CALIFORNIA ENERGY COMMISSION

California Energy Commission

**STAFF REPORT**

# Natural Gas Research and Development Program

## Proposed Program Plan and Funding Request for Fiscal Year 2016-2017

**Edmund G. Brown Jr., Governor**
**November 2016 | CEC-500-2016-063**

# California Energy Commission

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# ABSTRACT

Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) authorizes the California Public Utilities Commission to impose a surcharge on all natural gas consumed in California for funding energy efficiency programs and public interest research and development projects benefitting natural gas ratepayers. In 2004, the California Public Utilities Commission (CPUC) issued Decision 04-08-010, which designated the California Energy Commission as the administrator for the research funds. The Energy Commission manages the Natural Gas Research and Development program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. Each year, the Energy Commission submits a proposed program plan and funding request to the CPUC for review and approval.

This staff report, *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2016-17,* describes the Energy Commission's proposed research initiatives in energy efficiency, renewable energy, and energy infrastructure. The recommendations are based on input from California stakeholders, research institutions, and governmental partners. These initiatives were carefully chosen following an ongoing public outreach process that included administration of a questionnaire to California researchers seeking suggestions for research initiatives.

The proposed research funding for fiscal year 2016–17 is $24 million, and the budget plan covers the period from July 1, 2016, through June 30, 2017.

**Keywords**: California Energy Commission, California Public Utilities Commission, California Air Resources Board, natural gas research, PIER, energy research, R&D, energy efficiency, renewable energy, smart energy infrastructure

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# TABLE OF CONTENTS

# LIST OF FIGURES

Page



# LIST OF TABLES

Page

# EXECUTIVE SUMMARY

In 2014, Californians consumed about 23 billion therms of natural gas in homes, businesses, vehicles, factories, and power plants for electric generation, and spent more than $124 billion. This natural gas use resulted in 123 million metric tons of greenhouse gas emissions released into the environment. About 13 percent of natural gas used in California comes from in-state production, and this reliance on imported gas leaves the state vulnerable to price shocks and supply disruptions. For California to achieve its aggressive climate and energy goals, it is imperative to continue impartial public research and development investments in natural gas innovations and technologies. Advancing natural gas research will make California's energy safer, more reliable, efficient and less costly.

The California Energy Commission's Energy Research and Development Division administers the Natural Gas Research and Development Program (natural gas R&D with oversight by the California Public Utilities Commission [CPUC]). The Energy Commission has managed this program since 2004, funding 196 research agreements totaling more than $171.1 million.

The Energy Commission Research and Development Division (R&D) staff develops natural gas research initiatives guided by state energy policies, legislative mandates, and a public outreach process. These policies and mandates include CPUC Decision 04-08-010, the *Integrated Energy Policy Reports, Energy Action Plan, State Alternative Fuels Plan for Transportation, the California Energy Efficiency Strategic Plan*, and Assembly Bill 32, the Global Warming Solutions Act (Núñez, Chapter 488, Statutes of 2006).

## Research Vision and Goals

The *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2016-17 (FY 2016-17 Natural Gas R&D Budget Plan)* identifies and addresses emerging natural gas-related trends that are important to California's energy future. These trends include opportunities to reduce statewide natural gas consumption through energy efficiency and increase in natural gas alternatives, such as biogas and renewable natural gas. The plan also addresses California's transportation system using more natural gas to reduce carbon emissions. Furthermore, the program coordinates with the CPUC to respond to critical research issues, such as methane emissions, air quality, natural gas pipeline integrity and safety, and improvements to the operation of the natural gas system. The Natural Gas R&D program funds research to:

- **Stimulate** California's economic growth by attracting and developing businesses and creating and supporting jobs.

- **Achieve** long-term benefits to natural gas ratepayers by developing technologies and products that provide clean, diverse, and environmentally sound energy systems.
- **Provide** safe, reliable natural gas services by conducting research that focuses on the integrity and safety of the natural gas infrastructure.

## Research Approach and Stakeholder Participation

On January 25, 2016, R&D staff held a public workshop to present the proposed natural gas research initiatives. Recommendations from the workshop were considered and used to refine the *FY 2016-17 Natural Gas R&D Budget Plan.* A summary of comments from the workshop is included in Appendix B.

## Natural Gas Research Budget Plan for Fiscal Year 2016-17

The *FY 2016-17 Natural Gas R&D Budget Plan* divides the funding among primary research initiatives from four main program areas plus administration (Table 1). The program also allocates about 10 percent of the total natural gas research budget for program administrative expenses, which includes personnel and associated outreach costs.

The plan follows the state's "loading order," which allocates funding resources first to maximize energy efficiency and demand response, followed by investments to increase using renewable energy options, distributed generation, and combined heat and power applications. Adjustments, however, were made to this *FY 2016-17 Natural Gas R&D Budget Plan* to address the priorities to support pipeline safety and research supporting 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 proposed *Climate, Drought and Safety Natural Gas Budget Plan* on September 23, 2015, a supplement to the *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2015-2016*, discussing how to continue supporting efforts in these 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) from the excessive use and loss of groundwater
- Long-term strategic view of using natural gas in a carbon-constrained, water-efficient environment.

The proposed supplement to the *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2015-2016* was approved by the CPUC Resolution G-3513 on December 3, 2015.

Natural gas infrastructure research supports safety improvements, quantifying and reducing fugitive emissions, operational cost-savings, planning for climate change, biogas compatibility, and responding to the Aliso Canyon natural gas leak. Because safety is a primary focus, the majority of natural gas infrastructure projects develop new tools to monitor and measure pipeline and storage facility leaks. Early identification of defects to infrastructure integrity can be assessed and monitored by advanced technologies, with remedial strategies determined before the structural damage leads to a failure or the leaks result in public safety concerns.

This proposed *FY 2016-17 Natural Gas R&D Budget Plan* highlights research projects addressing the priority areas in the resolution, including an increase to the initiative, natural gas infrastructure safety and integrity.

**Table 1: Natural Gas R&D Budget Plan Summary FY 2016-17**

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

**(1) Energy Efficiency Program areas will alternate funding each year between building efficiency and industrial efficiency research. For FY 2016-17, the focus will be on the industrial, agriculture, and water efficiency sector. In FY 2017-18, the natural gas research will focus on buildings end-use efficiency. This approach will allow the funding of multiple projects in each research area.**

Source: California Energy Commission

# CHAPTER 1:
# Introduction and Program Overview

Recognizing the benefit of natural gas research to Californians, Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) directed the California Public Utilities Commission (CPUC) to impose a surcharge on all natural gas consumed in California to fund research and development specific to natural gas. In the 2004 CPUC Decision 04-08-010, the California Energy Commission was designated as the administrator for the Natural Gas R&D program. The CPUC currently allocates funding at $24 million per year and defines public interest natural gas research activities as those "directed towards developing science or technology, and 1) the benefits of which accrue to California citizens and 2) are not adequately addressed by competitive or regulated entities."[1] The decision also directs that Natural Gas R&D projects meet these criteria:

- 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 opportunities with other entities.

## Research Guides State Energy Policies

As the energy used in California and the way it's used changes, the state's energy policies and energy legislation have adjusted the scope of the research. Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006) updated the Natural Gas R&D program to include research resulting in safe and affordable services, and research on advanced transportation benefiting electric and natural gas ratepayers.

The Energy Commission's natural gas research is also governed by energy policies identified in the *Integrated Energy Policy Reports (IEPR), California's Energy Efficiency Strategic Plan*,[2] and the *Bioenergy Action Plan*.[3] To achieve the

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[1] CPUC Decision 04-08-010, p. 24.

[2] *California's Long-Term Energy Efficiency Strategic Plan*, (September 2008), http://www.californiaenergyefficiency.com/docs/EEStrategicPlan.pdf.

[3] *2012 Bioenergy Action Plan*
http://www.resources.ca.gov/docs/2012_Bioenergy_Action_Plan.pdf.

policy goals of Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), the Energy Commission and the California Air Resources Board (ARB) work together to identify and develop technologies and strategies that can help reduce greenhouse gas emissions.

Finally, Governor Brown's *Clean Energy Jobs Plan* provides incentives for increasing combined heat and power projects (*cogeneration*) by 6,500 megawatts during the next 20 years. It also establishes a timeline to make new homes and commercial buildings in California "zero net energy,"[4] using onsite renewable energy for all electricity and natural gas needs. These and additional policies unique to each of the research areas are described in this report (Table 2).

[4] A *zero-net-energy code building* is one where the net amount of energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building measured using the California Energy Commission's Time Dependent Valuation metric. (Source: California Energy Commission. *2013 Integrated Energy Policy Report*, Publication Number CEC-100-2013-001-CMG, page 5)

**Table 2: Summary of Policy Drivers for Natural Gas Activities**

| Research Area | Policy Drivers |
|---|---|
| Energy Commission's Primary Natural Gas Policy Drivers | • *Energy Action Plan*[5]<br>• *Integrated Energy Policy Report (IEPR)*[6]<br>• Assembly Bill 32 (Núñez, Chapter 488 Statutes of 2006)[7]—California Global Warming Solutions Act of 2006<br>• Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006)[8]<br>• Public Utilities Code Section 895 provides statutory authority for the Energy Commission to administer the natural gas funds using the PIER statutes.[9] |

[5] http://www.energy.ca.gov/energy_action_plan/.

[6] http://www.energy.ca.gov/2009_energypolicy/index.html.

[7] http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.html.

[8] http://www.leginfo.ca.gov/pub/05-06/bill/sen/sb_1201-1250/sb_1250_bill_20060927_chaptered.pdf.

[9] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=puc&group=00001-01000&file=890-900.

| Research Area | Policy Drivers |
|---|---|
| An Energy-Efficient California: Initiatives focused on buildings energy end use: efficiency; industrial, agriculture, and water efficiency; and energy efficiency-related environmental research. | • Energy Efficiency Buildings Standards (Title 24, Part 6,)<br>• Appliance Energy Efficiency Standards (Title 20, Division 2, Chapter *4, Article 4, Sections 1601-1608: Appliance Efficiency Regulations*)<br>• Assembly Bill 758 (Skinner, Chapter 470, Statutes of 2009) achieves greater energy savings in existing residential and nonresidential buildings.<br>• Assembly Bill 531 (Saldaña, Chapter 323, Statutes of 2009) discloses commercial building electric and natural gas use.<br>• Senate Bill 350 (De León, Chapter 547, Statutes of 2015) establishes annual targets for statewide energy efficiency savings and demand reduction that will achieve a cumulative doubling of statewide energy efficiency savings for retail customers by January 1, 2030.<br>• *California Energy Efficiency Strategic Plan*[10] requires:<br>  ○ Zero-net-energy (ZNE) buildings: all new residential construction by 2020 and 100 percent new commercial buildings by 2030.<br>  ○ Transformation of the heating, ventilation, and air-conditioning (HVAC) industry to ensure that the performance of HVAC equipment is optimized for California's climate zones.<br>  ○ Significant increases in the efficiency of natural gas use and on-site renewable energy use in the agriculture sector. |

[10] http://www.energy.ca.gov/ab758/documents/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

| Research Area | Policy Drivers |
|---|---|
| A Renewable Future: Renewable research initiatives target combined heat and power (CHP) and renewable energy-related environmental research and are driven by renewable energy generation and greenhouse gas reduction goals. | • Senate Bill X1-2—Renewables Portfolio Standard[11](Simitian, Chapter 1, Statutes of 2011) The Renewables Portfolio Standard sets goals for 20 percent of retail sales from renewable energy resources by end of 2013, 25 percent by end of 2016, and 33 percent by end of 2020.<br>• Assembly Bill 1613, the Waste Heat and Carbon Emissions Reduction Act (Blakeslee, Chapter 713, Statutes of 2007)[12]—The Waste Heat and Carbon Emissions Reduction Act requires an electrical corporation to purchase excess electricity from combined heat and power systems that comply with sizing, energy efficiency, and air pollution control requirements.<br>• Senate Bill 350, Clean Energy and Pollution Reduction Act of 2015 (De León, Chapter 547, Statutes of 2015)[13] Increases the electricity generated and sold to retail customers per year from eligible renewable energy resources to 50% by December 31, 2030<br>• Governor Brown's *Clean Energy Jobs Plan*[14] – Provides that California should develop 12,000 megawatts of localized energy by 2020, establishes a timeline to make new homes and commercial buildings in California "zero net energy," and provides incentives for the increased use of cogeneration by 6,500 MW by 2030.<br>• *Bioenergy Action Plan*[15] to implement Executive Order S-06-06, which set goals for the production and use of electricity and fuels made from biomass. |

[11] http://www.energy.ca.gov/portfolio/.

[12] http://www.leginfo.ca.gov/pub/11-12/bill/asm/ab_1601-1650/ab_1613_bill_20120208_introduced.pdf.

[13] http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_0301-0350/sb_350_bill_20151007_chaptered.pdf

[14] http://gov.ca.gov/docs/Clean_Energy_Plan.pdf.

