American Gas Foundation

Natural Gas End Use: A Vision for Today and the Future

September 22, 2009

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A Vision for Today and the Future

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Our Mission and Objectives

GTI is a research organization with "the energy to lead." We solve important energy challenges, turning raw technology into practical solutions that create exceptional value for our customers in the global marketplace. We are driven by three primary objectives, which span the energy industry value chain. They provide both the focus and enduring opportunity for our business endeavors. These objectives are:

- Expanding the supply of affordable energy
- Ensuring a safe and reliable energy delivery infrastructure
- Promoting the efficient use of energy resources.

TABLE OF CONTENTS

Natural Gas End Use: A Vision for Today and the Future
Executive Summary

Introduction
As a planning tool for the natural gas industry, its customers and government partners, this plan is intended to spur collaborative research efforts in areas of mutual interest and benefit.

Initial activities include awareness building through meetings with industry, government and policymakers highlighting benefits for consumers, manufacturers and the nation.

Residential and Commercial

Market Segment and Impact
The residential and commercial sectors comprise more than 110 million homes and nearly 5 million places of business, respectively. Total primary energy use in these buildings (21.6 quads and 18.5 quads, respectively) accounted for approximately 40 percent of total U.S. energy consumption in 2008, according to the U.S. Department of Energy (DOE).

Technology can play a major role in improving the efficiency of energy use and in reducing the emissions of GHGs from associated energy equipment for both sectors.

RD&D Goals
In considering priorities for natural gas-related RD&D in homes and businesses, it is important to identify the major end-use applications. In homes, space heating and cooling, water heating and cooking are the most prominent end-use applications. In commercial buildings, lighting, space heating and cooling, and water heating top the list. For maximum national impact space conditioning (heating and cooling) and water heating should be major areas of focus for RD&D. On-site combined heat and power (CHP) systems can play a significant role in satisfying the need for power, space conditioning and hot water.

The research plan recommends high-priority RD&D initiatives related to natural gas use in homes and businesses that can assist the industry achieve its long-term natural gas vision.

The Homes and Businesses RD&D program is intended to achieve two major goals by the year 2030:

- **Energy efficiencies resulting in a savings of more than 4.0 quads annually; and**
- **Reductions in GHG emissions resulting in nearly 290 million metric tons annually.**

Strategic goals for natural gas technologies in homes and businesses are:

1. Promote wider adoption of best current technology for major residential and commercial energy applications.
2. Provide technical and analytical support regarding development and application of codes, standards and legislation to promote efficiency.
3. Develop advanced equipment for space and water heating, and cooking based on combination configurations, improved heat transfer/recovery and emission controls.

4. Reduce GHG emissions and electricity end-use and delivery infrastructure costs through advanced CHP and renewables.
5. Improve efficiency, ensure indoor air quality, control emissions and reduce costs through building systems RD&D.
6. Integrate natural gas systems with the evolving smart energy grid.

7. Pursue breakthrough technologies through fundamental RD&D (e.g., combustion science).

Funding Required

Funding requirements for the RD&D program elements discussed above are summarized below. For every RD&D dollar spent over the life of this plan, there will be $14 of net consumer energy cost savings.

	Funding ($ millions)		
RD&D Initiative	**2010**	**2015**	**2020**
Space Conditioning	24	22	20
Water Heating	14	16	18
Cooking/Food Service	4	5	6
Combined Heat & Power	30	28	26
Building/Community Systems	20	21	22
Breakthrough Research	17	19	21
Total	**109**	**111**	**113**

Industrial

Market Segment and Impact

Implementing this plan will improve manufacturing competitiveness and stimulate employment in the vital industrial sector while addressing the nation's energy efficiency and environmental goals. Since 1989, the manufacturing share of the economy has declined from 17 percent to 12 percent of gross domestic product. From 2005 to 2006, more than 200,000 jobs were lost in energy-intensive manufacturing industries including paper, primary metals, and motor vehicle and parts

The Industrial RD&D program is intended to achieve two major goals by the year 2030:

- **Energy efficiencies resulting in savings of nearly 1.1 quads annually; and**
- **Reductions of GHG emissions by nearly 110 million metric tons annually.**

manufacturing. The industrial sector currently consumes 32 percent of all U.S. energy and 7,000 trillion Btu of natural gas (7.0 quads) annually. The RD&D plan focuses on large energy users in high-energy intensity sectors using steam, power or process heat. The plan also addresses increased use of renewable fuels to enhance energy sustainability and lower carbon emissions.

RD&D Goals

The plan focuses on expanding the deployment of previous technology successes, creating new

technology solutions, expanding energy efficiency programs and developing the next generation of industrial processes. It maximizes the value of each research dollar to achieve the goals of greater efficiency, increased productivity and renewable fuel use, improved environmental performance and carbon emission reduction and improving U.S. industry competitiveness. This crosscutting research plan identifies six program goals yet also suggests a need to focus a portion of the program on industry specific technology development that can provide substantial value in U.S. competitiveness and job retention and creation. These efforts can result in step-change technologies leading to unforeseen breakthroughs.

Strategic goals for gas technologies in industrial applications are:

1. Reduce energy consumption by 8 percent to 20 percent for industrial steam users by expanding the portfolio of ultra-efficient systems.
2. Improve the efficiency of industrial heating and on-site power generation systems to recover 25 percent of the lost energy to create more cost-efficient systems for a variety of industrial applications.
3. Reduce GHG emissions and electricity end-use and delivery infrastructure costs through advanced CHP technologies.
4. Increase the use of renewable fuels in the industrial sector by up to 15 percent leading to reduced carbon dioxide (CO_2) emissions and energy costs.
5. Provide recommendations that will allow manufacturers to reduce overall energy use by up to 20 percent in their process operations and facilities.
6. Improve manufacturing production and other industrial process efficiency by up 10 percent leading to reduced energy consumption and lower operating costs.

Funding Required

Funding requirements for the RD&D program elements discussed above are summarized below. For every RD&D dollar spent over the life of this plan, there will be $6 of benefit to U.S. economy.

	Funding ($ millions)		
RD&D Initiative	**2010**	**2015**	**2020**
Industry Specific R&D	31	36	40
Steam Generation	35	41	47
Process Heating Systems	49	58	66
Onsite Power Generation	62	72	83
Renewable Fuel Utilization	18	21	24
Industrial Energy Efficiency	16	18	21
Controls and Sensors	4	5	6
Total	**215**	**251**	**287**

Transportation

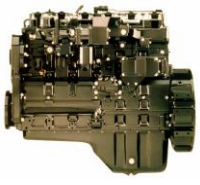
Market Segment and Impact

The transportation sector represents a vital part of the U.S. economy. Presently, 29 percent of total U.S. energy – nearly 28 quads of energy – are used to move commercial goods and for private transportation. U.S. reliance on imported petroleum and related products has steadily grown to 60 percent, contributing to a negative balance of trade along with heightened energy security concerns.

There are multiple pathways by which natural gas is currently being used in the transportation sector. The most significant is an indirect route via ethanol production. Natural gas is a key enabling energy source that is vital to ethanol production. More conventional direct routes for using natural gas in vehicles are CNG (compressed natural gas) and LNG (liquefied natural gas) vehicles. Current U.S. natural gas vehicle (NGV) fuel use is about 300 million equivalent gallons of gasoline per year – roughly 37 bcf of natural gas. There are approximately 120,000 vehicles and 1,100 NGV fueling stations in the U.S. Most fuel consumption is associated with heavy-duty vehicles such as transit buses, refuse trucks, and pick-up and delivery vehicles.

The Transportation RD&D program is intended to achieve two major goals by the year 2030:

- **Reduce emissions of greenhouse gases by nearly 40 million metric tons annually; and**
- **Reduce foreign crude oil purchases by over $16 billion – while increasing domestic jobs for energy production and delivery.**



RD&D Goals

The RD&D plan identifies six high-priority research, development, and deployment goals for ensuring natural gas is being used in the most efficient and environmentally acceptable manner in the transportation sector:

1. Integrate available and emerging ultra-low emission natural gas engines with vehicle manufacturers in priority weight classes.
2. Develop advanced CNG and LNG on-board fuel storage systems using advanced composite materials and alloy metals. Enhance vehicle fuel storage safety with nationally recognized codes and standards and certification programs.
3. Develop advanced CNG and LNG fueling station equipment and systems to reduce cost, enhance fuel delivery performance, and ensure accurate and timely filling of vehicles.
4. Develop advanced technology medium- and heavy-duty hybrid NGV platforms for use in trucks, transit buses and school buses.

5. Develop and deploy advanced renewable methane technology to ensure the fuel quality requirements of advanced technology vehicles are met with integrated gas clean-up systems.
6. Develop breakthrough vehicle and infrastructure technologies including; advanced natural gas hybrid commuter vehicles, special-purpose auxiliary power units (APUs) for medium and heavy-duty vehicles, and natural gas-to-hydrogen fuel stations for hydrogen fuel cell vehicles.

Funding Required

Funding requirements for the RD&D program elements discussed above are summarized below. The research program will also provide over $1 billion in transportation fuel cost savings annually for consumers and businesses.

	Funding ($ millions)		
RD&D Initiative	**2010**	**2015**	**2020**
NG Engine and Vehicle Tech	16	16	16
Fuel Storage Tech	5	6	7
Fueling Infrastructure	5	6	7
Renewable Methane	5	7	9
Safety, Codes, and Standards	2	2	2
Next-Gen Tech Development	2	3	4
Total	**35**	**40**	**45**

Section 1 Natural Gas End-Use Vision and Pathway

Introduction

Natural gas plays a key role in meeting the current and future energy and environmental needs of the United States. It is an abundant, affordable, efficient, clean, domestic energy source, delivered by an extensive, proven pipeline system for use in a wide range of efficient, reliable, and safe end-use equipment. Natural gas—primarily from North American sources—provided approximately 24 percent of all the energy the nation consumed in 2008.

However, the dynamics of the U.S. energy industry are changing.

- The disruption of the global financial system in 2008—coupled with dramatic swings in the price of oil—triggered a major reduction in economic activity and energy demand.
- The government is actively developing "low-carbon" energy policy scenarios for the future that may inadvertently increase near-term greenhouse gas emissions due to expanded use of fossil fuel-generated electricity that displaces natural gas end uses.
- The role of nuclear electric power generation is being re-examined.
- Wider use of renewable energy resources is being pursued.
- Researchers are evaluating a range of advanced energy technologies, including fuel cells, gasification, biofuels production and a "smart" energy grid.
- Consumers concerned about energy costs and the environment are increasing demand for efficient, cost-effective, and environmentally friendly end-use equipment.
- Emerging natural gas options such as large shale gas fields, coupled with extensive on-shore and off-shore conventional natural gas fields, can provide an abundant in-ground domestic natural gas resource for the foreseeable future.
- The government is actively pursuing opportunities to decrease the nation's dependence for imported petroleum.

Given the abundance of North American natural gas, the experience in the last two decades in developing non-conventional natural gas resources, the existence of a large and sophisticated North American natural gas distribution and transmission system, the inherently low-carbon intensity of natural gas, and the challenges facing all fuels in meeting the requirements of a low carbon future, the natural gas industry needs to examine what must be done to maintain the role of natural gas as a vital and integral part of a low-carbon and efficient energy portfolio in the United States.

In many instances, direct gas use can represent a more energy and environmentally efficient option compared to electric equipment. Examples include electric resistance equipment used for water or space heating – these end-use needs can be met more efficiently with natural gas. Other electric uses such as lighting and electronic equipment are clearly best done with electricity. However, central power plants – in particular, coal power plants – create significant energy losses and carbon emissions. For these other electric uses, high efficiency natural gas combined cycle power plants or onsite natural gas combined heat and power (CHP) systems are proven pathways for increasing total energy efficiency and reducing carbon emissions.

Natural gas should be recognized as an integral part of the energy solution to our nation's interest in a low carbon footprint and energy efficient economy. To achieve this objective, the natural gas industry must develop a clear vision for the desired future role of its premier fuel, as well as a pathway for realizing that vision – recognizing the fundamental role natural gas has played and will continue to play in meeting the nation's need for clean, domestic energy.

This document outlines a vision and a path forward for the natural gas industry, its customers and other stakeholders, with particular focus on research, development, and demonstration (RD&D) opportunities related to the core residential and commercial sectors.

Natural Gas End-Use Vision

The vision for the role of natural gas in end-use applications includes the following elements: Today and in the future, natural gas is considered to be part of the solution to address the nation's energy efficiency, climate change and other environmental goals. The attributes of natural gas - clean, abundant, efficient and American - are recognized as part of the solution today because existing infrastructure and end-use technologies in the residential, commercial, industrial and transportation sectors provide an immediate way

to reduce emissions (including carbon) and energy use cost effectively while preserving American jobs and enhancing the nation's energy security. In the future, natural gas will continue to play an important role in the nation's energy strategy as new and enhanced end-use technologies enter the marketplace.

A Pathway to the Vision

Achieving the elements of this vision will require a number of interrelated activities and initiatives. Gas producers, pipeline operators, and local distribution companies will need to ensure the production and delivery of adequate and cost-competitive gas volumes.

The gas industry will need to partner with key manufacturers to develop the equipment needed to explore for and develop gas resources, deliver natural gas to customers, and provide competitive gas-based energy services in key market sectors. The gas industry, manufacturers, and government agencies will need to work with researchers to identify and pursue technological advances that will bring forth equipment and systems (for gas production, delivery, and use) that will ensure a strong future role for natural gas and the most efficient use of this vital domestic resource.

Specific actions to bring the proposed vision to reality include the following:

- Communicate to legislators and other key stakeholders (a) the value of clean natural gas in a 'low-carbon' future, (b) the value of the existing natural gas storage and distribution infrastructure as a key element of energy security, (c) the potential costs and environmental impacts of a major shift to reliance on electricity, and (d) the importance of using 'source energy' rather than 'site energy' when comparing the efficiency of natural gas use to electricity use.
- Maintain strong collaborative relationships with developers and manufacturers of equipment used in gas industry operations or purchased by gas customers.
- Foster innovation in current operations and in planning for the future, encouraging the consideration of new approaches and tools for meeting business needs.
- Keep abreast of advances in technology that could have an impact on current competitive posture or that could present opportunities for future action.
- Establish a robust RD&D program to identify and bring into use the high-priority, advanced energy efficiency technology needed by the industry and by gas customers in the near-, mid- and long-term. Ensure adequate and sustained funding for such RD&D.

