Energy Research and Development Division
DRAFT PROJECT REPORT

NATURAL GAS ENERGY EFFICIENCY IN BUILDINGS

Roadmap for Future Research

Prepared for: California Energy Commission
Prepared by: DNV KEMA Energy & Sustainability

MARCH 2014
CEC-500-2014-036-D

PREPARED BY:
Betty Seto
Jarred Metoyer
Rachel Schiff
Jon Taffel

DNV KEMA Energy & Sustainability
155 Grand Avenue
Oakland, CA 94612
Phone: 510-891-0446 | Fax: 510-891-0440
http://www.dnvkema.com

Contract Number: 500-11-029

Prepared for:

California Energy Commission

Jeff Doll
Contract Manager

Virginia Lew
Office Manager
Energy Efficiency Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

DISCLAIMER

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

ACKNOWLEDGEMENTS

The authors acknowledge the many people who provided input and guidance in the development of this roadmap, including the many individuals who participated in interviews and attended the workshops. We would also like to recognize Christina Liebner (Integral Group) for providing support and technical review of the early drafts of the roadmap.

In particular, the authors thank the staff of the following companies, organizations, and agencies for their feedback on the research initiatives and priorities of the draft roadmap: the Gas Technology Institute, Southern California Gas, McHugh Energy Consultants, Lawrence Berkeley National Laboratory, and Pacific Gas & Electric (PG&E) Food Service Technology Center in addition to the staff of the companies, organizations, and agencies listed in Appendix A who also provided valuable input.

Furthermore, thank you to Southern California Gas and PG&E Food Service Technology Center for generously hosting workshops to support the stakeholder engagement process. Finally, we would like to extend our appreciation to our project manager, Jeff Doll at the California Energy Commission for his support and enthusiasm throughout the project.

PREFACE

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

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

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

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

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Natural Gas Energy Efficiency in Buildings – Roadmap for Future Research is the final report for the Buildings Natural Gas Roadmap Development project (contract number 500-11-029, work authorization number KEMA-11-004) by DNV KEMA Energy & Sustainability. The information from this project contributes to Energy Research and Development Division's Natural Gas Research, Development and Demonstration Program.

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

ABSTRACT

The California Energy Commission manages funding for natural gas research, development, and demonstration projects. This project conducted research and facilitated a stakeholder driven process to develop a roadmap to identify priorities for building energy-efficiency research initiatives for inclusion in future budget plans. The goal of this research was to identify initiatives that will reduce natural gas consumption and improve air emissions in a cost-effective manner with the greatest benefits to natural gas ratepayers.

The research roadmap is based on a meta-study of natural gas usage, literature review, interviews with industry experts, and four state-wide workshops. This roadmap summarizes the status of current research, existing research gaps, and identifies 22 recommended research initiatives for achieving state energy policy goals. The research initiatives are grouped into the following four categories: cross-cutting research initiatives, water heating, space heating, and cooking.

Each research initiative is described in detail, including the potential for cost-effectiveness, equipment advances that are possible with additional research, data gaps, timeliness of outcomes, and how the research overcomes barriers to adoption. The roadmap prioritizes the research initiatives into near-, mid- and long-term actions based on appropriateness of California Energy Commission support, efforts by other agencies and industry actors, likelihood of technical and market success, and commercialization opportunity.

Recommendations for near-term priorities include developing baseline data for natural gas use characteristics related to water heating, as well as whole building-based research on zero net energy and "smart buildings." Near-term priorities also include developing technologies for reducing air emissions while increasing energy efficiency, overcoming barriers for natural gas heat pumps and condensing technology for water and space heating, researching ways to reduce standby energy and idle rates, and developing economy-grade ENERGY STAR® commercial cooking appliances. Some of this research has longer time horizons to demonstrate cost-effective results and are prioritized to help meet state energy policy goals for 2020 and beyond. Promising technologies that are close to commercialization, or need help bringing down costs of existing commercialized products are also prioritized.

Keywords: Natural gas, energy efficiency, residential, commercial, buildings, space heating, water heating, food service, commercial cooking, zero net energy buildings, heat pumps, hot water distribution

Please use the following citation for this report:

Seto, Betty; Jarred Metoyer; Rachel Schiff, Jon Taffel. (DNV KEMA Energy & Sustainability). 2013. ***Natural Gas Energy Efficiency in Buildings.*** California Energy Commission. Publication number: CEC-500-2014-036-D.

TABLE OF CONTENTS

Acknowledgements ..... **ii**

PREFACE ..... **iii**

ABSTRACT ..... **iv**

TABLE OF CONTENTS ..... **v**

EXECUTIVE SUMMARY **1**

Introduction 1

Main Uses of Natural Gas 1

Research Initiatives for Natural Gas Energy Efficiency 2

Summary of Recommended Research Initiatives 3

Prioritization of Research Initiatives 5

CHAPTER 1: Introduction **9**

Background 9

Statewide Context 10

Overview of Methodology for Roadmap Development 12

Report Structure 13

CHAPTER 2: Baseline Assessment of Main Uses of Natural Gas **14**

Natural Gas Consumption in California from 1991-2010 14

Residential Building Sector 17

Commercial Building Sector 20

CHAPTER 3: Development of Recommended Research Initiatives **22**

Approach to Developing Recommendations 22

Summary of Recommended Research Initiatives 24

CHAPTER 4: Cross-cutting and Other Research Initiatives **28**

Research Initiative O1: Focus on Technologies for Reducing Air Emissions While Increasing Energy Efficiency 28

Research Initiative O2. Incorporate a Systems Perspective and Integrate Technologies to Achieve Zero Net-Energy Buildings That Include Natural Gas for Building Cooling 31

Research Initiative O3. Better Understand Technical and Economic Potential for Heat Recovery Across Multiple End Uses 35

Research Initiative O4. "Smart" Buildings, Controls, and Metering of Natural Gas Usage in Buildings, Including "Smart" Equipment and Appliances 39

CHAPTER 5: Water Heating Research Initiatives 45

Research Initiative W1. Collect and Characterize Energy Use Related to Water Heating Across Different Building Types, Designs, and Vintages 45

Research Initiative W2. Characterize Current Hot Water Distribution Systems to Support Higher-Efficiency Retrofit and Design 50

Research Initiative W3. Develop and Demonstrate Cost Effective High-Efficiency Water Heaters, such as Natural Gas Heat Pump Technology 54

Research Initiative W4. Develop and Demonstrate Low Cost Condensing Water Heater Technology 57

Research Initiative W5. Develop And Demonstrate Cost-Effective Waste Heat Recovery for Water Heating 60

Research Initiative W6. Develop Low-Cost Solar Water Heating Systems using New Materials and Improved System Design 62

CHAPTER 6: Space Heating Research Initiatives 65

Research Initiative S1. Conduct Research Related to Quality Installation Issues for HVAC Systems 65

Research Initiative S2. Develop and Demonstrate More Efficient Air Distribution Design 68

Research Initiative S3. Support Research to Reduce Ventilation Requirements 71

Research Initiative S4. Conduct Research Related to Controls for Both Individual Equipment, As Well As Whole Building 73

Research Initiative S5. Conduct Research for Solar Thermal Space Heating and Cooling 75

Research Initiative S6. Develop and Demonstrate Cost-effective Under-floor and Other Hydronic Heating Options 80

Research Initiative S7. Develop and Demonstrate Cost-effective and Energy Efficient, Condensing Packaged Rooftop Heating Units for Commercial Applications 82

CHAPTER 7: Cooking Research Initiatives **85**

Research Initiative C1. Focus on Developing Economy-Grade ENERGY STAR Cooking Appliances 86

Research Initiative C2. Focus on Reducing Standby Energy and Idle Rates, Including Use of Insulation, Controls, Temperature Setback, Lids, and Multistage Burners 88

Research Initiative C3. Develop and Demonstrate Select Commercial Food Service Appliance Types that are not Rated by ENERGY STAR 91

Research Initiative C4. Support Research Related to "Smart" or "Intelligent" Kitchens 95

Research Initiative C5. Support Research Focused on Cost-effective and Energy Efficient Residential Cooking 97

CHAPTER 8: Recommendations for Near-Term Priorities **100**

Near-term – Next Two Funding Cycles (2014-15, 2015-16) 100

Mid-term – Funding Cycles 2016-17 and 2017-18 101

Long-term – Funding Cycles 2017-18 and Beyond 102

GLOSSARY **103**

REFERENCES **107**

APPENDIX A: List of Organizations Interviewed **1**

APPENDIX B: In-Depth Interview Guide **1**

APPENDIX C: Summary of Interview Results **1**

APPENDIX D: Summary of Workshop Results **1**

Summary of Input from Attendees 1

LIST OF FIGURES

Figure 1: Historic Natural Gas Consumption in California Buildings 15
Figure 2: Natural Gas Consumption by Sector by End Use 16
Figure 3: California Residential Natural Gas Consumption by End Use and Building Type 17
Figure 4: California Residential Natural Gas Consumption per Dwelling Unit by End Use and Building Type 18
Figure 5: California Total Commercial Natural Gas Consumption 20
Figure 6: California Commercial Natural Gas Consumption per Square Foot 21
Figure 7: Example of Heat Source that Only Occasionally Matches with Heat Load (No Solar Thermal Storage) 77

Figure 8: Example of Thermal Storage System Potential 78
Figure 9: Prioritization of Research Initiatives by Energy Commission Funding Cycles 100

LIST OF TABLES

Table 1: Summary of Long Term Energy Efficiency Strategic Plan Goals (Natural Gas Related) 11
Table 2: Estimated Natural Gas Consumption by End Use (Billion Therms/Year) 16
Table 3: Presence of Natural Gas Appliances in California Homes 18
Table 4: Type of Primary Natural Gas Space Heating Appliance in California Homes 19
Table 5: Type of Primary Natural Gas Water Heating (WH) Appliance in California Homes 19
Table 6: Sources for Baseline Investigation of Past and Current Research Initiatives 22
Table 7: Distribution of Organization Types Represented 23
Table 8: Summary of Annual Site Energy for Three Modeled Office Buildings (Climate Zone 3) 34
Table 9: Space Heating Related Interview Responses 1
Table 10: Water Heating Related Interview Responses 3
Table 11: Cooking Related Interview Responses 6
Table 12: Other Research Recommended 7
Table 13: Cross-Cutting Research Related Attendee Input 2
Table 14: Water Heating Related Input 4
Table 15: Commercial Space Heating and Cooling Input 9
Table 16: Residential Space Heating and Cooling Notes 11
Table 17: Cooking Related Input 12

EXECUTIVE SUMMARY

Introduction

Combined, California's residential and commercial building sectors consume approximately one-third of the total state natural gas usage.[1] Although natural gas burns relatively clean compared with other fossil fuels, California will not meet its environmental and energy goals without significant improvements in natural gas energy efficiency and technology innovation. In the past decade, the state adopted several important new laws and policy recommendations that include aggressive goals for energy efficiency and environmental protection and these all impact natural gas consumption and use.

As new statewide energy policies and goals are adopted and emerging technologies are developed, roadmaps are useful tools to guide future spending on research. Roadmaps are one mechanism that help ensure that energy ratepayer funded research efforts prioritize energy-efficiency technologies that provide the greatest benefit to ratepayers. Roadmaps help to identify the status of current technology, research needs, and the technical and economic potential of different technologies.

The goals and objectives of the California Energy Commission's Buildings Natural Gas Roadmap Development project are identifying research and funding priorities based on the current status of technology and utilizing a stakeholder-driven process to develop and review the roadmap.

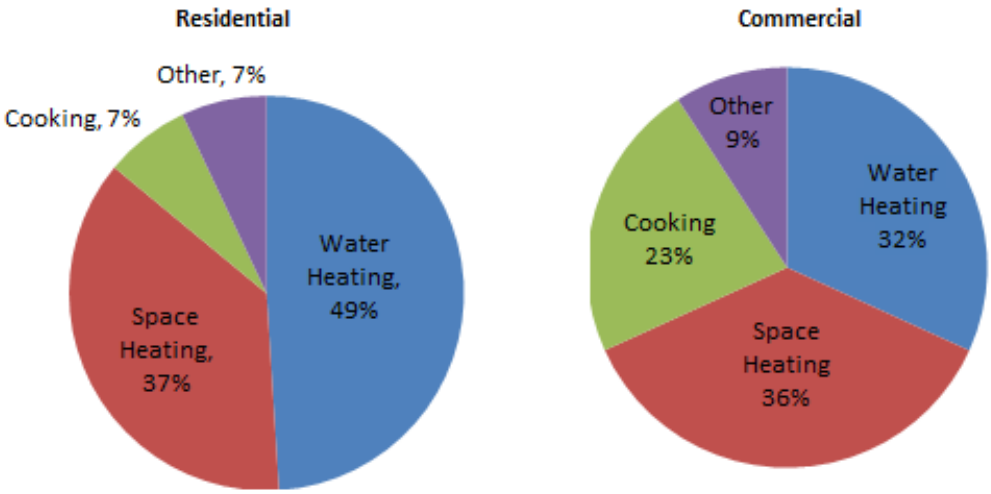
Main Uses of Natural Gas

This section provides a high level overview of natural gas consumption in residential and commercial buildings.

Figure ES1 and **Table ES1** displays the proportions of energy consumption for each end use in the residential and commercial sectors based on data from the California Energy Commission's 2009 Residential Appliance Saturation Study (RASS) and 2006 California Commercial End Use Survey, respectively.

[1] The remaining sectors are industrial (33%), electricity generation (29%) and vehicle fuel (1%). These proportions exclude lease fuel, plant fuel and pipeline and distribution use. http://www.eia.gov/dnav/ng/NG_CONS_SUM_DCU_SCA_A.htm

Figure ES1: Natural Gas Consumption by Sector by End Use



Source: Residential Appliance Saturation Survey (2009). Commercial End Use Survey (2006)

Table ES1: Estimated Natural Gas Consumption by End Use (billion therms/year)

End Use	Residential	Commercial
Water Heating	2.50	0.80
Space Heating	1.89	0.90
Cooking	0.36	0.58
Other	0.36	0.23
TOTAL	**5.10**	**2.50**

Source: Residential Appliance Saturation Survey (2009). Commercial End Use Survey (2006)

The California Energy Commission estimates that the residential and commercial building sectors consume approximately 5.1 therms and 2.5 billion therms a year, respectively. Residential natural gas consumption is driven mostly by space and water heating, followed distantly by cooking and other uses. The other residential uses include miscellaneous uses. Such as clothes dryers and pools. Similarly, commercial natural gas consumption is primarily from space heating and water heating, with cooking being a significant end use as well. Other end uses in commercial buildings include process loads such as commercial laundry, heated pools, and other loads such as paint dryers in auto shops.

Research Initiatives for Natural Gas Energy Efficiency

The roadmap development project focused on understanding the status of existing research and engaging industry experts and other stakeholders in the development of the recommended research initiatives. Characterizing the natural gas consumption of commercial and residential building sectors was an important first step to setting priorities for research.

The project began with a research and literature review to determine exisiting research and baseline gas consumption. Understanding the current stsus helped in developing the forward-looking strategic roadmap on natural gas energy efficiency in buildings. Subsequent project activities focused on stakeholder engagement. For the first activity in engaging stakeholders, the project team interviewed industry experts to identify technical research opportunities that will lead to new technologies, strategies, and models, and potentially ultimately inform building and appliance standards. For the second activity, the project team hosted four public workshops in both Northern and Southern California. This report presents the final recommended research initiatives based on roadmap development tasks and stakeholder input.

In particular, the stakeholder input process identified cross-cutting initiatives for several natural gas end uses that may have the largest impact. Additional priority research initiatives are presented in order of the size of the baseline natural gas end use.[2]

Summary of Recommended Research Initiatives

The recommended research initiatives are organized into the following categories:

- Cross-cutting and other research initiatives
- Water heating research initiatives
- Space heating research initiatives
- Cooking research initiatives

Within each category, specific research initiatives are described in more detail. In each of the following chapters, specific research initiatives are further presented in order of urgency based on feedback from industry experts and stakeholders. Recommendations that were provided by multiple stakeholders across the projects tasks are presented first. Research initiatives that were mentioned by fewer stakeholders or perceived to have less energy savings impact are listed later.

The initiatives include research and development of cost-effective, energy efficiency technologies in areas that the private sector is not likely to invest. There are also initiatives requiring demonstration of commercially available technologies that are not currently cost effective. Partnerships with laboratories and institutes are required to advance fundamental research. Partnerships with utility emerging technology and pilot rebate programs may be best suited where demonstration of available technologies is needed more than technology development.

Cross-cutting Research Initiatives

In order to achieve significant energy efficiency improvements, these cross-cutting research initiatives focused on the whole building, across all systems and multiple natural gas end uses

[2] Energy generation projects, such as Micro-combined heat and power (CHP) are not included in this roadmap. These areas are primarily under the purview of the Energy Generation Research Office at the Energy Commission.

For many technologies, such as residential furnaces, the individual equipment efficiencies are quite high and the remaining opportunities for significant reductions in natural gas use are related to reducing distribution losses, integrating equipment using sensors and controls, improving controls overall, and developing systems that recover waste heat from different system components.

The following research initiatives are identified:

- **Research Initiative O1**: Focus on technologies for reducing air emissions while increasing energy efficiency
- **Research Initiative O2**: Incorporate a systems perspective and integrate technologies to achieve zero net-energy buildings that include natural gas for building cooling.
- **Research Initiative O3**: Better understand technical and economic potential for heat recovery across multiple end uses
- **Research Initiative O4**: "Smart" buildings, controls and metering of natural gas usage in buildings, including smart equipment and appliances

Water Heating Research Initiatives

The most recently published California building sector market characterization studies show water heating exceeding space heating as the largest natural gas end use in buildings when residential and commercial sector usage is combined. Approximately 43% of all natural gas use is estimated to be consumed for water heating in both the residential and commercial building sectors combined. As other components of building systems (such as envelope and mechanical systems) become more efficient, water heating remains an area where significant savings are needed.

The following research initiatives are identified:

- **Research Initiative W1:** Collect and characterize energy use related to water heating across different building types, designs, and vintages
- **Research Initiative W2:** Characterize current hot water distribution systems to support higher efficiency retrofit and design
- **Research Initiative W3:** Develop and demonstrate cost effective high-efficiency water heaters , such as natural gas heat pump technology
- **Research Initiative W4:** Develop low cost condensing water heater technology
- **Research Initiative W5:** Develop and demonstrate cost-effective waste heat recovery for water heating
- **Research Initiative W6:** Develop low-cost, solar water heating systems with new materials and improved system design

Space Heating Research Initiatives

Space heating is the second most significant natural gas end-use overall after water heating when aggregated across both residential and commercial buildings. The research topics mentioned by industry experts ranged from the heating equipment technology itself to the need for optimal fresh outside air, reheating and building envelope systems. Since space heating equipment is already available at high efficiencies, the recommended research initiatives focus

on improving the overall system cost effectiveness and installation practices. However, high-efficiency furnaces remain expensive, and are not widely installed in commercial spaces. Other important research issues were related to sizing equipment appropriately (not over-sizing), installing heating units properly, sizing and placement of ductwork, and reducing duct leakage.

The following research initiatives are identified:

- **Research Initiative S1**: Conduct research related to quality installation issues for HVAC systems
- **Research Initiative S2**: Develop and demonstrate cost effective and energy efficient, air-distribution design
- **Research Initiative S3**: Conduct research to reduce ventilation requirements
- **Research Initiative S4**: Conduct research related to controls for both individual equipment, as well as whole building
- **Research Initiative S5**: Evaluate potential cost-effectiveness of solar thermal space heating and cooling
- **Research Initiative S6**: Develop and demonstrate cost-effective under-floor and other hydronic heating options
- **Research Initiative S7**: Develop and demonstrate cost-effective and energy efficient, condensing packaged rooftop heating units for commercial applications

Cooking Research Initiatives

The main uses of natural gas across different building types shows restaurants consume the largest amount of natural gas in California, with a significant portion related to commercial cooking. Furthermore, efficiencies in cooking technologies can result in reduced cooling loads. Within the residential sector, cooking represents the third largest end use but only 7% of total natural gas consumption, so the initiatives focus on commercial cooking.

The following research initiatives are identified:

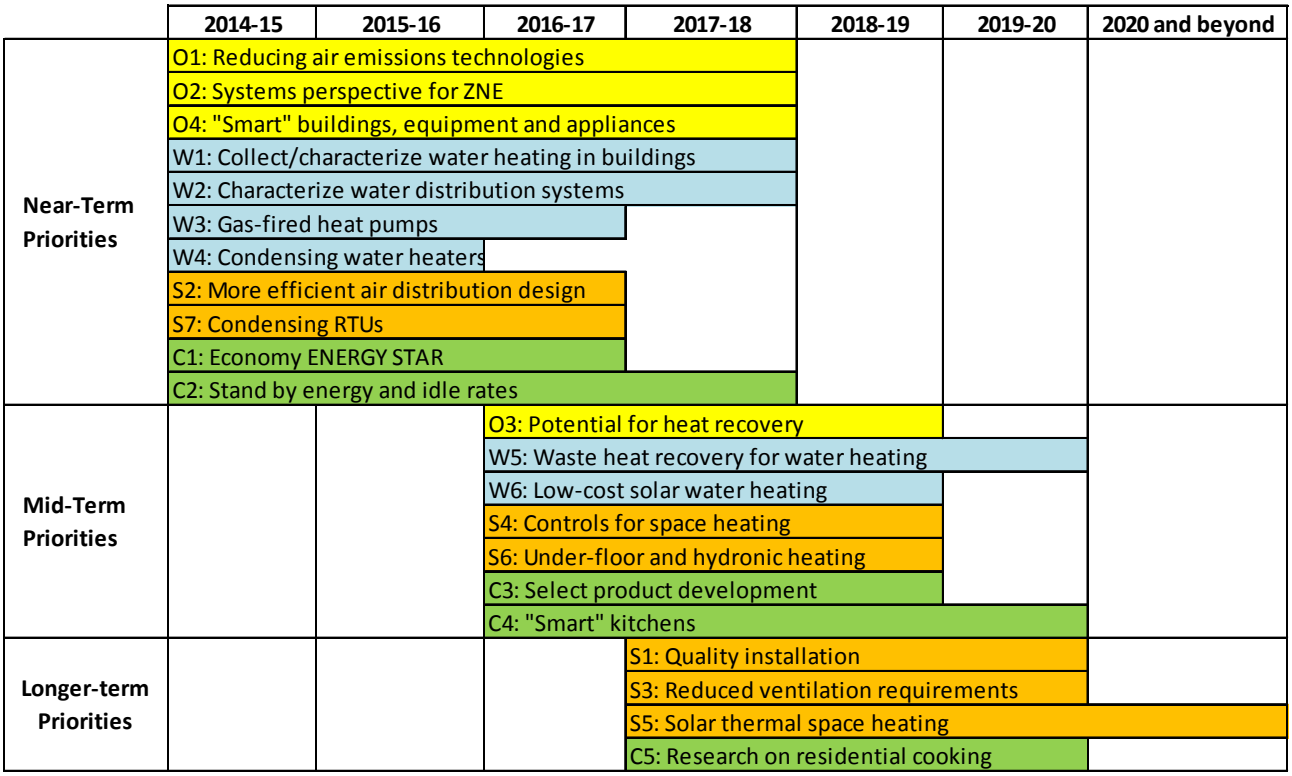
- **Research Initiative C1:** Focus on developing economy-grade ENERGY STAR commercialcooking appliances
- **Research Initiative C2:** Focus on reducing standby energy and idle rates, including use of insulation, controls, temperature setback, lids, and multistage burners for commercial applications
- **Research Initiative C3:** Develop and demonstrate select commercial food service appliance types that are not rated by ENERGY STAR
- **Research Initiative C4:** Support research related to “smart” or “intelligent” commercial kitchens
- **Research Initiative C5:** Support research focused on cost-effective and energy efficient residential cooking

Prioritization of Research Initiatives

The research initiatives are prioritized based on appropriateness of Energy Commission support, efforts by other agencies and industry actors, likelihood of technical and market

success, and commercialization opportunities. **Figure ES2** provides an overview of the near-term, mid-term and longer-term recommended research initiatives for each funding cycle.

Figure ES2. Prioritization of Research Initiatives by Energy Commission Funding Cycles



Source: DNV KEMA

Near-term – Next two funding cycles (2014-15, 2015-16)

Rationale: Near-term priorities are focused on research initiatives that provide baseline data for understanding energy use characteristics and whole building perspectives to inform future efforts related to energy-efficient technologies and opportunities. Some of this research has longer time horizons to achieve useful results and are prioritized to help meet state energy policy goals for 2020. Also prioritized as near term are promising technologies that are approaching commercialization and technologies that will help bring down costs of existing commercialized products. In addition, the Energy Commission should leverage efoort of theCalifornia Air Resources Board and local air districts that continue to lead the way on emissions standards.

Mid-term – Funding cycles 2016-17 and 2017-18

Rationale: Several of the recommended research initiatives have significant research support from other state and federal agencies, as well as trade associations. These research initiatives remain important priorities for the California Energy Commission to support in order to leverage complementary efforts and partnership opportunities. California Energy Commission should stay abreast of these developments and leverage key results to inform its future research priorities.

Long-term – Funding cycles 2017-18 and beyond

Rationale: Long-term priorities are related to research initiatives that may have smaller energy savings potential based on California's climate zones (e.g., waste heat recovery for water heating, drain heat recovery, and solar thermal space heating). Several identified long-term priorities have already made significant headway due to the efforts of other state agencies such asCalifornia Pubic Utilities Commission through their energy-efficiency programs and evaluations. These research initiatives remain important and the California Energy Commission should continue to support other agency efforts in these areas.

CHAPTER 1: Introduction

Each year, the California Energy Commission's (Energy Commission's) Energy Research and Development Division develops and submits a budget plan to the California Public Utilities Commission (CPUC) to identify the research initiatives to be funded in the succeeding fiscal year.

As new statewide energy policies and goals are adopted and emerging technologies are developed, roadmaps are useful for guiding future spending on technical and market research. Natural gas roadmaps are a planning mechanism and communication tool that establishes a clear link between the priorities of natural gas research and key California energy policy goals.

Roadmaps are one mechanism that help ensure that energy ratepayer-funded research efforts prioritize energy-efficiency technologies that provide the greatest benefit to ratepayers. Roadmaps help to identify the status of current technology, research needs, and the technical and economic potential of different technologies.

This natural gas roadmap for building energy-efficiency research identifies initiatives that can be included in future budget plans. The roadmap is intended to help guide and identify energy-efficiency research that provides the greatest benefit to stakeholders and ratepayers. The challenge is determining which areas and technologies require research to overcome technological, economic, or other barriers, and determining the estimated benefits to ratepayers when compared to existing technologies. This roadmap also identifies the status of current technology, new research needs, and an assessment of energy savings associated with various technologies.

Background

California households and businesses consume more than seven billion therms of natural gas annually.[3] Although natural gas burns relatively clean compared to other fossil fuels, California will not meet its environmental and energy goals without significant improvements in natural gas energy-efficiency and technology innovation.

In the past two decades, the state adopted several important new laws and policy recommendations that include aggressive goals for energy efficiency and environmental protection. In support of state energy goals, legislation was enacted in 2000 with Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000), thatrequired the CPUC to impose a surcharge on all natural gas consumed in California to fund various energy-efficiency programs as well as

[3] California Energy Commission. *The Natural Gas Research, Development and Demonstration Program. Proposed Program Plan and Funding Request for Fiscal Year 2012-13*. CEC-500-2012-084. March 2012. http://www.energy.ca.gov/2012publications/CEC-500-2012-084/CEC-500-2012-084.pdf

public interest research and development to benefit natural gas ratepayers. Assembly Bill 1002 also required the CPUC to designate an entity to administer the research component of AB 1002.

In 2004, the CPUC issued Decision 04-08-010, which designated the Energy Commission as the administrator of the research funds. The Energy Commission manages these funds through its Public Interest Energy Research (PIER) Natural Gas Program. For instance, in fiscal year 2012-13, the Energy Commission administered $24 million for natural gas research, development, and demonstration projects through the PIER Natural Gas Program.

Statewide Context

There are many guiding environmental and energy policy goals to direct natural gas energy-efficiency research needs for California. Assembly Bill 32, California Global Warming Solutions Act of 2006 (AB 32), sets an economy-wide cap on California greenhouse gas emissions at 1990 levels by no later than 2020. This aggressive goal represents nearly a 30% reduction from projected business-as-usual levels in 2020. Meeting the AB 32 goals requires unprecedented levels of energy-efficiency investment across all sectors and fuel types.[4]

Several other laws and policy documents support AB 32 by articulating specific goals for different programs and buildings sectors. Assembly Bill 2021 sets an energy-efficiency target of reducing forecasted consumption by 10% and requires the Energy Commission, in collaboration with the CPUC and the publicly owned utilities, to set statewide energy-efficiency targets for 2017.

The CPUC has also created a framework to make energy efficiency an integral part of our economy through its Energy Efficiency Strategic Plan (Plan).[5] The Plan sets forth three relevant programmatic goals ("Big Bold Energy Efficiency Strategies") related to natural gas efficiency:

1. All new residential construction in California will be zero net energy (ZNE) by 2020;
2. All new commercial construction in California will be zero net energy by 2030;
3. Heating, Ventilation, and Air Conditioning (HVAC) will be transformed to ensure that its energy performance is optimal for California's climate; and AB 32 Global Warming Solutions Act 1990 levels by 2020.

In addition to these "Big Bold Energy Efficiency Strategies," the Plan also establishes specific goals related to different building sectors and end uses. The ZNE goals pose a particular challenge for natural gas because of the lack of cost-effective renewable energy options to displace natural gas as a fuel. Therefore, natural gas efficiency in buildings is a particularly important strategy for achieving the ZNE goals. **Table 1** summarizes the January 2011 update to the Plan's goals and associated performance indicators that are most relevant to natural gas

[4] http://www.energy.ca.gov/2007_energypolicy/documents/2007-12-05_meeting/2007-12-05_EXECUTIVE_SUMMARY.PDF

[5] Include footnote to the CPUC website for the EE strategic plan.

efficiency. The Plan includes many other goals related to electricity consumption, as well as code enforcement and general education and outreach.

Table 1: Summary of Long Term Energy Efficiency Strategic Plan Goals (Natural Gas Related)

Strategic Plan Goal	Performance Indicator
Residential Sector	
New construction will reach ZNE performance (including clean, onsite distributed generation) for all new single and multifamily homes by 2020.	By 2011, 50% of new homes will surpass 2005 Title 24 standards by 35% and 10% will surpass 2005 Title 24 standards by 55%. By 2015, 90% of new homes will surpass 2005 Title 24 standards by 35%. By 2020, all new homes are ZNE.
Home buyers, owners, and renovators will implement a whole house approach to energy consumption that will guide their purchase and use of existing and new homes, home equipment (e.g., HVAC systems), household appliances, lighting, and "plug load" amenities.	Energy consumption in existing homes will be reduced by 20% by 2015 and 40% by 2020 through universal demand for highly efficient homes and products.
Commercial Sector	
New construction will increasingly embrace ZNE performance (including clean, distributed generation), reaching 100% of new starts in 2030.	An increasing percentage of the 50 million-120 million square feet per year of new commercial construction will be progressively more efficient and all new construction will be ZNE by 2030.
50% of existing buildings will be equivalent to zero net energy buildings by 2030 through achievement of deep levels of energy efficiency and clean distributed generation.	250 million square feet (1/20th of existing space) per year through 2030 reach deep levels of energy-efficiency improvements and clean, distributed generation through whole building approaches.
Heating, Ventilation, and Cooling	
Whole building design and construction practices fully integrate building performance objectives to reduce cooling and heating loads.	Integrated design and construction practices are standard practice by 2020.
New climate-appropriate HVAC technologies (equipment and controls, including diagnostics) are developed with accelerated market penetration.	At least 15% of equipment shipments are optimized for California's climate by 2015 and 70% by 2020.

Source: California Energy Efficiency Strategic Plan (January 2011 Update)

In order to support California's energy policy goals, Assembly Bill 758 ([AB 758] Skinner; Statutes of 2009) Comprehensive Energy Efficiency Program for Existing Buildings of 2009, requires the Energy Commission, in collaboration with the CPUC and stakeholders, to develop a comprehensive program to achieve greater efficiency in existing residential and nonresidential buildings. AB 758 directs the Energy Commission to consider effective ways to report building energy-assessment results to building owners, prioritize annual energy savings opportunities, and estimate customer utility bill savings that could result from the improvements. At the

writing of this report, Phase 1 is underway to finalize the Draft Action that outlines a number of voluntary and mandatory approaches to increasing energy efficiency statewide for both electricity and natural gas use in existing buildings.

Senate Bill 73 ([SB 73] Chaptered by Secretary of State. Chapter 29; Statues of 2013) further supports California's energy reduction goals by focusing on economically disadvantaged school districts to award both project funds on a competitive basis and technical assistance to all applicants[6]. The bill requires the Office of Public School Construction to establish a school district assistance program to distribute grants on a competitive basis for energy-efficiency upgrade projects. The program supports school facility projects that reduce energy consumption through improvements such as ventilation, lighting and controls, air infiltration, water use, fenestration, HVAC, electrical systems, and insulation. In addition with the passage of Proposition 39, schools will be receiving $2.75 billion over five years for energy-efficiency projects with some of these monies going into a revolving loan program administered by the Energy Commission.

Other environmental goals directly relevant to natural gas combustion are the reduction in emissions of oxides of nitrogen (NOx). California's emission standards for stationary sources are set by local air districts under the California Air Resources Board (ARB). In particular, the South Coast Air Quality Management District established a Regional Clean Air Incentives Market (RECLAIM) to set an emissions cap for NOx (and sulfur oxides) for the largest emitters in the South Coast Air Basin encompassing Los Angeles, Orange and Riverside Counties, and part of San Bernardino County. Reducing NOx may in some cases increase natural gas consumption which would raise levels of other greenhouse gas emmissions. Currently, the reduction of NOx emmissions and reduction of other greenhouse gas emissions are separate policy goals.

Overview of Methodology for Roadmap Development

The goals and objectives of the California Energy Commission Buildings Natural Gas Roadmap Development project were to identify research and funding priorities based on the current status of technology. This roadmap was developed based on:

1. Literature review
2. Interviews with subject matter experts
3. Public workshop input

The project utilized an expert- and stakeholder-driven process to develop and review the roadmap. Technical experts were particularly suited to identify the greatest research needs.

[6] California Energy Commission. Prop 39 Funding Allocation for Energy Efficiency Projects http://www.energy.ca.gov/efficiency/proposition39/documents/Prop_39_Funding_Allocation_for_Energy_Projects.pdf

Report Structure

This report is organized as follows:

- Chapter 2. Baseline Assessment of Main Uses of Natural Gas, provides a summary of where and how much natural gas is used in residential and commercial buildings in California
- Chapter 3. Development of Recommended Research Initiatives, describes project tasks in more detail and how the research initiatives were developed
- Chapter 4. Cross-cutting and Other Research Initiatives, focuses on research needed across multiple end uses
- Chapter 5. Water Heating Research Initiatives, focuses on research needed related to water heating
- Chapter 6: Space Heating Research Initiatives, focuses on research needed related to space heating
- Chapter 7: Cooking Research Initiatives, focuses on research needed related to cooking
- Chapter 8: Recommendations for Near-Term Priorities, identifies priority research tasks and next steps
- Chapter 9: Conclusion, provides final remarks

CHAPTER 2:
Baseline Assessment of Main Uses of Natural Gas

Combined, California's residential and commercial building sectors consume approximately one-third of the total state natural gas usage.[7] In this section, natural gas consumption trends in buildings are examined at both a high level and in more detail within the residential and commercial building sectors. Based on available data, the residential review includes the market saturations of different natural gas appliance and technology types. Commercial data includes consumption by building type, although the data is primarily available at the national level rather than California specific. With the upcoming release of California's Commercial Saturation Survey (CSS) in 2014, additional data will be available related to the saturation of different natural gas appliances and technologies in the California commercial building sector. The section below provides an overview of the data currently available related to natural gas use characteristics and equipment saturations for the California residential and commercial building sectors. Where gaps in data exist, these are noted. Note that natural gas is often as abbreviated to "gas," and any gaps in available data are cited.