[15] http://www.energy.ca.gov/bioenergy_action_plan/.

| Research Area | Policy Drivers |
|---|---|
| A Reliable, Secure, and Smart Energy Infrastructure: Initiatives target natural gas infrastructure research associated with natural gas pipeline integrity, environmental, and transportation research. | • Public Resources Code 25620[16]—For the state to undertake public interest energy research, development, and demonstration projects that are not adequately provided for by competitive and regulated energy markets and to advance energy science or technologies of value to California ratepayers through investments in advanced transportation technologies that reduce air pollution and greenhouse gas emissions beyond applicable standards, and benefit electricity and natural gas ratepayers.<br>• Senate Bill 1368, (Perata, Chapter 598, Statutes of 2006)[17] to accelerate carbon capture sequestration for industrial carbon dioxide.<br>• High Energy Efficiency, Low Emissions Combustion, and Control Technology Development Program[18]—Addresses the goal to improve environmental quality while meeting the wide-ranging demand for energy per the 2003 *Integrated Energy Policy Report*.<br>• Quantifying methane emissions from California's natural gas energy infrastructure[19]<br>• *State Alternative Fuels Plan*—Assembly Bill 1007, (Pavley, Chapter 371, Statutes of 2005)[20]—Strategies and actions that California must take to increase the use of alternative natural gas transportation technologies. |

[16] http://www.energy.ca.gov/renewables/documents/sb_1250_bill_20060927_chaptered.pdf.

[17] http://www.leginfo.ca.gov/pub/05-06/bill/sen/sb_1351-1400/sb_1368_bill_20060929_chaptered.pdf.

[18] http://www.arb.ca.gov/planning/sip/sip.htm.

[19] http://arb.ca.gov/cc/scopingplan/scopingplan.htm.

[20] http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_1001-1050/ab_1007_bill_20050929_chaptered.pdf.

| Research Area | Policy Drivers |
|---|---|
| • Governor's Climate Change, Drought Executive Orders, and Proclamation on Aliso Canyon gas leak<br>• Natural Gas: Leakage Abatement. SB 1371 | • 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.<br>• Executive Order B-30-15—Set greenhouse gas reduction target of 40 percent below 1990 levels by 2030.<br>• January 6, 2016 Proclamation to declare an emergency and detail the administration's ongoing efforts to protect public health and safety and ensure accountability of gas storage facilities.<br>• SB 1371, Leno. Natural Gas: leakage abatement[21]—with priority given to safety, reliability, and affordability of service, the CPUC must determine whether existing practices are effective at reducing methane leaks and promoting public safety and whether alternative practices may be more effective. |

Source: California Energy Commission

## Importance of Natural Gas Research

In 2014, Californians consumed about 23 billion therms, slightly less natural gas than in 2013. This natural gas was used in homes, businesses, vehicles, factories, and power plants for electric generation.[22] This resulted in more than $124 billion spent for natural gas, generating more than 123 million metric tons of greenhouse gas emissions.[23] In 2013, about 10 percent of natural gas used in

[21] http://www.leginfo.ca.gov/pub/13-14/bill/sen/sb_1351-1400/sb_1371_bill_20140921_chaptered.pdf.

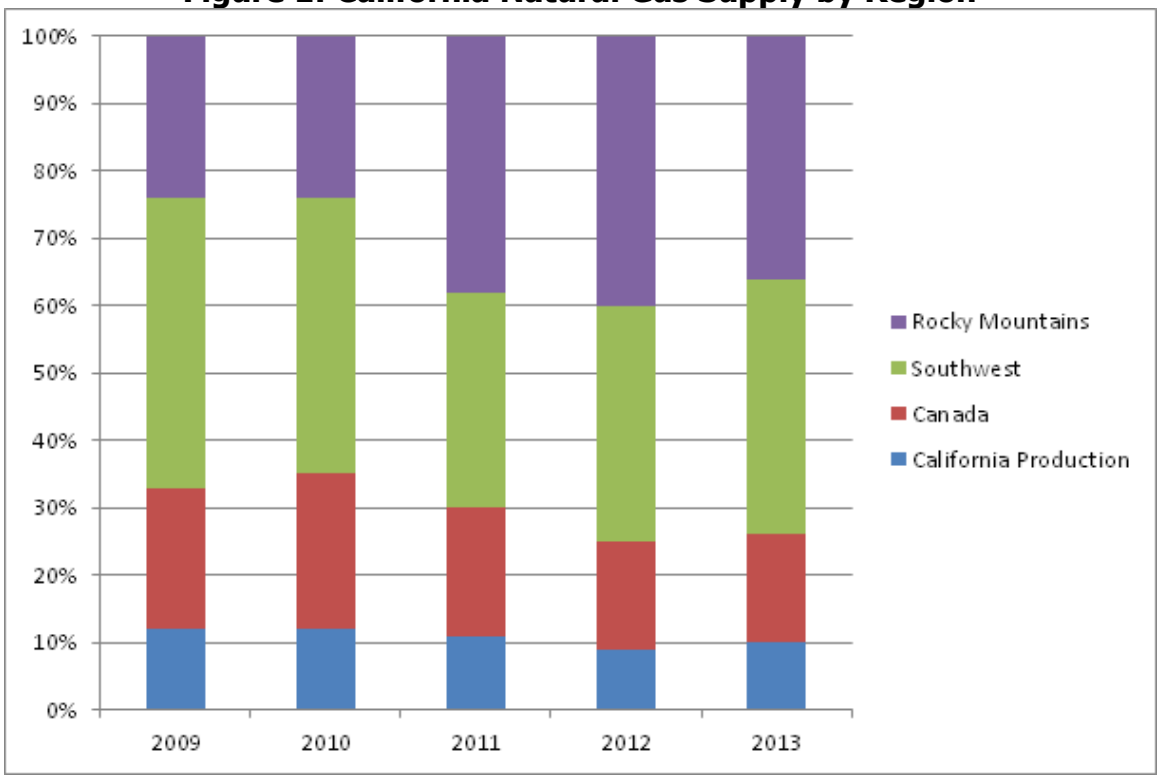
[22] http://www.eia.gov/dnav/ng/NG_CONS_SUM_DCU_SCA_A.htm. Natural gas consumption for 2013 without electricity generation is about 14.8 billion therms.

[23] Calculated from 2014 consumption data from the Energy Information Administration; Natural gas cost from Appendix B, California Energy Commission's *2012 Natural Gas Research, Development and Demonstration Report*. Conversion factor for greenhouse gas assumes 0.0053 metric tons per therm from the California Air Resources Board http://www.eia.gov/dnav/ng/NG_CONS_SUM_DCU_SCA_A.htm.

California came from in-state production, and this reliance on imported gas leaves the state vulnerable to price shocks and supply disruptions (Figure 1).[24]

Burning natural gas is relatively clean compared to other fossil fuels; however, California will not meet its greenhouse gas reduction goals or air quality mandates without significant technology improvements and innovation. In addition, efficiency gains are necessary to control energy bills. Natural gas is an important source of energy because most of the state's power plants rely on this fuel to generate electricity.

**Figure 1: California Natural Gas Supply by Region**




Source: California Energy Commission

Successful efficiency programs and increased use of renewable energy sources help slow natural gas demand and reduce costs. Energy efficiency is the cheapest, fastest, and most reliable way to save consumers money and cut environmental pollution. Since 2004, the Natural Gas R&D program has invested in research to develop technologies, tools, and strategies that increase energy efficiency, reduce energy cost, reduce air pollutants and greenhouse gas emissions, and improve the safety of pipeline infrastructure. For instance, research being conducted on natural gas pipeline inspection technologies used

[24] http://energyalmanac.ca.gov/naturalgas/overview.html; http://energyalmanac.ca.gov/naturalgas/natural_gas_supply.html.

throughout the world helps identify those most appropriate to inspect and monitor pipelines in California. A catalog of the most promising technologies will guide utilities and pipeline operators in selecting the best, most cost-effective tools, increasing safety and reliability of natural gas pipelines for all Californians.

The *Natural Gas Research and Development 2015 Annual Report* provides a full review of program achievements to the CPUC annually and describes the natural gas research activities in fiscal year 2014-2015.[25]

## Research Vision and Goals

The Energy Commission's Natural Gas R&D program focuses on identifying and addressing emerging natural gas-related trends important to California's energy future. These trends include exploring opportunities for nontraditional natural gas alternatives, such as biogas and other renewable natural gas replacements, using natural gas to diversify California's transportation fuel mix, reducing statewide natural gas consumption through energy efficiency, using natural gas efficiently through combined heat and power or cogeneration, and avoiding natural gas losses by improving pipeline integrity. Furthermore, the Natural Gas R&D program funds research to:

- Stimulate California's economic growth by attracting and developing businesses and creating and supporting jobs. Successful research projects lead to new companies or new products for existing companies.
- Achieve long-term benefits to natural gas ratepayers by developing technologies and products that provide clean, diverse, and environmentally sound energy systems that operate at a lower cost to the ratepayer than existing systems.
- Provide safe, reliable natural gas services by conducting research that focuses on the integrity and safety of the natural gas infrastructure.

## Investing Unspent Funds – CPUC Resolution G-3507

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

[25] http://www.energy.ca.gov/2016publications/CEC-500-2016-005/CEC-500-2016-005.pdf.

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 proposed supplement to the *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2015-2016* was approved by the CPUC Resolution G-3513 on December 3, 2015.

Given the priorities identified in the CPUC Resolution G-3507, this *FY 2016-17 Natural Gas R&D Budget Plan* highlights research projects addressing the significant areas in the resolution.

# CHAPTER 2:
# Natural Gas Research Budget Plan for Fiscal Year 2016-17

## Developing Research Initiatives

### Stakeholder Participation and Strategic Partnerships

The Energy Commission works with CPUC staff to develop a research portfolio responding to challenges in the natural gas sector. For example, the current National Ambient Air Quality Standards (NAAQS) requirements for ozone attainment cannot be achieved in California's worst air basins without significant reductions in oxides of nitrogen ($NO_x$) emissions from heavy-duty vehicle fleets. The Energy Commission cofunded research efforts with the South Coast Air Quality Management District and Southern California Gas Company (SoCal Gas) to develop an engine technology that reduces $NO_x$ emission rates to 90 percent below the 2010 standard.[26] The research projects will include a production readiness plan guiding developed natural gas engine technologies to commercialization.

The Energy Commission also collaborates with other California stakeholders, research institutions, governmental agencies, and industry and utility representatives to develop a shared vision of public interest energy research projects. This outreach improves accountability, transparency, communication, and responsiveness. The Energy Commission relies on these strategic partnerships to avoid duplication, build upon previous R&D work, generate new ideas, leverage public and private investments, and ensure the research portfolio provides benefits to the state's natural gas ratepayers.

### Collaborative Roadmaps and Workshops

*Roadmaps* are planning mechanisms and communication tools that establish a clear link between the priorities for research and key California energy policy goals. Research roadmaps define the topic area, significant issues and barriers, data gaps, information needs, research priorities, and potential partnerships. Energy Commission staff and a wide range of energy researchers and consumers participate in "roadmapping" activities in many program areas.[27] Participants can

[26] Observed rates below 0.02 grams per brake horsepower hour.

[27] Various roadmaps can be found at http://www.energy.ca.gov/publications/searchReports.php?title=roadmap.

identify natural gas research needs by program area and where they overlap. Collaborative thinking about energy solutions that cut across policy boundaries is integral to leveraging research dollars. Electricity and natural gas end users often face a complex array of regulatory issues where savings from one energy source are often offset by increased use from other sources. Bringing natural gas and electricity stakeholders together to roadmap minimizes resource shifting, encourages innovation, documents the process for better transparency, and yields outcomes that are more likely to address challenges that involve both areas.

To identify emerging research trends and gaps, the Energy Commission obtains direct feedback and recommendations from utilities, other state agencies, academic experts, industry associations, and technology developers. These meetings, workshops, and working groups provide a vehicle for California stakeholders to understand past, present, and future research and to provide guidance, recommendations, and improvements for the current program.

The following are workshops held by the Energy Commission Natural Gas R&D program staff in FY 2015-16:

***July 16, 2015*:** The Energy Research and Development Division's Natural Gas Pipeline Safety and Integrity Management R&D program held a staff workshop to discuss with stakeholders current research and future needs and opportunities for research on pipeline safety and integrity management technologies, tools, practices, and risk assessments. The Energy Commission staff provided an overview and presentations of the natural gas pipeline safety and integrity research and principles. Participants included representatives from natural gas utilities, CPUC, Gas Technology Institute, Pipeline Research Council International (PRCI), and Pipeline and Hazardous Materials Safety Administration (PHMSA). After a panel discussion, stakeholders recommended high priority research topics, including technologies and tools for improving situational information and risk analysis. The Energy Commission staff used these recommendations to prepare solicitations and future research initiatives.

Staff will continue such discussions with stakeholders by conducting public workshops and meetings in collaboration with key stakeholders such as natural gas utilities, CPUC, PHMSA, and PRCI.

***November 10, 2015*:** The Natural Gas R&D program held a staff workshop to gather and present information on the potential for subsidence, linked to groundwater extraction that would impact natural gas pipelines, storage, and emissions from abandoned natural gas wells. In addition to Energy Commission scientists, representatives from leading research groups, including NASA Jet Propulsion Lab and Lawrence Berkeley National Laboratory, presented their findings from California and other natural gas-intensive regions. Representatives

from Pacific Gas and Electric Co. (PG&E) and SoCalGas attended and focused their comments on how best to connect scientific research to their needs.