Report Scope and Potential

The proposed research activities found in this report represent end use sectors responsible for nearly all the energy consumption in the nation. The plan outlines natural gas end use research for three major sectors; homes and businesses, industrial applications, and transportation. Each sector research portfolio can be implemented independently; however, the most benefit will be gained through adoption of all three. Each end use sector has unique opportunities and challenges, and therefore, is discussed separately. However, a common opportunity and result of proposed research is significant reductions in greenhouse gas (GHG) emissions. Below is a summary table demonstrating the impact on GHG emissions, or carbon dioxide equivalent emissions (CO_2 e), a measure of GHGs and global warming potential.

Table 1. Reduction in Greenhouse Gases per Year (Million Metric Tons CO_2 e)

	GHG Reductions (Million Metric Tons CO_2 e)		
RD&D Portfolio	**2015**	**2020**	**2030**
Homes and Businesses	38	103	289
Industrial Applications	10	42	108
Transportation	5	16	40
Total	**53**	**161**	**437**

The plan's GHG reductions result from efficiency and process improvements (e.g. improved thermal efficiency for domestic hot water systems) and rational fuel switching (e.g., diesel to natural gas).

In 2030, the 3 RD&D portfolios are projected to reduce CO_2 e emissions by nearly 440 million metric tons. This is equivalent to the yearly emissions produced through operating over 36 million typical American households.

Section 2 Homes and Businesses RD&D Priorities and Recommended Funding

Market Impacts and Stakeholders

Two core markets for the natural gas industry are the residential and commercial sectors, comprising more than 110 million homes and almost 5 million places of business, respectively. Together, these markets accounted for about 8.0 quads of gas use in 2008, so it is vital that natural gas retain a strong position in meeting the needs of these customers.

For both sectors, technology can play a major role in improving the efficiency of energy use and in reducing the emissions of greenhouse gases (GHGs) from residential and commercial energy equipment.

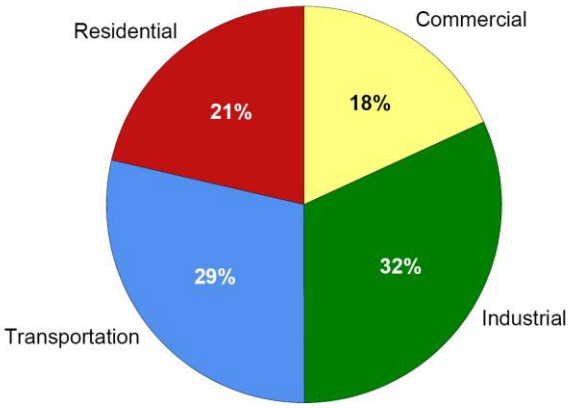
While the challenges facing the creation of very low-carbon natural gas end-use appliances are significant, there are at least three reasons to be optimistic. First, there are all of the advantages noted above. Second, research that may prove helpful is underway in related areas (carbon capture from the generation of electricity from coal and natural gas, fuel cells in cars and trucks), so the natural gas industry may benefit from work that does not directly focus on its end-use market but has synergies with end use technologies. Third, end use markets move slowly, so there is time to develop these technologies and still have substantial national impact.

This document identifies a path toward a lower carbon future using more efficient natural gas end-use technologies available worldwide today that will continue to reduce per capita end-use GHG emissions, and use this window of opportunity to focus on developing the next generation of very low carbon-emitting natural gas end-use technologies.

The following sections present a plan for identifying and pursuing high-priority RD&D initiatives related to natural gas use in homes and businesses that can assist the gas industry in achieving the long term natural gas vision. This natural-gas-based RD&D plan presents a set of priorities and recommended funding for RD&D programs intended to achieve two major goals by the year 2030 regarding energy use in U.S. homes and businesses:

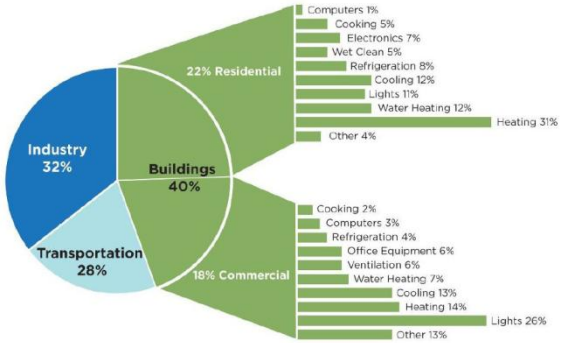
- Improve efficiency of energy use in homes and businesses to save an average of nearly 4,000 trillion Btu (4.0 quads) annually;
- Reduce average annual emissions GHGs by nearly 290 million metric tons annually.

Total primary energy use in 2008 in residential and commercial buildings (21.6 quads and 18.5 quads, respectively) accounted for approximately 40 percent of total U.S. energy consumption that year, according to the U.S. Department of Energy (DOE).



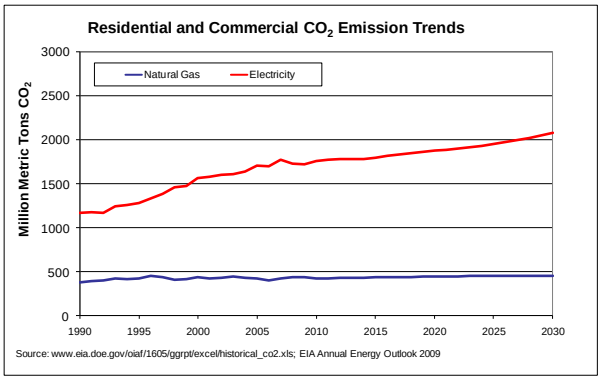
About 4.9 quads of natural gas were consumed in the residential sector and about 3.1 quads in the commercial sector, totaling nearly $98 billion consumer expenditures. Investing a portion of this – even as small as 0.1 percent, or $100 million – can help in realizing substantial energy efficiency and carbon reduction benefits.

In considering priorities for natural gas-related RD&D in these two sectors, it is important to identify the major applications in which energy is used. In homes, space heating, water heating, and space cooling are the highest end use segments; in commercial buildings, lighting, space heating, space cooling and water heating top the list. It is clear that space conditioning (heating and cooling) and water heating should be major areas of focus for RD&D. Complementary to this is the role onsite combined heat and power systems can play in satisfying the need for power, space conditioning, and hot water.



The RD&D should be aimed not only at improving energy efficiency but also at reducing emissions. In this respect, energy efficiency includes total energy use or what is referred to as full fuel cycle energy use. For example, Gas Technology Institute's (GTI) analysis of DOE's Energy Information Agency (EIA) forecasts show that between 2005 and 2030, expected wider use of electricity in residential and commercial buildings could raise emissions of carbon dioxide (CO_2)—a key greenhouse gas—23 percent (or 400 million metric tons/year).

This continues a twenty-year trend of growing carbon emissions and concomitant energy losses in the residential and commercial sector from expanded use of electricity – particularly from coal-based and, to a lesser extent, natural gas power plants. Displacing certain electric equipment (especially those based on resistance heating) with efficient gas-based technologies could help to substantially reduce this impact.



Gas distributors and equipment manufacturers make and maintain significant capital investments in gas distribution systems and in plant and products that use natural gas as an energy source. As a clean-burning fuel that is largely U.S.-produced, natural gas not only serves the needs of homeowners and commercial-building owners and tenants, it also benefits the nation, contributing to the nation's energy security, economic strength, and environmental quality. The RD&D priorities identified in this plan are designed to ensure that energy consumers in the residential and commercial sectors continue to have available natural gas-based end use technologies that provide significant value to customers and society in areas of increased energy efficiency, environmental protection, and carbon reduction.

In addition, the plan points to longer-term opportunities for developing advanced gas-based technologies, and for integrating natural gas-based technologies with evolving renewable fuel technologies (to assure greater energy supply security) and with energy monitoring and control systems (to secure the position of natural gas as a modern fuel source for today and tomorrow).

The plan supports the view that natural gas is the domestic fuel of choice in a low-carbon future, providing reliable, safe, efficient, affordable and environmentally superior performance in a range of energy service applications for homes and businesses.

Key RD&D initiatives to address these needs and opportunities have been identified by a coalition of stakeholders and external resources, including the following:

- AGA 2020 vision and member company recommendations;
- Energy Solutions Center staff and member information and guidance;
- European and Asian gas industry roadmaps, benchmarks, and technology options;
- DOE EERE roadmaps, especially from the Building America program;
- California Energy Commission planning documents;
- Gas equipment manufacturers observations and databases;
- GTI advisor guidance, especially UTD and public interest advisory committee members;
- NYSERDA planning documents;
- ACEEE and CEE recommendations;
- Affordable Comfort roadmaps and recommendations;
- UTD project information; and
- GTI staff experience and previous planning documents (especially GTI 5 Year Plans).

In similar fashion, it is expected that strategic partnerships would be established to help guide the proposed RD&D initiatives, tailored for the market sector, application, or research area of interest. These partnerships would include such entities as equipment manufacturers, trade associations, codes and standards officials, regulatory officials, energy efficiency and environmental associations, and professional groups or individuals with needed expertise in technical matters or market-related issues.

RD&D Plan Goals

This plan identifies high-priority research, development, and deployment needs. The high-priority goals shown below are designed to allow technology to support the gas industry vision and meet customer needs by providing increased value in energy efficiency, environmental performance and carbon reduction, and in supporting increased use of clean, efficient, abundant, domestic fuels. The strategic goals and targets for gas technologies for homes and businesses are:

Goal One (near-term – 2 to 5 years)

Promote wider adoption of 'best current technology' for major residential and commercial energy applications (heating, cooling, water heating, cooking/food service, larger scale combined heat and power (CHP) and controls) through installed-cost reduction, improvement of components/controls, venting solutions, and selective innovations.

Goal Two (near-term)

Provide technical and analytical support regarding development and application of codes, standards and legislation that affect gas-based energy systems.

Goal Three (mid-term – 5 to 10 years)

Develop advanced equipment for space heating, water heating and cooking/food preparation, based on 'combination' configurations, improved heat transfer/recovery, and more effective emission control.

Goal Four (mid-term)

Reduce carbon emissions, cost of electricity and investments in future generation, transmission and delivery upgrades through advanced CHP technologies and integration of natural gas with renewable energy systems such as solar thermal and biomethane.

Goal Five (mid-term)

Improve energy efficiency, ensure indoor air quality, control emissions, and reduce costs of energy system installation, integration and operation through building systems RD&D. Topics include zoned space conditioning, interior energy distribution, system sizing, building-envelope dynamics, humidity control and innovative venting concepts.

Goal Six (mid-term)

Improve reliability and efficiency of electric grid by integrating natural gas systems with the evolving smart energy grid.

Goal Seven (long-term – 10+years)

Improve energy use efficiency and reduce carbon emissions from selected energy systems through breakthrough research on such topics as combustion science, hydrogen enrichment of natural gas, flue-gas analysis/management, heat transfer, improvement of existing energy cycles and development of new energy cycles.

Funding Required

Table 2 summarizes the funding requirements for the RD&D program elements discussed above. This represents approximately 0.1 percent of total natural gas expenditures in the residential and commercial sectors.

Project funding would be staged to scale up mid-term and long-term projects over time as near-term projects are completed. In the initial years of RD&D funding, near-term projects would receive approximately 75 percent of the available funding. Funding for mid-term and long-term projects would progressively increase as near-term projects approach completion and receive greater contributions of manufacturer cofunding. Manufacturer cofunding for near-term projects is expected to be 20 to 50 percent of the total cumulative funds of the project, while mid-term and long-term projects would have progressively smaller amounts of cofunding.

Table 2. Proposed Funding Requirements for Buildings RD&D Initiatives

	Funding ($ millions)		
RD&D Initiative	**2010**	**2015**	**2020**
Space Conditioning	24	22	20
Water Heating	14	16	18
Cooking/Food Service	4	5	6
Combined Heat & Power	30	28	26
Building/Community Systems	20	21	22
Breakthrough Research	17	19	21
Total	**109**	**111**	**113**

Next Steps

This report defines high-priority research, development, and demonstration needed to address critical challenges affecting utilization of natural gas in buildings for distribution companies, end-users and suppliers, and the nation. As a planning tool for the natural gas industry, its residential and commercial customers, and government partners, this information is intended to spur collaborative research efforts in areas of mutual interest and benefit.

Initial activities include awareness building by the developers and stakeholders of the plan. This will include meetings with industry, government and policymakers highlighting benefits for consumers, manufacturers, and the nation.

The implementation of this plan can bring increased value in energy efficiency and carbon emissions reduction, while supporting expanded use of clean, abundant, efficient domestic fuels. This plan will spur collaborative RD&D efforts among stakeholders and government partners. The Supplemental Information section presents further details of the proposed RD&D Plan.

For every RD&D dollar spent over the life of this plan, there will be 14 dollars of net consumer energy cost savings.

Section 3 Supplemental Information for Homes and Businesses RD&D Plan

RD&D Initiatives

Presented below are potential RD&D initiatives (organized by application) designed to help achieve the plan goals.

Space Conditioning

- Reduce the cost of highly efficient condensing gas furnaces and boilers that are poised for wider market adoption.
- Reduce the cost and overcome other barriers preventing market entry and adoption of very high efficiency (>100 percent) gas-fueled heat pumps (engine-driven and sorption types).

- Improve the performance and reduce the cost of gas-fueled space cooling systems, including engine-driven, sorption, desiccant, and advanced-cycle types.
- Integrate natural gas heating and cooling products with low (<200°F) and medium-temperature (200-400°F) solar thermal energy systems along with suitable thermal energy storage technologies.
- Optimize strategies for the control of humidity and indoor air quality in conjunction with gas-based space heating and cooling systems.
- Reduce the cost and improve the performance of key controls and components in gas-based humidity and indoor air quality equipment.

Benefits

- Lower equipment purchase and installation costs, yielding net customer energy cost savings averaging more than $272 million dollars per year, 2015-2030, resulting in a research benefit-cost ratio of 12:1.[1]
- Reduced release of GHGs (including CO_2), yielding emission savings averaging more than 24 million metric tons per year, 2015-2030.
- Availability of new options for 'combination' energy services.