Natural Gas Consumption in California from 1991-2010

Residential and commercial building natural gas consumption has remained relatively flat for the past two decades despite increases in population, jobs, and gross state product (GSP).[8] During this period, Title 24 standards for new construction were increasing, as were investments in statewide utility energy-efficiency programs. Based on this historic trend, California is on track to meet greenhouse gas emissions and energy-efficiency goals from a natural gas perspective. However, most of the low-hanging fruit related to energy-efficiency improvements has been picked, and maintaining this flat natural gas consumption trend over the next decade is likely to be more challenging. Research on new technologies and reducing costs using proven technologies is necessary to help reduce natural gas consumption despite the forecasted increases in population and economic growth.

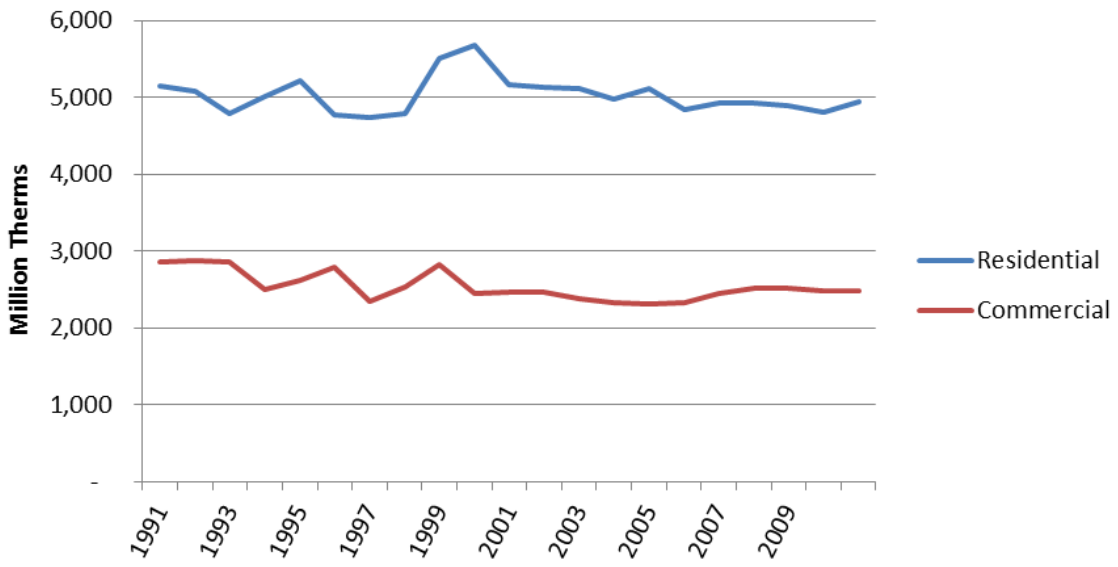
As shown in **Figure 1**, residential gas consumption has consistently been about twice that of commercial consumption from 1991 to 2010. With the exception of the slight and isolated jump in consumption in 1999, no significant or sudden changes were noted. In 2010, the residential and commercial building sectors were estimated to consume 4,949 million therms and 2,480 million therms of natural gas, respectively.

---

[7] The remaining sectors are industrial (33%), electricity generation (29%), and vehicle fuel (1%). These proportions exclude lease fuel, plant fuel, and pipeline and distribution use. http://www.eia.gov/dnav/ng/NG_CONS_SUM_DCU_SCA_A.htm

[8] GSP is a measurement of the economic output of a state or province. It is the sum of all value added by industries within the state and serves as a counterpart to the gross domestic product (GDP).

Figure 1: Historic Natural Gas Consumption in California Buildings[9]



Source: U.S. Energy Information Administration. State Energy Data System (SEDS). June 2012

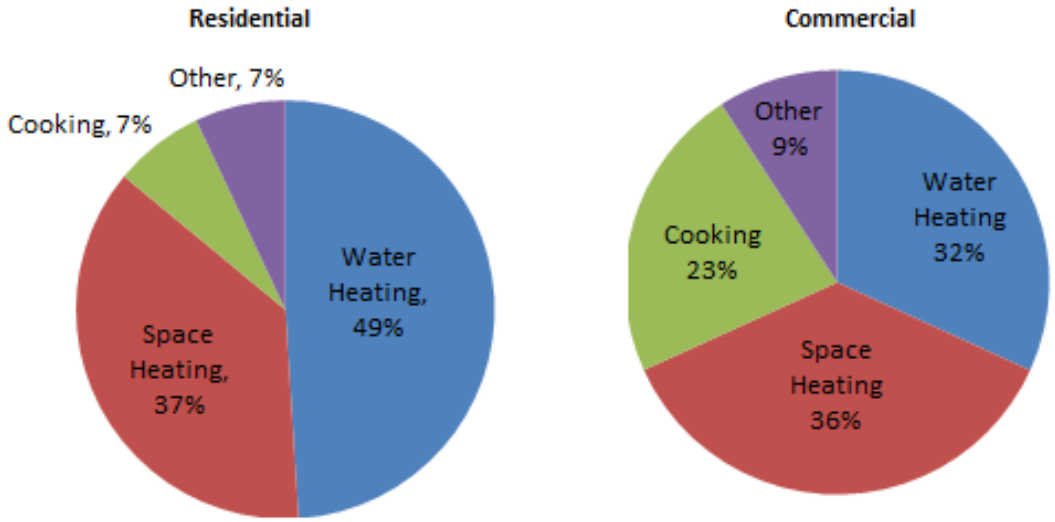
Figure 2 and **Table 2** below display the proportions of energy consumption for each end use in the residential and commercial sectors based on the Energy Commission's 2009 Residential Appliance Saturation Study (RASS)[10] and the California Commercial End Use Survey (CEUS)[11], respectively.

[9] U.S. Energy Information Administration. State Energy Data System (SEDS). June 2012. http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=CA#CompleteDataFile

[10] California Energy Commission. 2009 Residential Appliance Saturation Study (RASS) Executive Summary..CEC-200-2010-004-ES. October 2010, 9. http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF

[11] California Energy Commission. Commercial End Use Saturation Survey (CEUS). CEC-400-2006-005. March 2006. http://capabilities.itron.com/ceusweb/

Figure 2: Natural Gas Consumption by Sector by End Use



Source: Residential Appliance Saturation Survey (2009). Commercial End Use Survey (2006)

Table 2: Estimated Natural Gas Consumption by End Use (Billion Therms/Year)

End Use	Residential	Commercial
Water Heating	2.50	0.80
Space Heating	1.89	0.90
Cooking	0.36	0.58
Other	0.36	0.23
TOTAL	**5.10**	**2.50**

Source: Residential Appliance Saturation Survey (2009). Commercial End Use Survey (2006)

The Energy Commission estimates that the residential and commercial building sectors consume approximately 5.1 billion therms and 2.5 billion therms a year, respectively.[12] Residential natural gas consumption is driven mostly by space and water heating, followed distantly by cooking. Of the remaining residential consumption, approximately 3% is attributable to clothes dryers and 2% is related to pools and other miscellaneous uses. Similarly, commercial gas consumption is primarily from space heating and water heating, with cooking being a significant end use as well. The remaining consumption in commercial buildings includes commercial laundry and other miscellaneous uses.

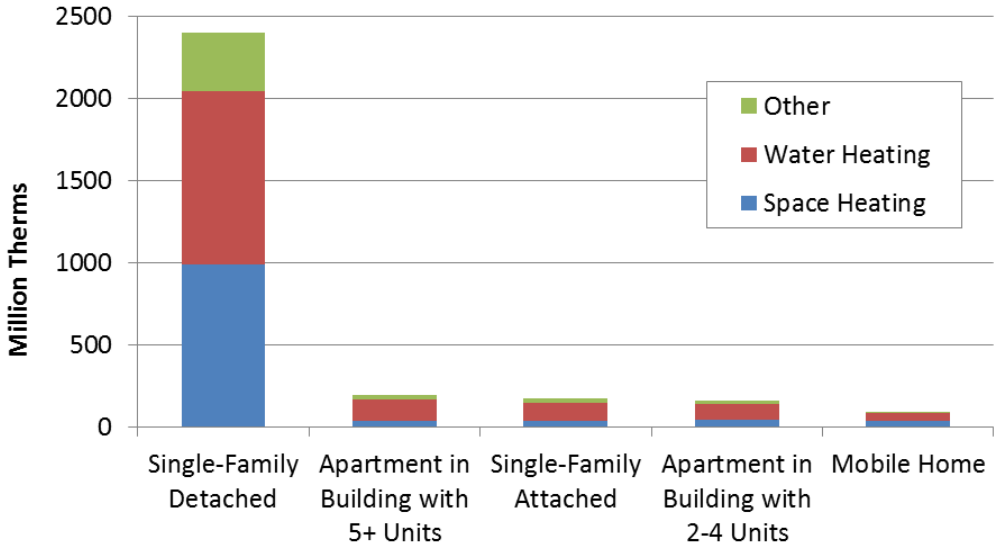
[12] California Energy Commission. *The Natural Gas Research, Development and Demonstration Program. Proposed Program Plan and Funding Request for Fiscal Year 2012-13*. CEC-500-2012-084. March 2012. (page 18). http://www.energy.ca.gov/2012publications/CEC-500-2012-084/CEC-500-2012-084.pdf

Residential Building Sector

Residential consumption of natural gas by end use is available at the California level and by building type in the Energy Commission's RASS.[13] Because RASS reports all end-use consumption on a per-dwelling unit basis, RASS estimates were multiplied by the population sizes of each building type as reported in the online Saturation Report tool.[14]

Figure 3 displays the estimated total annual natural gas consumption for space heating, water heating, and miscellaneous end uses for each building type. Single-family detached dwelling units make up the vast majority of the housing market and are typically larger in size. As shown in the figure, they consume more total natural gas than all other dwelling types combined.

Figure 3: California Residential Natural Gas Consumption by End Use and Building Type[15]



Source: California Energy Commission. Residential Appliance Saturation Survey (RASS) 2009

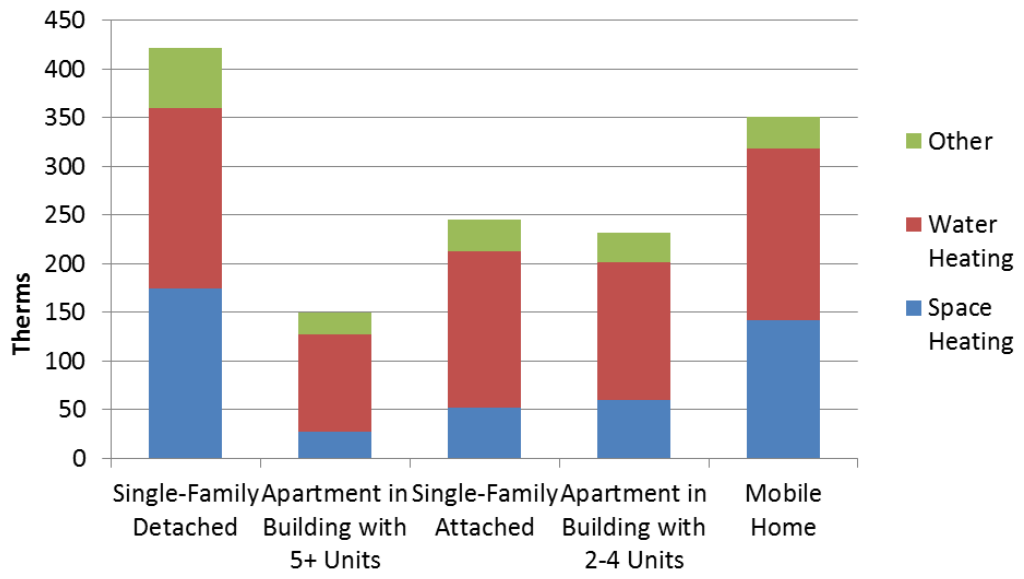
To better compare the distribution of natural gas consumption by end use, RASS calculates energy use per dwelling unit for each building type. These results are displayed in **Figure 4**.

[13] California Energy Commission. Residential Appliance Saturation Study (RASS). CEC-200-2010-004. October 2010.

[14] http://websafe.kemainc.com/rass2009/Default.aspx

[15] Based on the RASS population, which represents customers in PG&E, San Diego Gas and Electric, Southern California Gas Company, Southwest Gas, City of Coalinga, and Long Beach Gas Department territories.

Figure 4: California Residential Natural Gas Consumption per Dwelling Unit by End Use and Building Type



Source: California Energy Commission. Residential Appliance Saturation Survey (RASS) 2009

Appliance-level saturation data are reported in RASS for the years 2003 and 2009. The CPUC's new California Lighting and Appliance Saturation Study (CLASS) data set is expected to be available in 2014.[16] The CLASS data set represents the residential population of individually metered households within the territories of the investor-owned utilities (IOUs)[17] of California.

Table 3 details the estimated count and percentage of homes with major appliances that consume natural gas. Results are shown for surveys administered in 2003 and 2009. In both surveyed years, more than 70% of all homes are estimated to have a primary gas space heater, and more than 70% of homes are estimated to have a primary gas domestic hot water heater (DWH) and slightly less than 50% of homes have a gas oven.

Table 3: Presence of Natural Gas Appliances in California Homes

Appliance Type	2003		2009	
	Count	Percent	Count	Percent
Have Primary Gas Heater	7,514,382	73%	8,161,544	71%
Have Primary Gas DHW	7,432,288	72%	8,262,546	72%
Have Gas Clothes Dryer	3,580,774	35%	4,548,824	40%

[16] DNV KEMA is serving as prime contractor for the CLASS survey. The draft final data is expected to be delivered to CPUC in January 2014.

[17] California investor-owned utilities providing natural gas are Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Gas company (SCG)

Appliance Type	2003		2009	
	Count	Percent	Count	Percent
Have Gas Oven	4,814,119	47%	5,058,711	44%
Have Gas Range	6,396,375	62%	7,199,543	63%
Have Gas Heater for Hot Tub	340,453	3%	546,748	5%
Have Gas Heater for Pool	172,955	2%	438,974	4%

Source: California Energy Commission. Residential Appliance Saturation Survey (2003 and 2009)

A deeper review of residential end use saturation was performed within space heating and hot water heating. **Table 4** displays the type of the primary space heating appliance within homes that use natural gas as the primary heating fuel. More than 70% of these homes in 2003 and 2009 have a central forced air furnace as the primary space heating appliance. The category for "Other Gas Heater" is a rare response, but includes such items as hydronic under-floor heating, or natural gas space heaters.

Table 4: Type of Primary Natural Gas Space Heating Appliance in California Homes

Appliance Type	2003		2009	
	Count	Percent	Count	Percent
Central Forced Air Gas Furnace	5,274,621	70%	6,079,409	74%
Floor or Wall Gas Furnace	2,095,535	28%	1,786,127	22%
Hot Water Gas Radiator	86,740	1%	117,357	1%
Gas Fireplace	-	0%	74,019	1%
Other Gas Heater	53,941	1%	104,334	1%
Total	**7,510,837**	**100%**	**8,161,246**	**100%**

Source: California Energy Commission. Residential Appliance Saturation Survey (2003 and 2009)

Table 5 summarizes the prevalence of different types of natural gas water heating appliances in homes. In both 2003 and 2009, more than 95% of these homes used standard gas storage tank water heaters, with tankless water heaters making up 2% in 2003 and 4% in 2009.

Table 5: Type of Primary Natural Gas Water Heating (WH) Appliance in California Homes

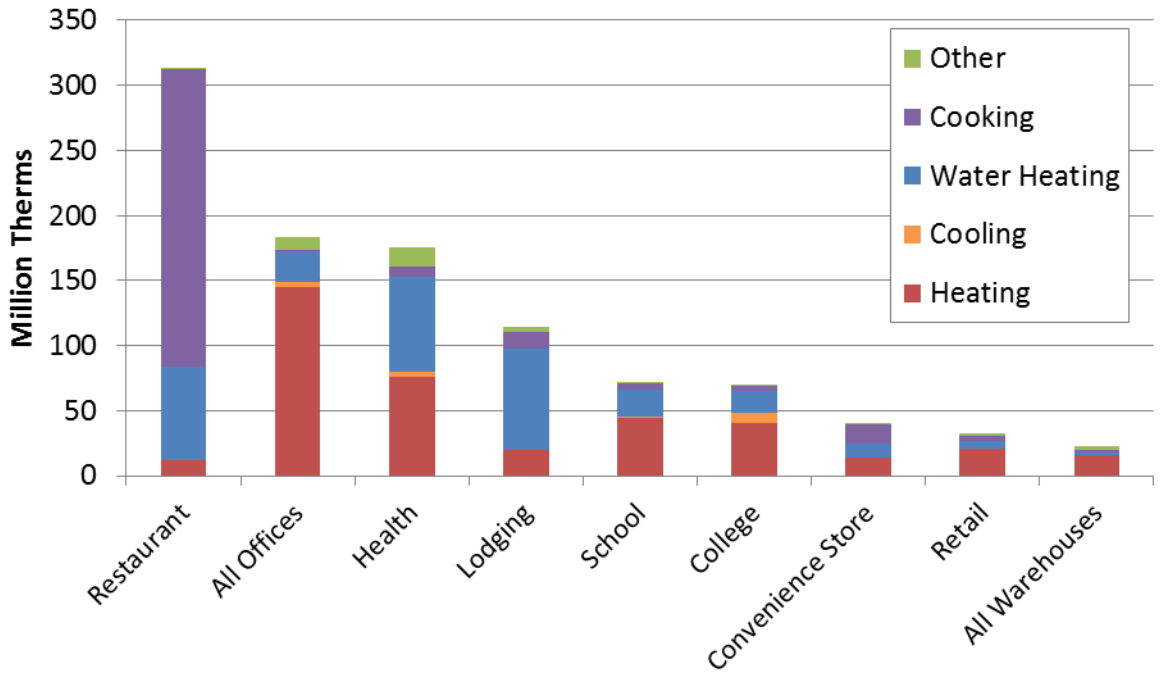
Appliance Type	2003		2009	
	Count	Percent	Count	Percent
Standard Storage Tank Gas WH	7,248,317	98%	7,862,576	95%
Whole House Tankless Gas WH	168,664	2%	305,454	4%
High Efficiency Condensing Gas WH	-	0%	85,827	1%
Solar Water Heater with Gas Backup	15,307	0%	8,689	0%
Total	**7,432,288**	**100%**	**8,262,546**	**100%**

Source: California Energy Commission. Residential Appliance Saturation Survey (2003 and 2009)

Commercial Building Sector

The commercial building sector's consumption of natural gas is characterized by building type, rather than by saturation of equipment or appliance. The California Commercial End Use Survey (CEUS)[18] provides consumption and intensity (consumption per square foot) data for several common end uses by building type. The CEUS study developed building simulation models and calibrated the models to annual bills and in some cases, end-use metered data. **Figure 5** displays the total commercial natural gas consumption for the ten building types that consume the most natural gas. This chart reveals that the largest consumers of natural gas in California are restaurants, followed by offices and health facilities.[19]

Figure 5: California Total Commercial Natural Gas Consumption



Source: California Energy Commission. California Commercial End Use Survey (CEUS) 2006

Figure 6 reveals the energy use intensity associated with each end use by building type. Notably, restaurant buildings consume the most natural gas overall across all building types, as well as per square foot. Within the restaurant building type, space heating, water heating, and

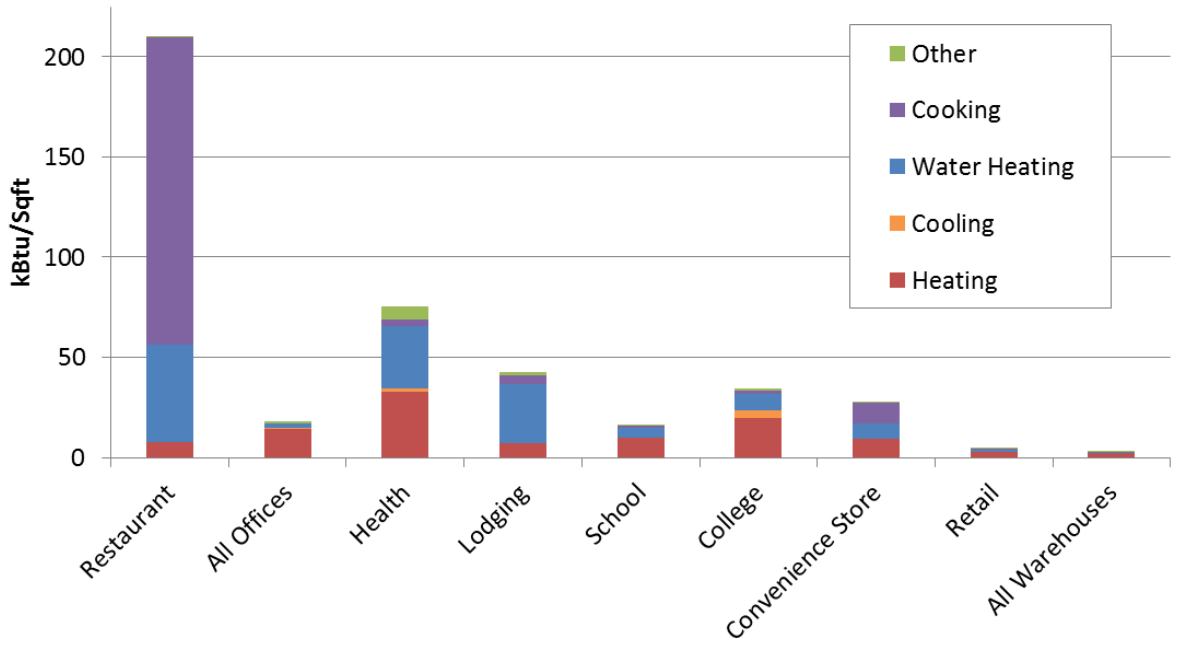
[18] California Energy Commission. California Commercial End Use Survey. March 2006. http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF

[19] Note that staff from the PG&E Food Service Technology Center believe that CEUS understates gas consumption for both water heating and cooking in the commercial food service sector.

cooking end use categories are all significant natural gas consumers, the largest of which is cooking.

Across all commercial building types, space heating remains the singularly dominant natural gas end use. While the saturations of natural gas equipment in the commercial sector would be a useful metric to include in this baseline investigation of the main uses of natural gas, this data is not yet publicly available. With the release of the CPUC Commercial Saturation Study (CSS) in 2014, the data set should be reviewed as it may prove directly relevant to this baseline review.[20]

Figure 6: California Commercial Natural Gas Consumption per Square Foot



Source: California Energy Commission. California Commercial End Use Survey (CEUS) 2006

Based on the data, space heating and water heating are the most significant residential natural gas end uses. Similarly, space heating, water heating, and cooking are the most significant commercial natural gas end uses. In the residential sector, the Residential Appliance Saturation Survey provides a fairly detailed picture on the breakdown of natural gas consumption in both quantity and energy intensity. The commercial natural gas consumption related to specific equipment types is not yet as rigorously documented in the public realm.

[20] Itron is preparing the Commercial Market Share Tracking and Commercial Saturation Survey for CPUC. According to the 2012 research plan, the final data and web tool will be available in 2014. http://www.energydataweb.com/cpucFiles/pdaDocs/824/ResearchPlanCSS_CMST_2.7.12.pdf

CHAPTER 3:
Development of Recommended Research Initiatives

The roadmap development project focused on understanding the status of existing research and engaging industry experts and other stakeholders in the development of the recommended research initiatives. Characterizing the natural gas consumption of commercial and residential building sectors was an important first step to setting priorities for research.

Approach to Developing Recommendations

Three research activities were completed to develop the recommendations contained in this report, including: literature review of existing research, interviews with industry experts, and statewide stakeholder workshops. This section provides a description of each approach, data sources identified, and scope of research.

Literature Review and Baseline Investigation

A literature review of publicly available reports was conducted with a focus on California-specific research conducted for natural gas energy-efficiency technologies in buildings. The literature review served as a baseline investigation into past and current research associated with different natural gas end uses for the residential and commercial building sectors. The research was conducted primarily through internet searches for information posted for the public. **Table 6** provides an overview of the primary sources that comprised the baseline investigation of existing research on natural gas efficiency in buildings.

Table 6: Sources for Baseline Investigation of Past and Current Research Initiatives

Type	Organizations
California Ratepayer Funded	California Energy Commission CPUC Evaluations Emerging Technologies Coordinating Council PG&E Food Service Technology Center Southern California Gas Company
Trade Organizations	American Council for Energy Efficiency Economy American Gas Association Gas Technology Institute
Federal Entities	U.S. Department of Energy National Renewable Energy Laboratory Lawrence Berkeley National Laboratory Oak Ridge National Laboratory Pacific Northwest National Laboratory

Source: DNV KEMA

The literature review and baseline investigation results were organized according to the end uses outlined in Chapter 2. An initial set of recommendations on research gaps and needs was developed based on the literature review.

Interviews with Industry Experts

Following the completion of the literature review, interviews with industry experts were conducted to obtain input to help build upon the initial set of recommendations. The results of the literature review task informed both the interview questions and identification of key industry experts. Specifically, the interview objectives were to identify the following:

- Status of energy-efficiency technology development
- Current technical opportunities
- Problems that need to be solved (e.g., reducing energy use, reducing air emissions, and improving interior and exterior air quality)
- Needed future research areas and associated rationale for the need (e.g., ratepayer benefits)
- Potential economics, size of market
- Market transferability and market potential of different technologies

Prior to beginning the interviews, DNV KEMA developed a preliminary list of industry experts based on the authors of literature researched, participants in recent Hot Water Roadmap workshops, and references from Energy Commission staff. This preliminary list of 55 industry experts was subsequently added to throughout the interview process, with respondents recommending other industry experts to be interviewed.

By the end of the interview period, DNV KEMA had identified 83 industry experts across a number of different end use types and building sectors. Interview scheduling was pursued for all identified experts and was usually completed with at least one expert per organization. A total of 43 interviews were completed, which exceeded the target number of 40 completed interviews. The 43 respondents who participated in the interviews represented a variety of industry perspectives ranging from consultants to utilities to government agency interests.

Table 7 provides a count of the organization affiliations associated with the interview respondents. The full list of organizations interviewed and the interview guide are provided in Appendix A and B, respectively.

Table 7: Distribution of Organization Types Represented

Organization Type	Count	Description
Consulting	14	Individual Consultants and Consulting Firms
Utility	8	Utility and Utility Program Representatives
Government	7	National Labs and Federal Agencies
Non-profit	6	Environmental and Energy-Efficiency Advocacy Organizations
Trade	4	Trade Groups of Manufacturers and Gas Technology Interests
Manufacturer	3	Manufacturers of Gas Appliances and Equipment
Academic	1	University Professor
Total	**43**	

Source: DNV KEMA

A preliminary list of priority natural gas efficiency research initiatives was developed based on both the literature review and interviews with industry stakeholders.

Statewide workshops

The purpose of the statewide workshops was to provide members of the public an opportunity to provide feedback on the preliminary list of recommended research initiatives. A total of four workshops were held across Northern and Southern California.

Workshop attendees were asked to focus on the following:

- Comments and questions about the initial list of research initiatives[21];
- Comments on the status of energy-efficiency technology development for residential and commercial buildings to reduce natural gas consumption;
- Identification of problems and challenges affecting natural gas energy efficiency for buildings;
- Identification of data and research gaps that are barriers to maximizing energy-efficiency technologies;
- Comments and recommendations for priority research needs to maximize energy efficiency; and
- Recommendations for partnership opportunities to gain synergies in research.

Two workshops focused on residential-related natural gas research and two focused on natural gas research for commercial buildings. Based on the input from the workshop, stakeholders felt strongly that there was a need for cross-cutting research across all natural gas end uses and that a systems and whole building perspective were necessary to achieve significant natural gas savings moving forward.

Summary of Recommended Research Initiatives

The remainder of this report presents the recommended research initiatives based on the roadmap development tasks and stakeholder input. The cross-cutting initiatives are across several natural gas end uses and may have the largest potential impact. Additional priority research initiatives are presented in order of the size of the baseline natural gas end use.[22]

The recommended research initiatives are organized into the following categories:

- Cross-cutting and other research initiatives
- Water heating research initiatives
- Space heating research initiatives

[21] See Appendix C and Appendix D for initial list of research initiatives from interviews (Appendix C) and those presented and commented on at workshops (Appendix D)

[22] Energy generation, such as micro-combined heat and power (CHP) was not included in this roadmap.

- Cooking research initiatives

In general, the research initiatives are broadly applicable to both the residential and commercial sectors, with a few exceptions (e.g., Research Initiative S7: Cost effective rooftop packaged heating units for commercial applications, and the commercial cooking research initiatives). All residential research initiatives are applicable to both single-family and multifamily buildings. These research initiatives focus on bringing technologies to market and can be included in low-income rebate programs.

Within each category, specific research initiatives are described in more detail. In each of the following chapters, specific research initiatives are further presented in order of urgency based on feedback from industry experts and stakeholders. Recommendations that were provided by multiple stakeholders across the projects tasks are presented first. Research initiatives that were mentioned by fewer stakeholders or perceived to have less energy savings impact are listed later.

Energy Policy Justification

The recommended research initiatives are selected to support California's energy, environmental, and economic policy goals as described in Chapter 2. In particular, the following related state policies are considered:

- **Air Quality Standards.** The local and regional air districts set air pollution emission standards for stationary source emissions. The districts, which are overseen by the California ARB also issue permits based on an entities ability to apply best available control technology requirements for mitigating air pollution and meeting air district standards. California's aggressive clean energy goals to reduce greenhouse gas emissions and natural gas consumption in the building sector must be met alongside its other environmental goals, such as meeting local air quality standards.
- **Zero Net Energy Goals.** Several initiatives are underway in support of the ZNE goals described in Chapter 1, including the PG&E Pilot Program and California Energy Commission Title 24 code updates, with the discussions underway in support of the 2016 Title 24 update. Research related to the role and interaction of natural gas in ZNE buildings is extremely timely and relevant, particularly as the state is evaluating different regulatory definitions of ZNE. A myriad of strategies are identified as part of the recommended research initiatives including reduced natural gas usage through improved building envelopes, reduced water heating distribution losses, reduced source emission of toxics in buildings and the resulting reduction for the need for high ventilation rates, reduced infiltration, ventilation air control, waste heat recovery, energy-efficient equipment, and preheating through solar renewable resources and controls.
- **Codes and Standards.** A number of initiatives described below will directly help to inform and improve upon upcoming updates to Title 24 and appliance standards. The initiatives support technology development to accelerate commercialization of promising high-efficiency natural gas appliances and improve installation practices to reduce natural gas use. In both the statewide IOU Codes & Standards program and the

Energy Commission's standards, staff meembers emphasize short and medium term residential energy (present to 2019) in support of the 2020 residential ZNE goal.

This roadmap identifies priority research needs to significantly reduce natural gas usage in commercial and residential buildings by targeting investments in promising technologies and overcoming barriers to natural gas efficiency. Ultimately, these research initiatives will help achieve California's energy goals by bringing down cost barriers across all building types and end uses.

Overcoming Barriers

Many of the barriers are similar across different initiatives and relate to issues such as end-user and market-actor awareness and education, high up front costs, current low cost of gas, and technology availability and maturity. To address these issues, the research initiatives generally identify the following strategies:

- Market barriers associated with awareness, education, and acceptance: Employ market research to understand specific knowledge gaps and perceptions preventing acceptance
- Technology availability higher for electric than for gas end use equipment: Conduct additional research and development for new technologies and monitoring and verification of technologies to justify energy savings and meeting energy efficiency goals
- Cost barriers: Conduct research and development, as well as market research to determine potential efficiencies and energy savings and economies of scale to facilitate rebate programs and justify cost-effectiveness

Research Beneficiaries

Many end users, state regulators, state and federal agencies, industry players (e.g. manufacturers, distributors, and installers), and other market actors (e.g. trade associations and efficiency advocates) will benefit from the recommended research initiatives. In particular, these include:

California residents and businesses

The recommended research initiatives are designed to improve the availability of energy-efficient, natural gas consuming equipment in buildings and improve installation practices to support comfortable homes and productive work environments. As a result, building owners will operate better performing buildings, increase comfort, and reduce energy and water costs. Furthermore, reducing energy costs improves the competitiveness of businesses located in California.

State agencies

The recommended research initiatives will help the Energy Commission identify focus areas for future research that will make progress toward state energy and environmental goals. The research supports CPUC's efforts to cost effectively direct ratepayer funds for meeting state energy-efficiency goals. Finally, several recommended research initiatives will help local and regional air districts to develop more effective air regulations based on cost-effective pollution control strategies while also maintaining or increasing energy efficiency of natural gas appliances.

Trade and professional organizations

Many industry players and associations promoting natural gas research and efficiency will benefit from the research initiatives identified in this roadmap. These include standards setting organizations such as the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), Air Conditioning Contractors of America (ACCA), and International Association of Plumbing and Mechanical Officials (IAPMO).

The research initiatives will also support the work of other associations such as the American Council for an Energy Efficient Economy (ACEEE), Consortium for Energy Efficiency (CEE) and Information Technology and Innovation Foundation, to name a few.

Market actors

Market actors including manufacturers, distributors, retailers, and contractors will benefit from new technologies and research results. New and improved products will allow them to differentiate themselves in the market with more cost-effective products that help their customers save money, improve their buildings while meeting the state's environmental requirements. Market transformation will help increase sales for all market actors as consumers demand highly efficient products and services due to improved technology, whole building solutions, and better installation practices.

Utilities

Finally, the research initiatives will also benefit California's energy and water utilities by making progress toward goals for natural gas energy efficiency and water savings. This will enable California's utilities to provide its essential services to the public at less cost and support a vibrant economy and healthy environment for many years to come.

CHAPTER 4:
Cross-cutting and Other Research Initiatives

Interviews with industry experts and stakeholder workshops identified the need for a greater focus on research that considers the whole building–across all systems and multiple natural gas end uses–in order to achieve significant improvements in energy efficiency. For many technologies, such as residential furnaces, the individual equipment efficiencies are high and the remaining opportunities for significant reductions in natural gas usage are related to reducing distribution losses, integrating equipment using sensors and controls, improving controls overall, and developing systems that recover waste heat from different system components.

The following research initiatives are described in further detail in this section:

- **Research Initiative O1**: Focus on technologies for reducing air emissions while increasing energy efficiency
- **Research Initiative O2**: Incorporate a systems perspective and integrate technologies to achieve zero net-energy buildings that include natural gas for building cooling
- **Research Initiative O3**: Better understand technical and economic potential for heat recovery across multiple end uses
- **Research Initiative O4**: "Smart" buildings, controls and metering of natural gas usage in buildings, including smart equipment and appliances

Furthermore, some industry stakeholders indicated that it was not sufficient to consider past trends, but that research initiatives must consider future trends specifically related to climate change in terms of temperature, precipitation, and other changes in the climate.

Research Initiative O1: Focus on Technologies for Reducing Air Emissions While Increasing Energy Efficiency

Initiative Description

Natural gas combustion, while generally emitting fewer air pollutants than other fuels, such as oil, coal or gasoline, remains a significant source of oxides of nitrogen (NOx). NOx emissions adversely impact local air quality by contributing to ozone formation, particulate matter, and acid rain.[23] More research is needed on opportunities and technologies available to enhance energy efficiency while reducing NOx emissions. Approaches include:

- Identifying cost-effective, energy-efficiency upgrade approaches and technologies associated with retrofitting equipment with boiler NOx upgrades in commercial buildings.

[23] U.S. EPA Frequently Asked Questions. http://www.epa.gov/reg3artd/faqs/APDFAQ.htm#nox

- Promoting new equipment designs that are aimed at improving energy efficiency while meeting new NOx regulations, particularly in the South Coast Air Quality Management District (SCAQMD) air basin.

Issue Statement

The amount of NOx generated is an exponential function of flame temperature. Unfortunately, typical techniques for reducing NOx formation, such as lowering flame temperature or adding flue gas recirculation, often results in reduced natural gas energy efficiency (i.e., increased natural gas consumption).

While all air districts within California have regulations related to NOx, those promulgated by the SCAQMD are some of the most stringent in the world. The SCAQMD has enacted a number of rules, including emission limits from residential-type, natural gas-fired water heaters. In order to be sold within the SCAQMD, the NOx generated by the water heater cannot be greater than 10 nanograms of NOx per Joule (ng/J) of heat output (approximately 0.1 grams per kBTU) .[24] Other air districts within the state tend to adopt similar limits to emissions within a few years of when the SCAQMD enacts its rules. Other rules contain emission limits from large water heaters and small boilers (under 2,000 kBtu/h), among other natural gas combustion appliances. Therefore, research is needed to ensure that cost-effective solutions can be found to maintain or improve equipment energy efficiency while meeting State air quality requirements.