***November 18, 2015***: California Energy Commission staff held the workshop "Advanced Distributed Generation Research: Current Status and Future Recommendations." This workshop received public input regarding the draft recommendations in the *Advanced Distributed Generation Research Roadmap*. Staff is developing this roadmap as a guide for future research and development activities, including funding solicitations, regarding distributed generation (DG). DG is electricity production that is onsite or close to the load center and is interconnected to the utility distribution system. The workshop included a staff presentation on current and planned future DG research, as well as a panel discussion with expert stakeholders. Panelists were from professional backgrounds including industry, academia, utilities, and local, state, and federal agencies. Facility owners and operators, technology manufacturers and providers, universities, utilities, and local, state, and federal agencies participated.

***January 19 and 22, 2016***: The Natural Gas R&D program staff held two public scoping workshops in Long Beach and Fresno to help develop the "Natural Gas Off-Road Vehicles" solicitation scheduled for release in 2016. These workshops identified market requirements and barriers affecting the off-road vehicle market preventing heavy-duty off-road vehicles from reducing emissions. The scoping workshops provided staff with insight on the current status of the off-road vehicle market and information on the technology needs and market potentials from the public, industry, and subject matter experts.

***January 25, 2016***: The Natural Gas R&D program staff held a public workshop to present the proposed natural gas research initiatives for fiscal year 2016-17. The presentations provided an overview of the goals and priorities of each research area, specific policy drivers, highlights and accomplishments, and a proposed budget plan. Workshop participants included representatives from investor-owned utilities, universities, and private entities; members of the public; and others.

The following is a summary of the main comments received from the workshop:

- Broaden research initiatives and scope to be more inclusive of other industries.
- Consider technology integration, such as efficiency and generation, to result collectively in greater carbon reduction emissions and help reach the state's ZNE goals by 2020.
- Include an update of past funding associated with building end-use efficiency since this area is not covered in this budget plan.
- Include solar thermal research for industrial applications.

- More funding for renewable natural gas and advanced generation is necessary.
- Include residential-scale micro-CHP (less than 25 kW) into the plan.
- Include focus on renewable natural gas development and production technologies, such as thermochemical and water electrolysis.
- A biogas roadmap to guide biogas investments is a must.
- Include research on developing cost-effective pollution controls that do not require biogas conditioning or sensitive catalytic post combustion treatment.
- Consider locomotive engine research as part of the planned transportation research area.
- Several workshop attendees felt that more than $24 million for the Natural Gas R&D Program is necessary to meet the overall natural gas research needs of the State.

The comments from the workshop were considered in the final proposed research initiatives contained in Chapter 2 and are included in Appendix B. The presentation from this workshop is at http://www.energy.ca.gov/research/notices/#01252016.

## Natural Gas Research Benefits

The Energy Commission continues to evaluate and realign its natural gas research portfolio to maximize the benefits to California's natural gas ratepayers, and build on lessons learned from past programs, creating new programs to meet today's priorities. Central to this effort is a continued focus on measuring the benefits of the Energy Commission's research. While the costs and quantifiable benefits of most commercially available products and technologies can be easily calculated, the same cannot be said for premarket emerging technologies. As a result, benefits estimates must be considered preliminary until more specific and detailed assessments can be developed and published. Furthermore, environmental and safety benefits cannot be fully quantified and will often be reported qualitatively.

The CPUC Resolution G-3507 directed the Energy Commission to prioritize research investments in natural gas pipeline safety, drought and climate change. In response, the writers of the *Natural Gas Research and Development 2015 Annual Report* focused benefits reporting on nine featured projects addressing these issues.

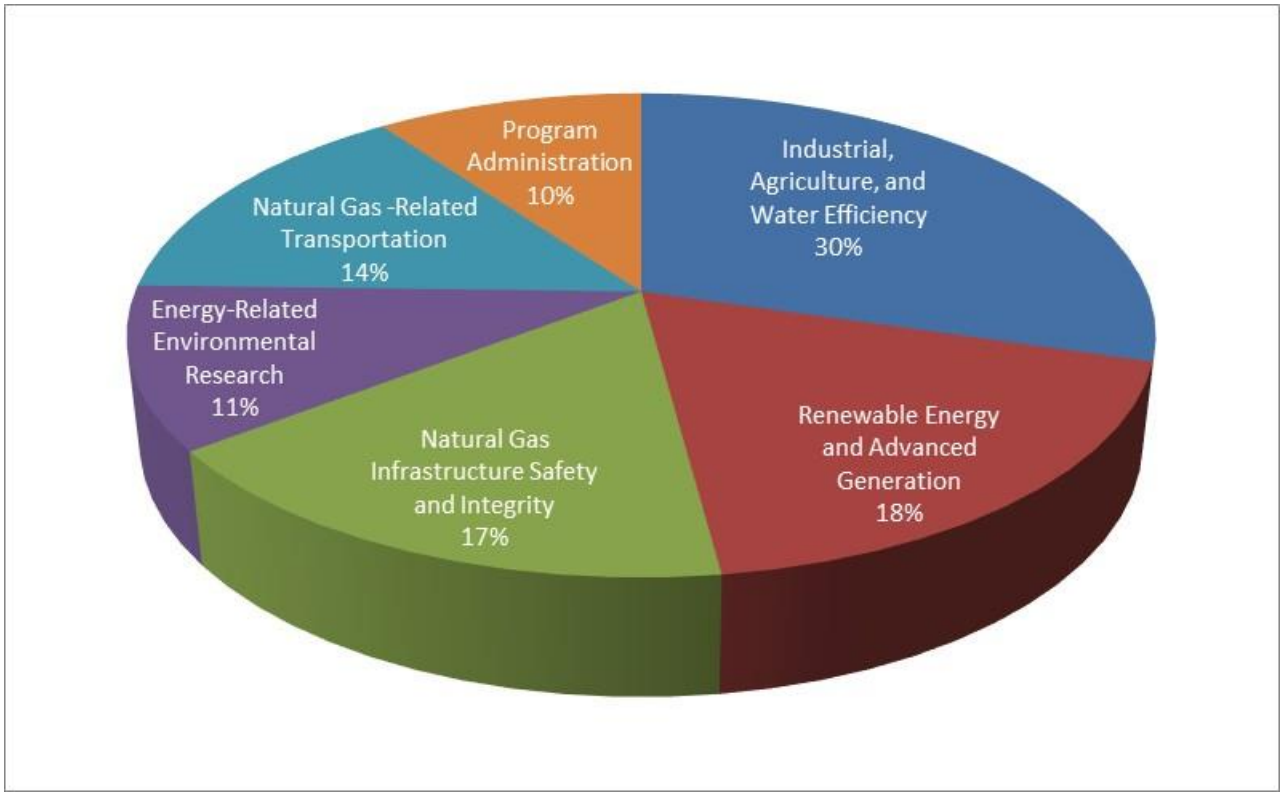
The nine featured projects appear on track to save natural gas ratepayers $87 million per year after they are widely disseminated, in about a decade. For comparison, the annual budget of the Natural Gas R&D program is $24 million. More importantly, the research may save lives by averting natural gas pipeline

explosions, thanks to automated pipeline fault detection and repair systems, while also contributing to GHG emission reductions caused by pipeline leakage as these leaks are identified and mitigated. An additional 126,000 metric tons per year of carbon dioxide ($CO_2$) equivalent greenhouse gas emissions should be avoided as a result of featured projects, saving an estimated 20 million therms and 148 million kWh per year. Two of the projects will save significant amount of water – 13 million gallons of water per year in current pilots, potentially leading to 960 million gallons of water per year after the technologies are more widely adopted. Finally, featured research to understand natural gas system emissions will lead to more informed climate policy-making that can have tremendous impact on climate outcomes.

## Proposed Budget

The Energy Commission's *Natural Gas Research and Development Program Proposed Program Plan and Funding Request for Fiscal Year 2016-2017 (FY 2016-17 Natural Gas R&D Budget Plan)* for $24 million adheres to the state's loading order and the other state policies identified in Table 2 in Chapter 1. The breakdown of the use of those funds is illustrated in (Figure 2).

**Figure 2: Proposed Natural Gas Research Budget Categories for FY 2016-17**




Source: California Energy Commission

## Proposed Research Initiatives

This proposed $24 million *FY 2016-17 Natural Gas R&D Budget Plan* includes research funding for energy efficiency, renewable energy and advanced generation, energy infrastructure (including pipeline safety), natural gas-related transportation, and program administration (Table 3). A research initiative consists of one or more research projects, each of which is designed to resolve issues associated with a technology or area of science. The Energy Commission's Natural Gas R&D budget process allocates funding to CPUC-approved initiatives that are later acted upon by developing specific projects selected through competitive solicitations.

**Table 3: FY 2016-17 Proposed Natural Gas Research Budget Plan Summary**

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

**(1) Energy Efficiency Program areas will alternate funding each year between building efficiency and industrial efficiency research. For FY 2016-17, the focus will be on the industrial, agriculture, and water efficiency sector. In FY 2017-18, the natural gas research will focus on buildings end-use efficiency. This approach will allow the funding of multiple projects in each research area.**

Source: California Energy Commission

## Response to CPUC Resolution G-3484

As requested by the CPUC, the Energy Commission has reviewed the unspent funds in the Public Interest Research Development & Demonstration Natural Gas Subaccount to identify the funds no longer available for expenditure under future grants or contracts. Fiscal year 2013-2014 is the most current funding cycle, with the encumbrance cycle ending June 30, 2015. In addition to the two-year encumbrance requirement, Energy Commission grants and contracts are

awarded and executed so that no agreement will exceed the approved amount of funding on the agreement. After the two-year encumbrance cycle, an agreement has a four-year liquidation period. The Energy Commission has learned from the many years of managing these agreements it is normal for these agreements to complete their activities with some amount of funds being unspent in the six-year cycle. This report to the CPUC on unspent natural gas funds will cover activities during a period of two years (2013 through 2015) and the relevant four-year liquidation cycle (2009 and earlier). The Energy Commission has identified $5.9 million to the CPUC for further direction. Consistent with the direction received from the CPUC for the unspent funds from the FY 2015-2016 Budget Report, the Energy Commission is requesting to use these unspent funds identified above for additional research in the areas identified by the CPUC in Resolution G-3507 of pipeline safety, responding to the Governor's Executive Orders on Climate and the Drought, assessing the long term strategic view of the use of natural gas in a carbon-constrained, water-efficient environment, and augmenting priority research areas such as bioenergy and $NO_x$ reductions. The Energy Commission would like to include research into the Aliso Canyon natural gas leak and completing research to address the issues encountered on this site to develop long term recommendations to avoid future potential challenges of the same nature. The Energy Commission requests the CPUC provide guidance as to how the Energy Commission should address these funds in time to include its decision in the state's FY 2017-18 budget cycle. If the CPUC concurs with allocating the unspent funds from the FY 2015-2016 Budget Plan to future research, the Energy Commission will provide the CPUC a supplemental budget plan to address the recommended use of the $5.9M in unspent funds within 90 days from the date the CPUC requests the Energy Commission provide such a supplement budget plan.

During the January 25, 2016 workshop with stakeholders, several attendees discussed the need to increase the amount of funding provided for natural gas research. The attendees expressed a desire for more research funding for bioenergy, pipeline safety and climate change research while continuing to support the areas of efficiency, renewables, advanced generation, natural gas infrastructure issues, environments issues and reducing greenhouse gas impact of the vehicle transportation system. Natural gas critical issues needing research have increased significantly over the last five years. With natural gas pipeline explosions, uncertainty on the amount methane leaking from the natural gas system, impacts such as subsidence and overall infrastructure deterioration from climate change and the recent natural gas leak from the Aliso Canyon storage facility the need for additional natural gas system research continues to grow. Historically, the funding for the program increased by 100% from 2005 until 2009 and has remained at the same level for the last seven years. Given the interest from stakeholders and the increase in the need for natural gas system

research, the Energy Commission request the CPUC consider evaluating the ability to increase the annual funding for natural gas research program in the near future to a level commensurate with the issues that need to be addressed.

## Energy Efficiency Research

As California's population grows and the demand for energy increases, energy efficiency continues to be an important strategy to reduce energy demand and greenhouse gas emissions in buildings and the industrial, agriculture, and water sectors. Energy efficiency is the strategy of first choice since it is the least expensive, most reliable, and most environmentally sensitive means for minimizing society's contribution to climate change.[28] Sustained development, enhancement, deployment, and operation of better energy efficiency-related technology for existing and planned buildings, and industrial facilities and processes, are essential to meet the state's energy efficiency and greenhouse gas reduction goals. Energy Commission R&D is focused on developing efficient technologies, strategies, models, or tools to reduce energy use in buildings and the industrial, agriculture, and water sectors.

The proposed research budget for energy efficiency is $7.1 million (Table 4). Research activities will be coordinated with other program areas, as appropriate.