Water Heating

- Reduce the cost of tankless, hybrid, and storage-type water heaters.
- Develop 'combination' systems that integrate water heating with boiler operation.

- Develop natural gas heat pump-based systems that offer very high-efficiency water-heating options.
- Integrate with low temperature (<200°F) solar thermal energy systems.

Benefits

- Lower equipment purchase and installation costs, yielding net customer energy cost savings averaging more than $261 million dollars per year, 2015-2030, resulting in a research benefit-cost ratio of 16:1.
- Reduced release of GHGs (including CO_2), yielding emission savings averaging more than 24 million metric tons per year, 2015-2030.
- Availability of new water-heating options and 'combination' energy services.

Cooking/Food Service

- Reduce the cost and improve the performance of critical heat transfer components in residential gas cooking equipment. Explore breakthrough approaches such as catalytic heat transfer.

- Reduce combustion-related emissions from gas-fueled residential and commercial cooking equipment.
- Develop methods for recovery and reuse of heat from ventilation/exhaust streams (such as heat to power) in commercial food service operations.
- Develop innovative improvements for selected commercial food service systems.

[1] All net energy cost savings represent the net present value (in 2007 Dollars) of energy cost savings after associated incremental capital costs are considered. See *Assumptions and Calculation Methodology* Section for further explanation.

Benefits

- Cost savings from more efficient equipment operation and waste-heat recovery, yielding net customer energy cost savings averaging more than $27 million dollars per year, 2015-2030, resulting in a research benefit-cost ratio of 6:1.
- Reduced release of GHGs (including CO_2), yielding emission savings averaging more than 2 million metric tons per year, 2015-2030.
- Improved productivity and food quality.
- More flexible equipment operation.
- Reduced release of cooking effluent.
- More flexible system operation based on improved heat transfer.

Combined Heat and Power/District Energy Systems

- Develop and optimize combined heat and power systems that can provide heating, cooling, and electric power efficiently from the same unit. Evaluate engine, turbine and fuel cell technology platforms – including 'micro' CHP units for individual homes and businesses.

- Develop centralized 'district' or 'community' CHP concepts for multi-family residential and multi-building residential and commercial users.
- Resolve interconnect issues to address local, regional, and national code requirements.

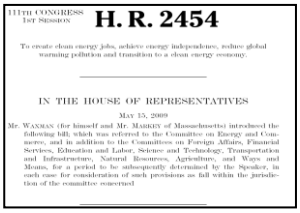
Benefits

- More efficient scaled equipment operation and waste-heat recovery, yielding net customer energy cost savings averaging more than $372 million dollars per year, 2015-2030, resulting in a research benefit-cost ratio of 13:1.
- Reduced release of GHGs (including CO_2), yielding emission savings averaging more than 50 million metric tons per year, 2015-2030.

Building Systems and Community Energy System Technologies

- Devise strategies for zoned space conditioning, explore interactions between energy systems and the building envelope, and optimize the size of energy systems and the configuration and operation of distribution systems that deliver comfort to occupants.
- Develop technologies to improve indoor air quality through reduction of unwanted airborne components from combustion and other sources.
- Evaluate advanced approaches for metering and sub-metering energy use to help customers and energy companies better understand energy use patterns and options, while quantifying the value of energy efficiency and carbon reduction investments.
- Reduce the cost and improve the durability and performance of interior gas piping systems.

- Develop approaches for optimized integration of gas systems with the evolving Smart Energy Grid concept, providing consumers with new options for energy management, comfort control, and communication with energy providers.
- Provide technical and analytical support to entities charged with developing or updating codes, standards and legislation that affect the competitive position and effective operation of gas-based energy systems.



111TH CONGRESS
1ST SESSION

H. R. 2454

To create clean energy jobs, achieve energy independence, reduce global warming pollution and transition to a clean energy economy.

IN THE HOUSE OF REPRESENTATIVES

MAY 15, 2009

Mr. WAXMAN (for himself and Mr. MARKEY of Massachusetts) introduced the following bill, which was referred to the Committee on Energy and Commerce, and in addition to the Committees on Foreign Affairs, Financial Services, Education and Labor, Science and Technology, Transportation and Infrastructure, Natural Resources, Agriculture, and Ways and Means, for a period to be subsequently determined by the Speaker, in each case for consideration of such provisions as fall within the jurisdiction of the committee concerned

- Develop a 'Plug-and-Play' utility room concept that provides all necessary connections for providing flexibility in energy and communication services to a home or building.
- Develop improved models and analytical tools that can aid architects, engineers, builders, community planners, end users, manufacturers, and other stakeholders in assessing new energy technologies for their energy efficiency and environmental benefits.
- Develop components and control strategies to enable the integration of gas-based energy systems (primarily for heating, cooling or power generation) with similar systems that use renewable resources (such as solar thermal energy and biomethane).
- Evaluate the feasibility of a centralized or 'district' energy system based on such integration.
- Develop protocols for creation of renewable energy portfolio standards by government entities.

Benefits

- Net customer energy cost savings averaging more than $287 million dollars per year, 2015-2030, resulting in a research benefit-cost ratio of 14:1.

- Reduced release of GHGs (including CO_2), yielding emission savings averaging more than 30 million metric tons per year, 2015-2030.
- Increased comfort and improved interior air quality for occupants/customers.

Breakthrough Technology Development

- Pursue basic combustion research, aiming to improve efficiency, reduce pollutant formation, increase heat transfer, or achieve other related goals to improve the operation of gas-based energy systems.
- Evaluate options for improving the efficiency of existing thermodynamic cycles used in engines, fuel cells, and sorption-type energy systems, and combining thermodynamic cycles to optimize efficiencies.
- Study catalytic and other approaches for improved management (e.g., formation reduction, capture, conversion, storage) of selected combustion byproducts (carbon monoxide, carbon dioxide, oxides of nitrogen) and methane that can degrade air quality.

Benefits

- Net customer energy cost savings averaging more than $373 million dollars per year, 2015-2030, resulting in a research benefit-cost ratio of 20:1.
- Reduced release of GHGs (including CO_2), yielding emission savings averaging more than 13 million metric tons per year, 2015-2030.

Impact of RD&D on Home and Business Owners and Tenants

Successful implementation of the RD&D initiatives proposed in this plan will provide a range of benefits to homeowners and to commercial-building owners and tenants. These include:

- Reduced purchase and operating costs of high value, energy-efficient natural gas equipment;
- A wider choice of competitive gas-based equipment options;
- Cost-effective compliance with environmental and safety requirements;
- More efficient 'combination' energy services (e.g., combined heat and power, space/water heating, integrated gas/renewable energy systems);
- A more cost-effective option for safe and convenient vehicle fueling;
- New options for monitoring and managing energy use and costs and for communicating with energy providers; and
- Potential new, non-traditional gas uses flowing from advanced and breakthrough research.

Impact of RD&D on the U.S. Natural Gas Industry

For the U.S. natural gas industry and its customers, the new and improved products, processes, systems and materials resulting from the RD&D initiatives proposed in this plan will, in broad terms, help to make natural gas an integral part of an efficient and low-carbon energy mix for today and tomorrow.

The RD&D portfolio provides a way to simultaneously:

- Upgrade and spur wider adoption of current and early-market-entry gas technologies that offer efficiency and performance advantages and reduce per capita end-use greenhouse gas emissions;
- Develop advanced, next generation gas based systems whose characteristics will make them even more attractive in a low-carbon energy future; and
- Pursue 'breakthrough' research that can lead in the longer term to gas-based technologies that offer dramatic improvements in performance.

Successful execution of this RD&D portfolio will help ensure long term vitality of the important residential and commercial market for the nation's natural gas industry.

Key Trends and Challenges

Energy cost is a concern for both homeowners and for commercial builders, owners and tenants. That includes operating cost as well as purchase and installation costs of energy systems.

To remain competitive with other energy equipment (particularly electric), makers of gas products and systems strive to control manufacturing costs while also working to improve efficiency (which helps reduce operating costs) and to incorporate features that maintain the reputation of natural gas as a clean, safe, reliable and convenient fuel.

In parallel, concern has been growing for several years about the environmental impact of energy use (of all kinds). The role of combustion-related emissions (particularly CO_2) in global climate change is much debated. Customers sensitized to the size of their 'carbon footprint' now factor

emissions into their equipment-purchase decisions, with an ongoing need to understand "full fuel cycle" energy implications from different end uses. Various regulatory agencies also monitor other compounds (carbon monoxide, oxides of nitrogen, sulfur dioxide) that can degrade outdoor air quality.

An additional trend is the emerging use of systems fueled by renewable resources, such as solar energy technology that generates electricity or thermal energy, biofuels – including those that generate biomethane like landfills, wastewater treatment plants, and digesters, and gasification of various biomass products. This trend may present an opportunity for synergistic integration of natural gas pipeline systems and end use products with such renewable energy systems. This is particularly true for intermittent renewable energy sources such as solar thermal systems.

CHP systems deliver both thermal energy and electricity and can be sized for single-building use as well as in a 'district' or 'community' configuration serving multiple buildings. CHP systems currently comprise about 9 percent of U.S. generating capacity, mostly in the industrial sector where they are used predominantly by chemical and petroleum manufacturers and the paper and food industry. Estimates place the annual energy savings from these systems at 1.9 quads and 248 million metric tons of avoided GHG emissions. Only about 12 percent of total CHP capacity is used in the commercial and institutional sector, with essentially no CHP systems in homes.

CHP adoption rates can be much higher – as evidenced in countries such as Finland and Denmark where 40 to 50 percent of power production is derived from CHP systems. Homes and businesses represent a significant untapped potential in the United States for substantial improvements in energy efficiency through the expanded application of CHP systems.

There are some who have a long-term view of all-electric homes and businesses, with power coming from carbon-free or carbon neutral power generation options such as nuclear, wind, solar, biomass and possibly even 'clean coal' if carbon capture and storage becomes technically and economically viable. This approach significantly undervalues the benefits of direct gas use and the societal value of the natural gas storage and distribution infrastructure as a parallel energy delivery channel that enhances energy security while keeping total energy costs to a minimum. A shift toward all electric homes and businesses would likely entail high risks and severe unintended impacts associated with a needed doubling of power generation, transmission, and delivery capacity – in an industry that is already challenged in each of these segments. It would also result in significantly increased GHG emissions if there were any delays in implementing unproven or expensive emission reduction strategies and technology options.

The efficient direct use of natural gas remains an important long-term energy security, economic competitiveness, and environmentally acceptable pathway for the United States. To help the gas industry be properly positioned to meet future societal demand in a long-term, low-carbon power generation future, it is necessary to invest in parallel RD&D initiatives, including:

- Breakthrough high-efficiency, low-emission direct gas use technologies;
- Small- and intermediate-scale CHP systems for homes and businesses, including ultra-clean and efficient fuel cell power systems; and
- Investigation of options for basic understanding of combustion-emission formation and cost-effective options to capture carbon dioxide at the point of generation from gas equipment.

Targeted RD&D initiatives are essential to addressing these trends and challenges.
In the near term, these initiatives can focus on incremental performance improvements and cost reduction, seeking to overcome the barriers that hamper adoption of current 'best available' gas systems as well as emerging gas technologies. Products of these near-term initiatives will be license-ready technologies, with manufacturer involvement anticipated to begin at the field test stage or earlier.

For the mid-term, a focus on advanced systems that challenge emerging competitors or meet new needs is necessary coupled with a growing use of hybrid renewable energy/natural gas technologies such as those employing solar thermal energy or biomethane and natural gas mixtures, or possibly hydrogen-enriched gas mixtures. Products and projects for midterm initiatives will be a mix of license-ready technologies, prototypes, and cost-effectiveness investigations.

And for the longer term, 'breakthrough' research is needed that can uncover new concepts, materials, cycles, and processes, leading to leapfrog

technologies that address the needs of tomorrow's energy customers as well as environmental concerns. Long-term projects include basic and exploratory research, fundamental systems design, and cost-effectiveness investigations and are expected to precede development of prototypes suitable for field testing.

In all of the research areas proposed, this plan seeks to maximize the value of each dollar invested invested in RD&D. Benefits will take the form of energy-use efficiency and cost savings for energy users, market strength for makers of gas-based energy systems and for the U.S. gas industry, and improved environmental performance, as well as support of national goals for wider use of clean, abundant, efficient domestic and renewable energy resources.

Performance Targets

Estimated performance targets for solutions to be developed through the RD&D initiatives proposed in this plan for homes and businesses are listed in Tables 3 and 4.

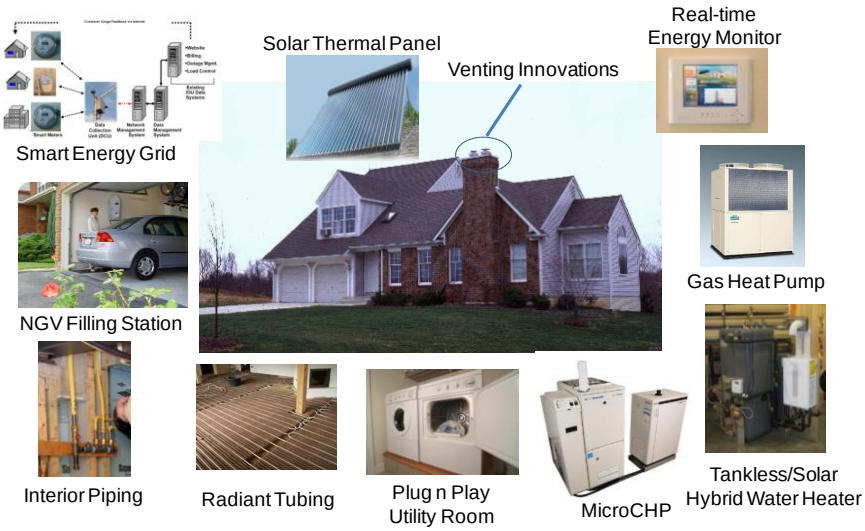


Table 3. RD&D Plan Performance Targets for Homes

RESIDENTIAL TARGETS	2015	2020	2030
Energy Efficiency Improvement (Trillion Btu)			
Space conditioning	70	200	570
Water heating	60	160	440
Combined heat & power	40	100	290
Building and community technology/integration	50	140	390
Breakthrough research	20	60	170
Total	**240**	**660**	**1860**
Reduction in Greenhouse Gases (Million Metric Tons CO_2e)			
Space conditioning	5	14	40
Water heating	4	12	35
Combined heat & power	3	8	22
Building and community technology/integration	4	10	29
Breakthrough research	2	4	13
Total	**18**	**48**	**139**

Table 4. RD&D Plan Performance Targets for Businesses

COMMERCIAL TARGETS	2015	2020	2030
Energy Efficiency Improvement (Trillion Btu)			
Space conditioning	20	40	120
Water heating	30	80	220
Cooking/food service	10	20	50
Combined heat & power/waste heat management	140	400	1200
Building and community technology/integration	60	160	460
Breakthrough research	30	70	200
Total	**290**	**770**	**2250**
Reduction in Greenhouse Gases (Million Metric Tons CO_2e)			
Space conditioning	1	3	8
Water heating	2	5	14
Cooking/food service	1	2	3
Combined heat & power/waste heat management	10	30	80
Building and community technology/integration	4	10	31
Breakthrough research	2	5	14
Total	**20**	**55**	**150**

Technology Priorities for Homes and Businesses

As noted earlier, there is a clear need for an aggressive RD&D effort to provide cost-effective natural gas end use options to meet the needs of homeowners, business owners, and tenants. The effort will also address the important role of natural gas in maintaining U.S. economic strength and energy security as well as helping to meet environmental goals.