Status of Past Research

There is significant research related to technology development to reduce NOx emissions, but technical challenges exist in finding air emission solutions that also result in reduced natural gas consumption. There are newer boiler designs that improve efficiency through techniques such as using less excess air and less flue gas recirculation to reduce makeup air heating consumption. However, these designs remain uncertain in terms of availability and performance.[25]

According to a recent study conducted by Lawrence Berkeley National Laboratory (LBNL), "one technology that is of interest to the study of fuel flexibility is the Low-Swirl Injector (LSI) developed over the past two decades because it has been found to stabilize several fuels over a wide range of conditions while maintaining low emissions. However, quantification of the LSI's performance at elevated pressures and inlet temperatures is still rather limited because only a

---

[24] SCAQMD Rule 1121 "Control of Nitrogen Oxides from Residential Type, Natural Gas-Fired Water Heater."

[25] Envoity Presentation on Boiler NOx Emissions and Energy Efficiency. Prepared for Boiler Operators and Facility
Managers. http://www.boilerenergyefficiency.com/forms/Boiler_NOx_and_Energy_Efficiency_2010.pdf

handful of studies have been conducted at these conditions."[26] While there has been little interest by industry, this technology development initiative has significant potential to scale well to reduce air emissions and increase energy efficiency, but it needs product development on a three-year timeline before it is ready for demonstration.

The Gas Technology Institute (GTI) is also working on fully premixed radiant burners for low NOx in residential scale equipment. This is proven technology, with burner suppliers and manufacturers working on prototypes that meet SCAQMD goals. On the commercial side, GTI has two initiatives – the superboiler and ultramizer projects that use transport membrane condenser technology and flue gas recirculation to achieve 5 parts per million (ppm) NOx with high efficiency. [27] [28] The superboiler and ultramizer technologies are currently commercially available[29].

Energy Savings Description

Basic strategies to improve energy efficiency associated with burner upgrades to reduce air emissions include:

- Installing a variable frequency drive (VFD) and associated controls on the burner fan, pumps, and other system motors to optimize combustion efficiency and minimize NOx.
- Installing a selective catalytic reduction (SCR) system and installing an ultra-low NOx burner (applicable for boilers larger than 30 MMBTU/hr).
- Developing and applying advanced burner designs (such as radiant burners) with low NOx levels.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Work with California ARB and local air districts to better integrate NOx and energy-efficiency regulations.
- Support development of nascent technology. There is often more funding for demonstration projects, but it is much harder to find development funding.
- Support technological research related to:

---

[26] Beerer, D. and V. McDonell, P. Therkelsen. Flashback, Blow Out, Emissions and Turbulent Displacement Flame Speed Measurements in a Hydrogen and Methane Fired Low-Swirl Injector at Elevated Pressures and Temperatures. Proceedings of ASME Turbo Expo 2012. June 11-15, 2012, 1.

[27] https://www1.eere.energy.gov/manufacturing/pdfs/webcast_2008-1120_super_boiler.pdf

[28] http://www.gastechnology.org/Expertise/Pages/ETP-Projects.aspx

[29] http://www.cbboilers.com/superboiler.htm and http://www.cannonboilerworks.com/ultramizer.html

    - Decreasing sensitivity of standard and low-emission burners to gas composition in the pipeline[30] and from potential renewable resources while maintaining or increasing energy efficiency
    - Improving system components (e.g., burners, sensors, and controls) and map their performance in relationship to combustion efficiency and emissions
    - Testing the actual efficiency gains associated with advanced controls that can track demand in real time and adjust turndown ratios.
- Encourage and support California ARB to develop an air emissions research roadmap to guide future technical and market research with a long-term planning horizon (e.g., 10 years) and integration of energy efficiency with reduced emissions.

Overcoming Barriers

The fundamentals of flame and combustion chemistry and the relationship to the amount of natural gas consumed at different flame temperatures and fuel/air ratios have been studied for more than 50 years and are well understood. However, research is needed on optimizing burner designs and application of those designs to higher efficiency equipment to minimize natural gas use and air emissions, with the addition of advanced controls. This research can provide technical solutions and data for overcoming the barriers associated and applications in the field.

Other barriers include demonstrating the cost-effectiveness of natural gas energy-efficiency upgrades at the time of any air pollution retrofit project. Research to share best practices and case studies across different building types and industries would help decision makers understand the benefits and cost-effectiveness of combined energy-efficiency and air pollutant equipment upgrades in commercial and residential buildings.

Research Initiative O2. Incorporate a Systems Perspective and Integrate Technologies to Achieve Zero Net-Energy Buildings That Include Natural Gas for Building Cooling

Initiative Description

Research is needed to better understand opportunities to reduce energy use from both a natural gas and electricity perspective. This includes: systems that shift heating loads to heat pump mechanisms when solar power is available to reduce natural gas consumption; using gas-fired heat pumps or absorption chillers for cooling to reduce electric peak loads when solar production cannot meet cooling demand, and interactive effects of electric efficiency measures with heating loads. Furthermore, much attention has been paid to electricity, and more research is needed to improve algorithms and calibration for natural gas in energy simulation models.Support and promote energy rating systems for new and existing buildings through efforts such as AB758 and the Home Energy Rating System (HERS) Index.

---

[30] GTI and LBNL commented at workshops that high efficiency burners may show potential using ideal natural gas in laboratories and then perform poorly when using actual natural gas which has some imputrities.

Issue Statement

The role of natural gas in California's ZNE goals remains an important topic for defining ZNE and within the existing time-dependent valuation (TDV)[31] framework for valuing energy in buildings. Several different definitions for ZNE have been considered, some of which exclude natural gas completely and others that account for natural gas in different ways (e.g., site versus source). Whole building performance is a path to achieving ZNE, as loads need to be reduced in order to reduce the size of equipment and to more cost-effectively install renewable energy systems.

One of the key challenges to incorporating natural gas into a ZNE definition is the lack of cost-effective renewable fuels with infrastructure and fuel markets in place to replace natural gas without fuel-switching to electricity. However, the CPUC and Energy Commission are moving towards a ZNE definition based on net TDV of energy consumption, which allows for solar photovoltaic (PV) and other renewable electricity to count towards offsetting the natural gas consumption.[32]

Furthermore, the CPUC requires that IOU energy-efficiency savings from electric measures in heated spaces such as lighting measures report negative savings (i.e., consumption increases) for natural gas due to a reduction in space heat compared to the old lighting. These effects have been researched in case studies and simulation analyses, but additional research is warranted in order to achieve ZNE goals. Since the large-scale utility programs claim savings for millions of lighting measures and thousands of other measures, these claims make achieving natural gas energy savings (reductions in consumption) goals for ZNE buildings more difficult. In the 2010-12 programs more than 88 million negative therms were claimed, emphasizing the importance of the calculations, reporting policy, and the need for more natural gas efficiency efforts to offset the increased space heating load.

Finally, if Multiple Listing Service (MLS) descriptions were required to list the energy rating of all (new and existing) homes for sale, this would provide a market differentiation of ZNE homes and help identify poorly performing homes. AB 758 includes some approaches for disclosure of energy performance ratings of existing buildings.[33] An MLS listing for residential buildings would differentiate ZNE homes from other homes in the market, create an incentive for energy-efficiency upgrades in the existing housing stock, and stimulate demand for high performance homes to help achieve state ZNE goals.

---

[31] Time-Dependent Valuation (TDV), the new method for valuing energy in the performance approach in the 2005 Building Energy Efficiency Standards. Under TDV the value of electricity differs depending on time-of-use (hourly, daily, seasonal), and the value of natural gas differs depending on season. TDV is based on the cost for utilities to provide the energy at different times.

[32] Note that currently, U.S. DOE only certifies buildings as ZNE if they are electric only.

[33] Draft Action Plan SB 758 CEC-400-2013-006-D.pdf

Status of Past Research

Several research projects have been completed recently to support California's ZNEgoals, including the following:

- The report for the Technical Feasibility of ZNE Buildings in California: Completed on behalf of California's IOUs assesses the technical feasibility of a full range of ZNE definitions and metrics for California policy-making purposes. The two ZNE metrics analyzed in this report assume that natural gas consumption at the site level would be offset with renewable electricity exports from the site.
  One key finding from the report is a "notable shift in the overall load balance from electric consumption to natural gas consumption in ZNE designs. While efficiency improvements were implemented on the heating systems, reductions in internal gains and envelope gains often created a need for additional heating to meet occupant comfort needs. Some nighttime natural ventilation pre-cooling strategies led to an increase in morning heating needs. These strategies resulted in overall reductions in TDV, but often increased natural gas consumption at a level that offset the heating efficiency gains."[34]
- The Road to ZNE – Mapping Pathways to ZNE Buildings in California established a ZNE framework to understand what progress has been made towards state ZNE goals and identified pathways for pursuing them. Natural gas is covered in the ZNE definitions evaluated by the study, including economic considerations and policy issues related to different ZNE definitions that may incentivize fuel-switching between electricity and natural gas.[35]
- Measured Home Performance research sponsored by the Energy Commission was established to achieve significant levels of energy efficiency through upgrading all major energy components in a home and carefully measuring a home's energy features as it is being installed. Although this research is primarily focused on existing buildings, these techniques are widely applicable to new construction.[36]

Energy Savings Description

Recent studies completed for the PG&E ZNE Pilot Program provide estimates of energy savings associated with ZNE new construction optimized before the addition of onsite PV systems. As an example, **Table 8** provides a summary of three modeled office buildings' estimated annual net-energy consumption, comparing a 2013 Title 24 Code compliant office building with an "exemplar" high energy-efficiency building. One issue is that the exemplar high-efficiency building consumes 41% less total energy than the 2013 Title 24 code compliant building on an annual basis, despite using 7% more natural gas. The buildings are identical other than energy-

---

[34] ARUP. 2012. *The Technical Feasibility of Zero Net Energy Buildings in California, 55*.

[35] Heschong Mahone Group. 2012. *The Road to ZNE: Mapping Pathways to ZNE Buildings in California*.

[36] California Energy Commission. Measured Home Performance website. Last accessed December 3, 2013. http://www.measuredhomeperformance.com/

efficiency measures and use of onsite renewable energy generation."[37] Though office buildings are a key non-residential building type, these results are meant to be illustrative and are not the same for all other building types.

Table 8: Summary of Annual Site Energy for Three Modeled Office Buildings (Climate Zone 3)

Building Type	Total Energy (Million BTU)	Annual Electricity (MWh)	Annual Natural Gas (therms)
2013 Title 24 Code Compliant	14,484	4,005	8,202
Exemplar High EE	8,506	2,237	8,745
ZNE Onsite Polar PV	*(8,505)*	*(2,493)*	*0*
ZNE (site energy def.)	0	-256	8,745

Source: Road to ZNE Study

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Improve algorithms and calibration for natural gas in energy simulation models. In building energy simulations, the performance curves for water heating and space heating equipment are fairly simplified compared to electric equipment. More advanced water and space heating technologies and control strategies will require updates to ensure all the benefits are capable of being estimated in simulations. In addition, residential and commercial advanced metering infrastructure (AMI) interval metering will allow for more robust calibrations of models.
    - Explore expanding the terms in performance curves beyond exterior temperature and creating separate curves for condensing and non-condensing equipment. Performance curves for systems with onboard adaptive algorithms should also be researched. Part-load performance is a large factor for heat pumps, but not for gas furnaces.
- Research into interactive effects requires studying overall heat balances in homes and businesses that are occupied.
- Understand how occupants and building controls respond to small changes in internal loads becoming more efficient. The proximity of the reduced waste heat to the occupant or control sensor may be an important factor that is not well studied.
- Integrate research related to gas-fired cooling (e.g. absoption chillers and heat pumps) and dual fuel heating and cooling, such as systems that only use electricity when offset by solar PV, and explore opportunities to harvest "free" heat when water heating load and space heating loads are simultaneous.[38]

[37] Heschong Mahone Group. 2012. *The Road to ZNE: Mapping Pathways to ZNE Buildings in California,* 120.

[38] ARUP. 2012. *The Technical Feasibility of Zero Net Energy Buildings in California*, page 55.

- Integrate past Energy Commission's Public Interest Energy Research (PIER) program research related to Measured Home Performance techniques into the ZNE framework for new construction such that builders measure the performance of the thermal envelope, HVAC, and water heating systems while the house is being built in order to optimize the size of the PV system.
- Create a "Future Home" demonstration of more efficient home envelope and integrated systems.
- Conduct research to support potential mandatory building energy ratings under AB758, including assessing the potential to use billing information as the basis for the energy rating by collecting billing data on HERS rated new homes to calibrate a billing rating model.

Overcoming Barriers

Substantial technical and market barriers exist to achieving California's goals for all new residential construction and all new commercial construction to be ZNE by 2020 and 2030, respectively. Key challenges include transitioning the adoption of ZNE technologies and approaches from early adopters to the mainstream market. This will require bringing costs down, training market actors and the workforce, increasing public awareness to drive consumer demand, and reduce uncertainty and risks associated with newer energy technologies.

There is general consensus that we are "below target" to achieve the state ZNE goals. However, the new residential construction market may be close in terms of technical feasibility. New commercial construction varies in readiness depending on building type.[39] In order to develop "market pull" for ZNE new homes through use of energy ratings, outreach to realtors is needed to show that this approach will not cause any delay or risk for home sales transactions. Furthermore, research is needed to automate the process of populating the necessary data into a simplified rating tool.

Ultimately, there is no single solution for achieving ZNE; a combination of strategies for minimizing energy loads in a building is needed. Furthermore, efficiency is not limited to technological solutions; integration with occupany behavior is needed and "ease of operation" should be taken into account to ensure that modeled energy savings are realized.

Research Initiative O3. Better Understand Technical and Economic Potential for Heat Recovery Across Multiple End Uses

Initiative Description

More research is needed to identify the potential for cost-effective residential and commercialwaste heat recovery from all sources, such as refrigeration, kitchen exhaust/cooking heat, and drain water. Heat recovery offers opportunities for preheating both hot water and air for space heating.

[39] Road to ZNE.

Therefore, research is needed to quantify the amount of waste heat available in existing buildings to determine the cost effective viability of different heat recovery technologies and help prioritize research to develop advanced heat recovery systems and to support commercialization of existing heat recovery systems. For instance, research into hydronic heating potential should also consider the added benefits of using waste heat to pre-heat water for space heating.

A technical and economic potential study for heat recovery would greatly benefit the energy efficiency and appliance manufacturing industries. Such a study wouldidentify focus areas and synergies between different technological opportunities for near-term commercialization and market penetration, and effects on appliance performance. The study would identify whether cost-effective applications for heat recovery may be limited to certain building types or for certain existing equipment.

Issue Statement

Instead of being "wasted" by release into the ambient environment, heat generated as a by-product of other building systems, such as refrigeration and cooling processes, or remaining after being utilized, such as drain water (from showers and dishwashers) and dryers, could be used in other building processes to reduce natural gas consumption.

There are many potential sources of waste heat, as well as opportunities for use of the waste heat. Many industry experts expressed interest in research related to heat recovery for water heating from other end uses, such as cooking, and HVAC systems.

For the food service sector, heat recovery from condensing units of walk-in freezers wasidentified as an area for high potential due to the consistent 24-hour operations and substantial heat rejection load. Heat recovery from walk-in freezers is particularly attractive compared with air-conditioning units, which has a more seasonal and time-of-day varying refrigeration cycle than walk-in freezers.

Status of Past Research

There are some past studies related to specific heat recovery systems, but none looked holistically at opportunities at the state level and across a full suite of different potential energy-efficiency and heat-recovery options. The following research papers and studies provide examples of heat-recovery technologies:

- **Combined-systems refrigerant heat-recovery system**. A study conducted at PG&E's Food Service Technology Center (FSTC) in 1993 examined an installed system that recovered heat from walk-in refrigerator/freezer refrigeration systems used to preheat water that is heated to 150°F by a commercial gas water heater.[40] According to the study, "the heat recovery system was monitored to determine the amount of heat recovered

[40] Ferlin, B., D. Zabrowski, D. Horton, D. Fisher and D. Kaufman. 1993. Refrigerant Heat Recovery System Learning Center Dining Facility.

from two refrigeration systems and the economic value of the recovered heat." These systems are now available, but are only eligible as rebated measures under the custom retrofitutility programs.

- **Research and Development Roadmap for Water Heating Technologies.** A recent report prepared for Oak Ridge National Laboratory outlined a roadmap for high-priority research, development, and demonstration (RD&D) activities for water heating that included many recommendations for heat recovery. The objective of the roadmap was to assist the U.S. Department of Energy (DOE) Buildings Technologies Program Water Heating Research and Development program in developing future R&Dactivities. The RD&D prioritization is based on stakeholder input, fit with overall DOE BTP priorities, and likelihood of technical and commercial market success.[41]

Energy Savings Description

The energy savings will vary across different technologies being analyzed. The purpose of this research initiative is to systematically study and estimate the technical and market potential of various heat recovery approaches and technologies to help prioritize future research.

As one example, the PG&E FSTC found an estimated payback of four years based on installed cost of $2,500 for an installed system that recovered heat from walk-in refrigerator/freezer systems used to preheat water. [42]

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- **Demonstrate cost effectiveness of combination equipment (i.e., across several building systems to recover waste heat).** Combining water heating with other building functions can help leverage the incremental cost of efficient technologies across several building systems, make use of "free" waste heat from other systems, or otherwise enhance the cost-effectiveness of high-efficiency water heating. Ensuring high reliability for combination equipment is critical due to the additional complexity of the system. A few examples include combining with other technologies such as micro-combined heat and power (CHP), solar, and geothermal, and small exhaust air-source gas-fired heat pump water heaters for lavatories.
- **Demonstrate cost-effectiveness and energy-saving potential of drain water heat recovery.** Drain water heat recovery systems capture heat from water going down the drain after the heated water is used for another purpose such as showering, clothes washing, or dishwashing. Residential, commercial, and institutional installations are

[41] Navigant. 2011. *Research and Development Roadmap for Water Heating Technologies*.

[42] Ferlin, B., D. Zabrowski, D. Horton, D. Fisher and D. Kaufman. 1993. Refrigerant Heat Recovery System Learning Center Dining Facility.

feasible. Although gaining popularity in Canada, drain water heat recovery has not been adopted in the United States. There are no current ENERGY STAR products or specific credits in residential new construction programs for drain water heat recovery systems. One reason for its popularity in Canada may be the inclusion of drain water heat recovery in ENERGY STAR for New Homes in Canada. The purpose of field-testing in a range of climate zones across California would be to demonstrate the potential and cost-effectiveness of the technology. Natural Resources Canada maintains a list of approved products[43], but does not have a published savings estimate based on typical water heating use similar to ENERGY STAR products.

- **More research on high-efficiency pool and spa heating with technologies that could easily be combined into space, water, and pool heating.** This is particularly applicable to Southern California due to higher saturations of residential pools.

As a mid-term recommendation, it is recommended that the Energy Commission consider supporting the following research:

- **Rating system for combined space and water heating appliances.** One industry expert mentioned that the appliance industry should be moving towards combination residential space and water heating appliances that are built around a single thermal engine. This could be based on a high-efficiency water heater supporting a fan coil for forced-air heating or a hydronic boiler loop for radiant floor heating. The expert recommends moving away from two combustion sources (e.g., two flames and two pilot lights) and having a single condensing appliance to support integration of all heating needs. This is particularly appropriate in California where space heating is moderate to low. The integrated product needs to be "plug and play" and easy to install for contractors..

  To achieve this, we need a rating method to help the market understand the value of these products. The U.S. DOE is required to move to a new water heating rating method, so this work has to be done anyway. There remains a time window for California to build a standard for a product that is not yet regulated. ASHRAE 124-2007R "Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances" and CAN/CSA-P.9-11 "Test method for determining the performance of combined space and water heating systems (combos)" would be a good place to start.

Overcoming Barriers

A key barrier identified in advancing heat recovery technology and equipment into the mainstream is the fragmented nature of contractors. Many heat recovery systems require working with both plumbing contractors along with those working on refrigeration or HVAC. This focus on end uses operating in buildings inhibits a systems perspective that is needed for reaching the next level of savings through integrated design and heat recovery.

---

[43] Natural Resources Canada. 2014. List of Drain-Water Heat Recovery Systems. http://www.nrcan.gc.ca/energy/efficiency/housing/home-improvements/12356

A potential study analyzing cost effective opportunities related to different heat recovery technologies can help to identify key areas where contractors across different end use industries could come together to overcome some of these barriers.

Research Initiative O4. "Smart" Buildings, Controls, and Metering of Natural Gas Usage in Buildings, Including "Smart" Equipment and Appliances

Initiative Description

A building controlled by a building automation system is often referred to as an intelligent or smart building. There is a new generation of energy management systems (EMS) that highten building intelligence and renewed interest in this across the commercial building sector. More research is needed to understand the cost-effectiveness and potential savings.

Many of these building controls have been focused on the electric monitoring, or optimized for electric efficiency. There is a need for less expensive and simpler gas controls, similar to those available for electric equipment. However, effective controls for gas-fired equipment can be challenging, especially on the whole building level. Small, accurate gas meters for individual appliances do not exist in the marketplace and an alternative mechanism that uses timers or sensors has not yet been developed.

More monitoring systems are needed for natural gas, such as small accurate meters for continuous monitoring and monitoring devices integrated with appliances. Furthermore, existing factory and aftermarket controls on gas heating equipment (e.g., commercial and larger residential boilers) can have very different results in different climates, so these variations need to be better understood. Research is needed to develop new appliances with onboard smart sensors and controls, which also need to be integrated with building-based monitoring and control systems.

Furthermore, there is tremendous opportunity to do model-based controls that look ahead, predict energy needs for natural gas and enable building operators and owners to reduce consumption. Part of the issue is finding buildings that have the potential to benefit from improved controls, and educating owners about the savings opportunities. Finally, demonstrations and case studies are needed to show the benefits of these technologies in reducing natural gas consumption.

Issue Statement

According to the Technical Feasibility ZNE Roadmap,[44] in order to meet state ZNE goals, "buildings and equipment must shift from operating in a constantly ready 'just in case' mode to a more strategic 'if and when necessary' mode." To support these efforts requires dynamic data collection, which includes the capture and analysis of data streams with building systems that can adapt and learn. For instance, new controls and building systems can include optimization

[44] ARUP. 2012. *The Technical Feasibility of Zero Net Energy Buildings in California*, 51.

protocols such that building efficiency increases as the system learns and adapts to dynamic changes.

Smart buildings with building automation are a significant aspect of "next generation" energy-efficiency strategies. Component-based, energy-efficiency measures are becoming more mature in California and the next push for energy efficiency is expected to be focused on whole building systems impacts and how to measure and quantify savings. Information technology and analytics can help organizations better allocate resources, detect faults, and optimize building operations.

Smart and intelligent building systems are fundamentally a different type of energy-efficiency strategy to be implemented, because it is more about investments in intellectual property than about purchasing an asset or equipment. For instance, instead of buying a condensing boiler, one is buying software and getting savings from optimization. There is a need to further develop real-time building simulation models that help optimize facility operations. Therefore, this is moving beyond building models as a static construct and towards dynamic simulation of buildings.

The most significant opportunities related to smart buildings may be in the institutional market (compared with commercial or residential), such as campus-wide energy management systems, holistic evaluation of thermal energy sources and sinks, and thermal storage. Institutional organizations (e.g., universities, hospitals, and multi-use campuses) generally have longer investment horizons and flatter hourly energy use profiles than commercial office space.

Status of Past Research

U.S. DOE, national labs, and the private sector have contributed to a significant body of research related to equipment level and building level controls, with a varying degree of focus on optimizing natural gas usage.

- **U.S. DOE Better Buildings Alliance Energy Management & Information Systems project.** Launched in 2012, this initiative addresses the evolving family of tools and services for managing commercial building energy use, including energy information systems, equipment-specific-fault detection and diagnostic systems, benchmarking and utility tracking tools, and building automation systems.[45]
- **Smart Building project at Microsoft**. In its initial pilot phase, Microsoft's smart building project focused on 13 buildings representing 2.6 million square feet. The pilot focused on three main areas: fault detection and diagnostics, alarm management, and energy management. One of the biggest single impacts the program has facilitated is the ability to identify building faults and inefficiencies in real time by analyzing the data streams extracted from building systems. The software is able to quantify wasted energy from

[45] http://www4.eere.energy.gov/alliance/activities/technology-solutions-teams/energy-management-information-systems

each identified fault, such as faulty damper positions, overcooling or overheating, leaking chilled water, etc.[46]

- **LBNL studies on building analytics and continuous (monitoring-based) commissioning.** Many studies have been conducted by LBNL to evaluate and improve performance monitoring tools for energy savings in commercial buildings. These studies include Open Energy Information System to validate and implement analytical and diagnostic algorithms, and user case studies.[47] Furthermore, LBNL has nearly completed a project for the Energy Commission on "Improved Standards through End-Use Meter Development" that addresses metering issues for gas and water end-uses in homes.
- **Demand-controlled ventilation.** The U.S. DOE Energy Efficiency and Renewable Energy (EERE) Building Technologies program recently sponsored an assessment of 182 technology options related to commercial building heating, ventilating, and air conditioning (HVAC) systems to identify research and development opportunities.[48] Demand-controlled ventilation (DCV) was identified as an energy-efficiency opportunity that eliminates excessive outdoor airflow when building occupancy falls below peak-design levels. By providing the required amount of ventilation based on actual occupancy, DCV maintains indoor air quality while helping the HVAC system consume less energy. The report cites research that found a payback of 6.8 years for an office located in Oakland, CA, and 0.3 years for retail store in El Centro, CA. The estimated cost is $300-$1000 per zone, with carbon dioxide (CO_2) sensors available for $200-$400 per unit. The technology is found to be commercially available except in the commercial foodservice arena where research is needed to develop an interconnectection with food service equipment.
- **Advanced boiler microprocessor controller**. Two studies were conducted of M2G boiler controls; one was developed by Sabien Technology Group and another by Greffen Systems. The studies evaluated the benefits of an advanced boiler microprocessor controller designed to optimize the efficiency of a hot water boiler system. The controller is designed for maintaining optimal heating for human comfort application in commercial buildings. The product is currently commercially available.[49] [50]

---

[46] http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Energy-Smart-Buildings.pdf

[47] http://eis.lbl.gov/

[48] U.S. DOE Energy Efficiency and Renewable Energy Building Technologies Program. Energy Savings Potential and RD&D Opportunities for Building HVAC Systems. Study conducted by Navigant. September 2011.

[49] Emerging Technologies Coordinating Council. Study in progress. M2G Control System Assessment.

[50] Emerging Technologies Coordinating Council. Study in progress. Evaluation of Greffen M2G Boiler Control Technology.

Energy Savings Description

- Whole building smart building studies:
  - In another study, LBNL benchmarked the impact of continuous (or monitoring-based) commissioning across 24 buildings, showing an average energy savings of 10%, with as much as 25% in some cases. [51]
  - In a study conducted by Lawrence Berkeley National Laboratory, Sysco launched a three-year energy-efficiency program using analytics as a critical component in cutting its portfolio use by 28%. [52]
- For demand controlled ventilation, there is a high retrofit potential for the market with potential savings ranging from 10%-30% reduction in HVAC energy use. [53]

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- **Interoperability standards for controls and communications.** Per the Technical Feasibility Study,[54] one recommendation is to "promote and/or regulate the application of control systems in buildings and homes to drive integration with more equipment in buildings. Continue to improve interoperability of the systems as well as installation simplicity is important in making the promise of sensor systems a reality. Further research establishing how a host of sensor applications will affect building equipment schedules within energy models will facilitate future analysis of the systems in the context of a building's overall energy use."
- **Add-on controls for rooftop units.** One industry expert[55] mentioned that there are many rooftop units that may not be installed correctly or have controls issues that should be addressed. More research and implementation of add-on packages for existing systems to optimize controls is needed to help run the rooftop units at the highest efficiency possible. Most of the add-on packages have been tested for fault detection diagnostics (FDD) and FDD is included in the 2013 Title 24 standards, but these packages have not been tested for optimal efficiency. There is an initiative underway by Consortium for Energy Efficiency to conduct a large number of tests to figure out controls and test

---

[51] Monitoring-Based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects, Mills and Mathew, June 2009. http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Energy-Smart-Buildings.pdf

[52] Building energy information systems: user case studies, Springerlink, Granderson, et al, May 2010. http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Energy-Smart-Buildings.pdf

[53] U.S. DOE Energy Efficiency and Renewable Energy Building Technologies Program. Energy Savings Potential and RD&D Opportunities for Building HVAC Systems. Study conducted by Navigant. September 2011.

[54] ARUP. 2012. *The Technical Feasibility of Zero Net Energy Buildings in California*, 51.

[55] See Appendix C. Summary of Interview Results.

energy savings and comfort. There are also hurdles with getting installers up to speed with the technology and reducing installation costs.

- **Upgrade energy-management system controls.** According to one industry expert, there are huge opportunities to go into existing commercial buildings and improve the efficiency of HVAC systems. One approach is to convert old inefficient buildings to direct digital controls (DDC) so they can implement more efficient control sequences (e.g., room setpoint setback during unoccupied hours and supply fan static pressure reset). More research is needed to develop standard sequences in controls software that establish schedules, react in real time between different system activities and can be easily implemented on projects. Also, pilot projects are needed to implement cost – effective controls upgrades and document the energy savings. A key barrier to overcome is adding digital controls to old analog devices. Pilots may determine when complete replacement is more cost effective than adding digital controls to analog systems or components.
- **Focus on the food service sector.** "Intelligent" or "smart" kitchens and restaurants. The "smart" kitchen of the future would have appliances that communicate with the overall building system. Unfortunately, many restaurant operators have no idea where the natural gas is consumed. For example, they may not know that 75% of the natural gas is going to a single conveyor oven. The industry is developing energy tracking systems (e.g., smart transducers), and it applies to different cooking appliances and food service equipment (e.g., range hoods). The Food Service Technology Center is working with the U.S. DOE's Better Building Alliance to put together guidelines and a list of eligible appliances which are compatible with an energy management system.
- **More demonstration projects and energy savings research into simulation software and real-time building simulation**, which requires data engineering. From a building standpoint, software such as DOE-2 isn't sufficient because building simulations need to run in real time with closed loop control.Very sophisticated digital electronic building energy management systems are available in the market, but more research is needed to show its applicability to different building types and conditions.

Overcoming Barriers

There is a lack of awareness of how data-driven analytics and optimization can reduce energy consumption. Buildings may be equipped with hundreds of sensors and controls, but the data must be used holistically in order to optimize energy usage. Real-time building simulation models are needed, perhaps based on a reduced form building simulation that is not too bulky or unwieldy. Part of the challenge is not knowing what the full potential of these systems are and the full potential may be evolving as new technology is developed. Furthermore, there are concerns about data security and confidentiality. While this may be a lesser concern in the public sector, it is potentially a major issue in the private sector.

Furthermore, these whole building systems need to integrate electricity and natural gas. This is less of an issue with utilities that provide both services, but for utilities with split delivery of electricity and natural gas, developing programs that incentivize these types of measures becomes more challenging.

CHAPTER 5:
Water Heating Research Initiatives

The most recently published California building sector market characterization studies show that water heating exceeds space heating as the largest natural gas end use in buildings when the residential and commercial sectors' usage is combined. The 2009 update to the California RASS now indicates that water heating is the largest natural gas end use in the residential sector (49% of residential natural gas use). According to the 2006 California Commercial End Use Survey, water heating comprises 32% of natural gas use in the commercial building sector. Approximately 43% of all natural gas is estimated to be consumed for water heating across both the residential and commercial building sectors combined, compared with 37% for space heating.

As other components of building systems (such as envelope and mechanical systems) become more efficient, water heating remains an area where significant savings are needed.

The following research initiatives are described in further detail in this section:

- **Research Initiative W1:** Collect and characterize energy use related to water heating across different building types, designs, and vintages
- **Research Initiative W2:** Characterize current hot water distribution systems to support higher efficiency retrofit and design
- **Research Initiative W3:** Develop and demonstrate cost effective high-efficiency water heaters , such as natural gas heat pump technology
- **Research Initiative W4:** Develop low cost condensing water heater technology to bring down costs
- **Research Initiative W5:** Develop and demonstrate cost-effective waste heat recovery for water heating
- **Research Initiative W6:** Develop low-cost, solar water-heating systems with new materials and improved system design

To support many of these initiatives, partnerships with water utilities is important but not current practice. This is partly due to the fragmented nature of the water utility providers across California, making transaction costs high to work with many small water utilities. Additional partnerships with water utilities may offer opportunities for larger savings and will require long term planning.

Research Initiative W1. Collect and Characterize Energy Use Related to Water Heating Across Different Building Types, Designs, and Vintages

Initiative Description

One of the most urgent research needs related to reducing natural gas use for water heating is to better understand how and where energy is used across different buildings in California. Research is needed to systematically obtain and organize data to characterize hot water use and

energy waste in different building types across different water system designs. Real-world data, based on field studies and onsite monitoring, would provide important characterization of the energy flows related to water heating for typical California households. The need for better data can be broken down into the following components:

- **Building type.** More data is needed to understand how hot water is used in commercial and residential buildings. There is a wide disparity in water and energy use between buildings. To better define water heating capacity requirements, the industry needs to know how much water is being used. The energy use data for water heating needs to be broken down by different building types for both commercial and residential.
- **Vintage.** There needs to be more data by age of building; in particular, how people use hot water in newer buildings, since many studies completed to date were focused on older homes and few have focused on commercial buildings.
- **Consumption (end use).** The research also needs to collect data related to fixture units (i.e., hot water demand related to different fixture types) and some fixture specific assumptions. For example, we need revised number of gallons attributed to fixture types and then calculations related to pressure drop in order to adjust the pipe sizing tables to reduce hot water waste.

Issue Statement

Characterization of hot water use in different building types for both residential and commercial sectors has not been significantly revisited in 50 years. There is a lack of information on how hot water is used in different building types, and very little data on how to optimize retrofits and building design by different types and uses.

The lack of water heating data from a systems perspective creates an often ignored but significant barrier to identifying real-world policy needs. Title 24, for example, would greatly benefit from data on how much water is wasted to get warm or how much hot water that fills the pipe after turning off. This type of data would also be useful to update the plumbing code. Both residential and commercial areas have significant needs in this area.

This initiative is closely related to Research Initiative W2, which recommends developing a baseline understanding of loads and use patterns to quantify the benefits of good design related to different building types, designs, and vintages.

Status of Past Research

There is still a great need for market and equipment characterization studies related to water heating. Recent studies with relevant research include some segment characterization but a great deal is missing (see also Status of Past Research section in Research Initiative W2). These past research efforts include:

- A Staff Workshop on Scoping Water Heating Systems for Future Building Energy Efficiency Standards was held at the Energy Commission on Tuesday, July 26, 2013.[56] The transcript of the meeting identifies needed research in both residential and commercial water heating related to updating Title 24. Specific focus areas include integration of tankless and storage tank water heaters with heat recovery systems, research into the energy impacts of intelligent recirculation systems in commercial buildings, pipe insulation benefits, and the performance of high-efficiency and standard-efficiency tankless and storage tank equipment with and without water recirculation for commercial food service applications. The need to study commercial water heating usage profiles in quick service restaurants as well as full service restaurants was identified.
- A project recently completed by PIER: *Residential Water Heating Program Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating* discussed the need for additional research in residential water heating systems[57]. Recommendations based on these findings included:
    - Further study by California utilities is warranted to develop a more robust understanding of performance impacts under different climates and load profiles. This project tested only a sample of the emerging high-efficiency products on the market.
    - Evaluating customer satisfaction of these emerging technologies is an important step in directing future activities. Careful tracking of maintenance needs and the associated costs is needed to better define the overall economics of the different technologies.
    - The Energy Commission and California utilities should stay abreast of emerging water heater technologies. The costs for many of these products should come down in the years ahead as production volumes increase.
    - Evaluate combined hydronic systems as a strategy to improve high-efficiency water heater cost-effectiveness. These systems offer the advantage of utilizing one high-efficiency heat source to provide both space and water heating. New product offerings from several manufacturers are expected in the near term.
    - Direct future Title 24 field research towards better quantifying hot water loads, cold water inlet temperatures in various locations statewide, and also identifying water heater setpoints at several hundred sites. This data can inform how water heating is modeled within the Title 24 code. The data collected here provided a start on that process
- PG&E's Foodservice Technology Center prepared a report on Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities

[56] California Energy Commission. Future Updates to the Building Energy Efficiency Standards. http://www.energy.ca.gov/title24/documents/index.html

[57] http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2013-060, 8.

to characterize water use and improve the efficiency of water heating and distribution in food service.[58] The report found a wide range of efficiencies, as low as 20% to as high as 90%. The most promising opportunities for energy-efficiency retrofits were:

  - Transforming the market to higher efficiency water heaters.
  - Applying optimized distribution systems strategies and moving away from continuous recirculation systems.
  - Decentralizing water heating systems in kitchens by utilizing dishwashers with integrated heat recovery and point-of-use heaters at hand washing sinks.
  - Utilizing waste heat (e.g., refrigerant heat recovery) and renewable energy (e.g., solar thermal preheating).

