figure 7: Testing Crossover and Unbalanced Recirculation Loops



This research project will use a laboratory, in part, to quantify the energy and water impacts of crossover and unbalanced recirculation loops in domestic hot water systems associated with multifamily buildings and identify best practices and tools for identifying and pinpointing these issues.

Credit: Enovative Group, Inc.

With Energy Commission funding, Enovative, Inc. is measuring how prevalent crossover and unbalanced recirculation problems are in multifamily and commercial buildings, and what the cost is in energy, water, and greenhouse gas emissions. It is evaluating designs and technologies that could cost-effectively solve these problems, and create recommendations for new Title 24 standards.

Benefits

Based on preliminary information, Enovative estimates that crossover and unbalanced systems waste 134 million therms of natural gas per year. This waste results in nearly 711,000 metric tons of CO₂eq emissions produced and \$152 million per year spent by consumers. A 1 percent reduction in this problem will result in annual savings of roughly 1.3 million therms, 7,100 metric tons, and \$1.5 million to consumers.

Demonstrating Efficient Hot Water Systems for Food Service

With \$889,036 from the Energy Commission and \$371,449 of match funding, San Ramon-based Fisher Nickel, Inc. will demonstrate efficient hot water systems in two commercial kitchens and develop tools to disseminate the lessons learned. Fisher-Nickel will monitor the hot water use in the two commercial foodservice facilities and then retrofit the kitchens to optimize recirculation systems, pipe insulation, and water heating at sinks and dishwashers. The project will demonstrate the benefits of a system using advanced gas-fired heaters, advanced distribution systems and controls, ultra-low-flow fixtures, and dishwashers with heat recovery.

The project intends to influence commercial hot water systems designs by developing a cost calculator for energy efficiency professionals and commercial kitchens to use to

minimize their hot water and energy use. The calculator will also help utilities calculate rebates for energy efficiency incentive programs.

Fisher Nickel estimates that intelligent retrofits in commercial kitchens could save 123 million therms per year. If even 1 percent of this goal is reached, savings would be 1.23 million therms per year, worth \$1.2 million a year, and 6,500 metric tons of CO₂eq and 11,300 lbs of NO_x emissions would be avoided each year. Water savings would also occur but were not estimated.

Benefits of Water Conservation

California is facing a severe water shortage, and any reduction of water use will be beneficial. In addition to causing subsidence that threatens the natural gas delivery system infrastructure, water shortages cost Californians comfort and money.

In 2015, the drought is estimated to have cost California agriculture \$1.84 billion and 10,100 jobs, according to a UC Davis study.²⁷ This affects the entire economy as farmers and farmworkers purchase fewer goods and services. The total loss is \$2.7 billion and 21,000 jobs. This loss will only worsen if the drought continues because 2015 surface water shortages of nearly 8.7 million acre feet are mostly offset by groundwater pumping 6 million acre feet, according to the study: a situation not sustainable.

In addition, groundwater pumping becomes more expensive and uses more energy as the water table sinks. Many rural homes have run out of well water and have to import water by truck.

In 2014, the U.S. Forest Service spent \$1.1 billion fighting California wildfires and expects the 2015 tab will hit \$1.8 billion, in addition to its \$1 billion fire readiness budget, according to a U.S. Forest Service report.²⁸ "Climate change has led to fire seasons that are now on average 78 days longer than in 1970. The U.S. burns twice as many acres as three decades ago, and Forest Service scientists believe the acreage burned may double again by mid-century," notes the report. Meanwhile, California

²⁷ Howitt, Richard, Duncan MacEwan, Josué Medellín-Azuara, Jay Lund, and Daniel Sumner. "Economic Analysis of the 2015 Drought for California Agriculture". *UC Davis Center for Watershed Sciences ERA Economics UC Agricultural Issues Center* August 17, 2015. Funded by California Department of Food and Agriculture, University of California – Davis with assistance from California Department of Water Resources.
https://watershed.ucdavis.edu/files/biblio/Final_Drought%20Report_08182015_Full_Report_WithAppendices.pdf.