From 2015 to 2030, the program targets average annual reductions of nearly 2.0 Quads in residential and commercial energy use and more than 140 million metric tons of greenhouse gases.

Energy use in buildings accounts for about 40 percent of total U.S. energy use and GHG emissions. Technology advancements in space heating, space cooling, water heating, food preparation, and building systems technology (controls, system/envelope interaction) can yield benefits in both market sectors. These benefits include lower installed costs, more-efficient energy use, reduced emission of greenhouse gases and other combustion products, and improved safety and reliability. The emphasis may be somewhat different in each sector based on specific needs, but most technology options noted below can apply to homes and businesses. Market-specific priorities and targets are noted as appropriate.

Near-Term Technology Priorities

The objective of the near-term technology priorities is to upgrade (and thereby spur wider adoption of) current and early-market-entry gas technologies that offer efficiency, performance, or environmental advantages.

Residential and Commercial Space Conditioning

Target Applications

Space heating, cooling and humidity control

RD&D Goals

Pursue targeted development efforts to reduce by at least 20 percent the first cost of selected gas-based equipment for space heating, space cooling, and humidity/indoor air quality control, including:

- Existing condensing furnaces and boilers;
- Existing gas-based cooling systems (engine-driven and thermally activated) and desiccant-based humidity/indoor air quality control systems;
- Emerging gas-fueled heat pump systems (engine-driven and thermally activated);
- Emerging ‘combination’ space/water-heating systems;
- Emerging CHP systems;
- Emerging radiant heating and cooling systems; and
- Emerging gas-electric hybrid heating and cooling systems.

Provide technical support to entities responsible for developing/revising codes, standards and legislation that affect the market viability of gas-based space conditioning systems.

RD&D Scope

This effort will focus on reducing the cost of components and/or assembly and installation of currently available or soon-to-be-introduced gas space conditioning systems, working closely with equipment manufacturers.

Commercial Space Conditioning

Target Applications

Space cooling

RD&D Goals

Develop gas-based engine-driven and thermally activated systems appropriately sized for space cooling and humidity/indoor air quality control in commercial buildings, while helping alleviate peak electric demand constraints.

RD&D Scope

Working with equipment makers, seek to scale existing and emerging systems appropriately and reduce the cost of components and/or assembly and installation. Address systems using prime movers and fuel cells as well as sorption processes.

Residential and Commercial Water Heating

Target Applications
Water heating for personal and business use

RD&D Goals
Pursue targeted development efforts to reduce, by at least 20 percent, the first cost of selected gas-based water heating systems, including:
- Current tankless (instantaneous) and storage types;
- Emerging hybrid solar thermal/natural gas systems; and
- Emerging 'combination' space/water-heating systems.

RD&D Scope
This effort will focus on reducing the cost of components and/or assembly and installation of currently available or soon to be available systems for domestic or commercial water heating.

Residential Building System Technologies

Target Applications
Interior energy-distribution technology

RD&D Goals
Develop more-efficient and cost-effective systems for:
- using circulating hot water as a source of radiant heating; and
- delivering natural gas to various points of use.

RD&D Scope
This RD&D will be conducted in coordination with makers of interior piping and other energy-delivery systems, as well as with builders, architects and codes and standards officials. The work will include laboratory development as well as performance testing in actual instrumented buildings.

Commercial Food Service

Target Applications
Commercial food preparation

RD&D Goals
- Developed innovative systems and components for targeted application in food service equipment; and
- Develop systems for cost-effective recovery and re-use of heat otherwise lost in ventilation streams in food service operations.

RD&D Scope
This effort will include laboratory and field-scale development to improve selected components of selected food service equipment. Recovery of heat from ventilation streams will be one important focus. RD&D will be coordinated with manufacturers and users of food service equipment.

Mid-Term Technology Priorities
The objective of the mid-term technology priorities is to develop advanced, next-generation gas-based systems that can compete effectively even in a low-carbon energy future.

'Combination' Energy Service

Target Applications
Provision of several energy services by a single piece of equipment

RD&D Goals
Develop cost-effective, energy-efficient and low-emission systems based on the following concepts:
- Hybrid gas/renewables systems for space/water heating; and
- Combination systems that provide (a) heating and electrical power, or (b) heating, cooling and electrical power, based on engine or fuel cell technology.

RD&D Scope
This effort will include laboratory and field development, working with manufacturers of solar-thermal or other renewable-resource systems and with makers of CHP systems. Particular attention will be given to integration/control and system sizing issues as well as safety and reliability (all of which will strongly impact commercial viability).

Residential 'Combination' Energy Service

Target Applications
Provision of several energy services by a single piece of equipment.

RD&D Goals
Develop cost-effective, energy-efficient and low-emission systems based on the following concepts:
- Small-scale space-plus-water-heating systems;

- Combination appliances in which waste heat from one is captured for use in the other or stored; and
- Cost-effective combined heat-and-power systems scaled for use in homes.

RD&D Scope

This effort will include laboratory and field development, working with manufacturers of space heating units, water heaters, appliances, and CHP systems. Particular attention will be given to integration/control and system sizing issues as well as safety and reliability (all of which will strongly impact commercial viability).

Commercial 'Combination' Energy Service

Target Applications

Provision of several energy services by a single piece of equipment.

RD&D Goals

Develop cost-effective combined heat-and-power systems scaled for use in businesses.

RD&D Scope

This effort will include laboratory and field development, working with manufacturers of large CHP systems. Particular attention will be given to integration/control and system sizing issues as well as safety and reliability.

Cooking and Commercial Food Service

Target Applications

Preparation of food in homes as well as commercial and institutional establishments.

RD&D Goals

Develop advanced cooking systems with improved heat transfer as well as lower emissions.

RD&D Scope

This effort will include laboratory and field development, working with manufacturers. It will develop improved components that increase energy and emissions performance of ranges, ovens, grills, griddles, fryers and other food preparation products.

Building Systems Technology

Target Applications

Advancements in the understanding of how gas energy equipment interacts with other systems and components in a building

RD&D Goals

Improve the efficiency and flexibility of operation of gas-based equipment when used in combination with emerging building technologies, new communications systems, and other energy systems. Cross-cutting research topics will include:

- Building and energy-systems interactions;
- Innovative Venting Technologies;
- Zoned space conditioning concepts;
- Advanced monitoring/controls technology, including integration with Smart Energy Grid concepts;
- Integration of gas systems with other systems (e.g., renewable-resource energy systems); and
- Advanced interior environmental quality.

RD&D Scope

Parallel attention will be given to both residential and selected commercial buildings. Different RD&D programs will be developed for selected building types (e.g., single-family home, new-construction home, retail building, institutional building) and regions (e.g., southwest, northeast).

RD&D will include laboratory research but will also comprise extensive testing in instrumented buildings that will serve as field test facilities. Research will be coordinated with architects and builders as well as with developers and manufacturers of emerging energy systems and associated components and controls.

Long-Term Technology Priorities

The objective of the long-term technology priorities is to pursue 'breakthrough' research that can lead to gas-based technologies that offer dramatic improvements in efficiency, performance, and environmental impact.

Target Applications

Various residential and commercial energy uses

RD&D Goals

Pursue basic and advanced research in a variety of promising areas, including:

- Hydrogen enrichment to reduce carbon emissions from gas equipment;
- Capture and/or conversion of carbon prior to combustion;
- Capture and/or conversion of carbon in vent gases;
- Catalytic combustion and advanced heat transfer concepts;
- A ‘plug and play’ utility-room configuration with preinstalled stubs for rapid and safe installation of gas and electric equipment;
- A gas-based ‘community energy system’ that provides thermal energy of varying grades and electric power (AC and DC) to multiple buildings from a central source;
- Region- or climate-specific building-design concepts for low-energy, low-carbon operation; and
- Combustion processes, innovative energy cycles (catalytic, chemical), heat-transfer mechanisms, and combustion-product management.

RD&D Scope

This initiative will make extensive use of longer-term laboratory research for ‘basic science’ topics. As promising concepts emerge, appropriate bench and field development will be conducted. RD&D focusing on innovative ‘systems’ (e.g., a community energy system, or a climate-specific building design) will likely rely more on field development and less on laboratory research.

Section 4 Industrial Applications RD&D Priorities and Recommended Funding

Market Impacts and Stakeholders

This plan is intended to reduce approximately 14 percent of all industrial natural gas consumption, over 100 million tons of GHGs, and over 1 million tons in criteria air pollutants (CAPs) by producing 1.1 quads of energy savings across all industrial sectors. The greatest impact will be on large energy users or high energy intensity sectors using steam, power or process heat, or those able to use renewable fuels. This major energy efficiency effort will improve manufacturing competitiveness, U.S. economic health, and the environment through reductions in GHGs and CAPs.

Foreign competitors are placing increasing pressure on domestic manufacturing firms, requiring them to make further improvements in productivity and reductions in non-labor costs such as energy. Recent increases in energy costs, price volatility, and supply constraints are compounding pressures on the industrial sector. Government and industry collaboration is needed to foster improvements in energy efficiency that can ease the impact of high energy prices while simultaneously reducing carbon emissions to help maintain a healthy and vibrant U.S. manufacturing sector.

Gas distributors and manufacturers make and maintain significant capital investments in gas distribution systems and plant and equipment that use natural gas as an energy source. As a clean-burning domestic fuel, natural gas not only serves industry needs, but also benefits the nation, contributing to domestic energy security, economic strength, and environmental protection. This plan is intended to accelerate innovation and adoption of new technologies and technical services in the industrial sector by setting the framework for coordinated efforts among the federal and state government, natural gas distribution companies, industrial end users, and equipment manufacturers.

The plan's priorities are designed for natural gas end-use technology to meet industrial energy users' needs by providing increased value in energy efficiency, process competitiveness, environmental performance and carbon reduction, as well as increased use of domestic and renewable fuels to assure greater energy supply security.

Key initiatives identified by a coalition of stakeholders include:

- Build upon the existing efficiency and environmental advancements in steam generation by deploying recently developed ultra-high efficiency industrial fire tube boilers, and rapidly extend program impact to all boiler types and configure them to use renewable backup fuels;
- Optimize thermal transport and heat recovery systems to improve efficiency and lower energy intensity in process heating applications;
- Expand use of efficient, reliable, onsite CHP systems and provide a choice of natural gas fueled and bi-fueled engine and turbine systems with very low emissions;
- Develop hybrid natural gas technologies that use renewable energy sources in industrial applications to assure greater energy supply security;
- Expand plant energy assessments to identify immediate opportunities to save energy; and
- Develop improved controls and sensors to allow more efficient use of energy.

Tomorrow's industrial users will seek energy solutions that enable them to compete aggressively in challenging marketplaces. The ideas herein will support competitiveness of the industrial base of the country and energy security of the nation.

For every RD&D dollar spent over the life of this plan, there will be $6 in benefits to the U.S. economy.

RD&D Plan Goals

This plan identifies high-priority research, development, and deployment needs. The high-priority goals are designed to allow technology to meet industrial energy users' needs by providing increased value in energy efficiency, process competitiveness, environmental performance and carbon reduction, and in supporting increased use of domestic fuels. The strategic goals and targets for industrial gas technologies are:

Goal One

Reduce energy consumption by 8 to 20 percent for industrial steam users by developing an expanded portfolio of ultra-efficient steam generation systems.

Goal Two

Improve the efficiency of industrial heating and on-site power generation systems to recover 25 percent of the lost energy to create more cost-efficient systems for a variety of industrial applications.

Goal Three

Reduce GHGs, CAPs, cost of electricity, and investments in future generation, transmission, and delivery upgrades through the development and deployment of CHP technologies.

Goal Four

Increase the use of renewable fuels in the industrial sector by up to 15 percent leading to reduced CO_2 emissions and energy costs.

Goal Five

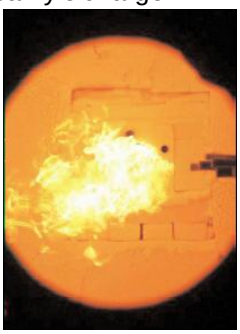
Provide recommendations that will allow manufacturers to reduce overall energy use by up to 20% in their process operations and facilities.

Goal Six

Improve manufacturing production and other industrial process efficiency by up 10 percent leading to reduced energy consumption and lower operating costs.

The plan focuses on these six goals yet also suggests a need to focus a portion of the program on industry specific technology development that can provide substantial value in U.S. competitiveness and job retention and creation. These efforts can result in step-change technologies leading to unforeseen breakthroughs in each technology area.