- LBNL summarized data from 12 different field studies across the U.S. to study the typical hot water use patterns in single-family residences. This study clustered different use patterns into small medium or large median daily hot water use. The analysis showed significant variation with the three different clusters, and higher than expected number of draws per day. Additional research into the start-up losses for tankless water heaters and losses of hot water distribution systems is needed. None of the studies used in this report provided data on the configuration of distributions systems, so additional information is needed.[59]
- Gas Technology Institute (GTI) recently finished water heating research related to quick-serve restaurants and multifamily buildings (based on monitoring and modelling), but characterization of all other building types is needed.
- Oak Ridge National Laboratory published a set of high-priority RD&D activities for water heating systems in 2011. Research into distribution systems by residential and commercial building type is necessary to understand patterns of use and quantify benefits of best practices. Data on distribution systems would enable technology development to further energy-efficient water heating systems.[60]
- DOE published a Commercial Reference Building Model of the National Building Stock, 2011[61] in order to develop a reference for future energy-efficiency research. Reference models may be used to "assess new technologies; optimize designs; analyze advanced controls; develop energy codes and standards; and to conduct lighting, daylighting, ventilation, and indoor air quality studies."
- In 2010, the Energy Commission released the Development of New Testing Protocols for Measuring the Performance of Showerheads.[62] The report found that the majority of

---

[58] http://www.energy.ca.gov/2013publications/CEC-500-2013-050/CEC-500-2013-050.pdf

[59] Lutz, Jim, and Moya, Melody. Typical Hot Water Draw Patterns Based on Field Data. Lawrence Berkeley National Laboratory for Northwest Energy Efficiency Alliance. November 2012.

[60] http://web.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf

[61] http://www.nrel.gov/docs/fy11osti/46861.pdf

[62] Development of New Testing Protocols for Measuring the Performance of Showerheads - Final Project Report. CEC-500-2013-130.

showerheads tested, approximately 65-78%, did not actually meet the specifications for flow rate, force, or coverage. Additional research is needed for manufacturers to redesign and improve products that provide accurate efficiency for real-world building types.

- LBNL conducted a pilot test in 2009 to evaluate the temperature and flow of indoor water use in California residences using wireless sensor network technologies. [63] Three houses were monitored for 22 days at one second intervals. The wireless sensors were successful in testing hot water usage but the study also recommended adding cold water data collection and additional software to manage the large amounts of data collected.

Energy Savings Description

The potential for energy savings is large but difficult to quantify. There are broad benefits to measuring and understanding existing water heating systems in California to quantify savings in the future.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Conduct basic research needed on using low-cost gas and water meters and using data from those meters to establish operating efficiencies. With that information, it will be possible to properly assess energy-efficiency opportunities.
- Provide data needed to update the Uniform Plumbing Code, and characterize buildings by:
    - Building type, vintage, system capacity, and consumption (fixtures), and
    - Real-world data on water system design including pipe insulation, pipe length and diameter, recirculation loops.
- Consider prioritization of the commercial top three buildings (restaurants, health care, and lodging) to understand how these facilities use water.
- Heating equipment. Data is needed to develop a database on how many and what types of water heaters are installed and the associated energy use, along with ancillary building data. This is envisioned to be something similar to RASS, but for water heating.

Overcoming Barriers

One of the biggest challenges is the expense of acquiring additional data and funding development of potential technologies. Although there have been many relevant studies across the U.S., the data are not consistent and are not in formats that are easy to aggregate.

---

http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2013-130

[63] Lutz, James; Peter Biermayer; Derek King. (Lawrence Berkeley National Laboratory). 2009. *Pilot Phase of Field Study to Determine Waste of Water and Energy in Residential Hot Water Distribution Systems.* California Energy Commission. Publication number: CEC-500-2013-135.

Additionally, different directives between stakeholder organizations, such as water, electric and gas companies, prevent integrated appliances. Overall, the focus on end uses operating in buildings inhibits a systems perspective that is needed for reaching the next level of savings. This relates to previous comments that individual equipment efficiencies (e.g., water heaters) are quite high and that whole building perspective and other cross-cutting issues need to be addressed to achieve significant improvements in energy efficiency.

Research Initiative W2. Characterize Current Hot Water Distribution Systems to Support Higher-Efficiency Retrofit and Design

Initiative Description

The majority of water distribution design is based on modelled information, not real-world data. In order to support energy-efficient plumbing design and identify cost-effective water heating energy-efficiency retrofit opportunities, new research should focus on a baseline characterization of current water distribution systems. This area is lagging behind improvements to the efficiency of heating equipment. More real-world data is needed on water system design, including pipe sizes, length of pipe, type of joints and relationship to fixtures, and water consumption.

A basic understanding is needed of how much water is wasted to get warm, or how much water fills the pipe after being turned off. The research should provide data on optimal configuration of piping and alternatives to recirculation systems. More research is needed particularly on how to cost effectively retrofit homes where water pipes are embedded under concrete slabs. This has been common building practice in California, and the heat loss is estimated to be significant.

Issue Statement

Much is unknown about the current state of hot water distribution in residential and commercial buildings. Hot water use is a major energy draw and includes multiple series of components (e.g., boiler, water heater, furnace, pipes, faucets, and showers). A lot of hot water is wasted sitting in pipes; the larger the pipe diameter and length, the more volume of water that cools in the pipe after a hot water draw ends.

Water distribution is both complex and reactive to end users. Interviewees and workshop participants emphasized it was challenging to recommend specific research initiatives related to water distribution design because there was such a critical lack of knowledge about the existing building systems and best practices in new and retrofit distribution systems. Once a baseline of behavior and impact of building characteristics is established, i.e., research that relates to Research Initiative W1, analytical tools could be created to model complete water heating systems. Modeling tools, including water heaters, distribution systems, and interactions between the two, would enable building designers and contractors to evaluate alternative system designs to assess energy consumption as well as cost-effectiveness.

Guidelines and modeling tools have the potential to improve energy efficiency as well as reduce total water use and improve the safety and comfort of the building. Current plumbing strategies

are 70-80 years old and do not focus on efficient system designs. As technologies become more and more efficient, it is important to provide contractors and homeowners with tools and training to ensure that retrofits and replacements optimize whole system efficiency in a particular home or building.

Status of Past Research

Similar to Research Initiative W1, more research in water distribution system design is needed, yet some important studies provide groundwork for further development, (see also the water heating projects mentioned in W1):

- In June 2013, the Energy Commission released the Multifamily Central Domestic Hot Water Distributions Systems PIER report[64] to examine recirculation systems and assess the potential savings from implementing recirculation system controls. The project studied hot water systems in 28 diverse multifamily buildings and found that recirculation system controls can help reduce heat loss. Additional research is needed to optimize design and address branch pipe performance.
- In 2012 the Energy Commission released a Water Heating Design Guide[65] to capture the current, most complete data, advance the current state of knowledge and share best practices. Water heating performance depends on a number of complex issues, primarily:
    - Building design, use points and usage characteristics.
    - Distribution system characteristics (e.g., type, pipe materials, pipe length and diameter, pipe location, and insulation),
    - Water heater type, capacity, and efficiency.
    - Climate, and occupants' hot water use.

  Distribution research in support and coordination with Title 24 is necessary, specifically:

    - Field data collection of distribution system performance in both new and existing homes.
    - Lab testing of alternative distribution system configurations (typical layouts and "improved" layouts) with realistic draw patterns at various use points. The testing would explore the impacts of different flow rates, hot water and environment temperatures, usage patterns and quantities, and behaviors.
    - Validation of advanced distribution modeling tools.
    - Completion of a comprehensive modeling study to assess performance of alternative distribution system configurations on different plumbing layouts with varying usage patterns."

---

[64] Multifamily Central Domestic Hot Water Distribution Systems - Final Project Report. CEC-500-2013-011. http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2013-011

[65] Water Heating Design Guide - Final Project Report. CEC-500-2013-126. http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2013-126

- According to an Enovate Group paper, the existing conditions of central domestic hot water systems (CDHW) are complex, particularly in multifamily buildings. In order to achieve energy-efficiency expectations for individual technologies it is necessary for the whole hot water system to be integrated and this is rarely the case. Some best practices have been recognized, including:
    - Insulation of the recirculation loop,
    - Demand controlled recirculation systems,
    - Optimized recirculation loop design, and
    - Monitored operation. [66]
- Oak Ridge National Laboratory published a set of high-priority RD&D activities for water heating systems in 2011. Research into existing water heating systems and development of "analytical tools to model complex systems" were both listed as high fit with DOE goals and high technical potential. [67]
- In December 2008, the Energy Commission released *Water Heaters and Hot Water Distribution Systems PIER report*.[68] The report developed recommendations for the 2008 Title 24 "included changes to the modeling of tankless gas water heaters, changes to the eligibility requirements for various residential hot water distribution systems, changes to the installation requirements for cross-linked polyethylene parallel piping hot water distribution systems, and changes to the calculation of costs and benefits to include water and wastewater tariffs."
- In December 2008, the Energy Commission released the *Hot Water Distribution System Research – Phase I report.*[69] The report presented results from a survey of Northern California hot water distribution systems and lab testing on common materials and piping. This report provides an important baseline to encourage updates and develop improved design manuals and processes.
- Davis Energy Group prepared the PIER final report on Synergistic Water Heating & Distribution Technologies Program in 2005.[70] The program included four R&D projects, one of which "applied a simulation model to analyze and optimize the design of hot water distribution systems." The model showed that "Continuous recirculation systems waste the most energy of all the systems."

---

[66] http://www.aceee.org/files/proceedings/2012/data/papers/0193-000030.pdf

[67] http://web.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf, 32.

[68] Water Heaters and Hot Water Distribution Systems - PIER Final Project Report. CEC-500-2008-082 http://www.energy.ca.gov/pier/project_reports/CEC-500-2008-082.html

[69] Hot Water Distribution System Research - Phase 1 Final Report. CEC-500-2005-161 http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-161.html

[70] Synergistic Water Heating and Distribution Technologies. CEC-500-2005-111 http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-111.html

Energy Savings Description

The potential energy savings are large, yet difficult to quantify. At the present time, it is estimated that, "[of the] total energy input of a [multifamily CDHW] system, roughly 35% of that energy ends up as usable hot water at the tap, 33% is lost in the recirculation loop, 1% in the remaining distribution pipes, and the rest through inefficiencies by the water heater. After the hot water has been generated, 49% of that heat energy radiates off the pipes and into the surrounding air, most often into [the] unconditioned space."[71] Baseline and characterization research will provide demonstrations on energy loss and savings potential.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Review and consolidate past research from previous studies to collect all available data in order to begin baseline characterization and avoid redundancies.
- Characterize system layout and use patterns from field data to establish understanding of water use and behavior:[72]
    - Analyze load and use patterns,
    - Quantify benefits of good design, and
    - Characterize different distribution system design by residential/commercial category, building type, and vintage (see Research Initiative W1).
- Focus on end-user behavior modification and develop an understanding of water use.
- Research potential areas of design best practices, such as:
    - Integrated system with short piping lengths, minimal bends with low pressure drops.
    - Residential research tends to point toward benefits of pipe insulation additions for existing buildings, and more work is needed to determine details.
    - Design system in a more efficient manner; potential opportunities for retrofits during re-piping.
    - New technologies, such as vacuum-jacketed, stainless steel piping needs more research and funding.
    - Food service and large commercial may be good applications for point-of-service water heating that is commercially available but needs demonstration and support for inclusion in designs and retrofits.
- Develop analytic tools and standard guidelines, such as:

---

[71] http://www.aceee.org/files/proceedings/2012/data/papers/0193-000030.pdf

[72] Recommendations from http://web.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf informed this section

- Developments of software – looking at water systems the same way we look at heating systems; holistic approach, providing plumbers with tools to redesign plumbing system.
- Create modeling packages along with contractor training to implement design and retrofit according to guidelines.
- Develop compact piping design guide in conjunction with leading house designers for subdivisions

Overcoming Barriers

A number of barriers exist in the characterization of water distribution systems. Since the knowledge needs are vast, the funding requirements can be a barrier to acquiring necessary information. There also has not been a critical mass of utility programs to support better hot water distribution system design, comprehensive buildings perspectives or a way to scale advanced distribution controls.

Another barrier is the plumbing industry has been resistant to change in systems perspectives of building and hot water system design. Plumbing contractors have generally little knowledge about impacts on water use. Disseminating information about best practices is a key strategy for transforming the market for energy-efficient water delivery in buildings. Without buy-in from the plumbing industry, building owners face additional barriers to understanding and adopting efficiency improvements they do not understand and may perceive as unnecessary or risky.

Research Initiative W3. Develop and Demonstrate Cost Effective High-Efficiency Water Heaters, such as Natural Gas Heat Pump Technology

Initiative Description

Natural gas-fired heat pump water heaters have been demonstrated to be technically feasible and field tested by GTI.[73] The technology is currently in the process of commercialization. Simple payback for the Northwest was estimated at 4-5 years for the non-condensing residential furnace. Payback for the milder California climate would be longer. Gas-fired heat pump water heater technology could result in significant energy savings for residential and commercial water heating. The focus has most often been electrical heat pumps, but gas heat pumps have potential and should not be overlooked in future research, particularly if energy saving should include source rather than site calculations.

Natural gas-fired heat pump technologies need additional research and demonstration in order to be cost-effective and determine whether they meet NOx emissions limits. For instance, natural gas engine driven heat pump technologies are common in other countries, such as

[73] Garrabrant, M. Gas-Fired Absorption Heat Pumps for Residential Applications. Presentation at ACEEE Hot Water Forum. November 5, 2013. http://aceee.org/files/pdf/conferences/hwf/2011/3B%20-%20Garrabrant.pdf

Japan. Therefore, it would be beneficial to look internationally for a model on how to commercialize the technology.

Issue Statement

The ENERGY STAR specification for water heaters was finalized in April 2008 and effective January 1, 2009. However, none of the existing, commercialized technologies has shown sufficient efficiency improvement to accrue large savings.[74] Advanced and higher efficiency options must be developed and demonstrated in order to take energy savings further and best utilize the program support already available. According to the interviewees and workshop participants, manufacturers need more incentives and support to be able to offer affordable gas heat pump water heaters.

A heat pump uses energy (typically electricity) to transfer heat from a low temperature heat source to a high temperature heat sink. The heat pump requires much less input energy for the same delivered heat than an energy conversion device. An absorption heat pump, also called a gas-fired heat pump, uses heat as their energy source, is commercially available for for the commercial and residential sectors but the cost is very high.[75]

Status of Past Research

The Department of Energy has supported research on advanced gas-fired heat pump technologies for space cooling and heat recovery from water heating. These technologies include absorption based gas fired heat pump, jet injector heat pumps, and engine driven heat pumps.

Other relevant studies and research include:

- Oak Ridge National Laboratory recently studied heat pump research needs finding that:
    - The priorities for next generation water heating technologies include: "absorption heat pump water heater, heat pump water heater with CO_2 refrigerant; air source and ground source integrated heat pump.[76]
- National Renewable Energy Laboratory reviewed five integrated heat pump water heaters for the residential market. The review found that this technology had a high coefficient of performance (COP): "electric resistance water heaters have a COP of nearly 1.0, but HPWHs are expected to provide annual COP values over 2.0".[77]

---

[74] http://web.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf

[75] http://energy.gov/energysaver/articles/absorption-heat-pumps

[76] http://www.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf

[77] http://www.nrel.gov/docs/fy11osti/52635.pdf

- International Energy Agency's (IEA) 2011 "Technology Roadmap for Energy-efficient Buildings: Heating and Cooling Equipment" listed specific goals for a 20% improvement in coefficient of performance (COP) by 2020 and 50% improvement by 2050. IEA also listed development of a hybrid heat pump system with solar thermal as another research priority.[78]

- Valley Energy Efficiency Corp and the Energy Commission developed a report on the Super Efficient Gas Water Heating Appliance Initiative (SEGWHAI) in 2008.[79] Because of large numbers of replacements, close to a million units per year, there is great potential to rapidly improve water heating efficiency. This report focused on developing the market for efficient gas water heaters. Outcomes include the development of a two-tier, performance-based, energy-efficiency criteria for natural gas storage water heaters.

Energy Savings Description

New developments in water heating may achieve additional energy efficiency but require considerable investment. Natural gas, gas-fired heat pump water heaters have been demonstrated to be technically feasible, but are not yet affordable. Therefore developing low cost options could lead to larger energy savings.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Continue field tests and demonstrations to support development of and compliance with new minimum efficiency standards[80] of high-efficiency water heaters besides condensing water heaters, such as natural gas-fired heat pump technology. Note that condensing technology is covered in the next initiative.
- Focus funding on advanced field demonstrations, especially for commercial buildings, which are necessary to scale up technology adoption and overcome awareness and perception barriers. Field demonstrations need to prove appliance efficiency and enable third party verification of energy savings.
- Develop smaller scale, energy efficient water heating technologies for the residential sector that also meets emissions requirements.
- Identify what applications and building types would be most cost-effective for natural-gas heat pump water heater technologies (e.g., by building type).

---

[78] http://www.iea.org/publications/freepublications/publication/name,3983,en.html

[79] Super Efficient Gas Water Heating Appliance Initiative (SEGWHAI). CEC-500-2007-105 http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2007-105

[80] http://www.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf

- Look to international markets and find ways to support introducing technology in the US. For example, consider supporting a contest to show benefits of triple integrated heat pumps, already robust internationally, and develop best product for US market. This may include demonstration projects of Japanese natural gas-fired heat pump products.

- Consider recommendations in the ORNL "Water Heating Technologies Roadmap,"[81] such as the following:
    - Completing feasibility analysis and estimate savings potential for natural-gas heat pump technologies
    - Conducting California-specific "proof-of-concept prototypes" and verify energy projects
    - Engaging manufacturing partners
    - Conducting additional analyses necessary for advanced prototype and refined savings potential
    - Conducting field tests and finalizing product designs.

Overcoming Barriers

Challenges for natural gas heat pump water heaters include technology adoption, high first costs and installation costs. The other barrier for heat pump water heaters are perceptions formed based on bad experiences with older technology that was less reliable than the equipment currently being commercialized.

Research Initiative W4. Develop and Demonstrate Low Cost Condensing Water Heater Technology

Initiative Description

Condensing gas water heaters are well established in European markets and much less so in the California market. Research is needed to support the penetration of cost effective condensing water heaters in the Californian market. Strategies include policy approaches (e.g., through financial incentives to customers from utilities, or minimum appliance efficiency regulation for manufacturers) and technical research to bring down costs.

Issue Statement

Gas condensing water heaters capture waste-heat from the high-temperature combustion by-product gases, instead of venting the gas directly outside.[82] Condensing storage and tank-less water heaters are both available commercially. ENERGY STAR standards for water heaters were put into effect in January 2009 with the goal of increasing sales of high-efficiency water heaters, including condensing storage and condensing tankless water heaters. However, none of the existing commercialized technologies are low enough cost to enable true market

---

[81] http://web.ornl.gov/sci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf

[82] http://www.energystar.gov/index.cfm?c=gas_cond.pr_how_it_works

transformation such that current high efficiency models can be adopted in future standards as minimum efficiency. More advanced and higher efficiency options must be developed and deployed at reasonable price points.[83]

Status of Past Research

Recent research on condensing water heater technologies includes:

- A report by GTI reported an average California household could reduce its annual natural gas water heating consumption by 35% using an advanced water heater combined with an improved distribution piping system. Yet barriers such as low gas prices were also noted. The report provided recommendations for improving the model related to the following:[84]
    - Radiant Heat Transfer: The 2008 HWSIM (hot water simulation software) version utilized a convective heat transfer pipe heat loss model. Integrating radiant heat transfer algorithms to increase accuracy is an important addition to the model.
    - Pipe Heat Loss Validation: Extensive runs were conducted comparing simulated pipe heat loss to laboratory results to confirm the validity of the model.
    - Multi-Run Capability: The original objective was to develop a parametric solver for comparative runs, however significant developmental tasks associated with the water heater integration effort delayed the development of this capability. Batch-run capabilities were developed as a first step toward meeting this objective.
    - Database Result Storage: A database was provided for storing and retrieving discrete results to accommodate the addition of high-fidelity output from the integrated water heater results.
    - Usability: Several changes were made to the user interface to make available the parameters necessary to run the specified piping and integrated water heater models, as well as to simplify the operation.
    - Updated Documentation: Software documentation was updated in conjunction with the upcoming release of the public domain software."
- A study sponsored by the PG&E Emerging Technology Program tested six residential gas water heaters under different load profiles. The Heat Transfer Products Phoenix modulating burner condensing water heater outperformed all of the other units, achieving the greatest efficiency at most levels of use (thermal efficiency 94.8% and energy factor test .833).[85]
- PG&E's FSTC conducted a comparison of water demand and energy use between a standard-efficiency gas-fired, tank-type (storage) water heater and the high-efficiency

---

[83] Navigant. 2011. *Research and Development Roadmap for Water Heating Technologies*.

[84] Kosar, D., P. Glanville and H. Vadnal (Gas Technology Institute). 2012. *Residential Water Heating Program: Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating*.

[85] http://www.etcc-ca.com/images/stories/reswhtestreport1.pdf

(condensing) gas-fired, tank-type (storage) water heater.[86] The study was based on metered data at a chain casual dining restaurant and found that the condensing water heater was more efficient than the standard-efficiency water heater, resulting in annual cost savings of 10%-20%.

Energy Savings Description

In initial estimates, FSTC found the condensing water heater to be 8-15% more efficient than standard-efficiency water heaters. For residential applications, U.S. Environmental Protection Agency (EPA) estimates that the average household could cut water heating energy use by 30% with a new ENERGY STAR qualified condensing model.[87]

Tasks and Next Steps

Research is needed to reduce the cost of condensing water heaters and determine the most economically viable application in different climate zones in order to increase sales volume and market saturation. Specific tasks and next steps to support this research initiative are to:

- Consider recommendations by the PG&E FSTC in their report on hot water heating systems to:
    - Develop design guidelines for water heating systems in commercial food service.
    - Include monitoring and verification for advanced water heating projects to support incentives for high-efficiency systems and applications (e.g., condensing water heaters for commercial applications).
- Provide demonstration and cost effectiveness case studies for advanced water efficiency measures in the restaurant sector; particularly related to system optimization and integration of condensing water heaters, time clocks on recirculation pumps and waste heat recovery.
- Research how to bring costs down for condensing tank-type water heaters, including complexities of installation.
- Identify areas where condensing water heaters are a least cost option (i.e. situations where flue venting must be replaced or sealed combustion is desirable for indoor air quality issues or the water heater is brought into a conditioned space.
- Suggest opportunities for bringing costs down through efficiency program initiatives

Overcoming Barriers

High first cost and low sales California, possibly as a result of difficulties of payback in a warm climate, are considerable barriers with condensing water heaters. Key changes in new Title 24 code should help reduce installation issues as a barrier to increased sales. The Title 24 change may not necessarily increase installations if first cost is not addressed through economies of

---

[86] http://www.fishnick.com/publications/fieldstudies/Commercial_Water_Heating_Systems.pdf

[87] http://www.energystar.gov/index.cfm?c=gas_cond.pr_savings_benefits

scale or utility rebates: "Gas or propane water heater installations in new homes are required to have an electrical outlet near the water heater (to power a future combustion air fan or vent damper), a venting system that can accommodate a condensing water heater and a condensate drain for future condensate removal."[88]

Research Initiative W5. Develop And Demonstrate Cost-Effective Waste Heat Recovery for Water Heating

Initiative Description

Waste heat recapture for water heating could be potentially integrated in residential and commercial buildings and is a specific type of heat recovery versus what was previously introduced in Research Initiative O3. For residential buildings, drain heat recovery from shower systems has potential as shown by Canadian experience. Demonstrations of drain water heat recovery across different climate zones, applications and piping configurations are needed to assess the viability and cost-effectiveness of the technology to California.

Issue Statement

Waste heat recovery captures energy that otherwise would be vented and lost, such as from hot waste water, and transfers the energy to water streams that have heating demand. Drain water heat recovery systems capture heat from water going down the drain after the heated water is used for another purpose such as showering, clothes washing, or dishwashing. Residential, commercial, and institutional installations are feasible.

Although gaining popularity in Canada, drain water heat recovery has not been adopted in the United States. Test procedures for rating drain heat recovery systems are available in Canada. One reason for its popularity in Canada may be the inclusion of drain water heat recovery in ENERGY STAR for New Homes. In contrast, there are no ENERGY STAR products or specific credits in residential new construction programs for drain water heat recovery systems in the U.S. Additionally, there is little available demonstration data and analysis of applicability to the California market. The purpose of field-testing in a range of climate zones across California would be to demonstrate the potential and cost-effectiveness of the technology.

The technology is under consideration for the 2016 Title 24 building efficiency standards with likely updates or expansion of requirements in the 2019 efficiency standards. Though standards are progressing, there needs to be measured performance data to characterize how technologies like heat exchangers perform.[89]

---

[88] http://www.energy.ca.gov/title24/2013standards/res_compliance_manual/Chapter-5_Water_Heating_Requirements.pdf

[89] Collins, Michael R., Van decker Gerald W.E. and Joel Murray. "Characteristics Effectiveness Curves for Falling-Film Drain Water Heat Recovery Systems." HVAC & R Research 19, no. 6 (2013): 649-662. Doil: 10.1080/10789669.2013.796857

For commercial buildings there are opportunities for drain water heat recovery in commercial kitchens and restaurants (common in Europe) from dishwashers, along with coil wrapped around drain pipe and whole building heat recovery.

Status of Past Research

There has been limited research on the potential of waste heat recovery in the US, but a number of projects internationally provide useful information for developing this technology.

- Internationally there has been research into the specific potentials of waste heat recovery, with significant progress in Canada and China. An online drain water heat recovery energy savings calculator is available (http://www.ceati.com/calculator) for Canada. In 2007, a Canadian firm produced a characterization report of drain heat recovery devices on the market. The report found that there was an optimal balance between performance and size of piping, in that shorter pipes perform best on a per foot basis.[90]
- One paper reviewed characteristics and applications of waste heat recovery technologies in China (e.g., heat transfer utilization, power generation technologies, refrigeration and heat pump, and organic Rankine Cycle systems).[91] Another paper evaluated shower water heat recovery with instantaneous water heaters in high-rise residential buildings of Hong Kong. Shower usage patterns and water temperature were significant factors in determining savings.[92]
- A study conducted in Ireland focused specifically on horizontal drain heat recovery. The paper discussed the development and testing of a horizontal drain water heat recovery system for domestic showers.[93]
- The U.S. DOE Industrial Technologies Program developed a road map for industrial waste heat recovery that catalogues variations and combinations of waste heat recovery technologies. These technologies have potential applicability to the commercial and residential sector with additional research and development.[94]

Energy Savings Description

Waste heat recovery is recognized as an important tool for saving energy, lowering energy consumption and reducing pollutants. In order to achieve savings, considerable investment in product development is required since retrofit and new installation technologies are not commercially available.

---

[90] http://gfxtechnology.com/NRCAN-6_29_07.pdf

[91] http://en.cnki.com.cn/Article_en/CJFDTOTAL-JNJS201102007.htm (2011)

[92] http://www.sciencedirect.com/science/article/pii/S0306261909003225

[93] McNabola, A. and K. Shields. Efficient drain water heat recovery in horizontal domestic shower drains. Department of Civil, Structural & Environmental Engineering, Trinity College Dublin, Ireland (July 2012)

[94] https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Test and validate waste heat recovery equipment to demonstrate savings, reliability and overall performance across different building types and climate zones. Field testing is needed to demonstrate the potential and cost-effectiveness of drain heat recovery.
- In the commercial sector, consider creating a prototypical "restaurant of the future" as a test facility in order to get the baseline of energy wasted and provide space for a variety of waste heat recovery demonstrations.
- Look to international markets and find ways to support introducing technology in the US.

Overcoming Barriers

A key barrier identified is that the technology is new to the California market, and it is unclear how cost-effective it is for the California climate zones. Contractors and building owners lack familiarity and understanding of how drain heat recovery systems work and the benefits. Therefore, demonstration projects and more localized data to California would help determine cost effective applications.

Research Initiative W6. Develop Low-Cost Solar Water Heating Systems using New Materials and Improved System Design

Initiative Description

Solar water heating works in a wide variety of climates and may include enhanced cooling, solar ventilation preheating, and solar water heating. Developments in new design and materials are necessary to reduce costs to an acceptable price point. Lower-cost materials with similar conductive properties to high cost copper and glass are needed.

New materials would enable development of specific water heater design that has potential for energy savings. A solar thermal system with a gas component is another area that could be further developed with lower cost materials. Research on thermal storage as a part of solar thermal water heating systems could also help to achieve additional savings.

Issue Statement

The technology exists for solar water heating yet the high initial first cost creates a barrier to widespreaduse. Research is needed to reduce the capital cost of these systems through development and demonstration of systems using lower cost materials.. International policy examples, such as solar generation in high rise residences in China, need to be further researched for application in California.

In the commercial sector, some companies (e.g., Suncatch collector), are working on developing low cost solar systems and some residential pilots have been done. However, solar water

heating technologies are perceived to only be available at a high cost ($5,000–$10,000 installed for typical homes)[95] making commercialization practically impossible.

Status of Past Research

There have been some reports on low-cost solar systems:

- Radically new designs with much lower costs (<$2000) are required to make solar domestic hot water (SDHW) systems cost-effective. A SDWH roadmap is under development by the National Renewable Energy Laboratory (NREL). NREL has set a cost goal of $1,000-$3,000 total installed system cost for existing homes at large market scale.[96].
- A demonstration project evaluated in-situ performance of a solar collector (or an array of collectors) and storage tank in two multifamily residential sites and six single-family residential sites. It was least effective in early morning hours and late nights and more effective in summer than in winter. The demonstration found that single family applications, without a rebate, had payback periods too long to make the unit a cost-effective option (77 years/ Los Angeles, 139 years/San Francisco. and 190 years/San Luis Obispo). In contrast, the multifamily payback was approximately 28 years due to the reduced labor installation costs and higher gas savings potential.[97]

Energy Savings Description

Affordable solar thermal energy generation has potential to reduce natural gas used for water heating by 50%.[98] The technology is an important tool for saving energy, lowering energy consumption and reducing air emissions, such as NOx.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Further develop specific components such as:
    - New collector technology,
    - Entire system and distribution layout,
    - Controls
    - Weatherproofing,
    - Materials for collectors.

---

[95] Energy Commission staff note that this estimate appears too high, and that costs should be down to $3,000 to $6,000 with mass market prices potentially being as low as $3,000.—what's the basis of these cost?

[96] http://www.nrel.gov/docs/fy12osti/54793.pdf

[97] http://www.etcc-ca.com/images/suncache_final_report_2-28-11_body_only.pdf

[98] U.S. EPA ENERGY STAR. http://www.energystar.gov/certified-products/detail/water_heater_solar

- Develop and demonstrate technologies to replace conventional solar collector materials such as copper and glass with new polymers that have similar conductive properties in order to reduce manufacturing costs and weight.
- Develop water containment technologies to have low-weight, compact products to install in attics.

Overcoming Barriers

There are still technical and market barriers impeding the commercialization of more efficient, low cost equipment and distribution systems. Development of new technologies using low cost materials, field tests and demonstrations to verify performance and cost effectiveness and support for new minimum efficiency standards development are needed to overcome these barriers. Other challenges are difficulty in moving water from panels on the roof through the rest of the building, and high installation costs.

CHAPTER 6:
Space Heating Research Initiatives

Natural gas consumption for space heating constitutes about 37% of residential and 36% of commercial building of total gas use. It is the second most significant natural gas end use after water heating for all buildings. The technologies that impact space heating energy usage are related to the heating equipment itself, the distribution system (e.g., ducts), and the building shell (e.g., insulation). Much of the existing building energy-efficiency research encompasses heating, ventilation and cooling systems as a whole with a significant focus on electricity savings.

The research topics mentioned by industry experts ranged from heating equipment technology to the need for optimal fresh outside air reheating and building envelope systems. Since space heating equipment is already available at high efficiencies, the recommended research initiatives focus on improving the overall systems and installation practices. However, high-efficiency furnaces cannot be economically justified for use in mild climates, and are not widely installed in commercial spaces. Other important research issues were related to sizing equipment appropriately (not over-sizing), installing heating units properly, placement and sizing of ductwork, and reducing duct leakage. Gas-fired technologies for space cooling are

The following research initiatives are described in further detail in this section:

- **Research Initiative S1**: Conduct research related to quality installation issues for HVAC systems
- **Research Initiative S2**: Develop and demonstrate more efficient air distribution design
- **Research Initiative S3**: Support research to reduce ventilation requirements
- **Research Initiative S4**: Conduct research related to controls for both individual equipment, as well as whole building
- **Research Initiative S5**: Evaluate potential cost-effectiveness of solar thermal space heating and cooling
- **Research Initiative S6**: Develop and demonstrate cost-effective under-floor and other hydronic heating options
- **Research Initiative S7**: Develop and demonstrate cost-effective and energy efficient, condensing packaged rooftop heating units for commercial applications

Note that a gas-fired heat pump research initiative is covered in Chapter 5, under water heating, although it provides space heating benefits as well. It is not listed as a separate research initiative in this chapter.

Research Initiative S1. Conduct Research Related to Quality Installation Issues for HVAC Systems

Initiative Description

Many industry experts emphasized the importance of more research related to installation practices for HVAC systems and ensuring that efficiency ratings reflect real-world installation

practices. More lab and field research is needed to demonstrate how HVAC systems are actually installed and how this can affect the efficiency of the equipment installed.

Other new approaches could include developing a home performance principles framework that could be used to incentivize quality installation, using set parameters and design targets for HVAC installation equipment size and types. Research should be conducted to quantify the potential energy and economic savings resulting from improved installation practices.

Issue Statement

HVAC installations involve a number of different components that must be properly designed and installed. There are also issues related to the efficiency ratings and the lack of verification of actual field performance. For instance, residential natural gas furnaces are sometimes delivered and installed with the air flow rate in heating mode set to the lowest rate. Therefore, the rating methodology and infield operations are different. Without field data, it is unknown what efficiency is actually achieved in the field for different furnace efficiency ratings.

As noted in the Department of Energy's (DOE) Building Technologies Program, 2012 Measure Guideline, proper installation also includes considerations for duct distribution systems, gas piping, vent system, and more.[99] The Energy Commission's *Measured Home Performance Guide to Best Practices for Home Energy Retrofits in California*[100] (Measured Home Performance Guide) provides some design parameters (e.g., duct leakage less than 25 cubic feet per minute (CFM)) and check numbers (e.g., rule of thumb of 1000 square feet per ton). More focus should be placed on the natural gas consumption side and the information could be put into a framework used to develop utility programs and other incentives for implementing best practices.

The Air Conditioning Contractors of America publishes standards for HVAC design, distribution, equipment installation, and system documentation/owner education aspects.[101] These standards, along with building codes and energy-efficiency programs would both support and benefit from research regarding improving installation practices.