²⁸ U.S. Forest Service. "The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work". August 4, 2015.

typically spends \$250 million a year on forest fire fighting but has spent \$205 million in just the first few months of this fiscal year.²⁹

Adding forest fire costs of \$1.8 billion to the \$2.7 billion effect of agricultural water cutbacks, the drought is costing Californians at least \$4.5 billion a year. Other California sectors hurt by the drought include semiconductor manufacturing, for which a factory can require 2 million to 4 million gallons of purified water a day,³⁰ snow season tourism, and food processing, which depends on agriculture. In addition, lack of hydropower can put upward pressure on electricity prices.

Climate Change-Related Projects

In the April 29, 2015, Executive Order B-30-15, Governor Brown established new GHG emission reductions targets of 40 percent below 1990 levels by 2030 and 80 percent below 1990 levels by 2050, and ordered the state to continue "rigorous climate change research." The Energy Commission's Natural Gas R&D program has been addressing both of these goals, reducing energy use from energy efficiency projects described previously and examining the problem of methane leakage in natural gas production, distribution, and consumption.

Keeping Track of Methane Leaks

The natural gas system consists of production in wells, processing, transmission, distribution, and final consumption (after the meters). Methane can leak from any of these places; however, the amounts of leakage are uncertain, perhaps 1.9 to 3.1 percent of natural gas produced.³¹

Methane is a potent greenhouse gas, and methane emissions from the natural gas system can reduce or eliminate the advantages of using natural gas in cars and power plants and other devices burning natural gas instead of other fossil fuels. For example, to realize an immediate net climate benefit from the use of natural gas, methane emissions from the natural gas system should be lower than 0.8, 1.4, and 2.7 percent of production to justify a transition from heavy-duty diesel vehicles, gasoline cars, and coal-burning power plants, respectively.³² Numerous researchers have reported that

²⁹ Rice, Doyle. "U.S. Nears Costliest Wildfire Season on Record." *USA Today*. September 8, 2015. <http://www.usatoday.com/story/news/nation/2015/09/04/costliest-wildfire-season-record/71716266>.

³⁰ "IEEE Spectrum. Semiconductor Manufacturing Plants can use as much water as a small city." August 31 2009. <http://spectrum.ieee.org/podcast/semiconductors/design/semiconductor-manufacturing-plants-can-use-as-much-water-as-a-small-city>.

³¹ U.S. Environmental Protection Agency. 2011. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*. EPA Publication 430-R-11-005.

³² Alvarez, Ramon A., Stephen W. Pacata, James J. Winebrake, William L. Chameides, and Steven P. Hamburg. "Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure." *Proceedings of the National Academy of Sciences of the United States of America* 109, no. 17 (Feb 2012.): 6435–40.

actual methane emissions from the natural gas system may be much higher than expected in California³³ and nationwide.³⁴ Without an accurate and comprehensive accounting of methane emissions from the natural gas sector, the climate benefits of natural gas as a transition fuel remain unclear.

A suite of projects selected and supported for research is substantially contributing to identifying where in the natural gas system these emissions originate, determining emission levels, and providing some initial indications on how to reduce these emissions.

Top-Down Quantification of Methane Emissions from California's Natural Gas System

UC Davis researchers are surveying natural gas and associated wells and distribution systems. An exploratory study involving 10 homes will be conducted to find out if there are significant emissions in consumers' homes. The overall measurements taken so far suggest that production sites and the distribution network are the main contributors to total emissions from the natural gas system. Emissions from homes, however, are important, and unburned methane in combustion devices in homes can be a source of such emissions. For these reasons, another project is surveying more homes in Northern and Southern California.

doi:10.1073/pnas.1202407109. Further calculations in: O'Connor, Timothy. "California IEPR Presentation Panel 2: Natural Gas Market Assessment and Methane Leakage." Environmental Defense Fund. June 23 2014.

³³ Jeong S., D. Millstein, M.L. Fischer "Spatially Explicit Methane Emissions from Petroleum Production and the Natural Gas System in California." *Environmental Science & Technology* 2014, 48(10):5982-5990.