- **Steam Generation.** Deploy at least 20 first-generation ultra-high efficiency boilers in a representative sample of industrial boiler applications to initiate replacement of boiler stock. Facilitate the use of condensing economizers and waste heat recovery systems as well as system optimization to elevate and maintain efficiency levels in existing boilers where replacement is not warranted or delayed. Extend ultra-high efficiency technology to other boiler configurations and apply advanced sensors and materials to enhance performance.
- **Process Heating Systems.** Crosscutting technology, in aggregate, can yield large energy savings opportunities across energy intensive industries and processes. Deploy crosscutting technology including high-temperature and low-quality heat recovery systems, improved heat transfer and reduction of flue gases via oxy/fuel and combustion improvements. Incorporate efficiency tools in a universal virtual process furnace model for energy efficiency analysis and provide enhanced energy efficiency information delivery systems. Support manufacturing change technologies including submerged combustion technology applications.



- **Onsite Power Generation or Combined Heat and Power (CHP).** Deploy natural gas engine system and drives (100 kW–3 MW), microturbines (50–500 kW), industrial turbines (500 kW and larger), and packaged and field-erected CHP systems complete with controls, interconnect features, and heat activated systems for industrial process heating and cooling. Industrial users with high thermal processing loads provide significant opportunities for energy intensity and CO_2 emissions improvements while reducing the need for less efficient, higher-GHG and CAP-emitting central power generation plants and increased electric transmission capacity.

- **Renewable Fuel Utilization.** The industrial sector is a leader in byproduct and opportunity (or “waste”) fuels application for CHP, steam generation, and process heating. Further, hybrid systems that combine solar thermal input with industrial water heating, boilers, and process systems provide a renewable and low cost energy pathway. Renewable fuels, hybrid solar thermal systems, and energy recovery generation technologies such as organic Rankine cycle turbines can be used to augment traditional natural gas uses in the industrial sector—leading to reduced demand for traditional fuels and lower CO_2 emissions.

- **Controls and Sensors.** Help industry improve its efficiency by up to 10 percent. Sensor and automation technologies are vital, yet often unseen, components of virtually every industrial process. Acting as part of a plant's "nervous system," these technologies - along with next generation controls, information processing, robotics, and wireless technology - improve process efficiency. Additionally, there is also a need for industry-specific RD&D in energy intensive industries such as aluminum, chemicals, forest products, glass, metal casting and steel. The historical accomplishments in industry specific technology development are well known.

- **Industrial Energy Efficiency.** Develop partnerships with 50,000 plants over a 5 year period with aim of reducing energy intensity by 2.5 percent per year for 10 years. Plant energy assessments help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans, and compressed air.

Funding Required

Table 5 summarizes the funding requirements for the program elements discussed above. It is anticipated that the funding required will grow by 3 percent per year through the year 2020. The suggested funding for industry-specific R&D is also shown below. It is also anticipated that approximately another $30 million designated within the other program areas will focus on industry specific technology development.

Table 5. Proposed Funding Requirements for Industrial RD&D Initiatives

	Funding ($ millions)		
RD&D Initiative	**2010**	**2015**	**2020**
Steam Generation	35	41	47
Process Heating Systems	49	58	66
Onsite Power Generation	62	72	83
Renewable Fuel Utilization	18	21	24
Controls and Sensors	4	5	6
Industrial Energy Efficiency	16	18	21
Industry Specific R&D	31	36	40
Total	**215**	**251**	**287**

Next Steps

The Industrial Applications plan defines high-priority research, development, and deployment needed to address critical challenges affecting industrial utilization of natural gas for distribution companies, industrial end-users and industry suppliers, and the nation. Initial activities include awareness building by the developers and stakeholders of the plan. This will include meetings with industry, government and policymakers highlighting benefits for the private sector and the nation.

The implementation of this plan can bring increased value in energy efficiency, process competitiveness, environmental performance and GHG emissions reduction, while supporting expanded use of domestic fuels. This plan will spur collaborative RD&D efforts among stakeholders and government partners.

Section 5 Supplemental Information for Industrial Applications RD&D Plan

RD&D Initiatives

Advanced technologies will be essential in meeting industry requirements and in keeping U.S. industries strong in highly competitive global marketplaces and sustain healthy employment in the manufacturing sector.

The program targets cumulative reductions of 1.1 Quads in industrial energy use, over 100 million metric tons of green house gases and over 1 million tons in criteria air pollutants (CAP), across all industrial sectors.

Advances in natural gas technologies are required to meet the escalating demands and expectations of industrial users. The future of natural gas in the industrial marketplace depends on innovation and new technology adoption. To remain the energy source of choice for industrial applications, natural gas must offer solutions that are even more productive, efficient, clean, flexible and controllable than today's best technologies.

Steam Generation

Target Applications

Steam generation in all industrial and large commercial sectors.

Industry Sector

Cross-cutting—Deploy ultra-high efficiency steam generation systems.

RD&D Goal

Complete development a family of ultra-high efficiency steam generation systems that will:

- Achieve 95 percent energy efficiency;
- Reduce emissions below 9 vppm NOx, 5 ppm CO, 1 ppm VOC, and 0.003 lb/MMBtu particulates;
- Reduce boiler footprint and weight by 30 percent;
- Improve response to load changes;
- Accommodate a range of backup and renewable or supplemental fuels;
- Reduce life-cycle equipment cost, and reduce water consumption; and
- Value engineer to provide an equipment payback of less than 2 years.

Technology Development and Deployment Scope

An ultra-high efficiency technology for innovative steam generation has been developed and has been deployed. This technology was created with the collaborative support of the DOE, Cleaver-Brooks, and GTI. It incorporates a novel approach to innovative heat management including recovery of heat from flue gas water vapor, which required a cross-cutting approach involving material science, systems analysis, modeling, and controls. The same technology also reduces boiler size and weight, reducing life-cycle costs and saving energy associated with transportation and plant infrastructure. A new combustion system is incorporated that achieves ultra-low emissions levels without sacrificing efficiency.

Key needs are:

- Facilitate the use of condensing economizers and waste heat recovery systems as well as system optimization to elevate and maintain efficiency levels in existing boilers where replacement is not practical.
- Extend ultra-high efficiency technology benefits by providing:
  - Ability to fire renewable fuels such as fuel oil, diesel, biodiesel, solid or gasified waste fuels with 50 percent NOx reduction and low levels of CO, VOC, and particulates;

  - Ultra-high efficiency and emissions benefits for high-pressure (up to 1000 psig) superheated steam (up to 1500ºF) boilers; and
  - Adaptability for industrial water-tube boilers.
- Sensors that measure flame stoichiometry, flame instabilities, and water quality/tube deposits.
- Tube materials/coatings that resist corrosion and deposits and double the tube life at double heat flux (up to 200,000 Btu/ft^2/h).

Benefits

Boilers for manufacturing alone consumed 2.54 Tcf of natural gas in 1998 per EIA reports. Impacts of this program go beyond manufacturing (paper, chemicals, food processing, refining, primary metals and other manufacturing) and also can impact CHP, industrial drying, and commercial applications. Potential savings are significant, constituting billions of dollars in fuel savings and avoidance of millions of tons of greenhouse gases. The program will yield benefits and spin-off technologies affecting packaged boilers, field-erected boilers, process heaters, reactor systems, and other large energy users. These include devices for recovering latent heat from stack gases, better combustion controls, integrative design tools, and new high-temperature materials.

Strategic Partnerships

The natural gas industry has worked with industry groups and helped establish the Super Boiler Industrial Advisory Group (IAG) and current Super Boiler RD&D plan recommendations. Various public-private partnerships consisting of government, end users, manufacturers, industry associations, and universities are included in the IAG. Additional funding and continued government participation is needed to successfully reach the objectives of the program.

Process Heating Systems

Target Applications

Processes in:

- Steel;
- Aluminum;
- Glass;
- Metal Casting;
- Petroleum;
- Chemicals;
- Materials;
- Heat Treating;
- Forging;
- Forest Products;
- Cement; and
- Other applications.

Industry Sector

Cross-cutting—Utilization and enhancement of thermal transport and heat recovery systems to improve efficiency and reduce energy intensity.

RD&D Goal

- Support the utilization of new improved energy technologies, industrial energy efficiency tools, and energy management best practices.
- Develop membrane, thermo chemical, and thermosyphon heat recovery systems, submerged combustion, and oxy-gas combustion systems to improve thermal efficiency, and reduce NOx and GHG by 25 percent in industrial process heating systems.

Technology Development Scope

Industrial combustion processes now operate between 20 to 70 percent thermal efficiency and at NOx emission levels from 25–600 ppm due to the wide variability in process conditions. Cost-effective capture of waste heat from flue gases can significantly reduce energy consumption. Key needs are:

- Cost-effective heat recovery technologies with short payback times, high reliability, resistance to corrosion, adaptability to a wide range of process and process sizes; and
- The ability to recover heat in process-usable forms (steam, thermal energy, electricity, feed preheat, etc.).

Benefits

Process heating systems used in manufacturing industries consumed 3.4 Tcf of natural gas in 1998 as reported by EIA. Thousands of furnaces, ovens, process heaters, drying processes and other devices help produce a myriad of industrial products through processes such as smelting, refining, melting, heating, calcining, fluid heating, heat treating, sintering, drying and materials production. Considering natural gas fired processes alone, the program targets cumulative year 2020 reductions of 350 trillion Btu of energy in industrial furnaces and boilers. Electrical consumption for heating will also be reduced through the program.

Strategic Partnerships

Natural gas industry local distribution companies, the government, industrial end users, and equipment manufacturers have common interest in energy efficiency, industrial productivity, the environment, and introduction of innovative high-impact technologies. Public-private partnerships and multi-party development consortiums are needed to complete the high-risk, high-return R&D projects envisioned by this program. The natural gas industry has a vested interest in improving the efficiency of combustion processes to keep its product and customers competitive. Industry resources are limited and government can play an important role in reaching the goals of the program.

Onsite Power Generation or Combined Heat and Power (CHP)

Target Applications

- Natural Gas Engine Systems and Drives (100 kW–3 MW).
- Microturbines (50–500 kW).
- Industrial Turbines (500 kW and larger).
- Packaged and field-erected CHP systems complete with controls, interconnect features, and heat activated systems for process heating and cooling.

Industry Sector

Cross-cutting—Efficiency increase, emissions reduction, and productivity improvements for all sectors.

RD&D Goal

- To provide the industrial customer with a choice of natural gas fueled and bi-fueled engine and turbine systems that can provide power, heat, and/or cooling for process needs at high levels of efficiency, very low emissions, and with the robust reliability and low-maintenance necessary in today's manufacturing environment.
- System designs must be cost-effective and include complete packaging with intelligent controls, sensors, and communication capabilities that will allow seamless interconnection with power distribution networks, effective power management, heat recovery optimization, and integration with more advanced thermally activated cooling technologies.

Technology Development Scope

Natural Gas Engine Systems and Drives

Although engines are used extensively in transportation and for emergency power generation, CHP applications require higher efficiencies, lower emissions, longer life, and longer maintenance intervals. Goals are to achieve ultra high electrical efficiencies of 55 percent, emissions of less than 0.1 g/hp-hr NOx while maintaining availability (greater than 95 percent), reliability, and current installed cost advantages. Development efforts should build on the initial results from DOE's Advanced Reciprocating Engine System (ARES) program and should leverage initiatives by the California Energy Commission Public Interest Program (PIER), and Advanced Reciprocating Internal Combustion Engines (ARICE) Collaborative. R&D is also needed on gas engines to enable next-generation high-performance designs that can effectively utilize fuel blends of natural gas and renewable fuels, including a growing number of biomethane sources (e.g., from landfills, wastewater treatment plants, waste digesters) as well as syngas or hydrogen-based fuel resources.

Key technology needs:

- Engine modifications, advanced engine control strategies, and/or implementation of concepts such as waste heat recovery via thermo-chemical recuperation that will raise large (1–3 MW) natural gas engine efficiency levels to 55 percent lower heating value (LHV) while simultaneously reducing engine emissions to the less than 0.1 g/hp-hr NOx (0.07 lb/MWe hr). CO, VOCs, and Particulate Matter (PM-10) must also be ultra low;
- Concepts that will improve part-load efficiencies;
- Engine packages that have very low maintenance requirements, are fully automated for ease of use, and provide reliable service (greater than 95 percent availability);
- New materials, components, and manufacturing techniques that will continue to reduce the cost of engine packages;
- Concepts that reduce engine sound and vibration levels;
- High performance engine designs capable of utilizing fuel blends of natural gas and renewable fuels; and

- Development of partial oxidation natural gas engines for the co-production of power, heat, and liquid fuels.

Microturbines

DOE funding had a profound effect on advancing the development status of microturbines. Microturbines in general are lighter, have a smaller footprint, and are anticipated to have lower maintenance requirements when compared to engine systems. Efficiencies for early production units (less than 100 kW) were in the low twenties. Heat recovery for onsite utilization is generally needed to obtain a positive return relative to purchasing grid power. Manufacturers are now introducing higher capacities (200 and 250 kW units) in order to improve efficiency and lower product costs on a $/kW basis. Support is needed to fully develop, refine, and deploy these larger microturbine systems. In particular, support is needed to integrate and package these machines with thermally-activated systems.

Key needs are:

- Microturbine efficiency levels (fuel-to-electricity) increased to a minimum of 35 percent (LHV);
- Product cost reduction, performance improvements, evaluations, and control system development for larger microturbine packages (200 kW and larger);
- Advanced configurations and controls for micro-grid applications;
- Combustor modifications for ultra-low NOx emissions and fuel flexibility;
- Advanced recuperators (lower cost, improved materials and construction techniques);
- Reduction in installed cost requirements for microturbines;
- Integration of microturbines with robust, reliable heat recovery systems and modified industrial boiler packages;
- Development of low-emission, duct-fired supplemental burner systems and control for heat demand management; and
- Reliable, low-maintenance natural gas pressure boosters for microturbines.

Industrial Turbines

Industrial turbines account for most of the power generated onsite at industrial sites in the U.S., and reliable and cost-effective technology exists for the cogeneration of steam.

There exists a need to further reduce NOx emissions and to refine the engineered packages for onsite power production combined with absorption chillers for cooling and refrigeration.

There exists a need to further develop smaller industrial turbines (mini-turbines) in the range of 500 kW to 1 MW. Units are available in these size ranges but have found limited deployment due to the higher cost relative to engine systems. Cost reduction and improved packages for higher quality steam production are needed to advance this area.

Novel system designs are also possible that increase the overall fuel efficiency while co-producing valuable fuel products. For example, one technology in development is a partial oxidation gas turbine (POGT) that can co-produce power, heat, and synthesis (fuel) gas that can be combusted or converted into higher value products such as industrial-grade hydrogen for use in the process industries.