Status of Past Research

A large amount of research has been done to evaluate the quality of installations, in order to increase efficiency of HVAC equipment. These include:

- In 2010, the California Public Utility Commission reported low installation rates in the duct sealing programs. Homes that received a duct sealing rebate were verified to ensure the measures were "installed and working properly." Depending on the utility

---

[99] http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/highefficiency_gas_furnaces.pdf (Page viii)

[100] Chitwood, Rick and Harriman, Lew. 2011. Measured Home Performance: A Guide to Best Practices for Home Energy Retrofits in California. Prepared for the California Energy Commission. http://www.measuredhomeperformance.com/pdf/BestPracticesGuide.pdf

[101] http://www.energystar.gov/ia/home_improvement/home_contractors/qispec.pdf

program, only 38 to 54% of tested systems passed the verification and had leakage below 15%. They note that the program simply rebates completed jobs, offering little incentive to promote high quality installations.[102]

- The Energy Commission's Measured Home Performance Guide[103] describes best practices which have provided homeowners with measured energy savings after retrofits.

Additional research can document the performance issues and potential gains with proper installation. This could be used to support incentives for better installation practices.

Energy Savings Description

By demonstrating the energy savings realized through improved installation practices, research can target improvements in specific sectors, demographics, and geographic regions. This effort has the potential to lower energy consumption through the development of standards and best practices.

According to EnergyStar.gov, duct leakage can account for a 15% loss in heating in a typical furnace, improper sizing can account for another 5% loss and improper air flow can account for another 3% loss.[104] These proprotions are also comparable for cooling.

The measures outlined in the California Energy Commission's Measured Home Performance Guide are aimed at achieving significant energy reductions of 40 to 60% of annual heating and cooling costs, which includes increasing the efficiency of the heating and cooling equipment, reducing the heating and cooling load, increasing insulation and other measures in addition to improving the quality of the HVAC system installation.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are:

- Lab and field research to demonstrate the ways that HVAC systems are installed and operated in the real-world and how both are not optimizing the efficiency of the equipment installed.
- Understand installation practices that impact the real-world efficiency performance of HVAC systems and why energy ratings are not achieved.
- Quantify the energy losses incurred from installing furnace and ductwork in the attic
- Define best practices for multifamily buildings and townhouses for insulating and sealing between units. Consider the benefits of sealing interstitial spaces.

---

[102] http://www.calmac.org/publications/Vol_1_HVAC_Spec_Comm_Report_02-10-10.pdf (Page 15)

[103] http://www.hersratingservices.com/uploads/BestPracticesGuide_12_01_10_indd_-_Newest_Version.pdf

[104] http://www.energystar.gov/index.cfm?c=hvac_install.hvac_install_index

- Design a credit-based approach to meeting various requirements, incentivizing measures such as improved filtration and frequent filter replacement or cleaning
- Develop a home performance principles framework that can be used for utility energy-efficiency programs and overall best practices. Current home performance programs focus on HVAC and envelope measures

Overcoming Barriers

According to the Energy Commission's Measured Home Performance Guide, "Best practices are not usually simple to execute. Large energy reductions and comfort improvements require redesign and reinstallation of a home's HVAC system along with extensive air sealing and insulation."

There are few incentives in place for installers to follow best practices for energy efficiency. The industry is driven by the practice of offering the lowest cost possible rather than the best installation. Furthermore, heating and cooling using combined gas and electric HVAC systems are usually optimized for cooling requirements.

Research Initiative S2. Develop and Demonstrate More Efficient Air Distribution Design

Initiative Description

More research is needed to quantify the potential energy and economic savings resulting from improved air distribution design. This includes research related to correctly sizing and insulating duct work, duct sealing, and design considerations for installing ductwork in conditioned spaces. Research is needed to better understand how new construction practices ultimately affect duct leakage, given that duct testing occurs before the building is completely closed up. Little research has been done on whether (and to what extent) ducts are damaged and new leaks introduced after the ducts are tested. This initiative will also demonstrate and evaluate different methods of bringing HVAC systems into conditioned spaces with a focus on feasibility, cost and ease of application associated with retrofits. Potential technologies include Structural Insulated Panels (SIPs), cathedral ceilings, and ductless systems (radiant panels, etc.).

Issue Statement

Distribution-based inefficiencies are due to both inefficient distribution designs and poor-quality installation practices. Convective and leakage losses account for approximately 30% of losses from HVAC systems. One key issue is that existing ductwork is not a regulated item; when ductwork is too small it restricts air flow, increases static pressure and reduces flow across the heat exchanger, which reduces overall HVAC system efficiency. Furthermore, while duct sealing programs exist, it is not clear that the work is actually targeting the areas where most of the leakage is happening.

Reducing duct leakage to the outside can be done by altering the distribution system design. One example of an adapted design would be to put ducts inside the conditioned space within the pressure boundary. Even with sealing, ducts can lose up to 20% of energy through small

leaks and minimal insulation and placing ductwork in conditioned space is a design option that requires getting builders, especially residential, and the trade organization comfortable with the design process. This could potentially be a relatively near-term strategy, as the key challenges are related to implementation, rather than the need for additional research. Additionally, advancing the use of products such as aerosol sealant will help reduce duct leakage. Little is known about how construction practices introduce leaks in the duct system. For instance, in new construction, the ducts are sealed before the walls are closed up, but afterwards subsequent work can crush ducts or punch holes into them.

HVAC systems that are entirely inside of conditioned space not only save significant amounts of energy, they also are more robust than HVAC systems which rely on long term integrity of duct systems in unconditioned attics. As a result this is one of the key measures under consideration for the 2016 version of the Title 24 building efficiency standards for residential buildings.

Status of Past Research

- The Building with Ducts in Conditioned Spaces project is funded by the U.S. DOE and Northwest Energy Efficiency Alliance (NEEA) and provides implementation strategies and resources such as a "Ducts Inside Conditioned Spaces Training Manual," resource guides for six different approaches to building with ducts inside conditioned spaces, PDFs of computer-aided design (CAD) drawing and case studies.[105]
- The Home Builders Guide to Ducts in Conditioned Space[106] was completed in 2003 and provides detailed descriptions of construction techniques that production home builders will need to successfully locate duct systems in the conditioned space. The Guide is a product of a three-year research project that included testing of 18 homes with the duct installed using one of three different approaches: dropped ceiling, unvented conditioned pitched attics and attic plenum.
- The US DOE has studied the performance and potential of several products and practices, many of which are not new to the market. The study reviews aerosol duct sealing, demand-controlled ventilation, placing ductwork in conditioned space, and duct-leakage diagnostics.[107]
- The Energy Commission's Energy Efficient Low Income Housing Program report calculated leakage in four houses that had moved ductwork into conditioned space. The study states that "although the rationale of locating ducts in a conditioned space is apparent, many of the details are not well understood by California installers. In practice, any of the methods for placing ducts in conditioned space requires a change in

[105] http://www.ductsinside.org/

[106] http://www.energy.ca.gov/2003publications/CEC-500-2003-082/CEC-500-2003-082-A-16.PDF

[107] http://www.aceee.org/files/proceedings/2012/data/papers/0193-000072.pdf (Page 3-70)

usual construction, design and practice." The study examined a few different interior duct system designs.[108]

Energy Savings Description

By demonstrating the energy savings realized through system efficiency upgrades, the potential reduction in duct leakage to the outside of the thermal envelope air will be better understood. This research has the potential to lower energy consumption through the development of standards and best practices.

One report by the Energy Commission's Energy Efficient Low Income Housing Program found that installing ducts in conditioned spaces reduced leakage into unconditioned space from 1.1% to 23.6% , compared to homes with conventional flex-ducts. According to the report, "the average annual energy savings from reduced air leakage and heat conduction are estimated to be 19.7% of heating energy."[109]

According to a project sponsored by DOE and NEEA, designing and building homes where HVAC ducts and air handlers are located inside conditioned spaces can reduce energy use by 15 to 20% compared to typical HVAC installations.[110]

Tasks and Next Steps

Specific tasks and next stepsinclude:

- Collect data on existing building distribution design to characterize the market and identify how many duct systems are in unconditioned space. This data would improve understanding of the potential energy savings resulting from improved air distribution design in California. This includes research related to correctly sizing ductwork and placing ducts in conditioned space.
- Assess duct sealing practices in both new construction and existing buildings.
- Conduct market research to understand barriers to installing ducts in conditioned space, roof deck insulation, and sealing attics including:
    - Demonstration of new technologies or approaches to bring ducts inside conditioned spaces. Demonstrations will include new construction examples and retrofit examples
    - Developing a design guide for ducts in conditioned space
    - Developing an installation guide for ducts in conditioned space for contractors
    - Evaluate and compare options based on performance and cost effectiveness by climate zone.

---

[108] http://www.energy.ca.gov/2007publications/CEC-500-2007-017/CEC-500-2007-017.PDF (Page 2)

[109] http://www.energy.ca.gov/2007publications/CEC-500-2007-017/CEC-500-2007-017.PDF (Page 2)

[110] http://www.ductsinside.org/

Overcoming Barriers

Any of the methods for placing ducts in conditioned space require a change in training and usual construction design and practice. The building industry does not fully recognize the potential savings associated with ducts and entire HVAC system (eliminating effects of leakage of the furnace and airhandler as well the ducts) inside the conditioned space. Barriers include uncertainties associated with new design methods, including cost impacts. New truss designs may be needed with some adjustments to design processes and new approaches related to construction and sealing of duct changes are also required. There may be aesthetic and sound transmission concerns related to ducts in conditioned spaces that need to be considered.

Research Initiative S3. Support Research to Reduce Ventilation Requirements

Initiative Description

With some types of furnaces reaching near maximum appliance efficiencies of 98% AFUE (annual fuel utilization efficiency), many of the efficiency improvements available to space heating end-uses lie in improving air distribution and ventilation system design. As we improve the building envelope to reduce infiltration and exfiltration, more research is needed on how different contaminants impact indoor air quality, since this impacts the amount of heating energy required to provide additional ventilation of outside air at appropriate temperatures.

Research should identify materials that are relatively inert to enable buildings to be sealed up safely and minimize unnecessary air change requirements. This may include identifying an optimum tradeoff between sealing the building to reduce the load and adding ventilation requirements that increase the gas consumption for space heating.

Issue Statement

Unless they are built with means of filtered mechanical ventilation, outdoor air leaks may have higher pollutant levels than those in the home. However, because some weather conditions can drastically reduce the amount of outdoor air that enters a home, pollutants can build up even in homes that are normally considered leaky.

As new construction improves to minimize leakage to control energy loss, these buildings (including homes) need mechanical ventilation to remove pollutants generated in the home and provide outdoor air in a controlled manner. ASHRAE 62.2 standards provides procedures for determining whole-house ventilation rates, including requirements for exhaust ventilation for kitchens, bathrooms, and other point sources (e.g., clothes dryers and venting for fuel-burning appliances).[111]

[111] http://www.epa.gov/iaq/homes/hip-ventilation.html

Status of Past Research

A substantial amount of research has been done related to ventilation requirements and indoor air quality.

- A study sponsored by the Energy Commission and the California Air Resources Board, "Ventilation and Indoor Air Quality in New Home," found that newly built single-family homes in California had significantly elevated levels of air contaminants such as formaldehyde. The study recommended additional consideration be given to the installation of mechanical outdoor air ventilation systems in new single-family homes, estimating additional operating costs to amount to $100-$300/year for fan energy and makeup air heating and cooling. This study based on a sample size of 63 homes, established a number of methods to measure indoor air quality while considering the relationships of window/door ventilation, mechanical ventilation devices, home leakage, and indoor air contaminants.[112]
- A follow-up study was conducted in 2008 to increase the sample size to 108 homes. Of these, 54 were in Northern California and 54 were in Southern California. Newly built single-family homes have minimal infiltration and exfiltration, and many homeowners do not open their windows allowing for natural ventilation, resulting in outdoor air exchange rates below the minimum 2001 California Building Code 1205 code requirement. The study cites good performance of heat recovery ventilators, and relatively poor performance of ducted outdoor air systems, and notes the contaminants that most frequently exceeded guidelines were formaldehyde, acetaldehyde, and benzene. In addition, the study recommends considering regulations to limit emissions of air contaminants from building materials. Finally, the study suggests further research be conducted to target additional sources for potential indoor formaldehyde reduction, develop a better understanding of the health impacts from inhalation of contaminants, and confirm the findings in this study and with consideration of other building factors.[113]

Energy Savings Description

As we improve the building envelope to reduce infiltration and exfiltration, improving indoor air quality has the added benefit of reducing the amount of heating energy required to provide additional ventilation of outside air at appropriate temperatures.

Tasks and Next Steps

Specific tasks and next stepsinclude:

---

[112] Offerman, F. (Indoor Environmental Engineering). 2008. Indoor Air Quality in New Homes: California Energy and Air Quality Conference Recent Research for Decision Making.

[113] Offerman, F., J. Robertson (Indoor Environmental Engineering), S. Brennan and D. Springer (Davis Energy Group). Undated. Window Usage, Ventilation, and Formaldehyde Concentrations in New California Homes: Summer Field Sessions.

- Research to determine the effectiveness and energy impacts of mechanical ventilation practices provided in new homes built to the 2008, building efficiency standards. Identify different approaches to meet indoor air quality standards that reduce the amount of energy required for ventilation while maintaining good indoor air quality.
- Research better controls for managing indoor air quality.
- Support ARB and other research on how different building materials impact indoor air quality and identify materials that are relatively inert.
- Support development of residential construction methods that reduce or eliminate building component generated contaminants, such as:
    - Developing test methodologies and criteria for different pollutants, and
    - Developing a pollutant simulation model, calibrated against measured data from homes of different construction practices.

Overcoming Barriers

There are many challenges to addressing indoor air quality issues at the source material, such as measuring a broad range of pollutants across many different building components. Furthermore, entrenched building materials with toxicity issues may resist findings and may not have readily available alternatives.

Some of these strategies to reduce ventilation requirements and duct leakage require education and outreach to the design community and HVAC contractors.

Research Initiative S4. Conduct Research Related to Controls for Both Individual Equipment, As Well As Whole Building

Initiative Description

Robust controls have been established for electric end uses, but are less commonly utilized for appliances powered by natural gas. Research and demonstration projects are needed for integrating natural gas controls into a building's systems. The integration would reduce idle operation, improve equipment-to-equipment communication, introduce appliance-level consumption data analytics, and apply diagnostic testing to reduce equipment failure rates and lead time on equipment repairs. Another goal is to develop HVAC controls best practices for heating sequences in general to address issues related to simultaneous heating and cooling. Cost-effective controls need to be developed, tested and demonstrated so that end users are aware of their value and reliability.

Issue Statement

Building controls address safety, health, comfort, and energy-efficiency needs. With the coincidence of cooling load and peak demand, efficiency gains through controls have historically been applied to cooling applications. They have been used much less commonly for heating systems and buildings with EMS still have simultaneous heating and cooling in different zones. Controls in a whole-building approach give building owners the opportunity not only to improve heating efficiencies, but also to maximize cross-cutting benefits. The Energy Commission noted the importance of cross-cutting benefits, such as low-energy buildings, in their 2013-2014 Energy Efficiency Research Funding Request, as a focus area in Buildings End-

Use Energy Efficiency Research.[114] This report encourages continued investment in this area. Controls will give building owners the tools needed to avoid needless losses in space heating efficiency.

Simultaneous heating and cooling in buildings commonly occurs in commercial buildings due to a lack of controls and system communication. One example is restaurants when the dining area needs to be heated and the kitchen needs to be cooled. Another needless efficiency loss occurs when makeup air and HVAC equipment operate on separate controls. These system inefficiencies are easily preventable when operated under a common control. Furthermore, if performance data can be collected, usage patterns can be analyzed and diagnostic testing can be incorporated. These diagnostic tests could alert end users of inefficiencies and pending equipment failures, reducing downtime and the need for expensive emergency repairs.

Status of Past Research

Two major studies were identified by this report that studied boiler controls.[115] One was developed by Sabien Technology Group and another by Greffen Systems. The studies evaluated the benefits of an advanced boiler microprocessor controller designed to optimize the efficiency of a hot water boiler system. The controller is designed for maintaining optimal heating for human comfort application in commercial buildings.

Energy Savings Description

Controls have the potential to save energy simply through increased and intelligent appliance scheduling, but also in the ability to create a building-wide, coordinated system. Interaction of appliances can reduce overlapping operation, and also create opportunities to control the capture and distribution of excess heat.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Develop and complete demonstration projects of controls that will:
    - Reduce idle equipment operation
    - Enable equipment-to-equipment communication
    - Regulate register activity based on occupancy levels
    - Detect HVAC equipment faults, such as non-functioning economizers
    - Integrate kitchen exhaust with HVAC use
    - Collect consumption data and use adaptive algorithms
    - Improve fault diagnostic detection, such as HVAC operation/performance issues

---

[114]The Natural Gas Research, Development, and Demonstration Program – Proposed Program Plan and Funding Request for Fiscal Year 2013-14, 16.

[115] http://www.etcc-ca.com/reports/m2g-control-system-assessment
http://www.sabien-tech.co.uk/products/m2g

    - Be easy to operate and can be used through multiple applications, such as PCs, tablets and smart devices.

- Develop HVAC controls best practices for heating sequences to improve energy efficiency

Overcoming Barriers

One of the most substantial challenges with implementing controls for gas appliances will be minimizing the impact of the user experience. Building operators are most concerned that appliances and equipment function as intended. If controls reduce ease of use but increase energy performance, they will not be successful in the market. Training is important to ensure maximizing the functionality of controls.

Research Initiative S5. Conduct Research for Solar Thermal Space Heating and Cooling

Initiative Description

More research related to solar thermal space heating is needed, particularly related to solar thermal storage and solar ventilation preheating, which preheats ventilation air entering the building. The scale for these systems may require starting with residential systems and integrating them with ZNE designs. Solar thermal storage is a technology that captures heat throughout the day and distributes that heat at night. With the addition of gas-fired cooling this technology could serve all HVAC needs for a ZNE home. While the technology's potential has been proven through research and field testing already, additional research is needed to identify standardized tank sizing and insulation requirements and take into consideration the rapidly decreasing costs of photovoltaic electricity generation. An additional consideration is the potential for use across multiple end-uses and combined heat and power. These may be substantial, but should be identified more comprehensively.

Solar ventilation preheating is a technology that is simple, proven, cost-effective and applicable to large offices, warehouses, garages, hangars and other commercial buildings. The system consists of dark colored or glazed panels that absorb solar radiation. Ventilation air is preheated when it passes through tiny holes in the panels and connected to the existing building HVAC system. Research is recommended to streamline the estimation, design and installation processes for different building types and develop a database of successful projects and best practices.

Issue Statement

As building designers, occupants, and owners strive for increased renewable and building integrated technologies, solar thermal space heating may become more common, especially if

introduced in the initial design stage.[116] Traditional heating demand peaks at night while solar energy potential peaks during the day. Array-based solar thermal systems have been designed and are available for hot water heating. These systems are most widely used in pools. As seen in Chapter 5, solar water heating systems have a very low penetration (less than 1%) of the market. Nevertheless, within the past several years, additional research has explored the opportunity of applying solar thermal to space heating.

Another promising technology is "solar ventilation preheating systems that consist of a transpired panel and duct system which preheats ventilation air entering the building. Wall or roof mounted, dark colored or glazed panels absorb solar radiation, and pass the thermal energy to ventilation air the panels through tiny holes. A duct with a blower connects the panels to the existing building HVAC system and delivers ventilation air up to above ambient, reducing or eliminating the need for conventional ventilation air preheating." [117]

Status of Past Research

Throughout colder climates, such as Alaska, Canada, and much of Europe, solar thermal research has been conducted in earnest since the early 2000s. Research in mild climates is limited. The Alberta Research Council Inc. developed and tested a cost-effective thermal solar collector with direct heat storage in 2000.[118] Research has established the potential for transferring daytime solar energy potential into evening heating demand and explored various solar capture, and storage materials and techniques to optimize efficiency.

The lack of coincidence of daytime solar energy potential with heating demand is clear. **Figure 7**, below, is a figure from a Cold Climate Housing Research Center report that shows, in blue shading, when available solar energy coincides with heating demand. The shading is only able to meet a small percentage of the demand.

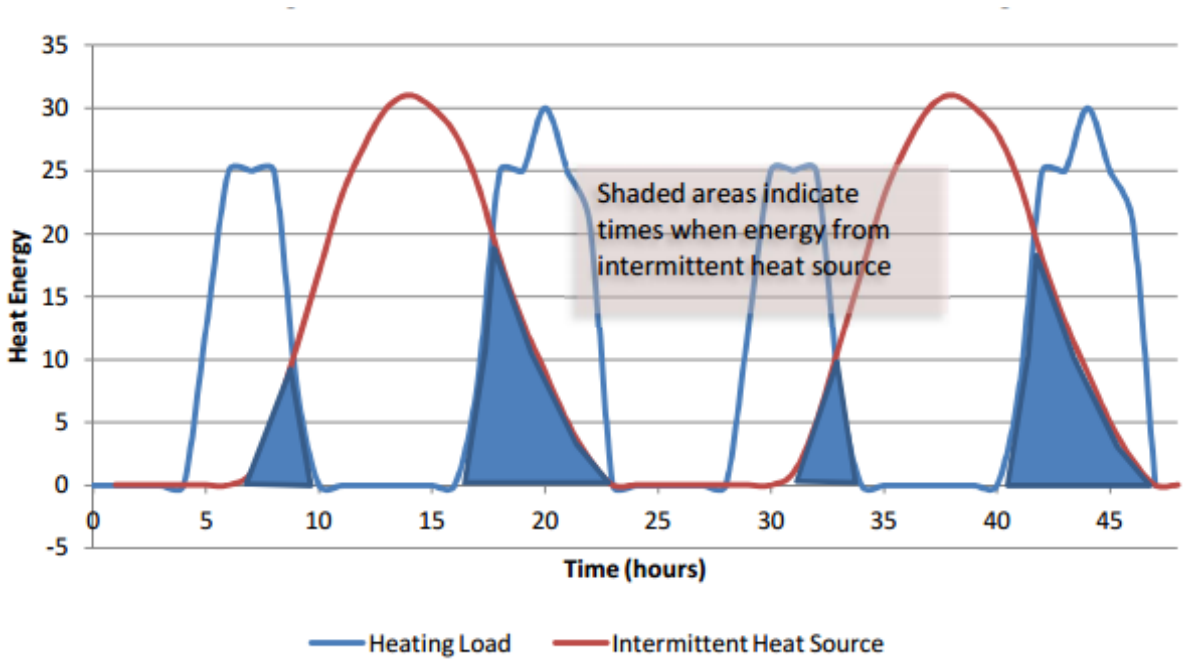
---

[116] U.S. DOE Energy Efficiency and Renewable Energy Building Technologies Program. Energy Savings Potential and RD&D Opportunities for Building HVAC Systems. Study conducted by Navigant. September 2011.

[117] U.S. DOE Energy Efficiency and Renewable Energy Building Technologies Program. Energy Savings Potential and RD&D Opportunities for Building HVAC Systems. Study conducted by Navigant. September 2011. (Page 59)

[118] http://www.builditsolar.com/Experimental/WallStorage.pdf (Page 1)

Figure 7: Example of Heat Source that Only Occasionally Matches with Heat Load (No Solar Thermal Storage) [119]

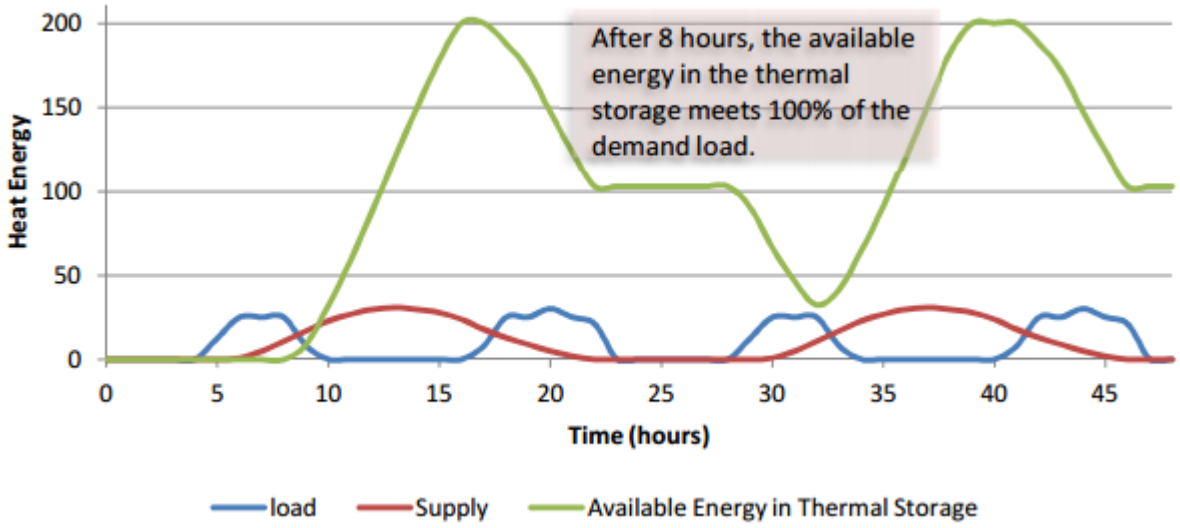


Source: Cold Climate Housing Research Center

The study does not specify the units for Heat Energy, but it is assumed to be therms as the example is applicable to a non-residential building. The same study estimated the potential of storing the solar potential and applying it to heating demand with energy left to spare. **Figure 8** shows, in green, the energy available from solar thermal when applied to space heating.

[119] http://www.cchrc.org/docs/reports/thermal_storage.pdf (Page 8)

Figure 8: Example of Thermal Storage System Potential[120]



Source: Cold Climate Housing Research Center

From 2003-2006, research heavily funded the investigation of phase change materials (PCMs) to avoid the use of an entirely water-based distribution system. The system, designed by the Alberta Research Council Inc brought together hot water generation and space heating but used PCMs built into insulated walls. This method, they explain, would prevent the use of water loops, improved thermal insulating capacity of the wall, and effective cooling opportunity for summer months.[121]

The U.S. DOE Energy Efficiency and Renewable Energy Building Technologies Program recently sponsored an Energy Savings Potential and RD&D Opportunities for Commercial Buildings HVAC Systems study.[122] The study identified 17 priority technology options for in-depth analysis based on a review of technology options with significant energy savings impact and applicability to commercial HVAC, with a focus on technology options at the end of their development cycle. Solar ventilation preheating was one of the final 17 priority technology options studied in more detail and included in the recommendations for research.

Energy Savings Description

As space heating is responsible for a substantial portion of natural gas consumption, solar thermal represents a substantial opportunity to reduce natural gas consumption in both residential and commercial applications.

---

[120] http://www.cchrc.org/docs/reports/thermal_storage.pdf (Page 9)

[121] http://www.builditsolar.com/Experimental/WallStorage.pdf (Page 3)

[122] http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/savings_potential_comm_hvac.pdf

Solar ventilation preheating replaces much or all of the energy required by conventional heating equipment to preheat outside air during occupied hours. The energy savings for this technology depend on the outside air requirement, type of heating fuel and cost, building location (climate zone), and occupancy patterns of the building, available wall or roof space, and site solar resource. The following studies provided estimated energy savings:

- A recent report by Reed Construction Data stated that transpired solar preheating panels are 80% efficient resulting in a 12% heating energy savings[123]
- SolarWall, the largest manufacturer of these systems has measured a 20% to 50% reduction in the total building heating costs for their customers using the solar preheating panels[124]

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Support development of solar thermal storage by:
    - Identify potential for increased cost-effectiveness by climate zone and building occupancy type
    - Design and demonstrate solar thermal storage cost-effectively in concert with PV
    - Document and rate various PCMs and storage methods based on cost effectiveness and performance
    - Define standardized tank size and insulation requirements
    - Develop and demonstrate market-ready product
- Conduct research supporting solar ventilation preheating by:
    - Building a database of successful projects
    - Improving modeling software
    - Supporting public demonstrations of the technology

Overcoming Barriers

There are many barriers to solar thermal space heating technologies, primarily related to costs and lack of awareness or familiarity with new technologies. Costs are the biggest barrier to the development of market-ready solar thermal technology. Yet the potential to use solar thermal in addition to PV or the possibility of improving solar thermal cost-effectiveness should be researched further.

Barriers to solar ventilation preheating include difficulties in modeling performance and lack of public awareness of the benefits and limitations of solar ventilation. These can all be addressed with more research and demonstration.

---

[123] Walker, Andrew. 2011. "An Overview of Solar Ventilation Air Heating." Retrieved from http://www.reedconstructiondata.com/.

[124] SolarWall. 2011. Conserval Engineering Inc. Retrieved from http://solarwall.com/.

Research Initiative S6. Develop and Demonstrate Cost-effective Under-floor and Other Hydronic Heating Options

Initiative Description

In workshop discussions, respondents requested the addition of hydronic heating to the list of research initiatives. Hydronic heating is known to be a duct-free heating method that can take advantage of highly efficient boilers. However, the cost-effectiveness of hydronic heating in buildings with tight ductwork and envelopes is uncertain. Additional research of the performance and cost effectiveness of hydronic heating will give HVAC contractors and building occupants better guidance regarding its applicability to different building types, as well as its efficiency and environmental impacts.

Issue Statement

Over the past several years, radiant floor or ceiling hydronic heating has been promoted as an energy-efficient heating option. Its benefits are noted on the DOE's website and within the Energy Commission's 2009-2010 Natural Gas Research, Development, and Demonstration Program Plan Funding Request.[125] [126] The lack of ductwork of a hydronic heating system reduces heat loss. Hydronic systems are also credited with improved indoor air quality. The Energy Commission notes that hydronic heating allows for a highly controlled heating environment, and that, due to elevated mean radiant temperatures, thermostats can be set at lower temperatures.[127] Lowering the temperature set-point will directly decrease energy use. However, numerous articles have been published that question the use of hydronic heating in buildings with tight envelopes. Build-it-green suggests that in such buildings, it may be easy to overheat spaces.[128] It also argues that the expensive installation of hydronic systems will be difficult to recover through energy savings. The potential for hydronic heating is apparent, but there does not yet appear to be a quantified or even qualified industry consensus on its limitations.

Status of Past Research

Modern hydronic systems place hot water loops throughout floors and walls. An article published in HVAC&R Research in 2012 presents findings from a simulation and field test comparing energy performance between air systems and hydronic systems. [129] In response to industry complaints that hydronic systems are expensive, the article noted that improvements have been made in material science that allows for safe, cheaper, and easier installations. It also

---

[125] http://energy.gov/energysaver/articles/radiant-heating

[126] http://www.energy.ca.gov/2009publications/CEC-500-2009-069/CEC-500-2009-069.PDF (Page 25)

[127] http://www.energy.ca.gov/2009publications/CEC-500-2009-069/CEC-500-2009-069.PDF (Page 25)

[128] http://www.buildinggreen.com/auth/article.cfm/2010/2/1/Radiant-Floor-Heating-Wrong-Choice-for-Green-Homes/

[129] http://www.tandfonline.com/doi/pdf/10.1080/10789669.2011.578700 (Page 692)

argues that new methods and simulation tools have been designed to take into account peculiarities of radiant systems. [130] The study found that in its simulations there was always a reduction of energy consumption in the adoption of a radiant system coupled with a suitable primary energy system (e.g., condensing boiler and ground source heat pump). In addition, it noted that in climates where cooling demand in higher than heating demand, the reduction in carbon dioxide emissions was most significant, in some cases as high as 60%.[131]

Research has been conducted that claims savings from hydronic heating, but from workshop discussions, it was noted that it has not achieved a large industry following. As proponents will aim to increase its use and critics question it, additional research can inform and clarify the discussion.

Energy Savings Description

Radiant ceiling hydronic heating and cooling was studied by PIER in a past program.[132] The results of the project identify the 20%-40% energy savings benefits associated with shifting to high-efficiency hydronic heating with a single thermal engine and the 19% electric space cooling benefits associated with generating and storing chilled water at night when the outdoor temperatures are lower and condenser performance is improved. The addition of solar thermal for space heating and improved hot and chilled water storage systems is suggested.

Some sources report substantial energy savings due to hydronic heating in additional to carbon dioxide reduction, while others question such savings in buildings with tight ductwork and envelopes. Additional research will help to clarify this picture and identify the most effective applications regarding cost and energy reduction. Cost effectivenesss and customer comfort concerns may remain as barriers even though there are promising energy savings,

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Develop and field test solar thermal hydronic heating with storage in conjunction with off-peak electric chilled water generation and storage.
- Support case studies of hydronic heating in an assortment of building types and vintages and various climate zones (note Heather has the list of commercial buildings with radiant systems—most are highly specialized special purpose buildings).

---

[130] http://www.tandfonline.com/doi/pdf/10.1080/10789669.2011.578700 (Page 693)

[131] http://www.tandfonline.com/doi/pdf/10.1080/10789669.2011.578700 (Page 704)

[132] Brand, Larry (Gas Technology Institute) and Allen, William; (Western Cooling Efficiency Center). 2013. ***Radiant Heating and Cooling and Measured Home Performance for California Homes.*** California Energy Commission.

- Develop software that can model the a unit's potential cost and energy savings from hydronic heating including first and operating cost, and the benefits of peak shifting for the cooling load.
- Draft a list of recommended applications to provide the best energy savings for hydronic heating technologies.

Overcoming Barriers

The expensive and intensive installation of hydronic systems makes it difficult to implement from a cost effective perspective. Hydronic systems are most easily installed in new construction over existing buildings. In general, installing hydronic systems in moderate climates is not cost-effective unless the cost is reduced.

Research Initiative S7. Develop and Demonstrate Cost-effective and Energy Efficient, Condensing Packaged Rooftop Heating Units for Commercial Applications

Initiative Description

Condensing technology, which recaptures heat by condensing the water vapor in combustion product gases, has enabled forced air furnaces to achieve AFUEs of 90% to 98% in the residential market. Although the technology of a condensing furnace does not differ between commercial and residential applications, interviews and discussions during workshops for this project found that the adoption of condensing rooftop units in commercial applications is much lower than in residential ones. This initiative would strive to lower first-cost of and increase market demand for condensing rooftop equipment for commercial applications in California.

Issue Statement

Gas packaged units provide both heating and air conditioning and are used extensively in commercial buildings. These gas packaged units have the potential to be replaced with e condensing technology. Condensing the flue gasses to extract additional heat from gas combustion is a robust and proven technology and can be incorporated into the gas packaged units.

From discussions in interviews and throughout the workshops hosted for this project, it was found that condensing furnaces, while popular in residential applications, are not as readily adopted among commercial end users with rooftop gas packaged units. One possible reason for reduced commercial adoption is that cooling hours in California coincide with commercial business hours whereas heating hours tend to coincide with unoccupied hours when setpoints are reduced. This reduction in commercial heating needs also reduces the opportunity for energy savings and lengthens the payback period. However, as the technology grows in popularity and costs are reduced, there will be opportunities to increase saturation of rooftop condensing equipment in commercial applications.

Status of Past Research

The technology of residential condensing furnaces has been developed to the point where 98% efficiency is proven. ACEEE estimates that upgrading from a 70% to 95% AFUE residential

furnace will reduce fuel costs by approximately 25%.[133] While this is estimated for residential furnaces, the temperate climate throughout much of California and the coincidence of heating hours with commercial off-business hours reduce the potential total energy savings and slow the financial payback for high-efficiency commercial heating systems. If condensing furnaces are not required by building code, the higher first cost inhibits broad acceptance of the technology.

A condensing unit is more expensive than a conventional rooftop unit because it requires a secondary heat exchange, a larger fan, a condensate draining system and a method of condensate freeze protection.[134] Developing and demonstrating a more cost-effective condensing rooftop unit would expand its adoption.

A study by GTI conducted field monitoring of condensing rooftop units across a small office, small retail store, and large retail store. The study found excess rooftop unit (RTU) heating capacity for buildings, as the systems were sized for air-conditioning. Not surprisingly, energy and cost savings were greatest for buildings with high RTU runtimes and high percentage of outside air.[135]

Energy Savings Description

Condensing technology reduces natural gas usage by recapturing heat from condensing the water vapor in combustion product gases. According to the GTI, northern climates may achieve up to 3,000 therms saved per year per unit, depending on unit size. Furthermore, dedicated outdoor air systems (DOAS) provide the best payback since they are dedicated to pre-heating outdoor air required to ventilate the building. DOAS systems coupled with high heating degree days, 24/7 retail stores, and "big box" retail accounts with established DOAS vendors provide the best early market payback scenario. [136]

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Design and demonstrate, through laboratory prototyping and in-field testing, a reduction in the technology's first cost. This cost reduction could include technical improvements, or systems that while highly efficient, do not have additional high-end features, such as humidity controls.