Peischl J., T.B. Ryerson, K.C. Aikin, J.A. de Gouw, et al. "Quantifying Atmospheric Methane Emissions From the Haynesville, Fayetteville, and Northeastern Marcellus Shale Gas Production Regions". *Journal of Geophysical Research: Atmospheres*, 2015, 120(5):2119-2139.

Wennberg, P.O., W. Mui, D. Wunch, E.A. Kort, D.R. Blake, E.L. Atlas, G.W. Santoni, S.C. Wofsy, G.S. Diskin, S. Jeong, et al. "On the Sources of Methane to the Los Angeles Atmosphere." *Environmental Science & Technology* 2012, 46(17):9282-9289.

³⁴ Allen, D.T. "Methane Emissions From Natural Gas Production and Use: Reconciling Bottom-Up and Top-Down Measurements." *Current Opinion in Chemical Engineering* 2014, 5(0):78-83.

Figure 8: Mobile Platform Designed to Measure Methane Emissions



An automobile was instrumented to measure methane at different levels to characterize the plume of emissions from a natural gas facility.

Credit: University of California, Davis

Improvement of an Airborne Natural Gas Leak-Detection System

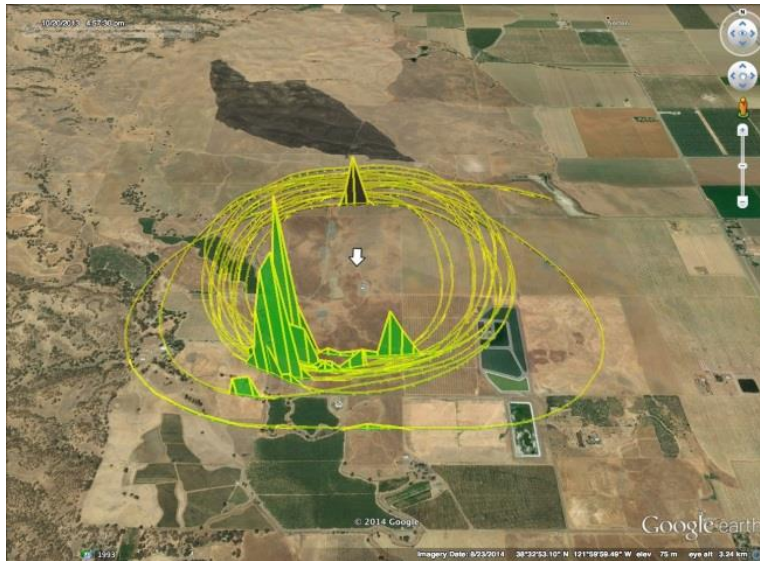
UC Davis researchers are developing a method to identify leaks in transmission pipelines using a small airplane equipped with highly sensitive sensors that measure methane and ethane. Ethane is used as a tracer to distinguish emissions from the natural gas system from other sources such as landfills and dairies, which also emit methane but without emitting ethane as well.

Figure 9: Using a Research Airplane to Detect Leaks



Credit: University of California, Davis

Figure 10: Measurements of Methane and Ethane Emitted from Natural Gas Facilities



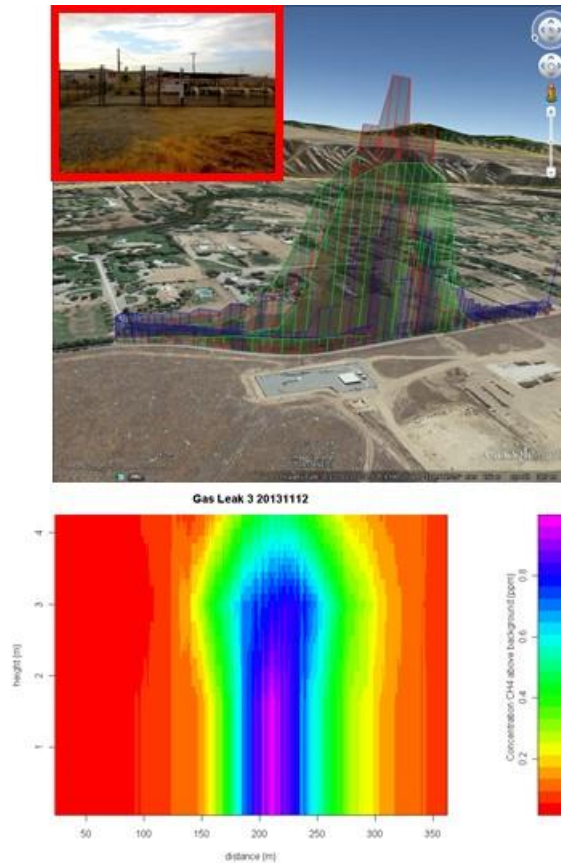
Measurements from these facilities, including transmission pipelines, can be used to identify methane leaks.