**Table 4: FY 2016-17 Proposed Natural Gas Research Budget Plan Summary – Energy Efficiency**

| Program Area – Energy Efficiency | Proposed Budget |
|---|---|
| **Industrial, Agriculture, and Water Efficiency**<br>**Proposed Research Initiatives:**<br>▪ Natural Gas Efficiency Research and Demonstration<br>▪ Heat Recovery and Improved Combustion Processes<br>▪ Roadmap Update | $7,100,000 |

Source: California Energy Commission

[28] *California Energy Efficiency Strategic Plan, 2011 Update:* http://www.cpuc.ca.gov/NR/rdonlyres/D4321448-208C-48F9-9F62-1BBB14A8D717/0/EEStrategicPlan.pdf.

# Industrial, Agriculture, and Water Efficiency Program Goals

## Industrial, Agriculture, and Water Efficiency Program Goals

The Industrial, Agriculture, and Water Efficiency program conducts research, development, and demonstration projects to help:

- Reduce energy use and costs.
- Increase energy efficiency.
- Develop measures to meet environmental challenges while maintaining or enhancing energy efficiency.
- Reduce water consumption or other finite resources.
- Maintain or increase productivity while reducing energy consumption and emissions (for example, low $NO_x$).

The program goal is to commercialize technologies within five years of project completion with a 1 percent penetration rate per year for targeted markets.

## Policy Drivers

- Integrated Energy Policy Report (IEPR)
- California Energy Efficiency Strategic Plan
- Assembly Bill 32 (Núñez, Chapter 488 Statutes of 2006)
- Senate Bill 350 (De León, Chapter 547, Statues of 2015)

## Proposed Research Initiatives: Industrial, Agriculture, and Water Efficiency

### Project 1: Natural Gas Efficiency Research and Demonstration

The industrial sector is a major natural gas consumer in the state, accounting for about 35 percent of total use in 2014.[29] In 2013, 14 California industries used more than 5.8 billion therms (Figure 3).[30] Consequently, the industrial sector represents a logical target to improve the efficiency of natural gas use by adopting new technologies and advancing energy management practices. Natural gas use in California industry is dominated, however, by a relatively small set of industrial users: oil and gas extraction/refining, chemicals and plastics, food processing, primary and fabricated metals, and cement and glass production.

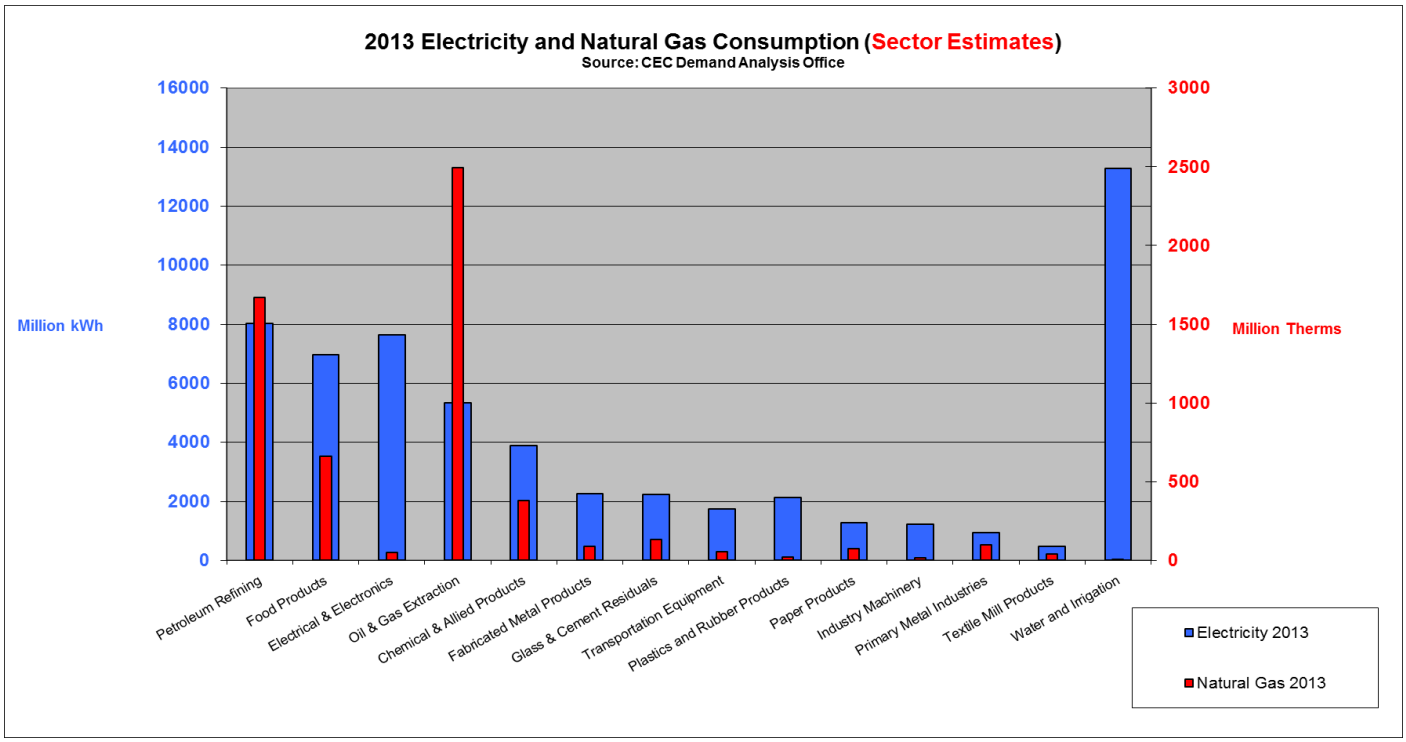
[29] EIA 2014 California Consumption Data., http://www.eia.gov/dnav/ng/NG_CONS_SUM_DCU_SCA_A.htm.

[30] California Energy Commission, Demand Analysis Office.

These sectors represent prime areas of opportunity for reducing industrial natural gas use.

These sectors are very risk averse in investing in new technologies and processes that may affect industrial output or quality since their primary business focus is on optimizing industrial output, not energy throughput. Further research is necessary to identify and demonstrate cost-effective energy efficiency solutions with documented measurable energy savings and greenhouse gas reductions. These demonstrations will help alleviate the risk associated with implementing new technologies and document actual natural gas benefits and cost effectiveness to the affected industrial sector, and. help reduce barriers and help industry to realize its full efficiency potential. Given the number and diversity of the industrial end-use base in California, the following sectors represent high energy-intensive industries and are examples for future research activities.

**Figure 3: 2013 Electricity and Natural Gas Consumption (Sector Estimates)**




Source: California Energy Commission

## Food Processing

The Issue: The food processing industry in California is highly diversified, processing more than 400 commodities sourced from California's 76,400 farms

and ranches collectively valued at $54 billion in 2014.31 Although agricultural and food processing activities occur throughout the state, these industries are concentrated in the Central Valley. The Central Valley is home to more than 3,000 factory sites[32] including the world's largest sites for processing fluid milk (California Dairies, Inc.), cheese (Hilmar Cheese Company), milk powder/butter (California Dairies, Inc.), wine (E & J Gallo), and poultry (Foster Farms). Past research includes solar thermal for small-scale wineries and food processing, advanced boilers, dryers and dehydration methods, advanced compression bailing technology and digestion of waste products to produce biogas to offset on-site natural gas use.

**The Research:** Research is necessary to develop and demonstrate the technical/economic feasibility of advanced energy efficiency measures that could benefit the food processing sector, including:

1. Heat recovery to preheat air and water for food preparation.
2. Heat recovery from process water.
3. Reducing water use in processing fruits, vegetables, and meats.
4. Using alternate or nontraditional water sources with natural gas savings.
5. Using on-site solar thermal to reduce natural gas consumption.
6. Pasteurization and sterilization of dairy products and canned vegetables.
7. End-use process improvements such as:
    - Pasteurization and sterilization.
    - Drying.
    - Roasting.
    - Frying.
    - Eliminating steam sparging[33]

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[31] California Department of Food and Agriculture

[32] http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2011-035, *PIER Industrial, Agricultural, and Water Energy Efficiency Program RD&D Targets: Consolidated Roadmap* - PIER Consultant Report, 2009.

[33] *Steam sparging* is the direct injection of steam into liquids. The process is inefficient, and as much as 30-40 percent of the steam energy could be lost to the atmosphere.

**The Benefits:**

- Market Connection. The estimated time to commercialization is five years, assuming research is successful and meets the stated goals and objectives.[34]
- Energy and Cost Savings. Staff estimates the savings would be $5 million/year in reduced natural gas costs based on $0.76/therm and 1 percent reduction in annual energy use by this sector.[35] Savings from associated process improvements, water savings, and lower emissions would be above the cost savings but cannot be estimated until specific projects are identified.
- Environmental Benefits. Staff estimates the environmental benefits include the reduction of 35,086 metric tons of carbon dioxide ($CO_2$) emissions.[36]

## Glass Industry

**The Issue:** Glass manufacturing in the United States is one of the most energy-intensive industries and, in 2006, used 219 trillion BTUs of natural gas nationwide.[37] The U.S. glass industry includes companies engaged in manufacturing flat glass, container glass, specialty glass, and fiberglass.

There are 13 glass manufacturing facilities operating in California estimated to use about 105 million therms annually (2013).[38] Three of these facilities are flat glass manufacturing facilities, five are container glass manufacturing facilities, four are fiberglass manufacturing facilities, and one is a specialty fiberglass plant.[39] Combined, these facilities were identified by the Air Resources Board as being energy-intensive based on the amount of energy required to melt raw materials in furnaces or melters and the level of greenhouse gas emissions generated. This industry has a significant potential for natural gas (and

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[34] This estimate is based on the assumption that the average time to commercialize a state-funded industrial/agriculture/water project is three years, with two additional years allocated for the manufacturer to develop production and marketing strategies.

[35] 662 million therms x 0.01 x $0.76/therm. Natural gas cost for the industrial sector ($0.76/therm) from http://www.eia.gov/naturalgas/ for 2014.

[36] 6.62 million therms x 0.0053 metric tons/therm.

[37] http://www1.eere.energy.gov/manufacturing/pdfs/glass_footprint.pdf.

[38] http://www.arb.ca.gov/cc/glass/docs/glasssurveys.pdf and CEC Demand Analysis Office Data.

[39] http://www.arb.ca.gov/cc/glass/docs/glasssurveys.pdf.

electricity) reduction by employing energy efficiency measures. No research and demonstrations have been conducted in this area in previous solicitation cycles, and as a result, it is a prime sector to target for energy efficiency improvements.

**The Research:** The following areas of interest are associated with glass manufacturing because of the associated high energy use:

1. *Glass melting, refining, and conditioning*. Heat is used in the manufacturing, refining, and conditioning process. After the refining step, the glass is conditioned to the desired temperature and temperature distribution. Research is needed to improve the energy efficiency of the glass melting and conditioning process.
2. *Submerged combustion melting.* In submerged combustion melting, fuels are fired directly into and under the surface of the batch material being melted. Research is needed on new and efficient combustion technologies.
3. *Oscillating combustion.* This technology forces the oscillation of the burner fuel to create successive, fuel-rich, and fuel-lean zones within the flame. This increases heat transfer by enhancing flame luminosity and turbulence. Research is needed on new and efficient combustion technologies.
4. *Recycled glass.* Research technologies for larger percentage of recycled glass to be used in overall glass manufacturing reducing natural gas consumption.

**The Benefits:**

- *Energy and Cost Savings*. The estimated savings by the glass industry would be $800,000/year in natural gas costs, based on $0.76/therm and a 1 percent reduction in natural gas use.[40]
- *Environmental Benefits*. Environmental benefits include an estimated reduction of 5,565 metric tons of $CO_2$ emissions.[41]

## Chemical Manufacturing Industry

**The Issue:** The United States has the world's largest chemical industry, an important industrial sector for California and the nation. Within the chemical industry, more than 70,000 diverse compounds[42] are produced with production

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[40] 105 million therms x 0.01 x $0.76.

[41] 1.05 million therms x 0.0053 metric tons/therm.

[42] http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/energy use loss opportunities analysis.pdf, pg. 21.

volumes ranging from a few grams to billions of pounds. The chemical industry also uses a significant amount of energy (petroleum derivatives and natural gas) as a raw material primarily for producing organic chemicals and ammonia. The total estimated natural gas used by California's chemical manufacturing industry in 2013 is 380 million therms.[43]

There are more than 150 chemical manufacturing plants in California.[44] The chemical manufacturing industry is diverse, with substantial opportunities to reduce energy consumption and greenhouse gas emissions while maintaining or enhancing the productivity of the plant. It is a prime sector to target for energy efficiency improvements since no research and demonstrations have been conducted in this area in previous solicitation cycles.

**The Research:** The following are areas of research interest because of the potential to reduce energy use in chemical manufacturing:

1. *Energy Management Programs and Control Systems*
2. *Distillation Process (Vacuum and Atmospheric):* Heat is used to separate different products based on respective boiling points.
3. *Heating, Cooling, and Process Integration*

**The Benefits:**

- *Market Connection*. Market adoption time varies, but it is anticipated that funded technologies will have the potential to reach commercialization within five years, assuming research is successful and meets stated goals and objectives.[45]
- *Energy and Cost Savings*. The estimated savings would be $2.8 million/year in reduced natural gas costs, based on $0.76/therm, and 1 percent reduction in natural gas use by this sector.[46]
- *Environmental Benefits*. The environmental benefits include the estimated reduction of 20,140 metric tons of $CO_2$ emissions.[47]

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[43] Energy Commission Demand Analysis Office data.