---

[133] http://aceee.org/consumer/heating

[134] http://www.sustainablebuilding.com/Advanced%20Buildings/High%20Efficiency%20Gas%20Rooftop%20Units_files/main_t_heat_high_eff_rooftop.htm

[135] http://www.centerpointenergy.com/staticfiles/CNP/Common/SiteAssets/doc/CondensingRooftopUnit_RyanKerr.pdf

[136] http://www.centerpointenergy.com/staticfiles/CNP/Common/SiteAssets/doc/CondensingRooftopUnit_RyanKerr.pdf

- Identify the most appropriate and cost-effective applications for condensing rooftop units and demonstration for early market entry points and by climate zone(e.g., 24/7 drug stores with high runtime RTUs).
- Support utility programs to include condensing gas heating specification as part of systems with high efficiency cooling (e.g., Commercial Building Energy Alliance RTU Challenge).
- Define best practices for combustion condensate management, including understanding what local building codes require in terms of disposal.

Overcoming Barriers

With California's moderate climate, the cost-recovery period of condensing furnaces is fairly long (close to or exceeding equipment lifetime) in most of the state, limiting the market for condensing furnaces. Jump-starting the market in California will be a significant barrier that will require a reduction in upfront first cost. These improvements will be challenging to identify as the first cost tends to be a question of materials and scale. Nevertheless, condensing rooftop equipment technology holds the potential for offering efficiencies up to 98%. Given the full cost of condensing furnances in packaged rooftop units will be much greater than the cost of therms saved, the potential market may only be the replace on burnout, building renovation, and new contrcution markets. In these markets the incremental cost of more efficient heating may be cost effective.

Although a condensing unit increases energy efficiency, controlling and eliminating the condensate presents technical challenges. Condensate removal requires additional insulation or piping requirements which may increase installation and maintenance cost. Typically an enclosure is provided to protect the unit against freezing conditions and the condensate piping terminates at an indoor drain. Education of commercial HVAC contractors is needed on local requirements for combustion condensate management and how to handle the condensate lines to help overcome these technical barriers.

CHAPTER 7:
Cooking Research Initiatives

The examination of the main uses of natural gas in different building types from Chapter 2 shows restaurants consume the largest amount of natural gas California, with a significant portion related to cooking. Furthermore, efficiencies in cooking technologies can result in reduced cooling loads. Within the residential sector, cooking represents the third largest end use for natural gas consumption.

The following research initiatives are described in further detail in this section:

- **Research Initiative C1:** Focus on developing economy-grade ENERGY STAR cooking appliances
- **Research Initiative C2:** Focus on reducing standby energy and idle rates, including use of insulation, controls, temperature setback, lids, and multistage burners
- **Research Initiative C3:** Support product development for select appliance types
- **Research Initiative C4:** Support research related to "smart" or "intelligent" kitchens
- **Research Initiative C5:** Research focused on residential cooking

Cooking equipment is designed with the end product in mind. The chef or cook uses the equipment to prepare a consistent high-quality food product for the patron with little focus on energy efficiency. As a result, food service equipment is notoriously inefficient and there are many cost-effective opportunities to increase efficiency that remain available. The food service sector is decades in the past in terms of technologies utilized and levels of energy efficiency. For instance, the efficiency threshold for ENERGY STAR gas fryers and convection ovens is 50% and 44%, respectively, which is well below the efficiency thresholds for water heaters and furnaces. Baseline full-load equipment efficiencies are in the 20%-30% range and part-load efficiencies, where cooking equipment spends much of its time, is in the 5%-10% range.[137]

A concerted effort is needed to increase efficiency in gas cooking equipment, particularly in the commercial sector. The process starts with improving equipment performance and then identifying test procedures and ENERGY STAR levels for listed products. Currently, only manufacturers who build more efficient equipment are testing their equipment. The need is to build a case for testing and reporting the energy efficiency of all equipment and focusing on ENERGY STAR performance incentives.

[137] Cole, Tim, Paul Glanville, Frank Johnson, Dave Kalensky, and Douglas Kosar. 2011. Advanced Gas Appliance Development. PIER Final Project Report CEC-500-2010-034, Des Plaines, IL.: Gas Technology Institute.

Research Initiative C1. Focus on Developing Economy-Grade ENERGY STAR Cooking Appliances

Initiative Description

Many of the cooking appliances in the field are commodity equipment and there is very little uptake of efficient technology because of concerns with up front costs. Even restaurant franchises demand the lower-cost, low-tech versions over the fancy, more efficient equipment and provide specifications that require the lower cost versions with fewer features. There is ultimately a need for ENERGY STAR models to cost less. Therefore, more research is needed to develop "economy grade" ENERGY STAR models that do not sacrifice cooking performance particularly for cooking equipment with well-established standards of efficiency in order to increase the market penetration. Priority appliance categories that need research and development support are convection ovens, steamers, conveyor ovens, and broilers.

Issue Statement

Technologies are available to significantly increase energy efficiency, but additional work is needed to research the market drivers and economics. Efficiency in the cooking equipment market is coupled with premium materials, which in turn, demand a premium price. Equipment costs can vary significantly, such as $600 for a low-end fryer model to $6,000 for a high-end ENERGY STAR fryer model that ostensibly operates the same. Two major fryer manufacturers (Pitco and Frymaster) have introduced economy ENERGY STAR models in the last year with street pricing in the order of $1,600.[138] Although the fryer market is relatively mature, many other appliance categories (e.g., convection ovens, steamers, conveyor ovens, and broilers) need research support.

Dealers typically don't carry efficient equipment because the perceived market is small and manufacturer incentives promote high-volume equipment, which tend to be the lowest-cost equipment.[139] The lowest-cost equipment also tends to be the least efficient equipment. Since cooking equipment in general tends to be quite inexpensive, and rudimentary in design, the efficient versions tend to be very expensive in comparison. With long-term paybacks and a restaurant failure rate around 80%, expensive appliances have high risk. Due to the high restaurant-failure rates, there is a substantial used food service equipment market for refurbished low-efficiency models that cost significantly less than new efficient equipment.

---

[138] Don Fisher, PG&E FSTC. Personal communications (November 27, 2013)

[139] Dealers participate in consolidated buying groups that use national purchasing from manufacturers to lower product price points for their members. Additionally, some manufacturers offer "back-end" rebates to the largest dealers to promote greater market share. The rebates allow dealers to sell product at close to wholesale cost, as profit is generated from the end-of-year rebates (instead of a mark-up on dealer's wholesale cost).

Status of Past Research

Within California, PG&E's Food Service Technology Center (FSTC) serves an important role in commercial kitchen energy-efficiency research and testing. The FSTC has developed more than 35 standard test methods for different commercial kitchen appliances and food service systems.

Currently, there are six types of commercial food service equipment fueled by natural gas that are eligible for the ENERGY STAR rating. These include fryers, ovens, griddles, steam cookers, hot food holding cabinets, and dishwashers.[140] In addition to providing rebates for these ENERGY STAR appliances, California IOUs provide incentives for combination ovens, rack ovens, and conveyor ovens.[141]

Description of Energy Savings

The energy impact potential is high due to the low efficiency levels of conventional food service equipment. According to EPA, ENERGY STAR certification across the six product categories offers energy savings of 10% to 70% more than standard models, depending on the specific equipment. EPA also estimates that outfitting an entire commercial kitchen with a suite of ENERGY STAR certified equipment can save 340 million BTU per year (or 3,400 therms per year). [142]

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Work with equipment manufacturers to identify opportunities to reduce cost and extra features from ENERGY STAR qualifying equipment but not affect cooking performance. Focus particularly on the ovens (all types), as this is the most populous commercial cooking appliance that is used frequently.
- Identify typical equipment specifications requested by chain restaurants determine features that are often not needed.
- Develop tiers of ENERGY STAR that are not top of the line, without dropping the threshold efficiency or raising the threshold idle rates. This would inherently mean that the top tier would recognize best-in-class cooking appliances.

---

[140] U.S. EPA ENERGY STAR Restaurant Equipment Energy Saving Factsheet. (December 2012). http://www.energystar.gov/ia/products/commercial_food_service/downloads/restaurant_equipment_savings_factsheet.pdf

[141] http://www.fishnick.com/saveenergy/rebates/

[142] U.S. EPA ENERGY STAR Commercial Food Service Program Administrator Guide for Utilities. (July 2013) http://www.energystar.gov/ia/products/commercial_food_service/downloads/ES-CFS_Guide_508.pdf

Overcoming Barriers

Most commercial food-service equipment energy efficiency has not been addressed simply because the industry is quite fragmented. The manufacturers are small companies that make a limited number of models and there is a diverse array of equipment supply channels across many different food service entities (e.g., institutional versus quick-serve restaurants).

According to ENERGY STAR, "in the retrofit market, purchasing often occurs when existing equipment fails, and the top priority is getting new equipment online quickly. Decisions on product selection and purchase are usually driven by product availability, price and advice from the equipment supplier. Many suppliers do not stock or promote energy-efficiency equipment due to price premiums which vary by product category."[143] Equipment costs are higher when a dealer needs to special order equipment that is not in stock. Therefore, research to bring down the cost of ENERGY STAR qualifying products can make the food service equipment more competitive with standard models. Explore and support utility program designs that provide education and incentives to suppliers to stock energy efficient cooking equipment, similar to the program design being used for HVAC equipment distributors[144].

Research Initiative C2. Focus on Reducing Standby Energy and Idle Rates, Including Use of Insulation, Controls, Temperature Setback, Lids, and Multistage Burners

Initiative Description

According to one industry expert, the actual utilization of cooking equipment is often less than 10% and peak usage is estimated at 70% for gas-fired equipment. Cooking equipment frequently stays hot, but is not actually cooking. The equipment needs to be in a ready-to-cook mode since customers can come into a restaurant at any time. This energy loss impacts the energy efficiency of the equipment.

Therefore, more research is needed to reduce standby energy consumption and idle rates through insulation, controls, temperature setback, and multistage burners. Technologies are needed to improve the heat transfer efficiency from the burner to the food cooking surface and the food itself. One area for research is enhanced temperature controls and temperature sensing to improve the overall efficiency of cooking equipment. There is a need to build manufacturer interest and energy user demand for these products through demonstration projects.

---

[143] U.S. EPA ENERGY STAR Commercial Food Service Program Administrator Guide for Utilities. (July 2013) http://www.energystar.gov/ia/products/commercial_food_service/downloads/ES-CFS_Guide_508.pdf

[144] Pacific Gas and Electric and Southern California Edison HVAC Distributor Incentive Program. (2004-2014) https://www.cainstantrebates.com/

Issue Statement

Cooking equipment is not very energy efficient, in large part because the actual utilization is quite low. It is rare to find a restaurant where "on" time of the equipment matches cooking time. However, the cooking equipment tends to be rudimentary in design; they are simple to use, simple to fix and maintain, and inexpensive to build. Many types of equipment, such as ranges, have controls based on the operator's visual judgment and burn rates that are set manually. One industry expert estimated that as many as 80% of cooking equipment has rudimentary electro-mechanical controls and no temperature feedback to control energy use. One technological opportunity is advanced atmospheric burners that are being developed that emit less NOx and burns with a shorter flame, as well as infrared burners.

Some control technologies exist to reduce standby energy rates, but they are expensive and negatively affect the user experience of the chef or cook, leading to low adoption rates. Equipment that allows the user to override auto-shut off controls is common and undermines potential energy-efficiency gains.

Status of Past Research

The PG&E FSTC Commercial Cooking Appliance Technology Assessment provided specific recommendations for technologies or strategies that increased energy efficiency across nine types of cooking appliances.[145]

- **Overarching research recommendations:** The research with the potential for greatest return is related to the application of existing technology, such as insulation, improved heat exchanger design, and enhanced controls. Other recommendations include:
    - Initiate research and development for improving part-load performance of gas cooking equipment, and reducing cost premium of more efficient equipment.
- **Product category recommendations include:**
    - **Ovens (all types, including convection, conveyor, and deck).** Identifying effective air circulation in the cooking cavity and ways to control heat loss are important research topics. Achieving proper air circulation relates to fan speed and size, cooking cavity and design and geometry, and location of flue inlet and exit (for direct-fired ovens). Also, studying insulation use in ovens is another important energy-efficiency strategy.
    - **Range top burners.** In some kitchens (e.g., catering kitchens), it is often more practical to leave open-flame burners lit when not being used, rather than turning the gas off and re-lighting each time. Strategies to improve utilization include an automatic shut-off and re-ignition device that is triggered by cookware detection, as well as cooking vessel temperature feedback.

[145] Fisher, D., T. Bell, C. Bohlig, D. Cowen, V. Kong, J. Nickel, G. Sorensen, R. Young, F. Wong and D. Zabrowski. 2002. *Commercial Cooking Appliance Technology Assessment*.

- **Fryers.** Improving part-load efficiency of fryers will have the largest impact on reducing overall fryer energy usage. Fryer part-load performance is primarily affected by the fryer's standby losses. Potential technologies or strategies include enhanced temperature control, fry pot insulation, advanced atmospheric burners, pulse combustion, modulating barriers, recirculation tubes, and/or flue dampers.
- **Griddles:** Improving temperature feedback is the most cost-effective way to improve energy performance. Embedding the thermostat sensors into the griddle plates would dramatically improve their response and result in better temperature uniformity. Potential technologies or strategies include investigating different strategies for plate temperature sensing, improving burner/heat exchanger design including potential of inshot[146] or powered burners and heat transfer fins.
- **Steamers.** The option of a stand-by switch is one option to reduce idle gas consumption. Increasing the level of insulation is another approach. Shorter cook times associated with boiler-based models gives them a perceived advantage over connectionless steamers. One strategy to reduce connectionless steamer cook times is to add a fan that circulates steam.

Other past research includes lidded underfired charbroilers and development of a prototype to improve real-world cooking efficiency at part-load, which is the most common real-world operating condition. The prototype included a retractable hood to lower cooking heat loss and thermostat control to modulate the burners, maintain cooking setpoint, and reduce idle energy use.[147]

Energy Savings Description

For the lidded underfired charbroiler, one study estimated that this technology was 50% more efficient than standard technology.[148] Another recent study by GTI estimates that this may result in 23% reduction in natural gas consumption related to charbroilers.[149]

---

[146] This is a specific type of burner that is usually used with induced draft systems that pull or suck combustion gases through the heat exchanger.

[147] Horsey, M. 2012. *What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens*. Paper presented at the American Council for an Energy-Efficient Economy.

[148] Horsey, M. 2012. *What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens*. Paper presented at the American Council for an Energy-Efficient Economy.

[149] Johnson, F. (Gas Technology Institute), D. Fisher (Fisher Nickel), L. Brand (Gas Technology Institute), and E. Huestis (PG&E ATS). 2013. *Advanced Foodservice Appliances for California Restaurants Final Report*. California Energy Commission, PIER Building End-Use Energy Efficiency Program. CEC-500-09-044.

In the same study, a low input burner range had an automatic pilot ignition system where the user was encouraged to turn it off at night. However it was not utilized very often and it was found that the pilots were left on at night almost 50%of the time. Therefore, doubling in-kitchen utilization efficiencies is a reasonable goal (e.g., cutting stand-by energy in half).

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Develop technologies that reduce standby energy losses and have minimize impacts to the user, including:
    - Designing products that users cannot disable while minimizing usability interference
    - Developing energy-savings reporting that allow the operator to see energy savings
- Focus on burner and heat exchanger design for convection ovens. Also, focus on powered burners (for range top burners) that were demonstrated and introduced two decades ago, but subsequently pulled from the market for minor technical issues.
- Build manufacturer interest and build end user buy-in to develop pull for more efficient products.

Overcoming Barriers

A key barrier to reducing standby energy and idle rates is that food service operators are much more of a focused on usability and reliability rather than energy efficiency. Usability of equipment is the highest priority for end users. Most restaurant operators do not have a facility manager to repair cooking equipment. Therefore, they have to be able to fix it easily and if too complicated, then restaurants have a hard time using it. There is also an opportunity for component-level retrofits (e.g., pilot ignition systems) in the secondary market, but these often violate safety certifications or warranties.

Research Initiative C3. Develop and Demonstrate Select Commercial Food Service Appliance Types that are not Rated by ENERGY STAR

Initiative Description

In some cases, additional product development is needed for specific cooking equipment technologies that have had recent advances in energy efficiency. These technologies include convection ovens, cookware, and lidded charbroilers. There is a large need to improve burner heat exchanger design, improve insulation, and sealing of doors in convection ovens. Recent developments in cookware related to the use of fins for improved heat transfer also appear promising.

There is a huge potential to increase efficiency through lids and optimizing heat transfer to reduce cooking temperatures and reduce waste heat. The simple use of lids for charbroilers and griddles is another opportunity. The lidded charbroiler technology has proof of concept, with

field studies showing that it works and that operators would close the lids and turn down the burners. The lidded charbroiler is close to being on the market, although the technology and product needs to be refined. These products are backed with research that shows proof of concept and effectiveness. Therefore, further research is needed to refine the products and more quickly bring them to commercialization and widespread use.

Issue Statement

Product development is the complete process of bringing a new product to market. The technologies and knowledge on effective heat transfer are well-known (e.g., heating and cooling coils) but many of the more efficient approaches are not part of food service equipment due to challenges related to cost and lack of demand. Industry experts and stakeholders involved in this roadmap project identified specific technologies that were ripe for focused product development to improve product design and bring technologies to market. For instance, the gas industry initiated an advanced range top development project with the goal of modernizing the standard gas range. This project effectively stalled out and needs additional research funding to produce a more efficient design that can be proven in the field.[150] Key product designs or concepts include lids for broilers and griddles, and cookware with improved attributes for heat transfer.

Status of Past Research

Most of the relevant past research has been conducted by the PG&E FSTC. Recent reports include:

- The FSTC Commercial Cooking Appliance Technology Assessment provided specific recommendations for technologies or strategies that increased energy efficiency across nine types of cooking appliances. The report summarizes specific research related to range tops included three advanced range top options: (1) state-of-the-art range top with atmospheric burner, (2) range top with enhanced output/heat transfer, (3) smooth top range top that features a closed smooth top with high-efficiency radiant burners. The report states that potential technologies or strategies include developing sealed combustion range tops for commercial food service, cooking vessel temperature feedback, and hot tops using infrared burners. Furthermore, the report recommends more industry focus on induction range tops, which are rapidly gaining popularity and

[150] The project to develop a more efficient gas range burner was not able to produce a viable product for a number of reasons, including technological challenges, durability of design, flexibility and usability of the prototype products, incremental cost when compared to standard range top designs, and manufacturer commitment. There is a clear need to overcome these challenges, as there are similarities between broilers and ranges in that both are extremely simple appliances with high energy use and relatively low price points.

may impact the market share of the traditional gas range. Gas utilities should promote the use of open burner or open-grate hot tops over full-hot tops.[151]

- A recent paper by E Source identified two promising technologies: turbo pots (more efficient pot) and advanced underfired charbroilers. [152]
    - **Turbo pots (more efficient pot).** According to the paper, "of the nearly 300,000 estimated food service establishments in the U.S., nearly all have at least one gas-fired range used to maintain a pot of simmering water as well as other pots for heating." This research focused on a specific type of pot manufactured by Eneron that incorporates metal fins into the base of standard restaurant-quality cooking pots to improve convective and conductive heat transfer into the pot, thereby boosting cooking efficiency. The more efficient 24-quart stockpot costs approximately $190 compared to about $140 for a standard version. The study found a simple payback period of seven months.
    - **Advanced underfired charbroiler.** The underfired charbroiler, primarily used to grill meat, consists of a top metal grate placed over gas burners. At part load, the most common real-world operating condition, efficiency can be as low as 6%. GTI, with funding from the Energy Commission's PIER program, developed the Advanced Underfired Charbroiler. The goal was to create a prototype that would improve real-world cooking efficiency well above the 6% part-load level, reduce heat gain to the space, and maintain the signature look and flavor of the cooked product. GTI's prototype included a retractable hood to lower cooking heat loss and to reduce the HVAC burden, as well as a temperature probe and thermostat control to modulate the burners, maintain cooking setpoint, and reduce idle energy. The Advanced Underfired Charbroiler is in prototype stage by GTI.

Energy Savings Description

The example technologies recommended for focused product development are estimated to be about 50% more efficient than standard technology for both the lidded underfired charbroiler and turbo pot.[153] Another recent study by GTI estimates that this may result in 23% reduction in natural gas consumption related to charbroilers.[154] The lidded underfired charboiler improves

---

[151] Fisher, D., T. Bell, C. Bohlig, D. Cowen, V. Kong, J. Nickel, G. Sorensen, R. Young, F. Wong and D. Zabrowski. 2002. Commercial Cooking Appliance Technology Assessment.

[152] Horsey, M. 2012. What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens. Paper presented at the American Council for an Energy-Efficient Economy.

[153] Horsey, M. 2012. *What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens*. Paper presented at the American Council for an Energy-Efficient Economy.

[154] Johnson, F. (Gas Technology Institute), D. Fisher (Fisher Nickel), L. Brand (Gas Technology Institute), and E. Huestis (PG&E ATS). 2013. *Advanced Foodservice Appliances for California Restaurants Final Report*. California Energy Commission, PIER Building End-Use Energy Efficiency Program. CEC-500-09-044.

energy efficiency with a retractable hood and burners that cycle off during idle periods. When the operator lowers the hood, the temperature under the hood rises quickly until the thermostat shuts the burners off at the cooking setpoint.

The turbo pot technology increases energy efficiency through improved heat transfer from the burner flame to the cooking pot. "Standard pots allow the flame to slide ineffectively around the smooth bottom of the pot and up the sides."[155] The turbo pot is designed with fins that capture and guide the burner flame into channels to increase the contact of hot gases with the fins and increase the surface area for heat transfer.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to focus product development on:

- Broilers, including:
  - Advanced underfired broilers that include controls with temperature feedback, advanced gas burners, and potentially a lid that can be lowered to retain heat.
  - High-efficiency overfired broilers with reduced heat loss.
- Ovens, including:
  - High-efficiency convection ovens with reduced standby losses and improved cooking uniformity.
  - Conveyor ovens with load-sensing capability and reduced standby losses during non-cooking periods.
- Range tops, including:
  - Automatic burner ignition systems for commercial range tops.
  - Advanced ranges with high-efficiency burners and utensil sensing capability.
- High-efficiency wok that does not require water cooling.
- High-production ENERGY STAR steamer with fast recovery.
- Supporting more research demonstration and effectiveness case studies. There is no limit to how many you can do to show restaurants that these work, and could apply to their situations.

Overcoming Barriers

The challenges are that product development takes time, and rushing these research efforts can result in misleading results. Furthermore, food service operators need time to get used to new products. For instance, "the Turbo Pot's fins make it look quite different from the standard pot, which could be off-putting to food service staff. And because a Turbo Pot cooks food more quickly, chefs will have to learn how to create the desired results in the shorter cooking time."

---

[155] Horsey, M. 2012. *What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens*. Paper presented at the American Council for an Energy-Efficient Economy, 3.

[156] Furthermore, the fins make the pot heavier, which negatively affects the chef's cooking experience. Therefore, research would help the industry understand the benefits in order to accept the compromise in usage experience. Demonstration projects and field studies are also needed to produce reliable data about operating hours, operating characteristics and savings to improve understanding of how these products are used in the real world and improve product design.

Research Initiative C4. Support Research Related to "Smart" or "Intelligent" Kitchens

Initiative Description

"Intelligent" or "smart" kitchens incorporate building automation technologies, energy management systems, and controls to improve energy efficiency through data, sensors, and monitoring systems. The food service industry is developing energy tracking systems (e.g., smart transducers), which are applicable to different cooking appliances and food service equipment (e.g., range hoods). Furthermore, the PG&E FSTC is working with DOE's Better Building Alliance to put together guidelines and a list of eligible appliances which are compatible with an energy management system. More research is needed to improve natural gas consumption monitoring at the equipment level and building level, interoperability of building system components and appliances, communication protocols, and understanding of the cost-effectiveness and potential savings of such systems.

Issue Statement

There is a new generation of EMS and renewed interest across the commercial building sector. For the food service industry, these technologies are applicable to the concept of "intelligent" or "smart" kitchens and restaurants. In particular, the industry is starting to see coordination of ventilation with specific equipment. Specific technologies include wireless communication and USB ports that are technologies that can be integrated into "smart" kitchens. The "smart" kitchen of the future would have appliances that communicate with the overall building system.

Due to lack of natural gas metering and monitoring, many restaurant operators have no idea where the natural gas is consumed in their building, much less the kitchen itself. For example, restaurant operators do not have the ability to know where most of the natural gas is being consumed on premise. This type of basic natural gas usage data can provide appropriate information to inform decisions related to maintenance and cooking equipment retrofit projects.

---

[156] Horsey, M. 2012. *What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens*. Paper presented at the American Council for an Energy-Efficient Economy.

Status of Past Research

Much of the research to-date has been focused on kitchen ventilation (i.e., demand-controlled ventilation). In particular, DOE's Better Buildings Alliance has an initiative to improve efficiency and implementation of demand controlled ventilation in commercial kitchen. Its activities include creating technical specification for more efficient equipment.

Demand controlled ventilation saves natural gas from reducing makeup air heating. Therefore, the technologies being pioneered are applicable to natural gas consumption and holistic "smart" kitchen technologies. For instance, to maximize the energy savings of demand controlled ventilation requires appliances to communicate with DCV to modulate the exhaust ventilation rate according to when the appliance is being used, sense smoke or exhaust, and the amount of heat being produced.

DOE's Better Buildings Alliance is also developing a guidance package for implementing energy management systems in restaurants. Components include guidance documents, case studies, and a vendor database.[157] A survey is also ongoing to collect energy and water data needed for creating an ENERGY STAR energy performance for restaurants. According to DOE's Better Buildings Alliance website, "the answers to this survey will provide the underlying data for an ENERGY STAR score, in EPA's online measurement and tracking tool, Portfolio Manager ®. Creating a 1-100 ENERGY STAR score would allow restaurants to understand how the energy consumption of their stores compares to the national, industry-wide average, as well as other stores within their brand." [158]

Energy Savings Description

The objectives of this research initiative is to provide better data on where natural gas is used in commercial kitchens and develop control strategies to help restaurant operators to reduce natural gas use. The research would support estimating the potential for energy savings and strategies for engaging market actors and end users to develop new technologies at both the appliance and whole building levels.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Design and support a kitchen of the future demonstration including ventilation controls and individual appliances, each of which can be submetered.
- Design dashboards for kitchen applications (e.g., similar to hybrid cars to influence energy usage behavior).

---

[157] http://www4.eere.energy.gov/alliance/activities/technology-solutions-teams/food-service/energy-management-systems

[158] http://www4.eere.energy.gov/alliance/activities/technology-solutions-teams/food-service/energy-performance-rating-scale

- Document and present the costs and payback; in particular designing appliance-level, low-cost gas meters that can be integrated into appliances and allow the restaurant operator to know how much individual appliances are costing to operate.
- Focus on quick service restaurants, which typically have fewer pieces of equipment and have significant influence with manufacturers that supply their cooking appliances.
- Develop affordable guidelines and systems for near-future breakdown detection to help demonstrate the value of "smart" kitchen components.

Overcoming Barriers

The most significant barrier to "smart" and "intelligent" kitchens is the low technology nature of most commercial kitchens. However, there are opportunities with larger chain restaurants and the commercial kitchens of major hotel chains. As with any existing building, retrofitting kitchens is expensive and the technology remains largely undeveloped at the appliance level. In general, technology and products for monitoring and controlling natural gas usage lag behind those for electric appliances, in large part due to the low cost of natural gas.

Research Initiative C5. Support Research Focused on Cost-effective and Energy Efficient Residential Cooking

Initiative Description

Basic research is needed to develop baseline efficiency assessments of existing residential cooking equipment, primarily related to ranges and ovens, the most common natural gas consuming cooking equipment in residential buildings. Despite the minimum federal efficiency standards for residential cooking appliances, manufacturers are not required to report the efficiency of the cooking appliances they manufacture. Therefore, very little is known about the efficiency of residential equipment. As the third largest natural gas end use in residential buildings, research is warranted to better understand saturation and efficiencies of baseline equipment as a first step to identifying opportunities for energy-efficiency improvement.

Issue Statement

As part of the Energy Policy and Conservation Act of 1975, DOE was given the authority to develop, revise, and implement minimum energy conservation standards for appliances and equipment that includes residential cooking appliances. Unlike other appliances, an energy-labeling program has never been instituted for cooking appliances. However, the California RASS and CEUS studies show that the residential sector has a higher energy use intensity, on a normalized basis (BTU/lb of cooked food) compared with the commercial sector; albeit, the total amount of energy used for residential cooking in California remains much smaller than in the commercial sector.

The efficiencies are low because of the small amounts of food being cooked and due to inefficiencies of the cooking appliances themselves. In part, flames are very inefficient in residential cooking, including the shift from open burners to sealed burners. Other technologies include induction range tops and halogen range tops, which have sealed cooking surfaces, but

are electric. With induction technology, the electric range top efficiencies are approaching 85%.[159]

Little attention has been paid to residential natural gas cooking appliances. The only existing energy conservation standard for conventional residential cooking appliances is the prohibition of a standing pilot light in all products manufactured after April 2012.[160] In comparison, significant research has been conducted for other residential appliances with lower overall natural gas usage (e.g., natural gas dryers).

Status of Past Research

DOE conducted research on residential cooking products with a study published in 1998 in support of the Energy Policy and Conservation Act to amend standards designed to improve efficiency in cooking products such as conventional ranges, cooktops, and ovens. [161] *The Technical Support Document: Energy Conservation Standards for Consumer Products: Cooking Products* (September 1998) included an assessment of baseline efficiencies based on manufacturers' data provided by the Association of Home Appliance Manufacturers, the Canadian Standards Association, and independently of any trade organization.

More recent research has been conducted on improving range top efficiencies. According to the PG&E FSTC Commercial Cooking Appliance Technology Assessment Study (Reference No. 26):

- The Canadian Gas Research Institute (CGRI) developed a prototype range top for residential applications, which featured standard gas burners under a glass ceramic surface. Each burner is surrounded by a ceramic cup, which is heated to more than 1,200°F during operation. Heat is supplied to the cooking vessel by conduction through the glass ceramic surface and by radiation. The burners are completely enclosed, and all combustion products are vented outdoors. The closed-burner design has the appeal of easy cleanup, a visible heat source, and according to GTI, a higher efficiency than standard gas open burners. The unit's easy cleanup, speed, and lower heat gain to the kitchen are part of the technology's appeal" (Reference No. 26, 5-8).

As of January 30, 2013, DOE published a notice of proposed rulemaking for amending its test procedures for residential kitchen ranges and ovens to include provisions for testing products that use induction heating. [162]

---

[159] Fisher, D., T. Bell, C. Bohlig, D. Cowen, V. Kong, J. Nickel, G. Sorensen, R. Young, F. Wong and D. Zabrowski. 2002. Commercial Cooking Appliance Technology Assessment.

[160] U.S. DOE EERE. Notice of Proposed Rulemaking. Public Meeting Presentation (March 4, 2013) http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/57#relatedrulemaking

[161] http://www.gpo.gov/fdsys/pkg/FR-1998-02-27/html/98-5084.htm

[162] http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/57

Energy Savings Description

The primary efficiency opportunities related to residential cooking are similar to the commercial sector, in terms of improving heat transfer from the burner to the food and better insulation to reduce natural gas usage. Part-load efficiencies are not as applicable to the residential sector, since equipment is not typically left on for long periods of time without being used to cook food. This research initiative would support the quantitative assessment of energy savings opportunities in for residential cooking appliances.

Tasks and Next Steps

Specific tasks and next steps to support this research initiative are to:

- Characterize the residential cooking appliance market to understand baseline appliance efficiencies and saturation of electric versus natural gas cooking appliances.
- Research optimal distance from the flame for residential applications to improve range efficiencies, designs, and cost effectiveness.
- Identify energy-efficiency opportunities in residential cooking appliances from both a technological, behavioral and cost effective standpoint.

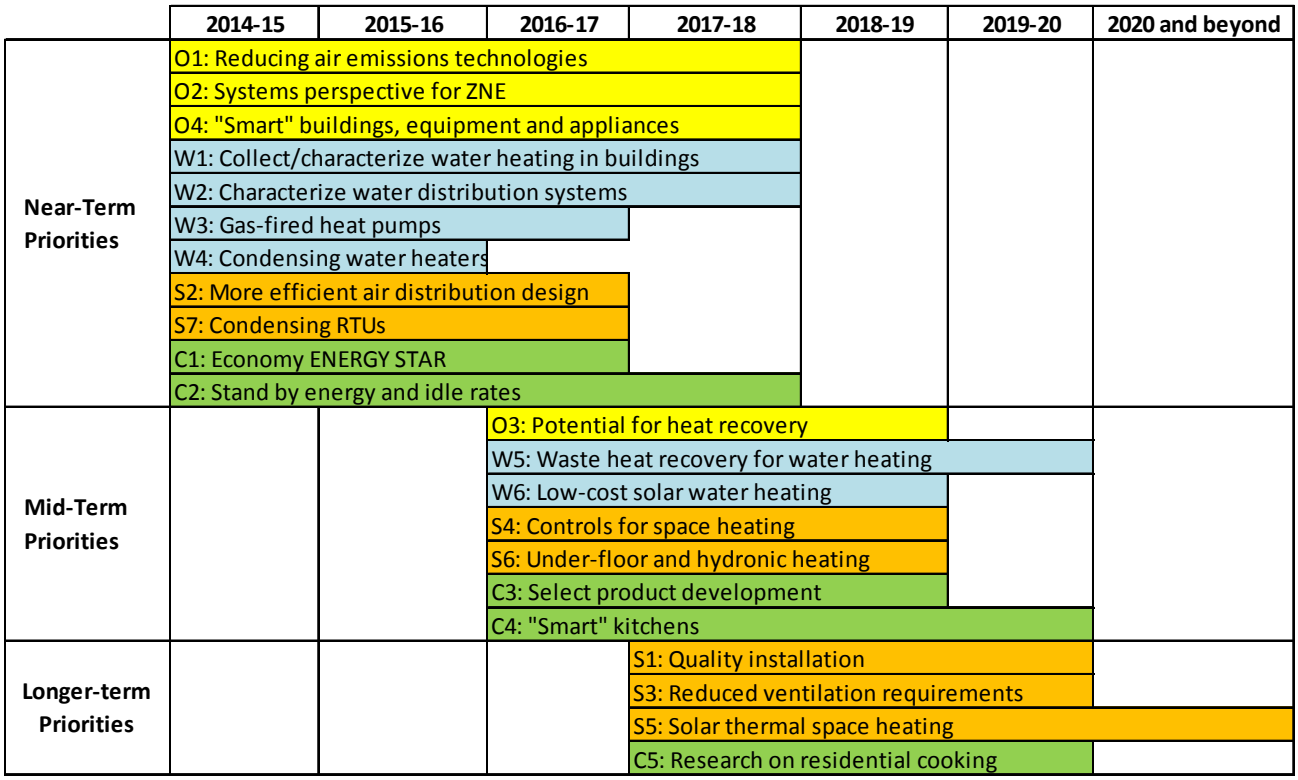
Overcoming Barriers

Most of the cooking equipment energy-efficiency research to date has been on the commercial side. One of the key challenges is that the manufacturers of residential cooking appliances are different from the commercial manufacturers. Furthermore, the residential end user market consists of many different segments of small users with different lifestyle habits, income levels, and associated purchasing behaviors and most cooking appliances are only replaced when they are broken or at the time of renovation. Given the full cost of residential ranges and ovens will be much greater than the cost of therms saved the potential market may only be the replace on burnout, home renovation, and new contrcution markets. In these markets the incremental cost of more efficient cooking appliances may be cost effective.

CHAPTER 8:
Recommendations for Near-Term Priorities

This chapter presents a prioritization of research initiatives based on appropriateness of Energy Commission support, efforts by other agencies and industry actors, likelihood of technical and market success, and commercialization opportunity. **Figure 9** provides an overview of the near-term, mid-term and longer-term recommended research initiatives for each funding cycle.