Credit: University of California, Davis

Evaluation of Opportunities to Mitigate Fugitive Methane Emissions from the California Natural Gas System

Lawrence Berkeley National Laboratory researchers designed this project to identify cost-effective measures designed to reduce methane emissions from the natural gas system. However, during this project researchers discovered it was necessary to further characterize emissions because they were not able to gain direct access to natural gas facilities in California, and the emission estimates were found to be more uncertain than originally anticipated. Researchers characterized methane emissions from underground storage facilities and abandoned wells and have established a series of small towers to measure methane and other compounds to characterize emissions using a relatively long measurement period. Past studies suggest that some emissions may be sporadic and that field studies lasting hours to days may under- or overestimate annual emissions, depending on the emissions during these short periods that may not be typical of overall annual emissions.

Figure 11: Upwind and Downwind Measurements of a Natural Gas Facility



The top photo shows measurements upwind and downwind of a natural gas facility. The bottom photo illustrates how a mobile instrument characterizes very well the plume associated with the methane emissions.

Credit: Department of Energy's Lawrence Berkeley National Laboratory

Benefits of Understanding Fugitive Emissions

Knowing where methane leaks occur is essential to cost-effectively stopping them and has policy implications. Every state and nation agreeing to limit its climate emissions carefully accounts for the amount of coal-based generation or petroleum based transportation replaced with natural gas and the amount of natural gas generation replaced with nonfossil energy, such as renewables. Yet no country can correctly total its carbon emissions and adjust its policy and power plant development to meet its greenhouse gas goals, if it doesn't know how much methane leaks from into the atmosphere from natural gas pipelines, wells, storage, and even homes. Methane is a potent greenhouse gas, with 25 times the global warming potential (GWP) of carbon dioxide over a 100-year period, or 72 times the GWP of carbon dioxide in the critical 20-year horizon. If the world underestimates fugitive methane emissions, it will overproduce natural gas generation and fail to meet climate targets, greatly increasing the risk of catastrophic damage to the ecosystem and economy.

There are costs to overestimating fugitive emissions as well. In situations where using some natural gas would be the cheapest way to meet a particular greenhouse gas target, overestimating the emissions cost will cause other more expensive approaches to be taken. This may cause economic hardships, or the additional costs may encourage countries to refuse to meet greenhouse gas standards, or negotiate more lax standards.

Because the economy and the environment are intertwined, the most severe costs would come in underestimating the climate footprint and overuse of natural gas. Combining estimates from climate economics studies, a White House study estimates the costs of failing to achieve climate change reduction goals.³⁵ If we ended up with an average warming of 3 degrees Celsius above preindustrial levels, rather than the 2 degrees that the global community has deemed feasible, the cost would be about 0.9 percent of gross domestic product every year, or \$20.6 billion per year for California. Missing targets by 2 degrees rather than 1 degree would cost 2.1 percent of output, or \$48 billion. As an example, California's \$3.2 billion wine grape industry would be threatened by warming.³⁶

These dollar values do not reflect human costs, however. Climatologists are projecting increased heat waves in California with global warming, according to a California climate action report, which notes, "Heat ranks as among the deadliest of all natural hazards ... In a 10-day California heat wave in 2006, over 650 people died due to heat-related conditions."³⁷ In addition to warmer average weather as greenhouse gas concentrations in the atmosphere have grown, the International Panel on Climate Change finds a "likely net increase in frequency/intensity" of Northern Hemisphere hurricanes and a "virtually certain increase in the frequency and intensity of the strongest tropical cyclones."³⁸ These have tremendous human costs: for example,

³⁵ Executive Office of the President of the United States. *The Cost of Delaying Action to Stem Climate Change*. July 2014. https://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.