[44] http://www.manta.com/mb_45_E8383000_05/chemical_preparations_nec/california.

[45] This estimate is based on the assumption that the average time to commercialize a state-funded industrial/agriculture/water project is three years, with two additional years allocated for the manufacturer to develop production and marketing strategies.

[46] 380 million therms x 0.01 x $0.76.

[47] 3.8 million therms x 0.0053 metric tons/therm.

## Project 2: Heat Recovery and Improved Combustion Processes

There are opportunities for heat recovery from combustion systems and natural gas burners (industrial processes in general). Technical and economic feasibility depends on finding the right combination of technology and an industrial partner who can use the waste heat in process operations. Since the industrial sector is risk-averse, widespread implementation of heat recovery systems will depend on successful demonstration of technical and economic viability. Though some technologies have been researched and demonstrated, it is essential to identify cost-effective heat recovery technologies that can reduce energy cost and greenhouse gas emissions.

Research opportunities include, but are not limited to:

- Very low-grade (-40 to 250 degrees F) heat recovery.
- Low-grade (250 to 500 degrees F) heat recovery.
- Mid- to high-grade (500 to >1000 degrees F and higher) heat recovery.
- Heat loss reduction.
- Advanced heat transfer (shapes, materials, flow patterns, coatings).
- Combustion systems improvement that results in increased energy efficiency and air emission improvement (for example, low NOx).
- Advanced natural gas burners.

Industries with the most potential for heat recovery and advanced burner systems include oil and gas, food processing, glass, cement and metals manufacturing, and petroleum refineries.

Adoption time varies depending on the nature of the industry. In general, it is anticipated that projects will have the potential to commercialize within five years, assuming research is successful and meets stated goals and objectives.[48]

### Oil and Gas Extraction and Refining Industry

The Issue: In 2013, the oil and gas extraction and refining industry in California consumed nearly 2,500 million therms. The industry is a major contributor to the California economy, employs more than 13,000 people, and accounts for 15 percent of the total value of manufacturing shipments from the state. In addition, California's refineries account for 12.5 percent of the workforce and value of shipments of the U.S. petroleum refining industry.[49]

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[48] This estimate is based on the assumption that the average time to commercialize a state-funded industrial/agriculture/water project is three years with two additional years allocated for the manufacturer to develop production and marketing strategies.

[49] Pg. 69: http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2011-035 and Energy Commission Demand Analysis Office data.

**The Research:** Areas of research interest include:

- Recovery of heat from gas conditioning plants, process heaters, crackers.
- Recovery of heat produced in the separation of oil into component parts.
- Recovery of heat generated from flares and thermal oxidizers.
- Advanced combustion technology, including air emission improvements. Some refining processes involve the combustion of waste gases in flares.
- New, cleaner technologies to combust waste gases to extract energy.

**The Benefits:**

- *Market Connection*. For the oil and gas extraction and refining industry, a 1 percent market penetration rate of targeted markets is a reasonable goal for these technologies during a five-year period.
- *Energy and Cost Savings*. The estimated savings would be $19 million/year in reduced natural gas costs, based on $0.76/therm, and 1 percent reduction in natural gas use by this sector.[50]
- *Environmental Benefits*. Environmental benefits include an estimated reduction of 132,500 metric tons of $CO_2$ emissions.[51]

**Cement Industry**

**The Issue:** In the United States, cement manufacturing accounts for between 1.5 to 2 percent of $CO_2$ emissions attributable to human activities. Worldwide, cement manufacturing accounts for about 5 percent of $CO_2$ emissions.[52] About one pound of $CO_2$ is emitted for every pound of finished cement produced.[53] Producing cement is energy-intensive and results in the emission of carbon dioxide from fuels consumption and the calcination of limestone.

California is the largest cement-producing state in the United States, accounting for between 10 and 15 percent of U.S. cement production.[54] The cement industry in California consists of 31 sites that combined consumed 30 million therms of

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[50] 2500 million therms x 0.01 x $0.76.

[51] 25 million therms x 0.0053 metric tons/therm.

[52] http://www.concretethinker.com/technicalbrief/Concrete-Cement-CO2.aspx.

[53] http://www.concretethinker.com/technicalbrief/Concrete-Cement-CO2.aspx.

[54] http://ies.lbl.gov/iespubs/59938.pdf, *Case Study of the California Cement Industry*, Fred Coito and Frank Powell, KEMA, Ernst Worrell and Lynn Price, Lawrence Berkeley National Laboratory, Rafael Friedmann, Pacific Gas and Electric Company, 2005, pg. 1.

natural gas (2013 estimate).[55] The industry is a significant emitter of greenhouse gas emissions and accounts for about 2 percent of statewide emissions.[56] Eleven of these sites are in full-scale cement production, while the remainder of the facilities provide grinding and mixing operations only. The 11 full-operation sites account for more than 90 percent of the California cement industry's electric use and 80 percent of the natural gas use.[57]

No research and demonstrations have been conducted in this area in previous solicitation cycles, and it is a prime sector to target for energy efficiency improvements.

**The Research:** Areas of research include:

- Advanced combustion technology, including air emission improvements.
- Recovery of heat from the kiln shell surface or other high-temperature surfaces.
- Particulate removal of clinker cooling air for reuse (heat recovery or raw material moisture control)
- Carbon capture technology improvements, such as low-drag coatings for pipelines, improvements to compressor technology, and optimization software with real-time pipeline monitoring sensors.
- Developing and demonstrating advanced concrete additives to reduce the amount of cement required for the concrete mix. This could result in reductions of greenhouse gas emissions and increased energy efficiency.

**The Benefits:**

- *Market Connection*. It is anticipated that commercialization can occur within five years, assuming research is successful and meets stated goals and objectives.
- *Energy and Cost Savings.* The estimated savings would be $228,000/year in reduced natural gas costs based on $0.76/therm and 1 percent reduction in natural gas use by this sector.[58]

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[55] http://ies.lbl.gov/iespubs/59938.pdf and Energy Commission Demand Analysis Office data.

[56] http://www.e2.org/ext/doc/8-CementFactSheet.pdf;jsessionid=F66AB1704F38FF492BE6EC32E1319E96.

[57] http://ies.lbl.gov/iespubs/59938.pdf, *Case Study of the California Cement Industry*, Fred Coito and Frank Powell, KEMA, Ernst Worrell and Lynn Price, Lawrence Berkeley National Laboratory, Rafael Friedmann, Pacific Gas and Electric Company, 2005, pg 2.

[58] 30 million therms x 0.01 x $0.76/therm.

- *Environmental Benefits*. Environmental benefits are unknown but most probably large, based on improvements to the cement formulation process that could reduce the $CO_2$ emitted in the clinker manufacturing process.

**Project 3: Roadmap Update**

**The Issue:** From 2003 to 2009, the California Energy Commission's Public Interest Energy Research Industrial, Agriculture, and Water program engaged stakeholders from various industries to assist in developing R&D roadmaps to guide funding priorities. Through these efforts, the Industrial, Agriculture and Water program produced the following roadmaps that have natural gas relevance:

1. Industrial Agriculture and Water Energy Efficiency R&D Program Overview (2007)
2. Technology for Reducing Natural Gas Use in California Industry (2007)
3. Energy Efficiency Roadmap for Petroleum Refineries in California (2006)
4. Energy Efficiency Roadmap for the California Food Processing and Beverage Industry (2009)
5. Energy Efficiency in California's Food Industry (2006)
6. PIER Water-Energy Strategic Plan and Technology Roadmap (2008)
7. Water and Wastewater Industry Energy Efficiency: A Research Roadmap (2004)

Though these roadmaps were consolidated (with minor updates) into a single roadmap in 2009,[59] the majority have not been updated for six or more years. To capture new opportunities, reprioritize initiatives, and ensure stakeholder input on proposed research, an updated consolidated roadmap, with a priority of natural gas research for the industrial sector, must be undertaken. This will ensure ratepayer funds are spent on the highest priority natural gas research.

**The Research**: This initiative advances science and technology by identifying the priority energy efficiency research, development, and demonstrations necessary in the industrial, agriculture, and water sectors. The identified research areas will address sector needs and link to achieving state policy goals including food processing, glass manufacturing, chemical manufacturing, cement manufacturing, metals processing/recycling, general and high technology manufacturing, water and wastewater, and other energy-intensive industries.

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[59] http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2011-035, *PIER Industrial, Agricultural, and Water Energy Efficiency Program RD&D Targets: Consolidated Roadmap* - PIER Consultant Report, 2009.

**The Benefits:** The major industries in California used more than 5.8 billion therms in 2013. An updated roadmap can help identify and prioritize research that focuses on California's industries while eliminating duplication and addressing state energy policy goals. However, the energy savings, technical and market potential, and other benefits reside with the technology and are accounted for when technologies are implemented through one of the previously identified research projects.

## Renewable Energy and Advanced Generation

Renewable energy resources are essential for reducing greenhouse gas emissions and reaching state energy goals. The Renewable Energy and Advanced Generation research area conducts research addressing barriers to increase market penetration of renewable energy, including distributed generation (DG) and combined heat and power (CHP) systems. A DG system uses small amounts of generation located on a utility's distribution system to meet local (substation level) peak loads and/or alleviate having to build additional (or upgrade) local distribution lines. Strategies include developing innovative systems based on performance and environmental attributes, developing hybrid generation and fuel-flexible systems, and demonstrating CHP systems using renewable natural gas systems.

The proposed research budget for renewable energy and advanced generation is $4.4 million (Table 5).

**Table 5: FY 2016-17 Proposed Natural Gas Research Budget Plan Summary – Renewable Energy and Advanced Generation**

| Program Area – Renewable Energy and Advanced Generation | Proposed Budget |
|---|---|
| **Proposed Research Initiatives:**<br>▪ Cost-Effective Waste Heat to Power Systems for California Industries<br>▪ Hurdling the Distributed Generation Barriers through Cost Effective Emissions Control and Other Novel Systems and Strategies | $4,400,000 |

Source: California Energy Commission

### Renewable Energy and Advanced Generation Program Goals

Reduce barriers and increase amount of renewable energy by:

- Advancing the development and market availability of clean and efficient DG and CHP technologies.

- Developing hybrid generation, fuel-flexible, energy-efficient, and low-emission natural gas DG technologies for alternative fuels, including biogas and natural gas.
- Developing and demonstrating diversified applications of advanced generation technologies that use renewable natural gas.

**Policy Drivers**

- Senate Bill X1-2 – Renewables Portfolio Standard
- Assembly Bill 1613, the Waste Heat and Carbon Emissions Reduction Act
- *Bioenergy Action Plan* to implement Executive Order S-06-06, which set goals for the production and use of electricity and fuels made from biomass.
- Governor's *Clean Energy Jobs Plan* (2010)

## Proposed Research Initiatives: Renewable Energy and Advanced Generation

### Project 1: Cost-Effective Waste Heat to Power Systems for California Industries

**The Issue:** Waste heat to power (WHP) uses the discarded heat created from existing industrial processes to generate electricity. Sources of waste heat may include heat generated to support thermal processes, heat rejected from mechanical processes, and heat from exothermic chemical processes. A recent market assessment identified a technical potential of 763 megawatts (MW) of WHP opportunities concentrated mostly at petroleum refineries, other oil and gas operations, cement plants, and natural gas compressor stations.[60]

Given the availability of reasonably standardized Steam Rankine Cycle and Organic Rankine Cycle generation equipment, ORNL identifies the principal technical barriers affecting project economics, including dispersed heat sources that are difficult to consolidate, or are from noncontinuous batch processes; seasonal or low-volume operations; contaminated or corrosive waste streams that complicate and raise the cost of heat recovery; physical size issues making it difficult to site WHP equipment at existing facilities; control issues related to integration with ongoing plant operations and interconnection with the electric grid; and modifications to processes that may trigger permitting issues.

**The Research:** The initiative proposes R&D to support technological advances to adopt waste heat to power in key industries statewide. Potential R&D approaches will address cost reductions and efficiency improvements in collecting and

[60] http://web.ornl.gov/sci/buildings/docs/ORNL%20TM-2014-620%20Waste%20Heat%20to%20Power.pdf.

managing the waste heat, improving the heat quality for power generation, and improving the power generation systems for waste heat. Examples of specific R&D solutions will address supplemental firing technologies and issues, and organic Rankine cycle cost and performance. Other possible research includes:

- Developing low-cost, prepackaged systems based on the Organic Rankine Cycle or other appropriate cycles (such as microturbine) suitable as WHP systems for typical natural gas fueled machinery.
- Developing WHP systems specifically designed to improve the economic performance for lower temperature resources (150°F - 400°F)
- Developing controls and strategies for integrating WHP into existing industrial processes.
- Developing strategies to simplify the collection of waste heat for delivery to WHP equipment.
- Developing compact, high-effectiveness, low-loss heat exchangers.
- Developing tools to help industry analyze and determine the best use for waste heat in commercial or industrial processes.
- Developing emerging technologies that show promise in reducing the cost of WHP by increasing the thermal efficiency or by reducing the complexity of deploying WHP systems. Possible projects might include systems based on the Kalina cycle or the supercritical $CO_2$ Rankine cycle, or employ solid-state thermoelectric generation or other emerging technologies.