Key technology needs:

- Improved dry low NOx combustors and combustor modifications for ultra-low NOx emissions and fuel flexibility;
- Improved post-combustion control techniques for ultra-low NOx emissions;
- Product cost reduction, performance improvements, evaluations, and control system development for the mini-turbine range (500 kW to 1MW);
- Advanced recuperators (lower cost, improved materials and construction techniques);
- Performance evaluation leading to improved integration concepts, energy management and control systems for engineered systems that combine industrial turbines with absorption chillers; and
- Development of partial oxidation gas turbines for the co-production of power, heat, and hydrogen.

Packaged and Field-Erected CHP Systems

Cost-effective, off-the-shelf packaged and field-erected systems that use engines, microturbines, or industrial turbines combined with effective hot water or steam heat generation for process use or activation of cooling devices are needed. Systems should have all the necessary controls, sensors, and communication devices for interconnection, power, and heat management.

CHP systems, at 80 percent efficiency, can create significant energy and GHG emission reductions compared to centralized electricity production and electric or even direct gas use for thermal loads. A typical power plant may deliver electricity at 40 percent efficiency, or less.

Key needs are:

- Integrated systems for power and process steam/hot water delivery;
- Integrated systems for power and cooling/refrigeration delivery (absorption chillers, steam turbine chillers, or desiccant dehumidifiers);
- Controls and communication modules for interconnect, power, and heat management (integration with industrial process); and
- Performance and reliability evaluations at industrial facilities complete with integration engineering that optimizes plant energy management.

Benefits

Current onsite power generation systems over 300 kW can meet or exceed the efficiency of grid-supplied electricity (less than 35 percent including generation, transmission, and distribution losses). Onsite CHP efficiencies can easily reach 70 to 80 percent when engines, microturbines, and industrial turbines co-produce power and heat. This provides a multitude of benefits, including reduced energy cost, enhanced energy security, and reduction of GHG emissions.

The Energy Solutions Center estimates that smaller systems, less than 20 MW, represent a large untapped market of approximately 40,000 MW for onsite power generation and heat recovery. For system capacities of 1 MW or less the projection is a market potential of about 10,000 MW.

Furthermore, machine drives alone currently consume 3 quads (3 Tcf) of electricity in the industrial sector. Assuming a 20% penetration of direct drive engine systems by 2020 and an overall energy efficiency improvement of 20 percent, the nation would save 120 trillion Btu per year of energy while substantially reducing CO_2 emissions.

Strategic Partnerships

The development of advanced, reliable, cost-effective, high-efficiency, ultra-low emission engines and packaged systems will provide regional benefits for gas and electric distribution systems, will reduce our dependence on foreign oil, will create jobs, and add to national energy security. This plan envisions partnerships that combine the efforts of DOE, U.S. Environmental Protection Agency's (EPA) CHP Program, state programs (such as California's PIER program and New York State's NYSERDA program) along with a number of energy utility consortia including the Energy Solutions Center's DG Consortium, the U.S. Combined Heat and Power Association (USCHPA), and GTI. It is expected that research institutions, universities, and key manufacturers and packagers will form the necessary teams to advance the state-of-the art in onsite power generation.

Renewable Fuel Utilization

Target Applications

Mid- to large-size energy users

Industry Sector

Cross-cutting—Enable use of renewable fuels and renewable energy in industrial applications.

RD&D Goal

Provide industrial energy users with increased flexibility in energy utilization by:

- Designing, evaluating, and testing a system that combines solar thermal input with natural gas industrial boilers, water and process heating energy equipment to provide 20 percent lower total energy costs and 20 percent lower capital costs than stand-alone solar energy systems; and
- Enabling the use of low Btu byproduct renewable and opportunity fuels through co-firing with natural gas. Facilitate implementation of LNG and hydrogen fuels in industrial plants. Focus on low cost solutions to current plant burner and gas mixing, distribution, measurement, and control systems to enable handling a broader range of fuel gases.

Technology Development Scope
Control systems are needed to integrate hybrid solar/natural gas systems in industrial processes. Gasification and pyrolysis type thermochemical platforms are being developed to produce syngas and liquid biofuels. Technology development is needed to allow implementation of these and other gas streams (landfill gas, anaerobic digester gas, biomass and biowaste syngas, etc.) in industrial processes such as glass and aluminum melting, cement and brick making, calcining, and steel reheating. When producing renewable fuels, fuel treatment may be necessary as often tars and oils are not completely removed which could impact distribution system equipment and plug burner nozzles. Syngas with hydrogen content can change flame speeds and flame shape characteristics, requiring burner adjustments to maintain furnace temperature uniformity. System turndown control is required to match plant energy demand with renewable fuel supply.

Benefits
Successful combination of solar and gas-fired industrial equipment will open up solar thermal to major new market applications. The use of solar and renewable fuels will provide industrial energy users with greater fuel flexibility and lower GHG emissions.

Strategic Partnerships
Strategic partnerships will be formed among industrial energy users, solar thermal collector manufacturers, industrial gas equipment providers, and producers of renewable gas supplies.

Industrial Energy Efficiency

Target Applications
Mid- to large-size energy users

Industry Sector
Cross-cutting— Efficiency increase, emissions reduction, and productivity improvements for all sectors.

Technology Development Scope
Expand the Save Energy Now Program and the Industrial Assessment Center Program to increase the number of plant energy assessments to help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans and compressed air.

RD&D Goal
Help industrial plants operate more efficiently and profitably by identifying ways to reduce energy use in key industrial process systems. Provide recommendations that will allow manufacturers to reduce overall energy use by up to 20 percent. Demonstrate energy and GHG saving opportunities through direct gas use compared to electricity produced by natural gas or otherwise. For thermal loads, the source energy use of an efficient gas appliance can be less than half the use of a comparable electric appliance.

Strategic Partnerships
Partnerships will be formed with companies, states, utilities and other industry groups to take part in a national effort to boost industrial efficiency and productivity while helping to ensure a reliable U.S. energy supply.

Control and Sensors

Target Applications
Mid- to large-size energy users

Industry Sector
Cross-cutting— Efficiency increase, emissions reduction and productivity improvements for all sectors.

RD&D Goal
Improve manufacturing production and other industrial process efficiency by up to 10% leading to reduced energy consumption and lower operating costs.

Elements supporting this goal include:

- Implement a comprehensive R&D plan to meets the measurement and control technology needs identified in industry-specific technology roadmaps;
- Fund projects that target the largest opportunities to save energy in a broad range of industries;
- Transfer sensors and automation technologies to industry;

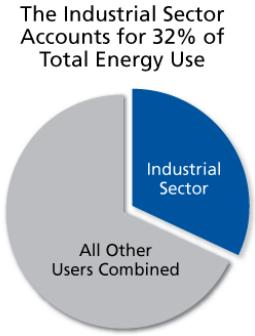
- Serve as a technical resource to assist ITP's industry-specific subprograms in developing their individual portfolios of projects;
- Coordinate technical management of sensor and control technology development efforts across ITP; and
- Maintain an information repository about sensors and control technologies.

Strategic Partnerships

Partnerships will be formed with designers and manufacturers of the latest controls and sensor equipment.

Impact on U.S. Industry

The industrial sector now consumes 32 percent of total energy and over 7,000 trillion Btu (TBtu) of natural gas.



The significant reduction in energy costs envisioned in this plan will help improve manufacturing competitiveness and stabilize employment and manufacturing's role in the national economy.

Since1989 the manufacturing share of the economy has shrunk almost 30 percent, shrinking from 17 percent to 12 percent share of nominal gross domestic product (GDP), and losing 200,000 jobs from 2005 to 2006 in energy intensive manufacturing industries including paper, primary metals, and motor vehicle and parts manufacturing.[1] This plan can assist in reversing these downward trends.
Industrial energy intensity is defined as the amount of energy used in producing a given level of production output, or by economic definition as the ratio of primary energy consumed to unit of gross domestic product. Information is more readily available for the economic definition of energy intensity and is used here to highlight the industry's most impacted by this RD&D plan as shown in Table 6.

This plan seeks to maximize the value of each research dollar in achieving the goals of greater efficiency, increased productivity, improved environmental performance and carbon emission reduction, supporting U.S. industry competitiveness and broader use of domestic and renewable fuel.

Table 6. Sector Energy Intensity, CAP Emissions, and Energy Consumption in 2002[2]

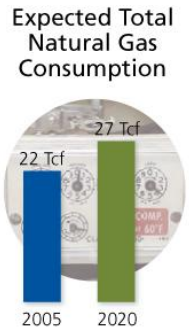
Sector	Energy Consumption (TBtu)	Energy Consumption per $ Value of Shipments (kBtu)	CAP Emissions (000 TPY)	Natural Gas Energy Consumption (TBtu)
Chemical manufacturing	3,769	8.5	1,536	1,678
Petroleum Refining	3,086	16.1	789	821
	2,361	15.2	721	504
Iron and Steel	1,455	27.8	850	388
Food manufacturing	1,116	2.6	395	575
Transportation equipment	424	0.7	60	203
Cement	409	56.0	544	21
Fabricated metal products	387	1.7		209
Wood products	375	4.2	183	57
Alumina and aluminum	351	12.2	539	130
Metal Casting	157	5.5	73	77
Other (estimated)	n/a	n/a	n/a	2,400

1. Sources: U.S. Department of Commerce and Federal Reserve, Bureau of Labor Statistics
2. Energy Trends In Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes, U.S. EPA, Final Report-March 2007 (from DOE Annual Energy Outlook 2006)

Key Trends and Challenges

Natural gas is largely a domestic resource that must continue to be utilized in a way that addresses key trends and challenges impacting the U.S. energy market. This RD&D plan is intended to help natural gas remain a vital contributor to a reliable, diverse and well-balanced U.S. energy portfolio in coming decades. If successful, this will further goals to protect the quality of our nation's environment and economy.

U.S. Natural Gas Projected Growth in Consumption



The industrial market is one of the major sectors of U.S. natural gas demand, along with the residential, commercial, and power generation sectors. Total natural gas consumption is projected to reach almost 27 Tcf by 2020, up from about 22 Tcf in 2005. Industrial-sector use is projected to grow from about 7 Tcf in 2005 to about 8 Tcf in 2020.

Natural gas is the primary fuel used by today's manufacturing and process industries.

- **Steam and onsite power generation** (including combined heat and power) represents the largest category of industrial energy use. Today, natural gas provides about two thirds of purchased energy for steam production from boilers.
- **Process heating** is the second largest category of industrial energy use[3]; natural gas accounts for about three quarters of purchased energy used.

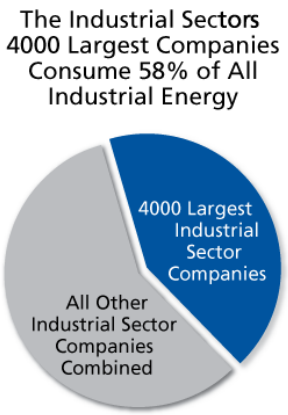
Characterized by large energy users (LEUs), the industrial sector's 4,000 largest companies consume 58 percent of all industrial energy. The largest natural gas users within these LEUs are:

- **Boilers** in the chemical, food, paper, mining, and refining industries, where steam is produced for turbines, drives, space heating, and combined heat and power applications and also for heating and drying operations.

3 This ranking excludes consumption of energy as a raw material (feedstock), which is the second largest industrial use of energy (6.5 quads). Natural gas feedstocks are not addressed in this document.

Furnaces, ovens, kilns, incinerators, and other types of direct process heating equipment used for melting, calcining, heating, and drying in the primary metals, refining, glass, chemicals and metal durables industries.

Increasingly, industrial energy users look for highly efficient, flexible, finely controlled processes and equipment for their operations. They also will want systems that help them comply with current and anticipated environmental regulations. New technologies will continue to have to provide solutions that enhance their productivity, product quality, profitability, global competitiveness and environmental leadership. This document identifies high-priority technology development opportunities to address these challenges.

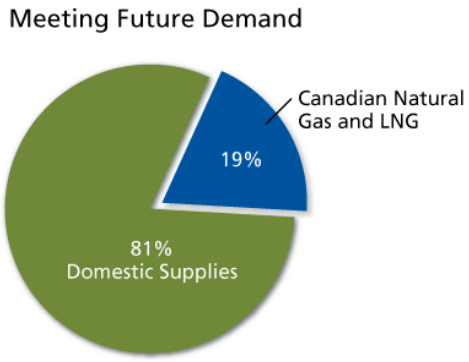


Today's industrial natural gas users face a range of dynamic and highly competitive market conditions. Key trends affecting the marketplace include:

- **Economic recession and layoffs.** Industrial natural gas users, especially in manufacturing, are under heavy pressure to reduce costs. In many cases, this manifests as personnel layoffs. Non-labor costs reductions like energy or alternative revenue sources, such as selling carbon credits resultant from efficient processes under pending federal legislation, can improve the bottom-line to keep people employed while allowing companies to hire back laid off workers.
- **Heavy competition from foreign manufacturers.** Foreign competitors are placing increasing pressure on domestic firms, requiring further improvements in productivity and reduced non-labor costs, such as energy. Collaborative efforts that reduce labor and other costs can help maintain a healthy and vibrant U.S. manufacturing sector.

Major increases in demand are anticipated in the industrial and power generation sectors.

- **Supply trends.** Domestic natural gas reserves are well over 100 years at current consumption levels. With gas from large domestic shales technically and economically viable, industry experts consider domestic natural gas an abundant, low-cost, low-carbon fuel. As the environmentally-preferred fossil fuel, natural gas use is projected to increase over the coming years, according to the EIA, from about 22 trillion cubic feet (Tcf) in 2005 to over 27 Tcf by 2020. Major increases in demand are anticipated in the industrial and power generation sectors. This demand is expected to be met by domestic supplies (81 percent) and Canadian natural gas and liquefied natural gas (LNG) imports from overseas (19 percent). However, recent evidence of significantly increased supply of natural gas from domestic resources will likely alter this projection in future forecasts, showing higher percentages of domestic supply.