³⁶ Union of Concerned Scientists. "Global Warming and California's Economy," n.d. <http://go.roguecc.edu/sites/go.roguecc.edu/files/users/MSmith/mth243/pdf/243caclimatesummary.pdf>.

³⁷ Heat Adaptation Workgroup, a subcommittee of the Public Health Workgroup, and California Climate Action Team (CAT). *Preparing California for Extreme Heat: Guidance and Recommendations*: California Environmental Protection Agency, California Department of Public Health, October 2013.

³⁸ International Panel on Climate Change. *IPCC Fifth Assessment Report: Climate Change: Climate Change 2013: The Physical Science Basis*, 2013. https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter02_FINAL.pdf.

Hurricane Sandy killed 286 people, made countless others suffer, and had economic costs estimated at \$50 billion.³⁹

In addition, the further the world is from reaching its greenhouse gas emissions target, the higher the chance climate change hits a tipping point where damage builds on itself until a new and less hospitable climate equilibrium is reached. For example, melting of permafrost causes methane releases, creating more warmth and more melting. Ocean absorption of CO₂ increases ocean acidity, which can create permanent changes to ocean ecosystems, including diminished coral reef building and diminished breakwater effect in protecting shorelines.

The carbon market can be used to obtain a rough value of accounting for methane emissions properly in policy planning. Economic theory suggests that with a cap-and-trade-system, society arrives at the economically optimal price for carbon, the price that not only efficiently achieves carbon reduction goals, but represents society's willingness to pay for carbon reductions. It turns out that the uncertainty in the amount of carbon emitted before climate tipping points are reached serves to increase the optimal carbon price, however. Some economists have estimated the increase in the optimal price of carbon as near 45 percent,⁴⁰ while others have estimated it as considerably higher.⁴¹ In other words, the insurance value of taking precautions to avoid catastrophe is estimated at more than 45 percent of the social cost of carbon emissions. This puts the value of eliminating uncertainty regarding the climate effect of natural gas use in California more than \$700 million a year.⁴² If even one-tenth of this uncertainty comes from not knowing how much methane is being leaked when natural gas is transported

³⁹ Toro, Ross. "Hurricane Sandy's Impact." *Live Science*, October 29, 2013. <http://www.livescience.com/40774-hurricane-sandy-s-impact-infographic.html>.

⁴⁰ Lemoine, Derek and Christian Traeger. 2012. *Tipping Points and Ambiguity in the Economics of Climate Change*. NBER Working Paper 18230

⁴¹ Cai, Yonyang, Kenneth L. Judd, and Thomas S. Lontzek. 2013. *The Social Cost of Stochastic and Irreversible Climate Change*. NBER Working Paper 18704.

Weitzman, Martin. 2009. "On Modeling and Interpreting the Economics of Catastrophic Climate Change." *The Review of Economics and Statistics* 91, 1: 1-19

⁴² Using an insurance value measure of 45 percent, if Californians are willing to pay \$12.52 per metric ton carbon they emit (August 2015 price), then to avoid the risk of catastrophe caused by uncertainties in the effects of their natural gas use, they would be willing to pay \$5.63 more per metric ton. Applying that to 125 million metric tons of CO₂eq greenhouse gases emitted by the combustion of natural gas in California in 2013 (per the California Air Resources Board Greenhouse Gas Inventory), the insurance value of knowing that natural gas use is only affecting the climate in the way current accounting predicts is \$5.63 x 125 million = \$706 million.

and used in combustion, the societal value of successful fugitive methane accounting research is at least \$70 million per year. The spillover effects are much greater, as the world can benefit from California's research to help avoid reaching a tipping point.