**The Benefits:**

- *Energy Sector*. Waste heat-to-power systems and facilities conserve natural gas by using the waste heat while providing supplemental power to industry; all have positive energy, environment, and economic benefits. Overall, advancing WHP in California industry will help reduce natural gas consumption and provide additional power generating capacity that can supplement industries' parasitic load, resulting in less electricity used.
- *Technology Potential*. ICF International estimates the technical potential for waste heat to power is 763.4 MW in California. Based on ICF's estimated market penetration of about 402 MW and assuming a conservative 75 percent capacity factor, this translates to roughly 2,640 GW-hr per year of electricity generated.
- *Market Connection*. WHP can be applied across a range of industries that use or transport natural gas. The most important industrial sectors include petroleum refineries, oil and gas operations, and pipeline operations (natural gas compressor stations) with significant applications in the chemical, metals, food processing and waste management industries.

- *Energy and Cost Savings*. Assuming estimated market penetration and the electricity from WHP consumed on site, the avoided grid electricity would be 2,806 MW-hr based on historical averages. As natural gas is expected to supply 67 percent of electricity in 2020, the displaced natural gas generation comes to 1,880 MW-hr, or 135 therms annually based on the average heat rate for a combined-cycle natural gas plant. The cost savings to the ratepayers would be nearly $280 million per year assuming 90 percent savings of a retail price of 11.75 cents/kW-hr. The value of the displaced natural gas would be about $40.5 million/year ($3/MW-hr).
- *Environmental Benefits*. At 0.005302 metric tons $CO_2$/therm, the avoided $CO_2$ emissions are 716,000 metric tons per year. Similarly, avoided $NO_x$ emissions are 337,000 lbs/year (.120 lbs $NO_x$ /MW-hr) and avoided $PM_{10}$ is 185,000 lbs/year (0.066 lbs PM10/MW-hr).

**Project 2: Hurdling the Distributed Generation Barriers With Cost-Effective Emissions Controls and Other Novel Systems and Strategies**

**The Issue:** Assembly Bill 32 and the Governor's Clean Energy Jobs Plan set aggressive goals for advanced generation technologies, including clean DG, CHP, and combined cooling, heat and power (CCHP) for California. In addition, the investor-owned utilities (IOUs) recently released their first round of distribution resource plans that aim to identify strategies, locations, and allowable capacities for grid integration of distributed energy resources.61

Despite these many drivers, DG, CHP, and CCHP systems have seen minimal growth in recent years. For example, only 2,163 MW of CHP capacity has been procured by IOUs since 2010, compared to a goal of 6,500 MW by 2030 as outlined in the Governor's Clean Energy Jobs Plan.62 Moreover, the majority of installations are at large industrial, municipal, or institutional facilities with significant thermal loads. Little adoption is seen outside these sectors because of reduced thermal loads, high capital costs per kilowatt installed, difficulty meeting emissions standards, scalability issues, and lack of existing prepackaged systems.

A major barrier to the success of DG, CHP, and CCHP systems is emissions control issues. Microturbines have shown some success achieving emissions compliance by using ultra-low NOx burners and sophisticated controls. Internal combustion engines generally require costly methods, such as selective catalytic reduction, to meet current emission standards. CHP-integrated fuel cells have

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[61] *Distribution Resource Plans*. California Public Utilities Commission Rulemaking (R. 14-08-013). 2015. http://www.cpuc.ca.gov/PUC/energy/drp/

[62] *Tracking Progress – Combined Heat and Power*. California Energy Commission. 2015. http://www.energy.ca.gov/renewables/tracking_progress/documents/combined_heat_and_power.pdf

also been deployed on a limited basis and have demonstrated the ability to support electric and thermal loads while achieving excellent emissions performance. Despite these successes, industry adoption has been slow.

Most existing DG prime movers (that is, the source of motive power) use pipeline-quality natural gas as the primary fuel source. For many of these systems, the emissions performance does not carry over to biogas (gas produced from a variety of waste sources, including agricultural activities, municipal wastewater processing, food processing wastewater, landfill gases, and food wastes). Each of these fuels may exhibit off-specification properties such as nonstandard BTU content and undesirable contaminants (compounds of sulfur, silicon, nitrogen, and others), making them unusable with conventional generating equipment. Unusable gas may be flared, at great expense to the environment.

Technological advancements are required to reduce the barriers and increase the economic attractiveness of DG, CHP, and CCHP systems for prospective buyers and installers. Breakthroughs in emissions control, fuel flexibility, performance, efficiency, or cost-effectiveness could serve as a "tipping point" to allow access to underserved or previously untapped markets.

**The Research:** Research under this initiative addresses technical and economic barriers to deploying DG, CHP, and CCHP in small commercial, light industrial, or multifamily residential applications in the small- to microscale range (250 kilowatts equivalent [kWe] to 25 kWe or other technically and economically justified small-scale range) and is grouped into two focused areas:

- Cost-Effective Emissions Control Systems. Potential research could develop a cost-effective way to reduce emissions of DG prime movers. Ability to meet state emission standards and attain Air Resources Board (ARB) certification can help streamline the permitting process with local air districts. This can lower design and engineering costs, helping remove barriers for prospective buyers and installers. These technologies must be able to meet air quality standards using natural gas and biogas. Potential research includes development and demonstration of enabling components such as unique low-cost emissions control technologies with fuel flexibility (natural gas, biogas with varying degrees of purity) or development and demonstration of an emissions-compliant DG, CHP, or CCHP system capable of attaining ARB certification.
- Novel Systems and Strategies for Small- and Micro-DG/CHP/CCHP. Potential technologies could introduce breakthrough advances in internal combustion engine, microturbine, and fuel cell technology. Possible advances include alternate configurations, new subsystems, or previously ignored applications that drastically increase performance, efficiency, and/or cost-effectiveness.

Potential advancements include hybrid or cascaded DG systems, where heat from one generator drives another. Small DG systems are typically less efficient when compared to larger counterparts. This often results in longer-than-desired payback periods for prospective buyers. Development of a small generator that could be driven by waste heat from another could improve the efficiency of DG systems, making them more desirable to consumers. Examples include small microturbine, ORC, or thermoelectric systems. These systems could be cost-effective if modest increases to overall efficiency are achieved (4-8 percent) at relatively low cost.

Potential technologies may also fall outside the internal combustion engine/microturbine/fuel cell paradigm often associated with commercial and light industrial CHP and can employ novel combustion/oxidation methods and emissions control strategies to meet air quality standards. Potential technologies could be extremely fuel-flexible, able to operate on a wide variety of off-spec gasses (for example, gasses that do not meet industry specifications) with minimal preconditioning (that is, stranded gas or sour gas) while still achieving emissions compliance.

**The Benefits:**

- *Energy Sector*. Increased installation of DG, CHP, and CCHP systems can potentially reduce statewide consumption of natural gas and provide increased reliability, flexibility, power quality, reduced transmission and distribution losses, and reduced transmission congestion on the local electric grid.
- *Technology Potential*. There exists a large potential market for DG, CHP, and CCHP systems in the commercial, light industrial, institutional, and multifamily residential sectors. ICF International identified CHP generation potential for existing facilities of about 2,766 megawatts (MW), with an additional 531 MW growth expected by 2030.[63]
- *Market Connection*. Small-scale combined cooling, heat, and power represent another pathway by which light industrial, commercial, and institutional entities can meet their on-site electric and thermal demands. CHP fills an important gap for facilities looking to increase energy security and reduce heating and electric bills through self-generation; and provides an option better tailored to higher electric-to-thermal load applications. Possible customers for small- and micro-scale CHP/CCHP include:
    - Hospitals

[63] *Combined Heat and Power: Policy Analysis and 2011-2030 Market Assessment*. ICF International for the California Energy Commission. 2012. CEC-200-2012-002 http://www.energy.ca.gov/2012publications/CEC-200-2012-002/CEC-200-2012-002-REV.pdf

    - Hotels
    - Schools
    - Multifamily dwellings
    - Small commercial buildings
    - Light industrial facilities
- *Energy and Cost Savings*. BEW Engineering and Lawrence Livermore National Laboratory estimates the potential energy savings of the 448 MW of micro-CHP identified to nearly 155 million therms per year with a cost savings of $105 million, based on 82 percent penetration in the stated megawatt range. This is a 90 percent capacity factor, and the commercial cost for natural gas is assumed to be $0.68/therm.[64]
- *Environmental Benefits*. Improved air and environmental quality and reduced climate change impacts may occur through reduced natural gas consumption, greenhouse gas emissions reductions, and water savings.

## Energy Infrastructure

R&D must address energy infrastructure issues to ensure that the entire system operates safely and effectively. The Energy Infrastructure area includes research associated with infrastructure safety and integrity management, energy-related environmental and climate issues, and natural gas-related transportation.

The proposed research budget for energy infrastructure is $6.6 million (Table 6).

[64] *Geographic Information System-Enabled Renewable Energy Analysis Capability Project Final Report*. BEW Engineering and Lawrence Livermore National Laboratory for the California Energy Commission. 2011. CEC-500-2011-026 http://www.energy.ca.gov/2011publications/CEC-500-2011-026/CEC-500-2011-026.pdf.

**Table 6: FY 2016-17 Proposed Natural Gas Research Budget Plan Summary – Energy Infrastructure**

| Program Area – Energy Infrastructure | Proposed Budget |
|---|---|
| **Natural Gas Infrastructure Safety and Integrity**<br>**Proposed Research Initiative:**<br>▪ Enhanced Methods, Tools, and Assessments for Natural Gas Infrastructure Safety and Integrity Management | $4,000,000 |
| **Energy-Related Environmental Research**<br>**Proposed Research Initiatives:**<br>▪ Identification and Quantification of Methane Leaks<br>▪ Characterization of $N_2O$ Emissions From Natural Gas Combustion Units Using Modern Air Pollution Control Devices<br>▪ Natural Gas Market Scenarios | $2,600,000 |

Source: California Energy Commission

## Natural Gas Infrastructure Safety and Integrity

### Natural Gas Infrastructure Safety and Integrity Program Goals

- Conduct research in natural gas infrastructure not adequately addressed by the regulatory and competitive markets.
- Provide research that results in tangible benefits to utility customers.
    - Focus on projects that have the potential to increase safety and enhance transmission and distribution capabilities of the natural gas system.

### Policy Drivers

- Public Resources Code 25620
- *2011 Integrated Energy Policy Report*
- Greenhouse Gas Emission Reduction (AB 32)
- Executive Order B-30-15
- Governor's Aliso Canyon Gas Leak Proclamation
- Natural Gas: Leakage Abatement (SB 1371)

## Proposed Research Initiative: Natural Gas Infrastructure Safety and Integrity Assessment

### Project 1: Enhanced Methods and Tools for Natural Gas Infrastructure Safety and Integrity Management

**The Issue:** California has a vast network of natural gas pipelines, including some pipelines running through highly populated areas to transport and distribute natural gas from production areas to consumers. The gas pipeline and gas storage infrastructure, built more than 100 years ago, has widely varying characteristics of age, type, size, and structural health condition. Maintaining and ensuring the safety, integrity, and reliability of the natural gas infrastructure are priorities for California. Despite such high priorities and enhanced efforts by California regulators and utilities, catastrophic events on California's pipelines and storage infrastructure have happened in the past five years. These events caused loss of life and property, as well as damage to the environment. The Aliso Canyon gas leak and its impact on the environment illustrate the criticality of the need for system improvement. In recent years, California has experienced an unprecedented drought. Excessive groundwater depletion and ground subsidence has increased the potential for damage to California's pipelines. In addition, subsidence and earthquakes have the potential to pose a significant threat to natural gas pipelines in California. A natural gas pipeline that is either buried or runs along the surface could experience deformation and/or rupture as a result of subsidence or seismic activity. The extent of impacts from these factors on pipeline safety and integrity is not fully known, and these impacts, in addition to others, are caused by encroachments or right-of-way violations.

Efforts are under way for all risks to the infrastructure to be fully analyzed, assessed, quantified and understood by using new tools and methods. To support natural gas safety and integrity requirements, new risk analysis modeling approaches are being developed. These advanced models must be able to adequately identify and quantify all infrastructure integrity threats and consequences concurrently. This also includes assessing the effectiveness of risk reduction measures. There is a general lack of appropriate risk assessment models and a lack of reliable data and information to run these models appropriately. New risk assessment techniques, methods, models, and assessments must be developed and adequately tested so that they can be adopted and used by the utilities and regulators and help avoid future infrastructure challenges like occurred in 2015 and 2016 in the Aliso Canyon natural gas storage facility. Also, real-time monitoring and inspections without halting operations are unavailable. It is necessary to identify and determine potential hot spots of developing defects, progressing corrosion damage, system leaks, and weakening structural health in advance of infrastructure damage, leaks, and explosions. The severity of unexpected catastrophic events demands research, development, demonstration, and deployment of new methods and

approaches based on virtual design and analysis, as well as real-time monitoring and inspection of pipelines using advanced virtual simulations.