- **High energy costs and volatile energy prices.** High price volatility is compounding pressures on the industrial sector. Improvements in energy efficiency can help ease the impact of volatile energy prices while simultaneously reducing GHG emissions.
- **Tightening environmental regulations.** Revised EPA or regional standards are expected to result in more stringent limits on nitrogen oxide, volatile hydrocarbon, and particulate emissions (including ultra fine and nanoparticulates).
- **Increasing pressure (due to global warming concerns) to reduce GHG emissions.** With the Supreme Court ruling that CO_2 should be considered a pollutant by the U.S. EPA, regulation of greenhouse gases is likely. Further, pending federal cap and trade legislation is aimed at GHG emission reductions over 80% from 2005 levels. The industrial sector ranks third in total U.S. GHG emissions (behind power generation and transportation). Increased combustion and process efficiency, along with expanded use of onsite CHP systems, can help reduce GHG emissions attributed to the industrial sector. With advanced technology solutions, major U.S. corporations are positioned to bring about GHG emission reduction while capturing potential economic value from CO_2 reduction credits.
- **Growing interest in fuel switching and fuel flexibility.** Industrial users will increasingly look to a broader mix of gaseous fuel supplies including waste and biomass fuels, renewable methane, solar thermal technologies and hydrogen-containing gasified products that will require process adaptations.

Tomorrow's industrial users will seek energy solutions that enable them to compete aggressively in tough marketplaces. They will demand the greatest possible value from their energy solutions, with the lowest possible risks. In making choices about process equipment, they will weigh not only returns on capital and lifecycle costs, but also impacts on product quality, productivity, safety and process flexibility and controllability. They will choose solutions that enable them to increase the total energy and resource efficiency of their operations, cost-effectively comply with existing or anticipated environmental regulations and that offer supply reliability and price stability. Continued investment in energy R&D is needed to maintain a robust U.S. manufacturing sector so that these challenges can be met.

Performance Targets

Table 7 lists estimated performance targets for solutions from the Industrial Applications RD&D Initiatives.

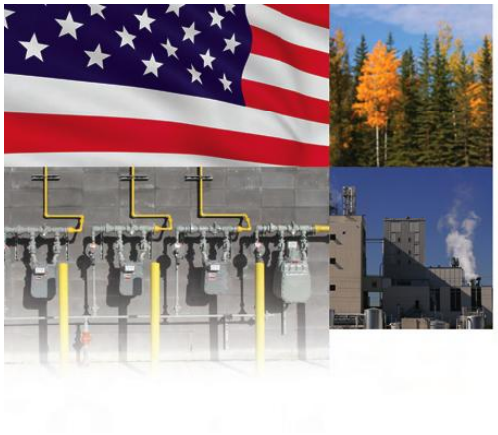


Table 7. RD&D Plan Performance Targets

TARGETS*	2015	2020	2030
Energy Efficiency Improvement (Trillion Btu)			
Steam Generation	60	240	350
Process Heating Systems	80	270	350
On-Site Power Generation (CHP)	40	150	200
Renewable Fuel Utilization	20	100	200
Total	**200**	**760**	**1,100**
Reduction in Greenhouse Gases, or GHGs (Million metric tons CO_2e)			
Steam Generation	3	14	40
Process Heating Systems	4	17	40
On-Site Power Generation (CHP)	2	8	23
Renewable Fuel Utilization	1	3	5
Total	**10**	**42**	**108**
Reduction in Criteria Air Pollutants, or CAPs (thousand tons per year)			
Steam Generation	30	160	400
Process Heating Systems	35	160	400
On-Site Power Generation (CHP)	25	100	200
Renewable Fuel Utilization	5	10	20
Total	**95**	**430**	**1,020**

*Notes:

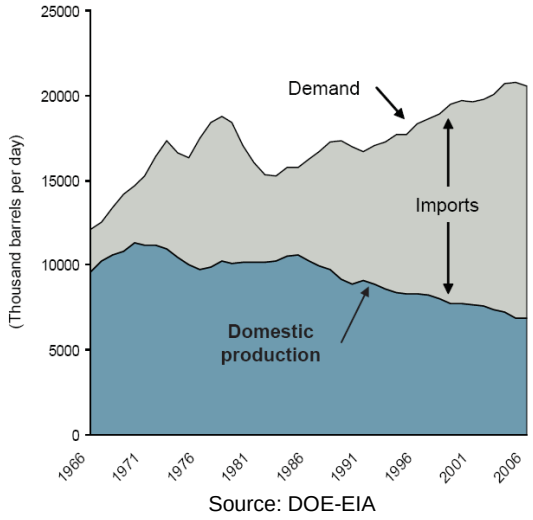
1. Steam generation energy efficiency assumes baseline efficiencies of 75 to 77 percent (Oak Ridge report) and an improvement to 94 percent efficiency. Unit replacement rates were provided by Cleaver-Brooks as well as baseline NOx of 64 ppm being reduced to 7 ppm, and CO baseline of 200 ppm reduced to 10 ppm.
2. Process heating energy and CAP estimates are derived in part from sector energy and “energy related” CAP emission estimates as presented in referenced EPA report.
3. The targets do not necessarily represent all actual expected benefits from implementation of the plan. For example, benefits derived from commercial applications are not included in the targets. Renewable fuel utilization savings is understated as the targets do not take credit for fossil fuels substitution savings but only credits improved energy efficiency benefits and related CAPs and GHG savings.

Section 6 Transportation Sector RD&D Priorities and Recommended Funding

Market Impacts and Stakeholders

The transportation sector represents a vital part of the U.S. economy. Presently, 29 percent of total U.S. energy – nearly 28 quads of energy – are used to move commercial goods and for private transportation. U.S. reliance on imported petroleum and related products has steadily grown to 60 percent – this contributes heavily to a negative balance of trade along with heightened energy security concerns.

U.S. Oil Production and Demand

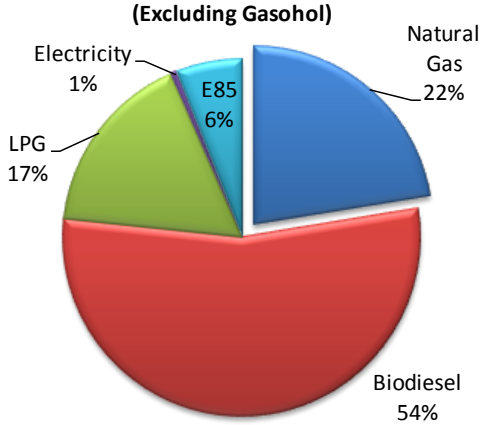


Source: DOE-EIA

The EIA forecasts that import reliance may decrease in coming years due to the combined effects of conservation – that is, more fuel efficient vehicles and other transportation modes – along with increased domestic fuel production using biofuels, natural gas vehicles (NGVs) and other alternative fuels. This will be a major national challenge given the steady increase in imported fuel reliance over the past 25 years.

The continued growth of biofuels depends heavily on new cellulosic ethanol plants becoming economically and technically feasible. Cellulosic ethanol is essential to enable shifting away from food crops – which are limited in quantity and are raising increasing concern of the impact of increased demand on food prices. A similar concern encircles biodiesel fuels – particularly those produced from soybeans. Feedstock diversification and use of waste oils is needed to transition biodiesel to higher levels. The DOE has a robust Biomass Program that provides substantial RD&D support for future biofuels – second-generation fuels made from forest products and residue biomass and third-generation fuels made from "energy crops."

Alternative Transportation Fuels
(Excluding Gasohol)



USDOE-EIA (2007 data)

Ethanol blended with gasoline (gasohol) is the most popular U.S. alternative transportation fuel, comprising nearly 4 percent of gasoline consumption. Beyond gasohol, the next most popular alternative fuels are biodiesel and natural gas – compressed natural gas (CNG) and liquefied natural gas (LNG).

There are multiple pathways by which natural gas is currently being used in the transportation sector. The most significant is an indirect route via ethanol production. Natural gas is a key enabling energy source that is vital to ethanol production. Annually, over 200 bcf of natural gas is estimated to be used to make ethanol for vehicle use. While improvements in ethanol production efficiency have taken hold in the past decade, the fact remains that making ethanol consumes large amounts of natural gas. A more energy efficient pathway is direct use of natural gas in vehicles.

Conventional direct routes for using natural gas in vehicles include CNG and LNG vehicles. Current U.S. NGV fuel use (CNG and LNG) is about 300 million equivalent gallons of gasoline per year – roughly 37 bcf of natural gas.

There are approximately 120,000 vehicles and 1,100 NGV fueling stations in the U.S. Most fuel consumption is associated with heavy-duty vehicles such as transit buses, refuse trucks, pick-up and delivery vehicles. NGV use is concentrated in certain regional markets in California, Texas, Utah and other states – where regional fueling station networks exist.

The Los Angeles, CA metropolitan area is an example of a robust and vibrant NGV fueling infrastructure. Public and private NGV fueling stations span the metropolitan area, providing convenient refueling, while helping the South Coast region address local air quality issues by reducing ozone precursor and particulate emissions.

Source: DOE Alternative Fuel Station Locater

NGVs can be an important component of the local and state implementation plans for air quality compliance. This is an important issue, especially with the new ozone standards that have increased the number of non-compliance areas in the country. Los Angeles serves as a case study on the role NGVs can play in major urban markets.

Taken together – that is, ethanol production and direct NGV use – natural gas is playing a niche but important role in diversifying the transportation sector fuel portfolio. This helps reduce U.S. demand for imported crude oil for gasoline or diesel fuel production, enhances energy security, reduces global warming gas emissions and improves the U.S. balance of trade. The current use of natural gas for transportation is estimated to provide a $3 billion balance of trade benefit by avoiding imported oil purchases.

The future role of natural gas in transportation fuels can be most efficiently expanded through greater NGV use. NGV America, the Nation's natural gas vehicle trade association, has a goal of achieving 10 billion gasoline gallon equivalent use per year of natural gas in ten years (see Table 8). This would amount to approximately 1.2 trillion cubic feet of natural gas – about 5 percent of current total annual US domestic natural gas per year. NGV America's goal could reduce foreign crude oil purchases by over $16 billion – while increasing domestic jobs for energy production and delivery. This could also offset an estimated 20 million metric tons of annual GHG emissions from conventional gasoline and diesel fuels.

Table 8 lays out future projections developed by NGV America for fleet NGV use. Importantly, these medium and heavy-duty vehicles – the core of the NGV market – are supplemented by a variety of light-duty vehicles.

Table 8. Fleet NGV Use Projections

Vehicle Class	Fuel Displaced (Million Gasoline Gallon Equivalent)
Freight Trucks	8,913
Refuse Trucks	579
Transit Buses	557
School Buses	432

Source: NGV America

There is a compelling near-term need to expand the availability of medium and heavy-duty engines and vehicle options available in the market – particularly in these leading fleet vocations. Substantial progress has been made in shifting the Nation's transit buses to natural gas, followed by growing acceptance in refuse trucks, freight trucks, and school buses.

Light-duty vehicle offerings are more limited. However, NGVs such as the Honda Civic represent a leading ultra-low emission vehicle option for fleets or commuters. This and other vehicle types can be used in fleets (e.g., gas utility vehicles, taxi and parking enforcement) as well as by personal commuters. The availability of small home fueling appliances (e.g., the Phill product) opens up an exciting pathway for commuters to use NGVs with convenient at-home fueling.

There are also a number of off-road vehicle applications where natural gas can play an important role. One example is industrial lift trucks (i.e., forklifts). Natural gas forklifts have been used for many years as an alternative to conventional liquid fuels or propane. CNG forklifts provide users convenience of onsite fueling, fuel cost savings, and improved indoor air quality through reduced CO emissions and odors. Other off-road vehicle applications for natural gas include farm vehicles, marine vessels, construction vehicles, and other specialty transportation uses.

On a worldwide basis, according to the International Association for Natural Gas Vehicles, there are approximately 9.6 million NGVs in service. Leading countries such as Argentina and Brazil have robust NGV use as a means of reducing reliance on imported oil and increasing use of domestically produced natural gas. Tax policy often plays a key role in providing market incentive to use natural gas over conventional liquid fuels. In some countries, such as India, the shift to NGV use is further enhanced by a desire to improve air quality. India currently has over 650,000 NGVs operating, with an emphasis on congested urban areas such as New Delhi. European use of NGVs is also growing, led by Italy and Germany. These countries have leading vehicle manufacturers who are producing dedicated CNG vehicles – a practice that has diminished in the United States but could return with growing market interest.

Fiat (left) and GM Opel CNG Vehicles

NGV product availability can be expanded by adding natural gas capability to domestically produced gasoline or diesel vehicles. Vehicle conversions of existing or newly produced domestic vehicles can be aided by further work to on certification programs for vehicle conversion operators. Alternatively, it may be possible to bring dedicated international CNG vehicles to the US by helping them meet Federal motor vehicle standards. In either case, further work is needed to coordinate with the U.S. Department of Transportation (DOT) and EPA to facilitate the expanded availability of natural gas vehicles that comply with U.S. safety and environmental standards.

An important facet of NGVs is the potential use of bio-methane – also called renewable methane. This is an alternative and renewable source of vehicle fuel that can be derived from landfill gas, wastewater treatment gas, and other methane-producing waste digesters along with biomass gasification facilities. In addition to being a renewable and sustainable fuel, renewable methane provides a substantial reduction in GHG emissions.

There is a growing recognition in several European countries and in parts of the United States of the synergistic benefits associated with renewable methane for vehicles. Sweden is a leader, with over half the CNG fuel used in the country provided by biogas; other countries such as Germany are also looking to biogas as a renewable vehicle fuel.

In the United States, California is a leader with their Low Carbon Fuel Standard, a measure that promotes the use of low-carbon alternatives such as renewable methane. With appropriate public policies, renewable methane production could grow along with NGV use – providing a renewable and sustainable fuel for the transportation market that does not substantially impact current natural gas demand. Several renewable methane facilities are either currently operating or under construction to bring this renewable fuel to the transportation market in the United States.

Another emerging, longer-term transportation fuel option is an indirect route using natural gas to produce hydrogen for fuel cell vehicles. Natural gas steam methane reforming (SMR) is the most efficient industrial route to produce hydrogen today and represents a pathway for distributed hydrogen production for clean, efficient fuel cell vehicles. There are a limited number of natural gas-to-hydrogen fueling stations in North America today, demonstrating the viability of this future transportation scenario. More effort is needed to improve this hydrogen production option and make it more cost effective and reliable.