Making Manufactured Homes Energy-Efficient

While California leads the nation in efficient homes built on site, it follows the rest of the country in having manufactured homes that still leak heat and cold. This leakage occurs because outdated and relatively lax 1994 U.S. Department of Housing and Urban Development energy efficiency standards for manufactured homes preempt any California regulations, and the market does not reward manufacturers choosing more energy efficiency. Competing on price, manufacturers have minimized the cost of envelope components and design and have created plans and assembly lines that work for their products. Any redesign would require investments in, and "expertise in building science, process engineering, material performance, code compliance, and a variety of other disciplines."⁴³ This is unfortunate because manufactured home buyers are largely low- and middle-income people who would benefit from the considerably lower energy costs and higher comfort associated with efficient thermal design, but cannot pay the higher first cost.

To address this challenge and help the state meet its zero-net-energy goals, The Levy Partnership (TLP) is conducting research and development that will bring down the first cost of manufactured home thermal envelope design. Researchers plan to develop highly efficient wall and roof components designed for assembly line production.

Figure 12: New Innovative Wall Insulation Leads to Less Energy Consumption for Manufactured Homes



By using a dense fill insulation coupled with an additional foam board, significantly higher levels of R-value can be achieved in manufactured homes.

Credit: The Levy Partnership, Inc.

⁴³ The Levy Partnership. Application for Natural Gas PON-12-503.

These will be incorporated into comfortable, attractive, energy-efficient homes. For example, they will use firm, easy-to-cut, and high R-value⁴⁴ insulation such as polystyrenes with structural sheathing rather than batting.

Figure 13: Insulated Manufactured Home Envelope Component



Credit: The Levy Partnership, Inc.

Representatives of California's major manufactured homebuilders are providing direct input into the research, and suppliers and industry allies are involved to ensure that issues are addressed to ease adoption by industry.

Benefits

Based on simulations using EnergyPro software, TLP expects annual energy savings per home of 142 therms and 1.5 kWh, saving the average customer more than \$400 a year. In addition, first cost will be recovered by downsizing air conditioning units by half a ton to one ton per home, which TLP estimates will reduce peak demand per home by 2 kW. These improvements will save 1.31 metric tons CO₂eq per year. Based on history, TLP estimates that an average of 10,000 new manufactured homes will be sold each year.

Assuming 10 percent of new manufactured homes are built with the new technology for the first 5 years, and then 20 percent for the next 10 years, estimated first-year savings

⁴⁴ R-value is a measure of how well a material insulates against heat and cold.

would be 1.4 million therms, 15,100 MWh of electricity, 20 MW of peak reduction, and 10,412 metric tons of CO₂eq emissions.⁴⁵

Total savings attributed to new, more energy-efficient manufactured homes would increase in every subsequent year that new manufactured homes are built, adding to the savings generated by the previous year's manufactured homes. By the fifth year, savings would generate 75,500 MWh and 7.0 million therms.

Capturing Greenhouse Gas in Greenhouses

Southern California Gas demonstrated a combined heat and power (CHP) and thermal energy storage system in Houweling's Tomatoes' 128-acre greenhouse complex in Camarillo, California, that grows tomatoes. The Energy Commission grant amount was \$1.5 million, with matched funding of \$3.9 million.

This project demonstrated an efficient natural gas-fueled engine-generator to produce electricity for lighting, while converting natural gas into water and carbon dioxide. The water, heated by combustion, either heats the greenhouse directly or goes into a thermal storage tank for later use, depending on the greenhouse temperature. The carbon dioxide remains in the greenhouse to accelerate photosynthesis, helping the plants grow quickly. Power produced when lights are not needed is sold to the grid.

Figure 14: CHP with TES for Modern Greenhouses Project Photos



(Top) Exterior photos of two of the six 21-acre greenhouses, a 1 million gallon hot water storage tank, and CHP housing unit. **(Bottom)** Interior photos of greenhouse-grown tomatoes and internal combustion engine CHP unit.

Credit: Southern California Gas Company

⁴⁵ Based on a projected savings of 1.51 MWh of electricity per home and 142.34 therms of natural gas per home. Also, 15,100 MWh of electricity saves 10,412 metric tons of CO₂ per <http://www.epa.gov/cleanenergy/energy-resources/calculator.html>.