**The Research:** In the past few years, the focus has been on using integrity assessment methods to detect defects that may lead to failure caused by corrosion and material failure. However, integrity management requires real-time monitoring of the infrastructure to obtain real-time operational data and analyze data in real time. This monitoring is necessary for identification, quantification, and reduction of risks associated with all threats to the energy infrastructure including large leaks in the infrastructure. Common threats include corrosion, manufacturing defects, equipment failures, third-party damage, incorrect operations, and leaks from storage facilities. Furthermore, integrity assessment methods must be assessed over the time span of the system.

This research will focus on developing new approaches that use advanced methods, technologies and high-speed, high-power computers for real-time infrastructure damage and flaw detection, risk assessment, hot spot identification, system leaks, and corrective action planning and implementation. These approaches include:

- Automated pressure cycle fatigue analysis system that processes supervisory control and data acquisition (SCADA) data and generates reports in nearly real time.
- Advanced analysis of corrosion, damage, defects, dents, and wrinkle bends using real-time pipeline monitoring and inspection data.
- Real-time finite element modeling of overpressure events on the network.
- Pipeline burst test simulations using high-speed, high-power computers to imitate and study the process of a real-world natural gas burst over time.
- Real-time natural gas storage system leak detection and notification when a leak occurs.

This research will be an important component in helping reduce natural gas infrastructure failures in California. This research will also generate information to enhance infrastructure safety and integrity management practices and procedures, in addition to future planning and siting of new natural gas infrastructure.

These funds will be used to support up to two projects through a competitive solicitation.

**The Benefits:**

- *Energy Sector*. The research will improve the safety, integrity, and reliability of the natural gas infrastructure for residential, commercial, industrial, and power generation sectors.

- *Technology Potential.* Technology has the potential to prevent catastrophic events and identify major system leaks so prompt action can be provided.
- *Market Connection*. This research will help better determine risk levels and hot spot locations and specific mitigating measures and technologies.
- *Energy and Cost Savings*. Preventing catastrophic events like the San Bruno gas explosion would avoid loss of life and economic losses. Preventing natural gas storage leaks and supply disruptions in California will help maintain a reliable gas supply and power generation and enhanced economic environment.
- *Environmental Benefits*. Preventing natural gas leaks and catastrophic events will prevent unnecessary natural gas waste and release of greenhouse gases.

## Energy-Related Environmental Research

### Energy-Related Environmental Research Program Goals

- Develop cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California; explore how new energy applications and products can solve/reduce environmental problems; identify vulnerabilities of the energy system to climate change; and develop cost-effective approaches to ensure reliable energy services.
- Complement research efforts by producing California-specific products that also inform policy formulation in these areas:
    - Energy – related climate change.
    - Energy – related air quality.
    - Energy – related terrestrial resources.
    - Energy – related aquatic resources.

### Policy Drivers

- Public Resources Code 25620
- *2011 Integrated Energy Policy Report*
- Greenhouse Gas Emission Reduction – AB 32

## Proposed Research Initiatives: Energy-Related Environmental Research

### Project 1: Exploratory Study of Innovative Methods to Assess Structural Integrity of Levees Protecting Natural Gas Infrastructure in the Sacramento-San Joaquin Delta

**The Issue:** A network of 1,115 miles of levees protects about 700,000 acres of lowland in the Sacramento-San Joaquin Delta. This network is the first line of defense against flooding for a major hub of natural gas infrastructure in the Delta, including transmission pipelines and storage. The integrity of Delta levees is critical to protecting people, property, man-made infrastructure, natural resources, and California's water supply. Delta levees are, however, vulnerable to damage from floods, wave action, seepage, subsidence, earthquakes, and sea level rise. Moreover, many of the Delta levees were built as simple peat dikes resting on marsh soils, before modern engineering analyses and methods were available.

Recent PIER Natural Gas work undertaken by the University of California, Berkeley, developed a hydrodynamic model to explore the impact of an extreme storm coupled with various increments of sea level rise ranging from 0 meter (m) to 1.4m.[65] This work found that while there is minimal risk for overtopping[66] of Delta levees with an extreme storm event, 1m to 1.4m of sea level rise would create a situation in which about 260 to 400 miles of natural gas pipelines would be inundated in the San Francisco Bay and the Delta. A worst-case scenario would pose inundation risks to Sherman Island, McDonald Island, a few natural gas transmission loops, and backbone transmission at Antioch. While this study offers a detailed examination of levee failure due to overtopping associated with extreme storms and sea level rise, it did not investigate challenges to the physical integrity of Delta levees. This is a crucial knowledge gap, as there are many modes by which levees can fail. For example, seismic events could induce liquefaction and/or collapse, lateral forces can cause sliding or breeching.

Substantial analysis of levee fragility was undertaken to evaluate the probability of failure of a variety of stressing events (for example, earthquakes, storms) and failure modes (such as overtopping, breaching) for Delta levees as part of the

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[65] J Radke and G Biging. "Sea Level Rise, Storm Surge, and Flooding in the San Francisco Bay and Delta: Risks to Critical Infrastructure." Presented at the *California Climate Change Symposium 2015: Using Climate Science to Plan a Resilient Future*, August 24-25, 2015, Sacramento, California. Research funded by California Energy Commission Contract 500-11-016. http://www.californiascience.org/

[66] Overtopping is a levee failure mode in which water flows over a levee crest.

Delta Risk Management Study.[67] However, the development of fragility curves was hampered by incomplete knowledge, including knowledge of levee material behavioral characteristics.[68] Also, since the fragility analyses were conducted, many levees have been enhanced. Improved knowledge of key geotechnical parameters that govern levee stability would help manage the various risks associated with the Delta.

Improved characterization of spatial variability of soil deposits associated with levee systems in the Delta is needed to improve fragility analyses. Although spatial variability of soil deposits is difficult to quantify, previous scientific research suggests different approaches on how to measure the stability of Delta levees. Researchers from Cal Poly and UC Berkeley used a field-based method based on cone penetration testing (CPT) methodology to characterize soil type and resistance to liquefaction. However, prior work did not consider the geomorphology (that is, surficial geology) of levees, so that subsurface CPT investigations could not quantify the vertical heterogeneity along with the horizontal heterogeneity of the Delta levees.

A field test of settlement behavior on Sherman Island of a nonliquefiable model levee resting on peat, as well as centrifuge tests at UC Davis of nonliquefiable and liquefiable model levees resting on peat, have been conducted by a collaborative team of researchers from UCLA, UC Irvine and Cal Poly. The main limitation of this study is that it addresses only one potential mode of failure (seismicity) and does not consider other internal imperfections that would render levees vulnerable to damage or failure due to other (nonseismic) circumstances.

Staff has consulted with the Department of Water Resources in the preparation of this proposed study to ascertain that it is complementary to and nonduplicative of its work. Staff has also been involved in developing the Delta Stewardship Council's Delta Levee Investment Strategy (DLIS), which endeavors to guide investments in protecting various interests in the Delta, including energy-related infrastructure and resources. Public workshops associated with development of the DLIS indicate that underlying risk assessment could benefit from improvement of fragility curves.

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[67] Department of Water Resources (DWR) 2006. *Initial Technical Framework Paper: Levee Fragility*. Prepared by URS Corporation/Jack R. Benjamin & Associates, Inc, in support of the Delta Risk Management Strategy (DRMS). September 6, 2006. http://www.water.ca.gov/floodsafe/fessro/levees/drms/docs/LeveeFragility_ITF.pdf

[68] S. J. Brandenberg and J. P. Stewart, "Public comment on the levee fragility section of the initial technical framework for the Delta Risk Management Strategy." http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/docs/LeveeFragility_ITF_cmts-BrandenbergStewart.pdf.

**The Research:** The proposed research will develop innovative noninvasive/nondestructive method(s) for assessing the structural integrity of levees in the Sacramento-San Joaquin Delta that directly or indirectly protect natural gas infrastructure. The research will include applying specific method(s) to strategically chosen levees protecting natural gas facilities. This initial work will test the technical and economic viability of the method(s). If promising results originate from this work, future natural gas solicitations may fund the implementing the selected method(s) at a larger scale to the levees directly or indirectly. The research will:

- Develop and test techniques to identify and characterize potential structural problems with levees in the Delta.
- Test the selected methods in actual levees protecting natural gas infrastructure in the Delta.
- Prepare a business case analysis of benefits and costs of a comprehensive large-scale of levees directly or indirectly protecting critical natural gas infrastructure in the Delta.

**The Benefits:**

- *Energy Sector*. This research will improve methods to assess the stability of a critical area to natural gas generation reliability and safety in California.
- *Energy and Cost Savings*. Multiple studies of energy security have stressed the importance of addressing potential infrastructure problems early—doing so also avoids later costs related to clean up, emergency response, and challenging repairs.
- *Environmental Benefits*. The levees of the Delta protect portions of a delicate ecosystem at the confluence of the Sacramento and San Joaquin Rivers, as well as protect human health by preventing flooding. This research will provide the necessary foundation to improve the safety and integrity of the Delta levees.

### Project 2: Improved Characterization of the Climate Implications of Natural Gas Consumption in California

**The Issue:** Knowing the sources and distributions of methane emissions is critical to effectively managing its environmental impacts. As a GHG with high global warming potential and an ozone precursor, methane is one of the three pollutants targeted by the Air Resource Board's Short-Lived Climate Pollutant Strategy.[69] Identifying and quantifying point sources in California are an essential step toward curbing methane emissions. Recent scientific publications offer

[69] http://www.arb.ca.gov/cc/shortlived/shortlived.htm.

growing evidence that a small fraction of natural gas facilities could be responsible for the majority of emissions from the natural gas system. These superemitters are spread over large areas, suggesting the necessity for remote sensing methane surveys. Moreover, as the enormous leak at Aliso Canyon demonstrates, it must be determined whether early detection can avert potentially massive releases of methane to the atmosphere.

One major California natural gas utility is arguing for the decarbonization of fossil-derived natural gas by substituting with renewable methane or biomethane. However, the actual climate benefits of such strategies are unknown because there are substantial uncertainties about methane emissions, and also the climate impacts of substituting natural gas with biomethane. There are 230 project sites in California generating, capturing, and converting biogas into energy.[70] In addition, there are hundreds of untapped sites where biogas by-products could be captured and used for energy production. For example, there are 244 landfills and roughly 1,900 dairies that could potentially be used to generate energy, as well as hundreds of wastewater treatment units.

ARB may use results from ongoing, PIER-funded field research investigating roughly a hundred homes as an initial basis for including methane emissions downstream of utility meters into California's GHG inventory. While this pilot study is an important first step, it must be expanded to robustly characterize residential emissions as a basis to update the state's GHG inventory. Another ongoing, PIER-funded pilot study probing methane emissions downstream of utility meters in commercial buildings may also merit expanding to consider a broader range of building types than those included in initial measurements.

Staff has consulted with ARB and CalRecycle on these issues, and both agencies support this proposed research initiative.

**The Research:** The proposed research includes extensive field studies to quantify GHG emissions of interest to California's natural gas system. Recognizing that results from several ongoing research projects are expected to reveal opportunities, focal points, and synergies, staff propose a single, large research project to improve characterizing climate implications of natural gas consumption in California.

The research will:

- Field test innovative methods to detect and quantify emissions from superemitters. These innovative methods should be distinct from methods

[70] http://www2.epa.gov/agstar/livestock-anaerobic-digester-database; http://www3.epa.gov/lmop/projects-candidates/index.html#map-area; http://biomass.ucdavis.edu/tools/california-biomass-facilities-reporting-system/; http://www.waterboards.ca.gov/ciwqs/

being supported through ARB and/or Energy Commission-supported research at the time the solicitation for proposals is released.

- Explore using these innovative methods and other techniques to early identify the potential and otherwise unanticipated large releases of methane that may pose a safety or public health concern.
- Deploy different measurement techniques to have enough data to validate models capable of accurately estimating the climate benefits of biomethane.
- Complement ongoing and planned research regarding methane emissions downstream.

**The Benefits:**

- *Environmental Benefits*. Developing an improved basis for identifying and quantifying methane emissions from the natural gas system, and in particular from superemitters, is crucial to supporting California's efforts to manage the climate and air quality impacts of methane emissions effectively. The knowledge of methane emissions from current and potential biogas projects is essential to determine climate benefits associated with the use of biomethane vs. natural gas.