Figure 9: Prioritization of Research Initiatives by Energy Commission Funding Cycles



Source: DNV KEMA

Near-term – Next Two Funding Cycles (2014-15, 2015-16)

Rationale: Near-term priorities are focused on research initiatives that provide baseline data for understanding energy use characteristics and whole building perspectives to inform future efforts related to energy-efficient technologies and opportunities. Some of this research will take a longer time to achieve useful results and are prioritized to help meet state energy policy goals for 2020. Additional promising technologies that are close to commercialization, or need help bringing down costs of existing commercialized products are also prioritized.

The following research initiatives are identified as near-term priorities.

- **Cross-cutting**
    - **Research Initiative O1:** Focus on technologies for reducing air emissions while increasing energy efficiency
    - **Research Initiative O2**: Incorporate a systems perspective and integrate technologies to achieve zero net-energy buildings that include natural gas for building cooling
    - **Research Initiative O4**: "Smart" buildings, controls and metering of natural gas usage in buildings, including "smart" equipment and appliances

- **Water Heating**
    - **Research Initiative W1:** Collect and characterize energy use related to water heating across different building types, designs, and vintages
    - **Research Initiative W2:** Characterize current water distribution systems to support higher-efficiency retrofit and design
    - **Research Initiative W3:** Develop and demonstrate cost effective high-efficiency water heaters, such as natural gas heat pump technology
    - **Research Initiative W4:** Develop low cost condensing water heater technology

- **Space Heating**
    - **Research Initiative S2**: Develop and demonstrate more efficient air distribution design
    - **Research Initiative S7**: Develop and demonstrate cost-effective and energy efficient, condensing packaed rooftop furnaces, particularly for commercial applications

- **Cooking**
    - **Research Initiative C1:** Focus on developing economy-grade ENERGY STAR commercial cooking appliances
    - **Research Initiative C2:** Focus on reducing standby energy and idle rates, including use of insulation, controls, temperature setback, lids, and multistage burners for commercial applications

Mid-term – Funding Cycles 2016-17 and 2017-18

Rationale: Several of the recommended research initiatives have significant research support from other state and federal agencies, as well as trade associations. These research initiatives remain important priorities for Energy Commission to support, in order to leverage complementary efforts and partnership opportunities. For instance, the California Air Resources Board and local air districts continue to lead the way on emissions standards. Energy Commission should stay abreast of these developments and leverage key results to inform its future research priorities.

The following research initiatives are identified as mid-term priorities.

- **Cross-cutting**
    - **Research Initiative O3**: Better understand technical and economic potential for heat recovery across multiple end uses

- **Water Heating**
    - **Research Initiative W5:** Develop and demonstrate cost-effective waste heat recovery for water heating
    - **Research Initiative W6:** Develop low-cost solar water heating systems with new materials and improved system design

- **Space Heating**
    - **Research Initiative S4**: Conduct research related to controls for both individual equipment, as well as whole building
    - **Research Initiative S6**: Support research on under-floor and other hydronic heating options to reduce cost barriers and demonstrate the technology

- **Cooking**
    - **Research Initiative C3:** Support product development for select appliance types
    - **Research Initiative C4:** Support research related to "smart" or "intelligent" kitchens

Long-term – Funding Cycles 2017-18 and Beyond

Rationale: Long-term priorities are related to research initiatives which may have smaller energy savings potential based on California's climate zones (e.g., waste heat recovery for water heating, drain heat recovery, and solar thermal space heating). Several of the long-term priorities have made quite a bit of headway already through other state agencies such as CPUC energy-efficiency programs and evaluations. These research initiatives remain important and the Energy Commission should continue to support other agency efforts in these areas.

- **Space Heating**
    - **Research Initiative S1**: Conduct research related to quality installation issues for heating systems in residential applications
    - **Research Initiative S3**: Conduct research to reduce ventilation requirements
    - **Research Initiative S5**: Evaluate potential cost-effectiveness of solar thermal space heating and cooling
- **Cooking**
    - **Research Initiative C5:** Research focused on residential cooking

GLOSSARY

Term	Definition
AB 1002	California State Assembly Bill 1002, which requires the CPUC to impose a surcharge on all natural gas consumed in the state in order to fund energy-efficiency programs and public interest research, and development for the benefit of natural gas ratepayers.
AB 32	California State Assembly Bill 32 (also known as the Global Warming Solutions Act of 2006), which sets an economy-wide cap on greenhouse gas emissions in CA at 1990 levels.
ACEEE	American Council for Energy Efficiency Economy
AFUE	Annualized Fuel Utilization Efficiency. A performance metric, typically applied to natural gas-fired boilers and furnaces that represent the yearly average ratio of heating energy output to fuel energy input.
AGA	American Gas Association
ARB	California Air Resources Board
Boiler	An HVAC equipment type that heats water. May include an integrated storage tank. See also, "water heater."
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CEUS	California End Use Survey
CFM	Cubic Feet per Minute. A unit of flow rate, typically used to describe airflow.
CHP	Combined Heat and Power. A device that combusts fuel and delivers useful electricity and heat.
COP	Coefficient of Performance. A unitless metric of efficiency, typically used exclusively for heat pumps, that is calculated as the ratio of heat moved to work performed. COP = Heat / Work.
CPUC	California Public Utility Commission
DCV	Demand-controlled ventilation. An HVAC control method in which CO2 sensors in the occupied space provide feedback to the central ventilation system and control the amount of outside air brought into the building.
DDC	Direct Digital Controls. A system of electronic sensors and actuators that rely on minute voltage or current changes to run HVAC equipment. DDC is the foundation of an EMS. DDC has almost entirely replaced pneumatic controls as a method of operating HVAC systems.

DHW	Domestic Hot Water. Includes end uses such as dishwashing, showers, and bathroom sinks.
DOAS	Dedicated Outdoor Air System. A type of HVAC equipment that moves, filters, and conditions only outside air and does not include recirculated air.
EERE	Energy Efficiency and Renewable Energy, a program within the U.S. Department of Energy.
EIA	Energy Information Administration
EMS	Energy Management System. A digital network of sensors that control and monitor HVAC systems (and may include lighting and other building systems). Also known as Building Management System and Building Automation System.
Energy Commission	California Energy Commission
ENERGY STAR	A program developed by the U.S. Environmental Protection Agency that certifies appliances and buildings according to specific efficiency standards.
ETCC	Emerging Technologies Coordinating Council
FHX	Foundation Heat Exchanger. A method of installing ground-source heat pump condenser loops in the foundation of a new construction building.
Flue gas	The waste air stream, or gaseous products of combustion
FSTC	Food Service Technology Center
Furnace	An HVAC equipment type that heats and moves air.
GHG	Greenhouse gas (e.g., nitrous oxide, carbon dioxide, and methane,)
GSP	Gross State Product
GTI	Gas Technology Institute
Heat pump	Any device that uses input energy to move heat from a low temperature reservoir to a high temperature reservoir.
Heat recovery	The practice of transferring heat to/from an exhaust stream (air or water) from/to an incoming stream (air or water).
HPWH	Heat Pump Water Heater.
HVAC	Heating, Ventilating, and Air Conditioning
HVAC&R	Heating, Ventilating, Air Conditioning, and Refrigeration
IEA	International Energy Agency
IOU	Investor-Owned Utility. In contrast to municipal utility.
LBNL	Lawrence Berkeley National Labs
LSI	Low-Swirl Injector

MMBTU/h	Thousands of British Thermal Units per hour. A rate of energy, where one British Thermal Unit is the amount of energy used to change 1 pound of water by 1 degree Fahrenheit.
Nanogram	One billionth of a gram
NOx	The family of compounds of nitrogen and oxygen.
NREL	National Renewable Energy Lab
Organic Rankine cycle	The Rankine cycle is a process for converting a temperature difference between two (or more) resevoirs into useful work. The ideal Rankine cycle is a thermodynamic process on a circulating heat transfer fluid, typically a refrigerant, in which liquid is pumped from a condenser to an evaporator, heat is added at constant pressure in the evaporator and the fluid changes from liquid to gas phase, and energy is removed as work at a constant entropy in a turbine as the fluid moves from the evaporator to the condenser. An organic cycle uses a refrigerant with a lower boiling point than water, at standard pressure.
ORNL	Oak Ridge National Labs
PCM	Phase Change Material. For building applications, a substance that transitions from solid to liquid at useful temperatures without significant volume change. Currently, many widely available PCMs are petroleum-based. Used in buildings as thermal energy storage and as thermal mass to delay heat conduction across the building envelope.
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research. A programfunded by ratepayer fees and administered by the California Energy Commission.
PV	Photovoltaic. A process that converts light energy into electricity and relies on semi conductive materials.
RASS	Residential Appliance Saturation Study
RECLAIM	Regional Clean Air Initiatives Market
RTU	Rooftop Unit. Refers to packaged HVAC equipment installed on the roof of a building.
SCAQMD	South Coast Air Quality Management District
SCR	Selective Catalytic Reduction
SDHW	Solar Domestic Hot Water
TDV	Time Dependent Valuation. A system that applies weighting factors to hourly energy use (and generation, for ZNE buildings), where greater weighting factors are assigned to hours of the day and times of the year when demand is high.
Therm	A unit of gas consumption, equivalent to 100,000 BTUs.
Title 24	24th part of the California Code of Regulations, which covers building codes. It includes Part 6, which is the California Energy Code.

VFD	Variable Frequency Drive. A device that modulates the frequency of input electricity to affect the speed of the motor it drives.
ZNE	Zero Net Energy. Relating to achieving a balance between energy consumed (onsite or at source) and energy produced (onsite or at source), typically applied to buildings. "Site zero net energy" is the most common use. The National Renewable Energy Lab (NREL) published four definitions for variations of "zero net".

REFERENCES

ADM Associates, Inc., Texas A&M University, Florida Solar Energy Center, University of Nebraska, Lawrence Berkeley National Laboratory. 2007. *Energy Efficiency Low Income Housing Program*.

ARUP. 2012. *The Technical Feasibility of Zero Net Energy Buildings in California*.

Ayala, G. D. and D. Zobrist. 2012. *Best Practices for Efficient Hot Water Distribution in Multifamily Buildings*.

Berman, M. (Davis Energy Group). 2005. *Synergistic Water Heating & Distribution Technologies (SWHDT) Program Final Report*.

Brand, L and W. Rose. 2012. *Measure Guideline: High Efficiency Natural Gas Furnaces*.

Business Economic Analysis and Research (Southern California Gas Company). 2008. *Steam Trap Billing Analysis*.

Cornelius, A., A. Karas, T. Bell, D. Fisher, D. Livchak and J. Rupp. 2013. *Energy-Efficient Commercial Foodservice – Scaled Field Placement*.

Delagah, A. and D. Fisher (Pacific Gas & Electric Company). 2010. *Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities*.

Denkenberger, D., S. Mau, C. Calwell, E. Wanless and B. Trimboli. 2012. *What Lurks Beneath: Energy Savings Opportunities from Better Testing and Technologies in Residential Clothes Dryers*. Paper presented at the American Council for an Energy-Efficient Economy.

Emerging Technologies Coordinating Council. Study in progress. *Evaluation of Greffen M2G Boiler Control Technology*.

Emerging Technologies Coordinating Council. Study in progress. *M2G Control System Assessment*.

Emerging Technologies Coordinating Council. Study in progress. *Ozone Laundry System – Commercial*.

Emerging Technologies Coordinating Council. Study in progress. *Wireless Steam Trap Monitoring*.

Ferlin, B., D. Zabrowski, D. Horton, D. Fisher and D. Kaufman. 1993. *Refrigerant Heat Recovery System Learning Center Dining Facility*.

Fisher, D., T. Bell, C. Bohlig, D. Cowen, V. Kong, J. Nickel, G. Sorensen, R. Young, F. Wong and D. Zabrowski. 2002. *Commercial Cooking Appliance Technology Assessment*.

Garrabant, M. (Stone Mountain Technologies). 2013. *Gas-Fired Absorption Heat Pumps for Residential Heating Applications*. Paper presented at the American Council for an Energy-Efficient Economy.

Goetzler, W., J. Burgos, H. Hiraiwa, J. Young, and R. Zogg. 2012. *Cool Ideas: Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems*. Paper presented at the American Council for an Energy-Efficient Economy.

Heschong Mahone Group. 2012. *The Road to ZNE: Mapping Pathways to ZNE Buildings in California*.

Hiller., C. (Applied Energy Technology). 2005. *Hot Water Distribution System Research – Phase 1*.

Hoeschele, M. and E. Weitzel (Davis Energy Group), D. Kosar, P. Glanville and H. Vadnal (Gas Technology Institute). 2012. *Water Heating Design Guide*.

Horsey, M. 2012. *What's Cookin'? A Suite of Gas Efficiency Technologies for Commercial Kitchens*. Paper presented at the American Council for an Energy-Efficient Economy.

Hunt, M. (Valley Energy Efficiency Corporation). 2008. *Super Efficient Gas Water Heating Appliance Initiative*.

Hunt, W., H. Upadhye, R. Domitrovic, P. Delany, B. Tsan and M. Vowles. 2012. *Variable Refrigerant Flow-Heat Recovery Performance Characterization*. Paper presented at the American Council for an Energy-Efficient Economy.

Hydeman, M. (Taylor Engineering), C. Higgins (New Buildings Institute) and C. Scruton (California Energy Commission). 2005. *Large VAVs (Variable Air Volume), Low Loads and High Performance - PIER TECHNICAL BRIEF*.

Im, P., P. Hughes, and X. Liu. 2012. *Demonstration and Performance Monitoring of Foundation Heat Exchangers (FHX) in Ultra-High Energy Efficient Research Homes.* Paper presented at the American Council for an Energy-Efficient Economy Summer Study, Pacific Grove, CA, August 12-17.

Information & Energy Services, Inc. 2010. *Liquid Pool Cover Engineering and Measurement Study*.

Information & Energy Services, Inc. 2011. *Raydronics Control Scaled Field Placement*.

Information & Energy Services, Inc. 2011. *Suncache*.

Karas, A and D. Fisher. 2006. *Evaluating the Water Savings Potential of Commercial Connectionless Steamers*.

Karas, A and D. Fisher. 2006. *Evaluating the Water Savings Potential of Commercial Connectionless Steamers*.

KEMA, Inc., The Cadmus Group, Inc., Summit Blue Consulting, LLC. 2010. *Evaluation Measurement and Verification of the California Public Utilities Commission HVAC High Impact Measures and Specialized Commercial Contract Group Programs*.

Kerr, R and M. Tondro. 2012. *Residential Feedback Devices and Programs: Opportunities for Natural Gas*.

Kosar, D., P. Glanville and H. Vadnal (Gas Technology Institute). 2012. *Residential Water Heating Program: Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating*.

Leni-Konig, K., R. A. Davis and E. G. D'Albora. (PG&E Applied Technology Services Performance Testing and Analysis Unit). 2008. *Laboratory Testing of Residential Water Heater*.

Lutz, J. (Lawrence Berkeley National Laboratory). 2008. *Water Heaters and Hot Water Distribution Systems*.

Lutz, J., P. Biermayer and D. King (Lawrence Berkeley National Laboratory). 2009. *Pilot Phase of a Field Study to Determine Waste of Water and Energy in Residential Hot Water Distribution Systems*.

Mowris, R. and B. Woody (Robert Mowris and Associates). 2010. *Development of New Testing Protocols for Measuring the Performance of Showerheads*.

Offerman, F. (Indoor Environmental Engineering). 2008. *Indoor Air Quality in New Homes: California Energy and Air Quality Conference Recent Research for Decision Making.*

Offerman, F., J. Robertson (Indoor Environmental Engineering), S. Brennan and D. Springer (Davis Energy Group). Undated. *Window Usage, Ventilation, and Formaldehyde Concentrations in New California Homes: Summer Field Sessions*.

PG&E. No publication date, research end year was 2004. *Tankless Residential Water Heater Feasibility Study*.

RLW Analytics. 2008. *Research and Development Roadmap for Water Heating Technologies*.

Schoenbauer, B., D. L. Bohac and M. J. Hewett. 2012. *Tankless Water Heaters: Do They Really Save Energy? Paper presented at the Americaon Council for an Energy-Efficient Economy*.

Spam, B., K. Hudon,, and D. Christensen. 2011. *Laboratory Performance Evaluation of Residential Heat Pump Water Heaters*.

Wallace, C., D. Fisher, A. Karas. 2007. *EE Potential of Gas-Fired Commercial Hot Water Heating Systems in Restaurants*.

Wallace, C., D. Fisher, A. Karas. 2007. *Energy Efficiency Potential of Gas-Fired Water Heating Systems in a Quick Service Restaurant*.

Wallace, C., D. Fisher, A. Karas. 2008. *Energy Savings Potential for Commercial Water Heating Through Retro-Commissioning*.

Zhang, Y. (Heschong Mahone Group, Inc.). 2013. *Multifamily Central Domestic Hot Water Distribution Systems*.

Zogg, R. A., and W. J. Murphy (TIAX LLC). 2004. *Design Refinement and Demonstration of a Market-Optimized Heat-Pump Water Heater*.

APPENDIX A:
List of Organizations Interviewed

Representatives from the following organizations were interviewed for this project:

- Affiliated International Management LLC
- Air-conditioning, Heating & Refrigeration Institute (AHRI)
- American Council for Energy Efficient Economy (ACEEE)
- ARP-E
- Balance Point Home Performance
- California Public Utilities Commission (CPUC)
- Center for Energy and Environment
- Chitwood Energy Management, Inc.
- CNT Energy
- Davis Energy Group
- DTE Energy
- E Source
- Ecova
- Energy Solutions Center
- Enovative Group, Inc
- Enovative Kontrol Systems
- Food Service Technology Center
- Gas Technology Institute
- Harpiris
- Heschong Mahone Group/TRC
- James J. Hirsch & Associates
- Koeller and Company
- Lawrence Berkeley National Laboratory
- McHugh Energy Consultants
- National Renewable Energy Laboratory
- Natural Resources Defense Council
- Oak Ridge National Laboratory
- PG&E Applied Technology Services
- Sempra Energy
- Taylor Engineering
- The Benningfield Group
- Trane
- US Energy Information Administration

APPENDIX B:
In-Depth Interview Guide

Thank you for taking the time to speak with me today. DNV KEMA is helping the California Energy Commission evaluate research needs related to increasing the efficient use of natural gas in buildings.

The purpose of today's conversation is to get your feedback on where future Energy Commission research should focus on in the near-term, mid-term and long-term for natural gas energy efficiency. For this interview, I'd like you to focus your comments on the residential and commercial building sectors. We'll be summarizing the feedback we get in aggregate, so your individual comments will be kept confidential.

[*If necessary: length of interview is 45 minutes, though total time depends on depth of responses*]

Background/overview

1. First, can you tell me your job title and responsibilities?
    a) How long have you been in this position?

Organization's Activities Related to Gas Efficiency

2. What are your organization's current activities related to reducing natural gas use in buildings by improving energy efficiency?
    a) [*Probe:*] Any additional activities?
3. Of the activities you listed, which one would you characterize as having the greatest potential for natural gas savings? [*Probe:*] Why do you say that?
    a) How long has your organization been working on this initiative?
    b) What are the goals of this initiative?
        i. [*Probe:*] Are there targeted sectors and building types?
    c) Who else is involved in this research/initiative?
        i. [*Probe:*] What other research has been done (or is currently underway) by others related to this initiative?
    d) How applicable is this to the existing buildings market versus the new construction market?
        i. [*Probe:*] Why?
    e) What are the expected natural gas savings and other benefits? [*For example, percent savings specific to end use (e.g., domestic hot water, space heating?), environmental (e.g., reduction in air emissions?)*]

f) What is needed in order for this technology/approach/strategy to achieve its full technical and economic potential for energy savings?

   i. [*Probe:*] What is the time frame for achieving full potential: near, mid or long term?

[Examples may include product or technology demonstrations and what's needed to cross the "valley of death" depending on how well developed their research/product/technology is.]

[*If needed: Near-term is defined as within the next three years; mid-term is three to five years from now and long-term is more than five years from now.]*

g) What are the challenges or barriers facing this technology/approach/strategy? [*For example, technical, market, cost, behavior/education/awareness, regulatory*]

h) How can these barriers be overcome or solved with research?

i) *[If needed:]* Is there any additional research or work you recommend to realize the full potential that we haven't already talked about?

Industry Activities Related to Gas Efficiency

4. What is another promising research area for significant natural gas savings? [*Probe:*] Why do you say that?

   a) Has your organization been working on this?

      i. [*If not:*] Who are the main organizations involved?

   b) Who else is involved in this research?

      i. [*Probe:*] What other research has been done (or is currently underway) by others related to this research?

   c) How applicable is this to the existing buildings market versus the new construction market?

      i. [*Probe:*] Why?

   d) What are the expected natural gas savings and other benefits? [*For example, percent savings specific to end use (e.g., domestic hot water, space heating?), environmental (e.g., reduction in air emissions)*]

   e) What is needed in order for this technology/approach/strategy to achieve its full technical and economic potential for energy savings?

      i. [*Probe:*] What is the time frame for achieving full potential: near, mid or long term?

[Examples may include product or technology demonstrations and what's needed to cross the "valley of death" depending on how well developed their research/product/technology is.]

[If needed: Near-term is defined as within the next three years; mid-term is three to five years from now and long-term is more than five years from now.]

f) What are the challenges or barriers facing this technology/approach/strategy? [*For example, technical, market, cost, behavior/education/awareness, regulatory*]

g) How can these barriers be overcome or solved with research?

h) *[If needed:]* Is there any additional research or work you recommend to realize the full potential that we haven't already talked about?

Recommendations for Other Research Needs

[*Note to interviewer: Be sure to cover both technology and policy recommendations*]

5. Overall, what other recommendations do you have regarding future R&D related to policy, regulatory or strategy to increase natural gas energy efficiency in buildings? [*Probe:*] Why do you say that?

6. Do you have any recommendations on who else we should contact as part of our research?

Name:
Organization:
Phone:
Email:

7. Is there anything else you would like the California Energy Commission to be aware of when developing its priorities for future energy efficiency research needs?

[*Reminder: Focus on building-related energy efficiency]*

8. Would you be interested in participating in a workshop in September to help shape the research priorities under development by the California Energy Commission?

9. Would it be okay if we followed up with you later if any other questions come up?

Thank you so much for your time and information.

APPENDIX C:
Summary of Interview Results

Table 9 through **Table 12** below provides a summary of priority research areas identified by interview respondents. The results of the interviews are grouped together by end use and subtopic area.

Table 9: Space Heating Related Interview Responses

Respondent	Description of Space Heating Research Needed
Heating Equipment	
Respondent 6	Collect existing data and research and summarize benefits of heat pumps. Good approach with potentially huge gas savings. This is a pretty well demonstrated technology that could easily be proven, but someone needs to collect the data and research completed and write it up.
Respondent 11	Understand actual operating efficiency of existing furnaces; need rooftop research on furnace efficiencies. The units are claiming a certain level of efficiency (rating) but who is verifying this. No one has paid attention to this to date.
Respondent 20	Publish a standard for rating commercial space heating boilers that is more representative of actual consumption. Current rating data is only for full-load efficiency rather than partial-load.
Respondent 23	Investigate opportunity for condensing furnaces for rooftop; special heat exchanger for furnaces for condensing technology. Does it make sense? We already have condensing systems for split systems.
Respondent 24	Need more broad based application and demonstration projects of natural gas heat pumps. The biggest challenge is first cost and air quality issues for residential. For commercial buildings, there are less air quality issues and more challenge of cost because not widely employed; demonstrations sites to try to show life cycle payback.
Respondent 29	Demonstration and best practices for condensing rooftop units. It needs to be demonstrated, best practices need to be defined for combustion condensate management (what local codes require in terms of disposal), educate contractors, what is required for laying the lines, disposal requirements, etc.
Respondent 31	More research needed around condensing furnaces and high-efficiency furnaces to bring costs down.
Respondent 32	Research how to apply steam and hydronic heating to particular building types, how to do it cost-effectively, and how to guarantee reliability. Additional case studies of innovative, efficient buildings would provide leading examples for other firms interested in marketing high-performing buildings.
Respondent 37	Research economy-grade furnaces and gas package units that are highly efficient (not just high end models), that is, seek to increase efficiencies of lower-end systems. Historically, high-efficiency has been reserved for the high-end HVAC models. A challenge that can be addressed by research: develop a low NOx system with high-efficiency and low cost.
Respondent 38	Demonstration studies of heat pumps for space heating to prove through larger scale field demonstration what the savings are, and engender gas utility support.
Quality Installation	
Respondent 3	Increase quality installation of rooftop units. There are a lot of RTUs that are installed and may not be installed correctly or there are controls issue that could be addressed. There are a handful of packages that could optimize controls and not use extra energy and run at highest efficiency they can. Most haven't been tested.

Respondent	Description of Space Heating Research Needed
Respondent 6	Increase quality installation of HVAC systems. Support research on energy savings related to quality installation, look at building performance using a verified design process and check values, put building performance design principles into a framework that could be incentivized.
Respondent 19	More lab and field research to demonstrate how installation and operations are not optimized for efficiency. The existing research doesn't deal with systems in an integrated manner and understanding how equipment ratings should reflect field installations and field installations should represent what was rated.
Building Envelope	
Respondent 6	Better understand air leakage and air changes required, and where most significant leaks occur. Evaluate metric and measurements for air leakage (air changes per hour) compared to the identification of small, but disproportionately significant leaks.
Respondent 18	Research into insulation materials like aerogels. Conduct research of phase change materials that haven't been thoroughly investigated; new forms of insulation are promising to put resources too, but not much seems to have high potential. Though cost reduction on aerogels would be great. Aerogels have 3-4 times the unit insulation in the same space.
Respondent 23	Develop a good comfort model (simulation model to generate a comfort rating). There is a comfort model in EnergyPlus and California Building Energy Code Compliance software, but it needs to be validated. The model doesn't include humidity and this is a big problem.
Respondent 23	Improve efficiency of skylights through low-E materials. Skylights are required in the energy code now, and we should look at practicality and feasibility of better insulation including louvers or low-E coating plastic materials.
Ventilation	
Respondent 11	Better understand the energy load related to make-up air in California and also strategies for reducing load and reducing exhaust rate with efficient hoods design, bringing air in at different locations. This is particularly relevant for the food service industry.
Respondent 11	Research benefits and impacts of variable speed exhaust. We need to quantify the savings numbers based on lab tests and demonstration projects.
Respondent 29	More research on indoor air quality and relationship to air changes needed. There is a standard that requires you to reduce ozone to a certain level by introducing outside air into the building. There needs to be further research into the impact into the ozone removal from outside air for building ventilation and from a building air quality perspective, it's unknown.
Respondent 23	More research on indoor air quality and sealing; understand appropriate materials with less VOC. Recent study by Bruce Wilcox found that all new buildings exceeding standards for formaldehyde, even with high air exchange rates. All savings from 2008 standards were offset by need for mechanical ventilation of homes.
Respondent 32	More testing of new technologies in existing buildings and better prediction of performance of high-efficiency units in old buildings. For example, improved data on impacts of new, efficient boilers. As you push new technologies, it's not clear how they interact with an old building. More data is needed on cost-effectiveness of high-efficiency equipment in a variety of old buildings. In particular, there is little information on buildings that are being over-ventilated, where air is heated or cooled and immediately leaving the space.
Ductwork	

Respondent	Description of Space Heating Research Needed
Respondent 19	Look at reality of how things happen in the field – e.g., do we crush ducts or punch holes when seal up the wall? There is a lot of talk about duct leakage, but not a lot of research on what is actually happening in the field, at looking at new construction separately from retrofits.
Respondent 25	Research into best practices for ductwork design in conditioned space. This is mostly a design issue and getting builders and market actors comfortable with the design process.
Controls	
Respondent 4	Identify effects of poorly programmed boiler controls. Need to increase impact of controls by identifying climate and building needs and programming accordingly.
Other	
Respondent 23	Use satellite imaging to identify which homes have highest heat loss. This can be used to target energy-efficiency marketing campaigns and make data public so people know how much heat they are losing from their homes.
Respondent 26	Conduct more research on transport membranes which enables low temperature heat recovery within the system (transport humidifier) where the water vapor is used to humidify supply air. More research such as demonstration sites and pilots to make it plug-and-play.

Table 10: Water Heating Related Interview Responses

Respondent	Description of Water Heating Research Needed
Water Heater Equipment	
Respondent 12	More research on heat pump water heaters and opportunities to incorporate a low-cost solar capture system. Research indicates better suitability with a storage tank than passive collector.
Respondent 18	Materials and systems testing for low-cost solar water heating. Polymer materials have a great promise for cost reduction but there is uncertainty about their lifetime and durability. Huge need for new materials and system. Also need for some system testing to verify the new approaches towards overheating and freeze protection in particular.
Respondent 21	Research how to bring costs down for condensing tank-type water heaters, including installation which is not a drop-in. You have fans and igniters and the exhaust system is more complicated.
Respondent 21	Look at how to bring cost of tankless water heaters down, and look at ways to keep a small amount of hot water on hand. You have to put in a bigger gas line, so doesn't seem purely cost-effective, but great on efficiency.
Respondent 25	Reduce standby losses related to pilot lights. When you look at California, where most people have natural gas water heaters, the energy to keep the pilot light energy gets to be a significant number. It's an inefficient system, but the load is small so it makes it economically challenging to do efficiently especially for retrofit. For new construction, you could go tankless.
Respondent 25	Getting durability and maintenance picture defined for tankless water heaters and more demonstration projects. Perhaps a tankless water heater with a small storage tank to optimize deliverability.
Respondent 28	More research on natural gas heat pump water heaters to achieve a "triple integrated appliance": combine end uses using natural gas heat pump. Ideally get heating, cooling, and water heating rolled into one system. Additionally, you could also use solar thermal to preheat the water.

Respondent	Description of Water Heating Research Needed
Respondent 31	Research how to integrate systems like solar thermal with high-efficiency water heater and how to bring costs down. How do you integrate the technologies?
Respondent 38	Support field demonstrations of heat pump technologies for natural gas water heating. There are a number of technical issues involved in getting this developed and getting the prototypes to work and cost of the manufacture down to targets.
Data and Use for Modeling	
Respondent 10	Organize the data related to water heating systems, develop a database of how many and what type of water heaters installed and associated energy use (and associated building data). Need a RASS for water heating.
Respondent 10	More field research on existing buildings and better modeling of energy use. There is a wide disparity in water and energy use between buildings and not a lot of best-practices that are well-known. Lots of the projects are based on modeled information, not real-world data.
Respondent 15	Improve tools for water system efficiency and optimization at design phase. We need help understanding interactive effects of different components of a hot water system (e.g., choice of faucet interacts with choice of water heating and plumbing affecting overall system efficiency). I want to demonstrate how a hot water system works. Develop a test plan that allows you to plug-and-play different water heaters, and adjust the plumbing layout and then measure pressure temperature and flow. Need a research and test center to test the plumbing and try different options.
Respondent 15	Better characterize water use in different building types for both residential and commercial sectors to characterize water use. This hasn't been in 50 years. We don't know how much about how hot water is used in an office building other than it is less than restaurant, so need segment analysis.
Respondent 16	Need more data on understanding how water is used in commercial and residential buildings. You can't decide the capacity and the need until you know how much water is used. You also can't do Title 24 water efficiency without knowing how much water is wasted to get warm or how much hot water that fills the pipe after turning off. And even though residential needs lots of knowledge, commercial needs much more. There are an often lots of commercial buildings that have the wrong hot water systems. And we are moving very hot water all around the building even though it isn't needed.
Respondent 21	We need field studies on how much waste there is in water heating systems. There is a huge opportunity in the existing construction and would be good to characterize and develop policies to address the hot water systems.
Respondent 21	Improve on simulation models for water heating. The existing models need more work and validation to be able to put the model into Title 24; we can't drop it into a building energy model right now.
Respondent 22	Collect more real-world data on water system design, including pipe sizes, joints, and relationship to fixtures and usage. The real-world demonstration projects with real people (not labs or lab techs) and more research on pipe diameters, insulation and effect on pipe sizes and serious effects on pipe joints.
Respondent 23	Research needed to better understand algorithms for pipe diameter right sizing (e.g., based on fixture types, fixtures, revised number of gallons to fixture unit, and pressure drop).
Respondent 16	Understand how people use water in newer homes. One element of water heating is that more basic research would be valuable to better characterize where the energy flows are for typical CA households. And also how people use hot water needs research especially looking at newer homes. A lot of studies are in older homes and we need to know profile of newer homes.

Respondent	Description of Water Heating Research Needed
Respondent 27	Research potential for and develop better central domestic hot water system monitoring and optimization. There is not a good optimizing tool or enough data about operations. There is a set of algorithms inside of EnergyPro that gives you an idea of how effective it is to put insulation or controls, but those algorithms are designed for new construction.
Hot Water Distribution	
Respondent 1	Field research into alternatives to recirculation systems and quantify savings for alternatives. A lot of field research to characterize different systems in the field and different measure interaction to then create a design guide and from there the Energy Commission can create a performance standard to guide people to build an efficient system.
Respondent 14	Need utility program support for recirculation controls which needs program support in form of rebates and incentives to bridge incremental cost gap.
Respondent 14	Research technologies such as balancing valves for balancing water distribution systems; we are working on project now looking at what products exist that we can put in and help balance the system to make the controls more feasible.
Respondent 19	Research to understand impact of losses from inefficient distribution system - where are the biggest losses? The inefficiency may outweigh the increased efficiency of water heaters. Particular focus needed on alternative ways to route or configure piping. You need a good sample size to capture variations in building characteristics.
Respondent 22	Develop codes and standards for pipe insulation and design. Pipe insulation is a problem because builders hide pipes under slabs in CA, but that can be solved with codes.
Respondent 36	Develop rating method for hot water distribution systems.
Policy	
Respondent 21	Research how to put efficiency requirements in building code related to plumbing structure, or criteria to reduce wasted hot water because of plumbing structure, particularly in new construction.
Respondent 21	Develop rating efficiency of plumbing system for whole house, which would serve as a performance indicator (e.g., this type of plumbing system is good) and require hot water distribution systems to have a certain rating to pass.
Respondent 25	Update the uniform plumbing code.
Other	
Respondent 11	Need research demonstration and effectiveness case studies for water efficiency in restaurant sector; particularly related to technologies relate do system optimization, condensing water heaters, timeclocks on recirculation pumps, and waste heat recovery.
Respondent 13	Need more field testing to demonstrate savings associated with efficient design or equipment. There is a lot of skepticism or uncertainty of the efficiency conclusions of existing studies, so the field research still need to establish the efficiency claims.
Respondent 19	Research should look at piloting new designs related to hot water controls in multifamily systems for better methods and controls, focused on the system as a whole. A lot of the program evaluations have only focused on what was done (on a individual component basis), rather than the potential alternatives (from a systems perspective).
Respondent 21	Figure out a way to characterize strategies to address hot water systems in existing homes (how do you go back and replumb homes). You can also take the data and assess whether the more efficient water heaters are cost-effective relative to re-plumbing a home.

Respondent	Description of Water Heating Research Needed
Respondent 27	Research how much energy is wasted in MF systems built in the '60s and '70s where boiler is outside and linked to several buildings, and is there a cost-effective fix? Back of the envelope shows potential of billions of BTU of gas being wasted.
Respondent 39	Research design approaches to improve efficiency of water heating and distribution. People tend to think that only using high-efficiency equipment is enough. There are also system design issues that depend on market practice and research can address that with better design practices and assess how those practices can be implemented.