Benefits

The CHP system requires less energy than separate heat and power and results in a lower carbon footprint. In addition, the process saves water, sequesters carbon dioxide on site rather than having it trucked in, and pays back for itself in less than four years.

The system costs \$5.2 million and is generating \$1.4 million per year in savings for the Houweling operation. The annualized net benefit for a 30-year system life is \$1 million per year, making it an attractive option for the other two mega-greenhouse operations in California. If these two operations adopt the technology, the total savings value should be roughly \$3 million per year. SoCal Gas estimates that the Houweling project saves 9,500 gallons of water per day, or nearly 3.5 million gallons of water per year, which could be roughly tripled for a statewide potential of 10.5 million gallons per year saved, or about 32 acre-feet.

Smaller greenhouses would have a longer simple payback period of nearly 10 years, so they might not adopt the technology without project cost incentives in addition to the incentive provided by a feed-in tariff.

Projects Completed in FY 2014-15

Appendix B provides project information for 38 projects completed in FY 2014-15. The projects conducted research across several program areas focusing on natural gas-related transportation, advanced generation for renewables, energy-related environmental research, efficiency research for the industrial, agriculture and water sectors, and energy efficiency and emerging technologies for buildings. As highlighted in Chapter 3, several recent projects promote natural gas distribution safety, water conservation, and/or greenhouse gas reductions. Benefits from completed projects are seen and anticipated in the areas of environmental quality and public health, energy security and reliability, lower operating costs, and reduced energy use, among others.

CHAPTER 4

Conclusion

Key Results for the Year

Implementing the Natural Gas Research Program and developing the *2014-2015 Natural Gas Research Program Budget Plan* achieved these following milestones in FY 2014-15:

- The Energy Commission filed its 2014 Natural Gas Annual Report to the CPUC as required by October 2014 for activities during the period of July 1, 2013, through June 30, 2014.
- The Energy Commission awarded \$23.1 million to 27 natural gas research projects.
- In January 2015, the Energy Commission held an annual public workshop with stakeholders and experts in natural gas energy research for input to develop the FY 2015-16 budget plan. The Energy Commission filed its FY 2015-16 Natural Gas Research, Development, and Demonstration Program, Proposed Program Plan and Funding Request with a budget of \$24 million to the CPUC as required in March 2015. CPUC approved the budget plan on June 25, 2015, by Resolution G-3507.
- The Energy Commission held a public workshop in April 2015, "Research Opportunities for Application of Carbon Capture Technologies to California Natural Gas Power Plants."
- The Energy Commission held a public workshop on October 15-16, 2014, "Natural Gas Vehicle Technology Forum and ARPA-E MOVE 2014 Meeting."

Next Steps for Natural Gas Research Program Budget Plan

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

- The Energy Commission will continue to release competitive solicitations and requests for comment according to the schedule available on the Energy Commission's Electric Program Incentive Charge Web page (<http://www.energy.ca.gov/research/pier/>) and provide updates to the schedule, as necessary.
- Consistent with its budget plans, the Energy Commission will continue to release a notice of proposed award for each competitive solicitation and approve each award at a public business meeting.
- The Energy Commission will hold an annual public workshop when developing each budget plan.

- In September 2015, as a supplement to the FY 2015-16 budget plan, the Energy Commission filed its required *FY 2015-16 Natural Gas Research, Development and Demonstration Program, Proposed Supplemental Climate, Drought and Safety Budget Plan and Funding Request* with a budget of \$3.6 million to the CPUC.

The Energy Commission continues to prioritize its future natural gas project investments to support climate change and drought issues as directed in the CPUC Resolution G-3507 and defined in the Governor's Executive orders B-29-15 and B-30-15:

- Natural gas pipeline safety
- Impacts from climate change, drought and natural gas infrastructure
- Using natural gas in carbon-constrained, water-efficient environment

APPENDICES

Appendix A: Table of Active and Completed Projects in FY 2014-15 and Appendix B: Completed Natural Gas Research Projects in FY 2014-15 are available upon request by contacting Tiffany Solorio at Tiffany.Solorio@energy.ca.gov.