**Project 3: Chemical and Isotopic Fingerprints of Natural Gas Basins to Support Full Fuel Cycle Accounting**

**The Issue:** Traditional supplies of fossil fuels are uncertain, as the in-state production of crude oil and natural gas has been declining over the past three decades. California accounts for less than 1 percent of total U.S. natural gas production and provides about one-tenth of total state demand. California imports natural gas extracted from various out-of-state basins. Given concerns about the climate, health, and environmental impacts of fossil fuel use, it is important to develop methods that would help reliably describe and differentiate between natural gas sources because they are associated with different GHG profiles. Governor Brown recently signed Assembly Bill 1496 (Thurmond, Chapter 604, Statutes of 2015), which requires developing the scientific knowledge base to support "carrying out a life-cycle greenhouse gas emission analysis of natural gas produced and imported into the state using the best available and cost-effective scientific and technical methods."[71]

Current life-cycle analyses assume the same methane emissions from each unit of natural gas consumed at the national and California scales. This assumption is problematic because different production basins have substantially different

[71] Assembly Bill 1496, Methane Emissions, filed with the Secretary of State October 8, 2015. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB1496

methane emissions profiles. For example, the following methane emissions rates have been reported for different basins as a percentage of natural gas extracted:[72] (Table 7)

**Table 7: Estimated Methane Emission Rates**

| Basin | Estimated Methane Emission Rates |
|---|---|
| Permian Basin, Texas | 1% to 2% |
| Unita/Piceance Basin, Utah/Colorado | 6% to 12% |
| San Juan Basin, New Mexico | Unknown but emissions are "visible" by satellites |
| Los Angeles, CA | Possibly > 10% |

Source: California Energy Commission

President Obama's goal of reducing methane emissions from the natural gas sector by 40 percent will not be enough to negate the detrimental climate impacts of natural gas. Knowing the real climate impact of natural gas consumed in California would also encourage natural gas producing regions to reduce emissions as much as possible.

In addition, the vast and complex network of pipelines transporting natural gas from the producing basins to the consumption regions makes it difficult to determine the exact basin of origin of natural gas consumed. Transmission companies are obligated to supply only the amount of natural gas contracted for delivery; they are not obligated to ensure that the gas comes from a given basin or to provide any documentation regarding basin of origin.

**The Research:** This project will include empirical research focused on analyzing the chemical and isotopic composition of natural gas samples from different basins. The data may determine the origin of natural gas arriving or consumed in California based on these chemical "fingerprints." Previous research has shown certain hydrocarbons can help determine the source of petroleum.73 Similar work has not yet been undertaken for natural gas. There is some evidence that measuring the distribution of carbon isotopes could be used to determine the

[72] Franco, G., S. Ziaja, Y. Hou, A. Bining. Methane Emissions Associated with Natural Gas Consumption in California. Draft CEC Staff paper.

[73] J. S. Brown, P. D. Boehm, A.D. Little, "The Use of Double Ratio Plots of Polynuclear Aromatic Hydrocarbon (PAH) Alkyl Homologues For Petroleum Source Identification," Oil Spill Conference, Cambridge, Massachusetts, 1993.

source of natural gas.74 This research will explore the feasibility of differentiating between samples based on double ratios of certain molecule or isotope concentrations and other methods. The evaluated experimental results will be compiled in a database so they can be used in assessments of the life-cycle GHG emissions of natural gas imported to California.

The proposed research will:

- Design and execute a field campaign to collect natural gas samples from different basins in the United States, Canada, and basins in California that could potentially serve the California market.
- Perform quantitative and qualitative sample analysis using chromatographic and spectroscopic methods or alternative techniques that are appropriate in this context.
- Establish an evaluation method to differentiate between natural gas samples originating from various basins.
- Compile a database with chemical fingerprint information for various natural gas samples.
- Test the method analyzing natural gas consumed in California and determine the basin or combination of natural gas basins from which the natural gas originate.
- Perform a preliminary estimation of GHG emission contributions from natural gas depending on the origination based on published studies on GHG emissions from different basins.

**The Benefits:**

- *Environmental Benefits*. This research will help determine the life-cycle greenhouse gas emissions from natural gas imported to California. Because the emissions from different basins vary, it is crucial to have a database that would distinguish between different natural gas mixtures based on chemical composition and isotope distribution. If this study is successful, more meaningful and practical life-cycle assessments would be possible.

## Natural Gas-Related Transportation

The Energy Commission's Transportation research area develops and advances state-of-the-art technologies and scientific approaches that reduce petroleum consumption, greenhouse gas emissions, and air pollutants from the state's transportation sector.

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[74] A. T. James, "Correlation of Natural Gas by Use of Carbon Isotopic Distribution Between Hydrocarbon Components," *AAPG Bulletin,* 1983, *67(7),* 1176-1191.

The proposed budged for Natural Gas-Related Transportation is $3.5 million (Table 8).

**Table 8: FY 2016-17 Proposed Natural Gas Research Budget Plan Summary – Natural Gas Related – Transportation**

| Program Area – Natural Gas Related-Transportation | Proposed Budget |
|---|---|
| **Proposed Research Initiatives:**<br>▪ Improving the Economics of Onboard Compressed Natural Gas Storage Research and Development<br>▪ Improving Heavy-Duty Natural Gas Engine Operating Efficiency Research | $3,500,000 |

Source: California Energy Commission

## Natural Gas-Related Transportation Program Goals

The goals of transportation-related research projects are to:

- Accelerate the commercial availability of natural gas vehicles.
- Improve energy efficiency of natural gas vehicles.
- Advance the clean and cost-effective production of renewable natural gas for transportation use.

As a transportation fuel, natural gas has the potential to:

- Offset more than 885 million gallons of gasoline and diesel per year by 2022.[75]
- Reduce annual GHG emissions by 4.4 million metric tons by 2022.[76]
- Save consumers in the state about $1.35 billion annually in fueling costs.[77]

## Policy Drivers

- Senate Bill 1250—Perata

[75] *State Alternative Fuels Plan* (AB 1007), Page 34, Refer to Table 4.

[76] *State Alternative Fuels Plan* (AB 1007), Page 34, Refer to Table 4.

[77] *Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report* (Pub #CEC600-2011-007-SD), Forecasted fuel price differential based on Figures B-3 and B-6, Pages B-5 and Figure B-10 , respectively. http://www.energy.ca.gov/2011publications/CEC-600-2011-007/CEC-600-2011-007-SD.pdf.

- State Alternative Fuels Plan- Assembly Bill 1007, (Pavley, Chapter 371, Statutes of 2005)
- *Integrated Energy Policy Report*
- Public Resources Code 25620

## Proposed Research Initiatives: Natural Gas-Related Transportation

### Project 1: Improving the Economics of Onboard Compressed Natural Gas Storage Research and Development

**The Issue:** On-board compressed natural gas (CNG) tanks used today for the medium- and heavy-duty natural gas vehicle market are made of high-strength steel and provide an economical storage method, but are heavy. Heavier onboard storage tanks result in decreased fuel efficiency and reduced vehicle range. The industry has developed lighter alternatives; however, the cost is a significant barrier for wide-scale commercial adoption. The natural gas vehicle market is pushing to use these lighter tanks, but the cost of these storage tanks represents more than half the cost of the vehicle technology. The Energy Commission's *Natural Gas Vehicle Research Roadmap* lists "Develop On-board CNG Storage with Improved Capacity and Design Features" as a research priority.[78] To improve the economic viability of natural gas vehicles, the cost of onboard CNG storage must decrease to increase fuel capacity improving vehicle range.

**The Research:** This research will improve the economics of lightweight gas storage by developing more cost-effective, fuel-efficient, and adaptable CNG storage options for medium- and heavy-duty natural gas vehicles.

**The Benefits:**

- *Energy Sector:* The current total natural gas demand for transportation is roughly 130 million gasoline gallon equivalents (GGEs) annually, and by 2020, demand is forecasted to exceed 200 million GGEs or 228 million therms.[79] Reduced cost for lighter cylinders will increase market adoption of natural gas vehicles.
- *Technology Potential:* This research targets medium - and heavy - duty natural gas vehicles as a primary application; however, technology

[78] http://www.energy.ca.gov/2008publications/CEC-500-2008-044/CEC-500-2008-044-F.PDF.

[79] Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report (Publication Number: CEC-600-2011-007-SD), Refer to Table 3-11 on Page 83.

advancements from this research can have multiple natural gas applications, including light‐duty vehicles and other natural gas storage.

- *Market Connection:* This research is in the early stages of development but will be able to advance quickly by using existing medium‐ and heavy‐duty-based natural gas fleets. The estimated market path for this technology is roughly five years, due to the advantages of building on existing storage technologies, with the potential for accelerated market penetration using additional government funding and collaboration. The benefits can also be applied to hydrogen fuel cell vehicles because these alternative vehicles share common technology for storing the compressed fuel.
- *Energy and Cost Savings:* This research is expected to reduce the cost to manufacture lighter storage cylinders, allowing natural gas vehicles to travel further on a single fill.
- *Environmental Benefits:* Lighter natural gas storage cylinders will reduce the vehicle weight and fuel need, increasing the overall vehicle efficiency and range, while reducing $NO_x$ emissions.

**Project 2: Improving Heavy-Duty Natural Gas Engine Operating Efficiency Research**

**The Issue:** Vehicle technology and engine development for natural gas vehicles have advanced substantially in recent years as consumer demand and regulatory requirements have changed. The medium- and heavy-duty market has created a demand for natural gas-fueled engines in various platforms. The spark-ignited stoichiometric natural gas engine technology with passive three-way catalyst is a more prevalent technology in the medium- to heavy-duty market and a suitable pathway to clean burning engines.

Continued efficiency, performance, and emission improvements are necessary for medium- and heavy-duty natural gas vehicles. These improvements will be driven by fuel economy standards and the increasing pressure to decrease $NO_x$ emissions to meet air quality requirements in California's air basins (potentially 90 percent reduction of current standards). Both objectives will likely require improved design strategies such as higher levels of exhaust gas recirculation, advanced ignition and fuel injection systems, and improved engine controls.

Reducing the efficiency gap between spark-ignited stoichiometric natural gas engines and diesel engines is increasingly important to increase greenhouse gas benefits. Fuel efficiency penalties can range between 10 percent to 20 percent depending on the application and duty cycle. Additional research is required to identify the technology opportunities to reduce and, ideally, eliminate this performance gap. Addressing this barrier for natural gas engine technologies will

improve the value proposition of natural gas vehicles and make them a more viable alternative fuel transportation option.

**The Research:** This research will develop and demonstrate new medium- and heavy-duty natural gas engine technologies with a particular emphasis on increasing efficiency and emission performance. New research will build on previous transportation research in advanced technologies such as cylinder deactivation, advanced ignition, and combustion methods.

**The Benefits:**

- *Energy Sector:* The current total natural gas demand for transportation is about 130 million gasoline gallon GGEs annually, and by 2020, demand is forecasted to exceed 200 million GGEs or 228 million therms.[80]
- *Technology Potential:* This research targets medium- and heavy-duty natural gas vehicles as a primary application; however, technology advancements from this research can be applied to multiple natural gas uses, including light-duty vehicles, stationary engines used for power generation, and combined heat and power systems.
- *Market Connection:* The early stages of development should be able to advance quickly by using existing medium - and heavy - duty based natural gas fleets. The estimated market path for this technology is about five years due to the advantages of building and advancing existing engines with accelerated market penetration, accompanied by additional government funding and collaboration.
- *Energy and Cost Savings:* This research is expected to accelerate distribution of more efficient natural gas vehicles in the medium - and heavy - duty market, exceeding current emission standards.
- *Environmental Benefits:* California will benefit from expanded natural gas vehicle operation, lower criteria pollutants, petroleum reduction, and reduced GHG emissions. Local communities will experience benefits from improved health as a result the significantly lower particulate matter tailpipe emissions from heavy - duty vehicles using natural gas vehicles instead of diesel - fueled vehicles.

[80] Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report (Publication Number: CEC-600-2011-007-SD), Refer to Table 3-11 on Page 83.

# LIST OF ACRONYMS

| Term | Definition |
|---|---|
| ARB | California Air Resources Board |
| BTU | British Thermal Unit |
| CCHP | Combined Cooling, Heat, and Power |
| CHP | Combined Heat and Power |
| CNG | Compressed Natural Gas |
| $CO_2$ | Carbon Dioxide |
| CPT | Cone Penetration Testing |
| CPUC | California Public Utilities Commission |
| DG | Distributed Generation |
| DLIS | Delta Stewardship Council's Delta Levee Investment Strategy |
| GGEs | Gasoline Gallon Equivalents |
| GHG | Greenhouse Gas |
| HVAC | Heating, Ventilation, and Air-Conditioning |
| IEPR | Integrated Energy Policy Reports |
| IOUs | Investor-Owned Utilities |
| MW | Megawatts |
| NAAQS | National Ambient Air Quality Standards |
| $NO_x$ | Nitrogen Oxides |
| ORC | Organic Rankine Cycle |
| ORNL | Oak Ridge National Laboratory |
| PG&E | Pacific Gas and Electric Co. |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| PRCI | Pipeline Research Council International |
| R&D | Energy Commission's Research and Development Division |
| SCADA | Supervisory Control and Data Acquisition |
| SoCal Gas | Southern California Gas Company |
| WHP | Waste Heat to Power |
| ZNE | Zero-Net-Energy |

# APPENDIX A:
# NATURAL GAS RESEARCH INITIATIVES FOR 2016-2017 PRESENTATION

Refer to: http://www.energy.ca.gov/research/notices/2016-01-14_workshop/presentations/FY2016-2017_Natural_Gas_Research_Initiatives_Presentation.pdf

# APPENDIX B: NATURAL GAS RESEARCH PROGRAM'S STAKEHOLDER GROUP WORKSHOP QUESTIONS AND COMMENTS

Refer to: http://www.energy.ca.gov/research/notices/2016-XX-XX_workshop/2016-01-XX_Questions_and_Answers.pdf