Table 11: Cooking Related Interview Responses

Respondent	Description of Cooking Research Needed
Cooking Appliances	
Respondent 9	Research more efficient underfired broilers. There is a huge potential to increase efficiency through lids and optimiziing heat transfer and reduce waste heat and cooking temperature.
Respondent 9	Research into economy grade ENERGY STAR models through demonstration projects. There is a need for ENERGY STAR models to cost less. Currently, the ENERGY STAR models have a lot of extra features and premium construction. There is a potential market for equipment that meets ENERGY STAR without the bells and whistles.
Respondent 9	Focus on standby energy use and idle rates. Approaches include reducing idle rates through insulation, controls, temperature setback, multistage burners. Lots of different strategies have been employed on the industrial/factory scale (e.g., ovens for baking paints on cars, industrial potato chip fryers).
Respondent 9	Develop CEC database for efficient cooking appliances (like what was done for refrigeration) and potentially start mandatory reporting.
Respondent 9	Better understand vintage and EUL of cooking equipment. Most equipment comes with a 1- or 2-year warranty and after that the manufacturer is not doing the service or maintenance. There is a substantial secondary market for food service equipment.
Respondent 9	Research related to burner ignition technology to reduce the standby pilot energy use. There is technology for burner ignition without the standing pilot, but there are issues related to reliability, robustness, costs, functionality, and consistency of lighting.
Respondent 11	Product development for specific technologies that have had recent advances and specific potential efficiency increases (e.g., turbo pot, lidded charbroiler, and lidded griddles)
Respondent 9	Develop more efficient steamer, through recycling steam. Steamers reun flat out whether they are cooking or not and they do that to maintain level of production. ENERGY STAR saves energy, but there is a performance impact (i.e., takes longer to cook things).
Other	
Respondent 11	More field research to understand usage patterns and savings. We need hard data about operating hours, operating characteristics, and savings achieved. We have had a lot of lab tests and CPUC doesn't always believe the operating hours, so we need more field monitoring.
Respondent 11	Develop database of what is energy efficient. For instance, there is no inventory or database on energy efficiency of specific technologies such as kettles and braising pans. Also quantification of gas usage to get better database of equipment and typical usage patterns.

Respondent	Description of Cooking Research Needed
Respondent 11	Research intelligent/"smart" kitchens. There is a new wave of EMS, and the kitchen of the future would be more automated and allow the manager to see and monitor the energy use and know where the gas and electric consumption is going (e.g., the conveyor oven).

Table 12: Other Research Recommended

Respondent	Description of Other Research Needed
Whole Building	
Respondent 17	Research whole house approaches and training contractors. The Energy Upgrade California is all about that and it's a great idea to foster, including creating some simplified summaries of what they should do by style of house, and the order that they should be doing.
Respondent 33	Research smart buildings and frameworks for incentive programs. Understand how big the savings opportunity is and how to structure utility incentive programs. Develop case studies and understand what makes these smart building work; also develop dynamic simulation software that building operators can use.
Heat Recovery	
Respondent 9	Research how waste heat from cooking equipment could be captured and used for hot water heating.
Respondent 9	Research dishwasher drain heat recovery, where it is a water to water heat exchange.
Respondent 12	Research into drain heat recovery for commercialization.
Respondent 16	Develop rating method for combined space and water heating, specifically combination space and water heating appliances that are built around a condensing gas engine.
Respondent 9	Research into refrigeration waste heat for water heating. You really need to focus on walk-in freezers, where the superheat load is substantial enough for hot water heating which is a 24/7 opportunity (rather than using air-conditioning waste heat that only runs during certain times of the day and year). Unfortunately, refrigeration and plumbing are fragmented and involved different contractors.
Respondent 21	How to promote electric heat pump water heaters and how to make them cost-effective, particularly recovering waste heat from the air-conditioning part of the heat pump.
Respondent 23	Characterize the opportunities and research better designs for drain water heat recovery, such as horizontal heat exchangers. The technology is primarily vertical film heat exchangers so this works for a two-story, but not a one-story house. All the various opportunities are not well-characterized. How much of the Canadian work can be extrapolated to California?
Respondent 24	More demonstration for hydronic heating systems; research whole systems and real world applications.
Respondent 25	Make drain heat recovery feasible, including single family homes.
Respondent 26	Research transport membranes to capture flue gas water vapor for hot water. More research including demonstration sites and pilots to make it plug-and-play: Low temperature heat recovery within the system using the transport condenser allows for water vapor to be captured as hot water which can be used for boiler feedwater or laundry washing machines, among other things.
Combined Heat and Power (CHP)	

Respondent	Description of Other Research Needed
Respondent 5	Better understand opportunities with hydronic floor cooling and crossover issues. Conduct and publish case studies of innovative and efficient building design.
Respondent 13	Research how CHP can provide more functions.
Respondent 16	Research opportunities for small scale CHP. We still need a better understanding of efficiency vs. size for things like absorption chillers and small co-gen. Residential scale combined heat and power have no applicability in CA, but we need breakthroughs to use any combined product in small sizes. There are a lot of issues related to what gas can do related to distributed generation and what scale is the smallest that makes sense.
Respondent 23	Technologies such as fuel cell that makes use of waste heat for space heating and generating electricity, or waste heat for hot water use. Would this make sense for residential?
Respondent 33	Methodologies to value upstream savings and how to realize the benefits of CHP when the gas savings are more system wide.
Other Appliances	
Respondent 8	More research on gas dryers; improve testing and develop ENERGY STAR standard. Current tests use a fabric that isn't representative of actual clothes and the amount of moisture that gets into the load is not accurate to field conditions. Develop better ENERGY STAR rating system. Develop a better ENERGY STAR rating system that better captures the benefits of natural gas dryers.
Respondent 1	Research into more efficient commercial dishwashers and savings potential, including exhaust air heat recovery which is an area that the Energy Commission needs to do more work in and it will take collaboration with the mechanical and plumbing codes to really grasp the savings. We also need field characterization and field monitoring in order to characterize the savings in a lab and then those savings can be fed into a calculator to estimate system efficiency for different systems. And based on savings the Energy Commission can use code to achieve that savings.
Controls	
Respondent 4	Develop program to implement retrocomissioning, smart controls, communicating gas meters. One existing program tried combining behavior initiatives with low-cost measures to maximize savings potential. One main goal was to get customers to understand the importance of maintaining efficiency.
Respondent 20	Improve standard sequences in building controls that establish schedules and react in real time between different system activities. Identify gaps in education where, with better instruction, building operators could improve efficiency through use of controls.
Policy and Programs	
Respondent 13	Evaluate impacts of codes and standards already adopted. Can we look back and quantify if the regulations have had its intended effect? How do we improve implementation of regulations?
Respondent 27	Look at creative Title 24 TDV approaches that don't encourage gas switching. Right now, the TDV approach discourages use of electricity (especially at peak daytime periods) and results in more gas infrastructure in buildings.
Respondent 35	Assess feasibility of having builders pay utility bills for first three years to incentivize more efficient HVAC system design and installation. Right now, market interests are misaligned and little attention is paid to quality installation, resulting in a lot of inefficient HVAC systems.

Respondent	Description of Other Research Needed
Respondent 7	Improve design of efficiency programs and track saturations of inefficient equipment. Programs face a few common challenges. First, comprehensive retrofits are not fully taken advantage of. Second, the building shell measures, such as adding insulation, are often difficult to sell. Dan believes these barriers should be reviewed and addressed, perhaps with innovative financing mechanisms.
Miscellaneous	
Respondent 36	Research hybridized solar PV and thermal. For hybridized PV, we would need a way to bind them together since usually it's bonded by plastic, it wouldn't take much to bond it together, thermally glue it to the front the panel.
Respondent 18	Further test polymer heat exchangers such as other materials that will work in high temperatures. A good copper heat exchanger exceeds cost goals (way too expensive); we want to look at other materials that will take high temperatures better. Polymer materials show great promise for cost reduction but there is uncertainty about their lifetime and durability.
Respondent 34	Demonstration projects to reduce NOx emissions with high-efficiency equipment. Design and demonstration projects are important to develop the equipment and prove its historical success. The challenge will be getting better NOx with high-efficiency and low cost. It will be important to make sure the technology or technologies can fit multiple system types, so retrofitting is practical.

APPENDIX D:
Summary of Workshop Results

The purpose of the workshops was to obtain public input to inform the development of a natural gas roadmap for building energy-efficiency research. The goal of the roadmap is to identify the research needed to achieve reductions in natural gas energy usage and greenhouse gas contributions in residential and commercial buildings.

Members of the public were provided an opportunity to provide feedback on the initial research initiatives at the workshop, which were based on a literature review and extensive stakeholder interviews. The public was asked to focus on the following:

- Comments and questions on the initial list of research initiatives;
- Comments on the status of energy-efficiency technology development for residential and commercial buildings to reduce natural gas consumption;
- Identification of problems and challenges affecting natural gas energy efficiency for buildings;
- Identification of data and research gaps that are barriers to maximizing energy-efficiency technologies;
- Comments and recommendations for priority research needs to maximize energy efficiency; and
- Recommendations for partnership opportunities to gain synergies in research.

The workshops provided a summary of the preliminary recommendations for research priorities to improve natural gas energy efficiency in buildings based on the literature review and interviews with industry stakeholders conducted to date.

Summary of Input from Attendees

In this section, we summarize the input and comments provided by workshop attendees on the preliminary research initiatives and project results to date, along with insights related to technology development, next steps and research tasks needed and possible partnership opportunities to leverage other research funds and synergistic initiatives.

Cross-cutting Related Input

Workshop attendees emphasized the need for cross-cutting research across all natural gas end uses and the importance of a systems and whole buildings perspective for energy efficiency going forward. For many technologies, such as water heaters and furnaces, the individual equipment efficiencies are quite high and that the key opportunities for deep reductions in natural gas usage are related to reducing distribution losses, integrating equipment using sensors and controls, improving controls overall, and developing systems that recover waste heat from different system components.

Other important cross-cutting research was mentioned for combustion sources (burners) generally related to air emissions regulations that is a competing priority with energy-efficiency strategies. Although not directly part of the initial research initiatives presented during the

workshops, combined heat and power was also mentioned several times by different workshop attendees. **Table 13** summarizes the input from workshop attendees.

Table 13: Cross-Cutting Research Related Attendee Input

Issue Area	Cross-Cutting Input
Research Initiative: Focus on Technologies for Reducing Air Emissions While Increasing Energy Efficiency	
Status of Technology Development	There are already specific requirements for NOx in the SCAQMD that must be met currently or imminently. Additional regulation is needed for technology to integrate increasing energy efficiency while meeting emissions requirements. One common theme: need for emissions reduction technology. Emissions research agenda or emissions roadmap is a significant need. Specific air emissions standards (NOx, CO, CO_2 and particulate matter) are needed for: • Combo units (similar to the specific targets for water/space heaters), • Indoor air quality, particularly as homes get tighter, • Indoor emissions from ovens and stoves, • Biogas and role in emissions, • New materials impact on indoor air quality in new homes, and • System integration demonstrations for ventilation and energy efficiency SCAQMD has current regulations for NOx and has released information about what future NOx regulations may be as well. Therefore, in identifying energy-efficiency opportunities for equipment, consideration of a long-term planning horizon (e.g., 10 years) may be appropriate related to anticipating future NOx regulations. This is a priority for the Southern California Gas Company.
Specific Tasks and Next Steps	• Need developmental funding for nascent technology. There is often a lot more funding for demonstrations but hard to find development funding. For example, LBNL has technology that scales well with emissions and energy efficiency, but it needs development, probably a 3-year timeline. • Decrease the sensitivity of more efficient burners to gas composition. • Combustion efficiency related to system components (e.g., burners, controls) is the “new frontier” related to advanced controls that can track demand in real time and adjust turndown ratios.
Partnership Opportunities	SoCalGas and other utilities
Research Initiative: Incorporate Systems Perspective with Whole Building Performance	
Status of Technology Development	The ZNE deadline for residential new construction is 2020, many things apply and the market needs to look at the integration and envelope along with energy efficiency: • No definition for dual-fuel (gas and electric) ZNE home, only definition is all-electric. • Cost effectiveness of any technology is greatly impacted by codes and standards. • Whole building performance is key to ZNE, even without investment in new technology. • In existing buildings, loads can be reduced through building retrofits, enabling reduced size requirements for equipment. Then with the addition of renewables, a building can reach ZNE. • Home energy management – needs to be addressed for gas. Add sensors and controls for gas, inform homeowner on best uses of appliances (including appliance to appliance communication technologies). Behavioral based measures: For example, nest thermostats could be applied to gas.

Issue Area	Cross-Cutting Input
	• SoCalGas is installing five million residential smart meters for natural gas, with capabilities for hourly interval metering. But now behavioural based measures not accepted for program, until 2015.
Specific Tasks and Next Steps	• Need a definition of ZNE gas building. • Create a "Future Home" demonstration of more efficient home envelope and integrated systems.
Partnership Opportunities	• CPUC, California Gas Utilities
Other Comments	• Research needs to consider trends of the future, not just historical and specifically temperatures and climate change.
Research Initiative: Support Improvement of Codes and Standards	
Status of Technology Development	Codes and standards (T20) is impacted by emissions regulations as NOx and SCAQMD regulations apply to specific equipment. Title 24 includes references to indoor air quality which impacts whole house performance and other cross-cutting issues. It is necessary to incorporate energy efficiency in codes and standards and include updates with high-efficiency technology. Health-based standards are a movement of the future - most likely going to increase ventilation heat recovery (enthalpy wheel or other); optimize system view for health and energy Codes and standards can also restrict equipment component retrofits for energy efficiency that void standards ratings.
Specific Tasks and Next Steps	• Focus on the areas of greatest savings and act on existing buildings now. • Codes and standards can lead the market. • Need better codes for tighter homes and improved insulation practices. • Need controls for the whole envelope vs. just by end use. Integrated controls require lots of demonstration because its added complexity in the system, but it could benefit the user in the end by taking people out of the equation and making the use easier.
Partnership Opportunities	Local Air Districts, California Air Resources Board, Title 20 and Title 24 Development Teams
Research Initiative: Combined Heat and Power (CHP) - Gas	
Status of Technology Development	There are a number of barriers to CHP, but there is a smaller fuel cell technology micro-CHP out of Japan/Europe. It is very expensive and market entry is difficult. Also, maintenance is expensive. Potential emissions standards? • In California, CHP systems must meet stringent emission requirements and meet California ARB 2007 emissions standards for NOx, which is very challenging. • Develop additional efficiency rating systems for CHP. • Consider how the CEC can fund projects that address natural gas and electricity. • Micro-CHP – all technologies are about 2-5x too expensive. Cost reduction is a big need.
Specific Tasks and Next Steps	Develop additional efficiency rating systems for combined space and water heating systems. Need additional research to bring fuel cell technology to residential customers and bring down first cost and operational cost.
Partnership Opportunities	Coordinate with Energy Generation Research Office at California Energy Commission

In addition to the feedback on specific research initiatives, workshop attendees also commented that research should encompass the following:

- Leverage community-based research rather than just individual residential units (also can consider commercial/residential mixed use buildings). TRC is developing a high-level road map, not talking about specific technologies. Some initiatives are being done, but they need to be better integrated.
- Need to look at end-use reduction: reduce the amount of hot water used: energy water cascading, refrigerant/water heating combo-right now they don't integrate but they could. And there is a pressure heat exchange for solar water heating that is ready for a demonstration.
- Consider that homeowners tend to want gas fireplace; so potentially more focus on high-efficiency gas fireplaces is needed, particularly since there is a mandate against wood fireplace in Los Angeles basin, and no-burn days (voluntary).
- Need to research and understand the impact of codes and standards previously adopted. Are we getting the savings we thought we would?
- Research into communication equipment for homes and communication protocols for buildings.
- Gas "backup" cooling systems to reduce electric peak demand.

Water Heating Related Input

Workshop attendees provided many comments on the energy-efficiency research recommendations related to natural gas used for water heating. In addition to natural-gas fired heat pump technologies and bringing costs down related to condensing water heaters, workshop attendees also emphasized the importance of systems perspectives, such as better understanding of distribution systems for hot water. **Table 14** summarizes the input from workshop attendees.

Table 14: Water Heating Related Input

Issue Area	Water Heating Input
Research Initiative: Develop High-Efficiency Water Heaters Leveraging Natural Gas Heat Pump Technology	
Status of Technology Development	DOE has invested in advanced gas fired heat pumps (HP) with the following status: 1) absorption based gas fired heat pump is in development; 2) jet-injector HP could be applied to residential space heating/water heating; 3) engine-driven HP is not cost -effective yet because of emissions and cost challenges; and 4) engine driven HP for space cooling and heat recovery from water heating needs development. Challenges for natural gas heat pumps include technology adoption, high first costs and labor costs. Gas engine driven heat pump technology is also common in Japan, and we should investigate how to bring the technology over here.
Specific Tasks and Next Steps	At this point the technology needs scaling: • Consider funding advanced field demonstrations. The commercial space needs a lot of work to scale up technology and field demonstrations to

Issue Area	Water Heating Input
	prove efficiency and third-party verification of energy savings. • For residential sector, development of smaller scale technology is needed that also meets emissions requirements. • A market characterization should identify what applications and building types would be most cost-effective, with particular focus on how chain restaurants and health care facilities use water, would greatly benefit the field. • Look to international markets and find ways to support introducing technology in the US. For example, consider supporting a contest to show benefits of triple-integrated HP, already robust internationally, and develop best product for U.S. market. • Demonstration projects of Japanese gas-fired heat pumps.
Partnership Opportunities	• There is ongoing work with GTI • It is necessary to include manufacturers in development process • U.S. DOE
Research Initiative: Develop Condensing Water Heater Technology to Bring Down Costs	
Status of Technology Development	There are considerable barriers with condensing water heaters, including the high first cost and low sales in Southern California, probably because it is unclear how to get payback in its warm climate. There are technologies we can adapt to California; "every water heater in Europe is condensing," so this is a proven technology internationally.
Specific Tasks and Next Steps	Research is needed to address first cost issue, appropriate use in different climate zones and scale volume.
Partnership Opportunities	Air-conditioning, Heating and Refrigeration Institute
Research Initiative: Develop and Demonstrate Cost-Effective Waste Heat Recovery for Water Heating	
Status of Technology Development	Water heat recapture could be potentially integrated in residential and commercial sectors: For residential buildings, heat recovery from the shower system has potential. More research is needed particularly on how to cost effectively retrofit homes where copper water pipes are embedded in concrete slab. Also include airside energy recovery which is already available in Australia and Canada. For commercial there are available technologies for expanding heat recovery: • Heat absorption from exhaust commercially available now in industrial • Walk-in freezers with a continuous load • Drain water heat recovery is being used in Europe and drain water heat exchanger could improve the grease capture in restaurants • Passive heat recovery devices (in residential and commercial) • Waste refrigerant heat recovery technology is available and needs demonstrating and stimulating Additionally, coil wrapped around drain pipe and "DrainX" whole building heat recovery are potentially available for heat recovery in both sectors. There are test procedures for rating drain heat recovery systems in Canada.
Specific Tasks and Next Steps	Demonstration projects are needed. • Energy recovery ventilation is a fast-growing market, and research is needed to develop integrated solution for residential sector. • In commercial sector, consider creating a prototypical "restaurant of the future" as a test facility. • Look to international markets and find ways to support introducing technology in the U.S.

Issue Area	Water Heating Input
	For drain heat recovery, we need a study to show how much BTU is avaiablle in a typical home – how large is this waste stream?
Partnership Opportunities	Panasonic and other manufacturers
Research Initiative: Develop Low-Cost Solar Systems with New Materials and Improved System Design	
Status of Technology Development	Low-cost polymer materials with similar conductive properties to high cost copper and glass are needed. Additionally, challenges include difficulty in moving water from panels on the roof through the rest of the building, and high installation costs. New materials would enable development of specific water heater design for warm or cold climate which has potential for energy savings. Another area of interest is solar thermal system with gas component. Thermal storage has to be part of solar thermal. Multifamily buildings may be more effective for this technology, but then submeter/payment questions arise. In the commercial sector, some companies (e.g., Suncatch collector), are working on develop low cost solar systems and some residential pilots have been done. Parking lot installations are good for photovoltaic, but large heat loss for water increases material cost.
Specific Tasks and Next Steps	Develop: • New collector technology. • Entire system and distribution layout. • Controls. • Weatherproofing. • Materials for collectors. For commercial is it necessary to integrate with existing technologies and find appropriate locations.
Partnership Opportunities	IOUs need to be involved through all issues. • DOE Building America, manufacturers, National labs • SoCal Gas and GTI working on this now
Research Initiative: Improve Understanding of Current Water Distribution Systems to Support Higher Efficiency Retrofit and Design	
Status of Technology Development	More attention is needed for systems perspective. In this area, development is lagging behind improvements to efficiency of heating equipment. The field needs information on optimal configuration of piping and alternatives to recirculation systems. Commercial sector: • Vacuum-jacketed, stainless steel piping needs more research and funding. • Integrated system with short piping lengths, minimal bins with low pressure drops. • System integration is key. • Food service and large commercial may be good conditions for point of service water heating. • Code needs to be updated. Codes require continuous recirculation pump if water heater is <60 ft away from use. T24 should include pipe size and distance, not just square footage. A simulation model would be able to help collect necessary data. • Plumbing strategies are 70-80 years old and not priced for efficient system. • With commercial buildings, there is more turnover of space between tenants and owners, so there is an opportunity to regularly address plumbing layout. • Need to make sure pressure drops are balanced. • This area is particularly reactive to end users, requiring more information on how water is used and more education on energy-efficient behaviors.

Issue Area	Water Heating Input
Specific Tasks and Next Steps	• Review and consolidate past research from the Energy Commission, TRC, and GTI. • Focus on behavioural modification and developing and understanding of water use. • Additional research to characterize different distribution systems design by commercial category/building type and vintage. The distribution losses are all over the map and we need a sense for exactly how "all over the map" it is to characterize the systems and identify research and development. • Residential research tends to point toward benefits of pipe insulation, and more work is needed to determine details. • Developments of software – looking at water systems the same way we look at heating systems; holistic approach, providing plumbers with tools to redesign plumbing system. Design system in a more efficient manner; potential opportunities for retrofits during re-piping
Partnership Opportunities	California Energy Commission Codes and Standards (Title 24) team, GTI
Research Initiative: Collect and Characterize Energy Use Related to Water Heating Across Different Building Types, Designs, and Vintages	
Status of Technology Development	There is a great need for more data in these areas: • GTI recently finished research related to quick-serve restaurants and multifamily (based on monitoring and modelling), but characterization of all other buildings types is needed • More data on efficiency degradation over time: combustion efficiency based on vintage (applicable to other end uses as well – GTI study on space heating found no degradation over time). GTI study on tankless water heating degradation • Health care is a particularly high energy use, so there is a huge opportunity to focus on this building type. Although there has been a great deal of data collected, the data is not consistent or in formats that are easy to aggregate.
Specific Tasks and Next Steps	Characterize buildings by (1) building type, vintage, and consumption (fixtures), and (2) real-world data on water system design. Studies with larger sample sizes are needed. Previously, it has been difficult to monitor water use and the largest study by Energy Commission involved 18 homes. Data needed to update uniform plumbing code. • Prioritization of next steps: first focus on the commercial top three buildings (restaurants, health care, lodging). • Basic research needed on meters and operating efficiencies because without that information, then it is not possible to properly assess energy-efficiency opportunities. • Research on determining optimal combinations between storage and instantaneous, balance between water distribution and gas distribution.
Partnership Opportunities	CPUC, Energy Commission

In addition to the feedback on specific research initiatives, workshop attendees also commented that research should encompass the following:

- Consider supporting component development for better support of packaged units or optimizing components to enable greater system efficiency. This is a retrofit challenge; if you cannot replace entire system, you could replace components of the system

- Submetering for multifamily and multitenant buildings
- Commercial laundry should be considered: washing and drying – water usage, energy, no ENERGY STAR gas dryer; washer efficiency
- Fuel switching is a factor in considering energy efficiency. For example: electric HP's are pretty robust and may make sense to fuel switch. Also consider a way to investigate high-efficiency water heater that allow for fuel flexibility (biogas or just change in gas composition that's supplied by the gas company)
- Additional emphasize on important topic of reducing water use
- Third-party programs have turnkey solutions for lighting etc., but not for hot water reduction or water heating. There is potential to be specialized for each application, building type, etc for piloting. Water company partnership is important but not usually done
- Increased need for high-efficiency pool and spa heating for Southern California focus, could easily be combined into space, water, and pool heating
- Research and identify potential for burners that utilize different gases to explore the possibility of utilizing more biogas

What problems or challenges need to be overcome:

- One of the biggest challenges is expense both of acquiring additional data and funding development of potential technologies. Additionally, different directives between stakeholder organizations, such as water, electric, and gas companies, prevent integrated appliances. Overall the focus on end uses operating in buildings inhibits a systems perspective that is needed for reaching the next level of savings.

Space Heating and Cooling Related Input

Workshop attendees provided comments related to HVAC natural-gas-related research needs. Since the comments and input appeared to be specific to the commercial and residential sectors, the feedback is summarized separately for each sector.

For the commercial sector, workshop attendees discussed research needs related to heating equipment primarily related to rooftop condensing furnaces and natural gas heat pumps. A large focus was also on the HVAC system as a whole, including air distribution (e.g., ducts) and issues related to building envelope sealing, mechanical ventilation, and indoor air quality. More research related to controls was also discussed during the workshops. **Table 15** summarizes the input from workshop attendees related to commercial space heating and cooling.

Table 15: Commercial Space Heating and Cooling Input

Issue Area	Commercial Space Heating and Cooling Input
Research Initiative: Develop and Demonstrate Cost-Effective RoofTop Condensing Furnaces for Commercial Applications	
Status of Technology Development	The technology is commercially available, but not really utilized in California due to cost barriers related to our climate. Buildings with rooftop units should be well-suited.
Specific Tasks and Next Steps	• Demonstrate field and long-term performance data • Improve installation practices, such as correct airflows needed for system to perform correctly
Partnership Opportunities	HVAC manufacturers
Research Initiative: More Research Related to Natural Gas Heat Pump Technologies and Combined Space Heating and Water Heating Technologies	
Status of Technology Development	Natural gas heat pumps exist abroad, but are expensive and not in commercial use here in the U.S.
Specific Tasks and Next Steps	• Develop a cost-effective cooling/heating/water natural gas heat pump • Address scale up issues
Partnership Opportunities	International manufacturers
Research Initiative: Support research to improve efficiency of air distribution systems, including leakage and the need for ventilation and make-up air	
Status of Technology Development	• Systems are built for design condition (peak) • There are Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) manuals for airtightness in high pressure ducts, but otherwise a lack of standards • ASHRAE looking at fractional air leakage (%). The ASHRAE handbook was updated and research continues to be done on this issue • CEC funded duct leakage intervention study, which measured use before and after sealing. Impacts agreed with theory • There will be DOE requirements for fans, but not systems
Specific Tasks and Next Steps	• Collect data on existing building distribution design • Improve standards for leakage and how they are measured • Develop a rating for the whole system (including motors, fans, belts, VFDs, ducts), not just leakage • Research how envelope retrofits impact system sizing • Review air distribution end-to-end and write better standards for acceptable leakage criteria • Optimize fan efficiencies as they impact gas usage as well as electric
Partnership Opportunities	LBNL and ASHRAE are conducting research on air distribution
Other Comments	Leakage affects gas and electric, demanding an integrated approach to research
Research Initiative: Conduct More Research Related to Controls for Both Individual Equipment, As Well As Whole Building	
Status of Technology Development	• Controls are currently in place for cooling, but there has been less of a focus on controls for optimizing heating systems • Controls address safety, health, comfort, and energy efficiency • Simultaneous heating and cooling in buildings can occur, and is particularly common in restaurants • Makeup air and HVAC are often on separate controls • Study showed that rooftop package equipment might need to be tested and balanced and systems would benefit from controls such as demand controlled ventilation or other integrated controls to reduce energy usage

Issue Area	Commercial Space Heating and Cooling Input
Specific Tasks and Next Steps	• Collect data to provide insight on behavioral changes and develop adaptive algorithms (such as used by Nest) • Collect data to better inform appropriate control selection • Improve fault diagnostic detection • Integrate kitchen exhaust controls and HVAC controls • Improve and increase automation of register controls • Develop and demonstrate registers based on occupancy levels, under-floor registers • Improve non-functioning economizers and increase maintenance knowledge • Research effects of high pressure drops with the duct system on energy usage
Partnership Opportunities	LBNL, Stanford

In addition to the feedback on specific research initiatives, workshop attendees also commented that research should encompass the following:

- Research gap exists for efficiencies of unit heaters and outdoor space heaters,
- Assess strategies for targeting conditioned air and heating to the building occupants, such as through under-floor diffusers
- Research advanced absorption chillers, and how to reduce the size of chillers to meet air quality
- Integrate other space heating approaches such as thermal space heating
- Reduce thermal use of building by using better windows, cool roof technologies, cool ducts, evaporative cooling
- Consider hydronic heating in addition to forced air for commercial applications

What problems or challenges need to be overcome:

- Manufacturers aren't likely to identify integrated approaches on their own
- Basic understanding of building physics is low
- Behaviors of building occupants are variable with significant impact on energy consumption
- Poor communication and industry politics exist between manufacturers of components

For the residential sector, workshop attendees discussed the need for combined space heating and water heating research, including natural gas heat pumps. Fundamentally, however, many felt that low-hanging fruit was related to improve the quality of the HVAC systems in homes because the existing furnaces themselves are already quite efficient. Similar to the commercial sector, many workshop attendees discussed the need to improve the efficiency of air

distribution (e.g., ducts) systems and issues related to building envelope sealing, mechanical ventilation and indoor air quality. **Table 16** summarizes the input from workshop attendees.

Table 16: Residential Space Heating and Cooling Notes

Issue Area	Residential Space Heating and Cooling Notes
Research Initiative: More Research Related to Quality Installation Issues for Heating Systems in Residential Applications	
Status of Technology Development	• Furnaces are still being installed in the attic • Research underway to increase size of return duct to ensure rated efficiency is achieved • Current DOE Building America project with GTI to assess where the most efficient operating point is for furnaces
Specific Tasks and Next Steps	• Change Title 24 to prohibit installation of furnace and ductwork in the attic • Increase code enforcement • Identify impacts on air quality as homes get tighter
Partnership Opportunities	Western HVAC Performance Alliance (WHPA), including utilities and manufacturers
Research Initiative: More Research Related to Natural Gas Heat Pump Technologies and Combined Space Heating and Water Heating Technologies	
Status of Technology Development	Covered in water heating category
Specific Tasks and Next Steps	• Demonstrate absorption equipment • Demonstrate systems combining space heating and water heating • Identify correct installation techniques
Partnership Opportunities	
Research Initiative: Support Research to Improve Efficiency of Air Distribution Systems, Including Leakage and the Need For Ventilation and Make-Up Air	
Status of Technology Development	• As homes are made tighter, ventilation needs increase • Aero-seal duct sealing exists, but needs further demonstration • Building codes require that ventilation be measured and verified, or a rated product used from a prescriptive list
• Specific Tasks and Next Steps	Insulation and sealing to tighten homes: • Demonstrate and improve tools such as aero-seal duct sealing • What are best practices for multifamily buildings and townhouses for insulating and sealing between units. Is it worth it to seal the interstitial spaces? Ventilation practices: • Gather information on how ventilation is being provided in new homes and how different approaches impact indoor air quality • Research better controls for managing indoor air quality • Better understand the impacts on space heating load from tighter ductwork, and increased ventilation • Design a credit-based approach to meeting various requirements, allowing for credit incentives such as improved filtration Test procedures • New test methods are needed related to ventilation • Create new test procedures for variable speeds fans and kitchen hoods
Partnership Opportunities	CPUC

In addition to the feedback on specific research initiatives, workshop attendees also commented that research should encompass the following:

- Consider gas-powered space cooling
- Thermal storage can capture heat in the afternoon and distribute at night. Research is needed to identify tank sizing and insulation requirements. Thermal storage can also play a role in CHP
- Include solar space heating as an option in Title 24
- Research into sensors and controls to improve efficiency of space heating and cooling systems

What problems or challenges need to be overcome:

- Enforcing code compliance is difficult
- Achieving low emissions, high-efficiency, and affordability is one of the fundamental challenges

Cooking Related Input

Finally, the workshop attendees also commented on research needs associated with reducing natural gas usage related to cooking. They were generally supportive of research to develop lower cost ENERGY STAR cooking equipment, developing technologies to reduce standby losses, and product development for key cooking appliance types with the greatest potential for natural gas savings. Workshop attendees also discussed "next generation" kitchens and opportunities to further leverage information technology, monitoring, and controls to improve operator understanding of natural gas usage in kitchens. A few recommendations were also provided for research aimed at reducing natural gas use in residential buildings related to cooking. **Table 17** summarizes the input from workshop attendees.

Table 17: Cooking Related Input

Issue Area	Cooking Related Input
Research Initiative: Focus on Developing Economy-Grade ENERGY STAR Cooking Appliances	
Status of Technology Development	• Technologies are available to double energy efficiency, but additional work is needed in consideration of market drives and economics • Dealers typically don't carry efficient equipment because the perceived market is small • Efficiency is coupled with premium materials, which demand a premium price • Energy impact potential is high but challenges are large
Specific Tasks and Next Steps	• Modernize burner systems to address efficiency and emissions cost-effectively • Develop tiers of ENERGY STAR that are not top-of-the-line • Modernize kitchen demand ventilation systems
Partnership Opportunities	Continue partnerships such as GTI and PG&E Food Service Technology Center

Issue Area	Cooking Related Input
Research Initiative: Focus on Reducing Standby Energy and Idle Rates, Including Use of Insulation, Controls, Temperature Setback, Lids, and MultiStage Burners	
Status of Technology Development	Some technologies exist, but they are expensive and negatively affect the user experience, leading to low adoption rates Allowing the user to override auto-shut off controls is common and undermines potential gains
Specific Tasks and Next Steps	• Develop technologies that reduce standby energy losses and have minimize impacts to the user • Design products that users cannot disable while minimizing usability interference • Develop energy savings reporting that allow the operator to see energy savings • Design appliance-level, low-cost gas meter that can be integrated into appliances and avoid increase in gas leak risk
Partnership Opportunities	• Manufacturers can offer feedback by appliance • Companies such as Synapsense and Nest can continue product development • Safety certifications such as EL, CSA, and NSF can design retrofit standards • Codes and Standards: ASHRAE, NFPA Environmental Health, IAPMO
Research Initiative: Support Product Development for Select Appliance Types	
Status of Technology Development	• There are categories of commercial cooking appliances that don't have ENERGY STAR products. Fisher-Nickel website has list of technologies currently in development • LBNL submitted an energy-efficient burner with low emissions, but gained no manufacturer support • Cooking appliances are often an "emergency replacement," leading to frequent least capital cost purchases
Specific Tasks and Next Steps	• Increase use of better insulation materials • Develop products with shorter payback • Develop affordable guidelines and systems for near-future breakdown detection • Develop commercial dishwashers that do not use electric supplemental heat • Conduct more commercial food service-related energy audits
Partnership Opportunities	
Research Initiative: Support Research Related to "Smart" or "Intelligent" Kitchens	
Status of Technology Development	• Industry is starting to see coordination of ventilation with specific equipment • Smart controls developed in walk-in refrigeration • Wireless communication, USB ports are technologies that can be integrated into "smart" kitchens
Specific Tasks and Next Steps	• Design and support a kitchen of the future demonstration including ventilation controls, each of which can be submetered • Design dashboards similar to hybrid cars to affect behavior • Document and present the costs and payback
Partnership Opportunities	Appliance and technical manufacturers Data analytics companies
Research Initiative: Support More Research Related to Residential Cooking	
Status of Technology Development	Flames are very inefficient in residential cooking. The cooktop flames are fairly robust and we have shifted from open burners to sealed burners.

Issue Area	Cooking Related Input
Specific Tasks and Next Steps	• Research into optimal distance from the flame for residential applications. • Better understanding of interaction with the pot • Consider efficiency standards for pots and cooking ware
Partnership Opportunities	

In addition to the feedback on specific research initiatives, workshop attendees also commented that research should encompass the following:

- Research the impact of gas cooking equipment on indoor air quality and subsequent impacts on appliance design, including fuel use and efficiency
- There is an opportunity for component-level retrofits in the secondary market, but these often violate safety certifications
- Identify potential for refrigeration recovery. Interactions between the refrigeration and plumbing team are presently minimal
- Develop better process to ensure compliance with codes and standards

What problems or challenges need to be overcome:

- Usability of equipment is the highest priority for end users
- Cost effectiveness and market drivers make energy efficiency a low priority for restaurants
- Changes in behavior and perception tend to be very difficult to achieve
- Restaurant managers have a lot of various responsibilities, and there isn't a contact person for energy management
- With long-term paybacks and a restaurant failure rate around 80%, expensive appliances have high risk
- Heat recovery challenges for the food service sector include cost, grease in the air stream, and minimal heating load compared to cost recovery