Hydrogen fuel cells are an ultra-clean vehicle powerplant technology – their byproduct emission is water. This is an attractive approach for vehicle use in congested urban markets and for indoor vehicles such as industrial forklifts used in a variety of commercial and industrial applications. Natural gas, with its high hydrogen content, is a highly attractive pathway for hydrogen production using SMR technology. Importantly, hydrogen production from methane can also be done in a renewable and sustainable manner by using renewable methane; the SMR process can also be enhanced by using solar thermal energy to improve the conversion efficiency of transforming methane into hydrogen.

The plan outlined in this document supports the view that natural gas is the domestic fuel of choice in a low-carbon future, providing reliable, safe, efficient, affordable and environmentally superior performance. Direct use of domestically produced natural gas and renewable methane in CNG and LNG vehicles provides the most efficient route for using natural gas in the transportation sector. This includes a compelling need for near-term RD&D aimed at increasing the availability of natural gas engines and vehicles – particularly for medium and heavy duty fleet users.

Key RD&D initiatives to address these needs and opportunities for natural gas in the transportation sector have been identified based on information from gas industry stakeholders and external resources, including:

- NGV America (NGVA), International Association for Natural Gas Vehicles (IANGV), and the Clean Vehicle Education Foundation (CVEF);
- DOE Office of Energy Efficiency and Renewable Energy (EERE), the Natural Gas Vehicle Technology Forum and national laboratories;
- Vehicle, engine, and component manufacturers;
- GTI advisor guidance, especially UTD and public interest advisory committee members;
- California Energy Commission, California Air Resources Board, and South Coast Air Quality Management District, and NYSERDA documents;
- European and Asian gas industry roadmaps, benchmarks, and technology options; and
- H.R. 1622 to provide for a program of research, development and demonstration on natural gas vehicles.

It is expected that strategic partnerships would be established to help formulate a detailed plan and guide the proposed transportation sector RD&D initiatives, tailored to application, or research areas of interest. These partnerships would include such entities as equipment manufacturers, trade associations, codes and standards officials, regulatory officials, and professional groups or individuals with needed expertise in technical matters or market-related issues.

RD&D Plan Goals

This plan identifies high-priority research, development, and deployment goals for ensuring natural gas is being used in the most efficient and environmentally acceptable manner in the transportation sector:

Goal One (near-term – 2 to 5 years)
Integrate available and emerging ultra-low emission natural gas engines with vehicle manufacturers in priority weight classes. Cooperative programs with heavy-duty engine manufacturers on advanced emission controls and efficiency improvements; field testing to validate performance, efficiency, durability, and emissions; and potential collaboration on an international basis to expand product availability.

Goal Two (near-term)
Develop advanced CNG and LNG on-board fuel storage systems using advanced composite materials and alloy metals. Develop condition monitoring and safety devices for high-pressure CNG storage along with subsystems for LNG boil-off management. Enhance vehicle fuel storage safety with nationally recognized codes, standards and certification programs.

Goal Three (near-term)

Develop advanced CNG and LNG fueling station equipment and systems to reduce cost, enhance fuel delivery performance, and ensure accurate and timely filling of vehicles. Develop advanced CNG compressors and fuel dispensers. Develop and deploy a next-generation home fueling device. Enhance fueling station safety and the development of nationally recognized codes and standards as well as equipment certification.

Goal Four (mid-term – 5 to 10 years)
Develop advanced technology medium and heavy-duty hybrid natural gas vehicle platforms for use in trucks, transit buses, and school buses. Leverage advances in new engine powertrain, electric motors, controls and batteries from liquid fuel vehicles. Undertake field testing to validate performance, efficiency, durability, and emissions benefits.

Goal Five (mid-term)
Develop and deploy advanced renewable methane technology to ensure that the fuel quality requirements of advanced technology vehicles are met with integrated gas clean-up systems. Integrate renewable methane resources with CNG and LNG fueling station systems. Develop advanced sensors for real-time fuel quality monitoring.

Goal Six (long- term – 10+years)
Develop next-generation vehicle and infrastructure technology, including advanced natural gas hybrid vehicles, special-purpose auxiliary power units (APUs) for medium and heavy-duty vehicles to address anti-idling requirements (especially for natural gas utilities), and natural gas-to-hydrogen fuel stations for hydrogen fuel cell vehicles.

Funding Required

Table 9 summarizes the funding requirements for the RD&D program elements discussed above and in further detail in Section 7.

Project funding would be staged to scale up mid-term and long-term projects over time as near-term projects are completed. In the initial years of RD&D funding, near-term projects would receive approximately 75 percent of the available funding. This includes a compelling near-term need to expand the availability of natural gas engines and vehicle options – particularly for medium and heavy-duty trucks and buses. Funding for mid-term and long-term projects would progressively increase as near-term projects approach completion and receive greater contributions of manufacturer cofunding.

Table 9. Proposed Funding Requirements for Natural Gas Transportation RD&D Initiatives

	Funding ($ millions)		
RD&D Initiative	**2010**	**2015**	**2020**
NG Engine and Vehicle Tech	16	16	16
Fuel Storage Tech	5	6	7
Fueling Infrastructure	5	6	7
Renewable Methane	5	7	9
Safety, Codes, and Standards	2	2	2
Next-Gen Tech Development	2	3	4
Total	**35**	**40**	**45**

In addition to the transportation research portfolio outlined herein, it will be important that Congress continue to support existing incentives for the purchase and production of natural gas vehicles and direct use of natural gas as a vehicle fuel. This will help to spark investment and leverage research developments and breakthroughs.

Next Steps

This plan outlines a framework for pursuing cost-effective, efficient use of natural gas within the transportation sector. This is intended to serve as a planning tool for the natural gas industry, government partners, and other transportation industry stakeholders – including NGV America and the Clean Vehicle Education Foundation among others – to spur collaborative research efforts in areas of mutual interest and benefit.

Initial activities include awareness building by the developers and stakeholders of the plan. This will include meetings with industry, government and policymakers highlighting benefits for consumers, manufacturers, and the nation.

The implementation of this plan can bring increased value in energy efficiency, carbon emissions reduction, and enhanced national security by diversifying fuel use in the transportation sector through the use of clean, abundant, efficient domestic fuels. This plan will spur collaborative RD&D efforts among stakeholders and government partners.

The Supplemental Information section presents further details of the proposed RD&D Plan.

Section 7 Supplemental Information for Transportation RD&D Plan

RD&D Initiatives

Presented below are potential RD&D initiatives (organized by application) designed to help achieve the plan goals.

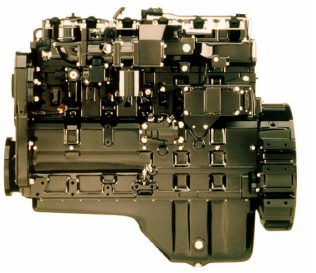
Natural Gas Engine and Vehicle Technology

Natural gas engine technology is based on modification of gasoline and diesel engines to optimized natural gas operation. Keys to a sustainable NGV market are:

- Maintaining emissions superiority over diesel and gasoline;
- Improving the performance and efficiency of natural gas engines;
- Expanding product offerings of engines and vehicles to meet a wider range of customer needs, including the growing interest in marine and off-road applications; and
- Developing long-term hybrid natural gas/EV options.

Further R&D is needed in order for natural gas engines to meet customer requirements for performance, efficiency, reliability, and durability. In addition to improving efficiency and performance, cost to the consumer must be reduced. Significant progress has been made in the economic attractiveness of natural gas vehicles, due in part to increasing costs for diesel engines to comply with new environmental regulations.

Efficiency improvements are essential to help improve consumer economics, increase driving range, and reduce greenhouse gas emission rates. This is vitally important for large fuel consuming fleet vehicles. Many of today's natural gas engine offerings come close to matching diesel engine fuel efficiencies at full-load but are up to 30% less efficient at part-load. The best energy efficiency demonstrated by current heavy duty diesel engines is approximately 42 percent. Advanced natural gas engine technology development is approaching 39 to 40 percent. Narrowing this gap in energy conversion performance will contribute to the significant life cycle cost benefits.



The comparisons in part-load efficiency are more challenging. This reduction occurs due to "throttling losses." In urban applications, where vehicles operate for long periods of time at idle or low-load conditions, throttling losses are significant and negatively impact overall fuel efficiency and, hence, life-cycle economics. Promising technologies such as "skip-fire," Miller cycle, charge air-cooling, exhaust gas recirculation, variable geometry turbocharging, turbo-compounding, advanced controls, multiport fuel injection and even compression ignition need further investigation to overcome these losses.

Another area in which natural gas engines need to be improved is power density. Current natural gas engines have power ratings 10 to 20 percent lower than their diesel counterparts. Power enhancements including combustion chamber geometry optimization, air motion, heat transfer characteristics and materials with greater thermal capacity are examples of technology developments that would allow for diesel-like power density from natural gas engines.

Development of cost-effective closed-loop control systems is critical to maximizing performance and minimizing emissions of NGVs. Keys to this technology are cost-effective sensors with sufficient performance (e.g., range, repeatability, accuracy, life, contaminant tolerance, etc.) to detect engine knock, engine misfire, engine torque, exhaust gas oxygen and NOx content, and fuel composition. Development and testing of these concepts should be included as part of the engine development R&D program.

Post-combustion treatment is also helping natural gas emission achieve even lower levels compared to conventional liquid fuels. Further advancements are needed to lower NOx and particulate emissions (including ultra-fine particulates) as well as unburned hydrocarbons (including methane and formaldehyde).

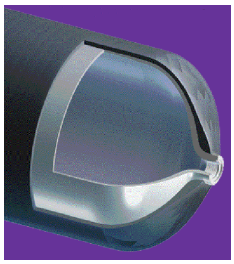
The development of advanced engine technology must be complemented by investments in vehicle integration to ensure new powerplants are available in a wide array of vehicle platforms – for example, transit buses, school buses, refuse trucks, long-haul trucks, pick-up and delivery vehicles, and other vocational uses. Integrated engine and vehicle solutions also require field testing to validate performance, efficiency, and durability.

Longer-term efforts should include the development of medium and heavy-duty natural gas hybrid vehicles. Hybridization can result in significant improvements in efficiency (miles per gallon equivalent) and attendant reduction in carbon dioxide emissions. Importantly, electric motor drives can help improve torque response that is desired by some commercial users. Finally, hybrid medium and heavy-duty natural gas vehicles would allow for either increased driving range (for a given amount of storage) or the ability to reduce the on-board fuel storage required (thereby reducing vehicle first cost).

Benefits

- Lower first cost engine and vehicle equipment;
- Life-cycle cost savings through energy efficiency improvements;
- Reduced emission of conventional criteria pollutants such as NOx and particulates; and
- Reduced emission of greenhouse gases (carbon dioxide and methane in particular).

Fuel Storage Technology



CNG cylinders are designed to hold high pressure gas at pressures of 3000 or 3600 psig over a design life of 15 to 20 years. At these pressures, natural gas still requires four to five times the tank volume of liquid fuels. By minimizing the amount of material used in these containers, size, weight, and cost can be kept to a minimum. Since materials represent more than 60 percent of the cost of these containers, development activities should focus on advanced new materials (e.g., high-strength steels, aluminum alloys, and composites) and processes that can be designed to optimize storage within NGV vehicle platforms.

LNG is stored on vehicles as a cryogenic liquid. LNG is the fuel of choice for many heavy-duty applications, especially long-haul trucking, because its energy density is greater than that of CNG. Research is needed to improve the performance of LNG fuel containers with respect to long-term storage of fuel without allowing venting or loss of the vacuum integrity that is so critical to this low-heat-gain operation. There is a need for improved LNG boil-off management systems to avoid release of methane to the atmosphere. Finally, lower-cost LNG on-board systems are needed to improve customer economics.

Federal, state and local regulations require periodic visual inspection of natural gas fuel cylinders to detect problems that could compromise safety. Visual inspection is costly and time-consuming for the owner of the vehicle. There is a need to develop “smart fuel storage systems” that incorporate non-destructive monitoring systems in CNG and LNG fuel containers. The intent is to provide continuous monitoring of the structural and thermal integrity of CNG and LNG fuel containers. These systems would provide early warning to the vehicle operator when a problem with the storage system is detected. The systems could also serve to track in-use cylinders and notify

when their end-of-service life limit has been reached.

Both CNG and LNG require on-board safety systems, including pressure relief devices. Continued advancements are needed to ensure these devices are safe and effective.

Benefits

- Lower first cost equipment; and
- Enhanced safety and reduced probability of safety-related in-use incidents.

Fueling Infrastructure

CNG and LNG fueling stations are a critical part of the NGV industry. These stations need to store and deliver fuel on demand and at the lowest possible costs to be competitive with conventional liquid fuels. This includes public access fueling stations as well as private fleet stations (e.g., transit bus fueling stations).

Additional research is needed to develop more cost effective and reliable compressors for both conventional public access stations and larger heavy-duty operations. Compressor durability and reliability need to be improved. Better controls are needed to reduce electrical operating costs and better manage vehicle fill operations. Better materials and/or designs are needed to improve service and maintenance performance. Alternative compressor technologies (e.g., hydraulic compressors) need to be optimized for the cost and performance demanded by a rapidly expanding market.

Lower cost station peripherals (e.g., dryers and dispensers) also need to be pursued. Dispenser technology must be improved to communicate with the compressor to make sure a full-fill can be achieved. Dispensing protocols need to be standardized for all vehicles. A novel aspect of natural gas vehicles is the ability of consumers to fuel at home with a natural gas fueling appliance. This approach provides a convenience for commuters who can refuel their vehicles overnight.

In many cases, LNG infrastructure needs parallel those for CNG – lower cost, as well as improved durability, reliability and safety. LNG fueling station technology is relatively new (in comparison to industry experience with CNG) but offers great promise in being able to deliver fuel at much higher rates than CNG.

LNG technology has its roots in the aerospace and cryogenic gas businesses where specialty needs justify the relatively high cost of equipment. Lower cost versions of this technology are required to support adoption of LNG into fleets.

Pumping, metering, and dispensing of LNG are complicated by the cryogenic nature of the fuel. Lower-cost systems are needed that are capable of performing through repeated fueling operations. In most LNG operations, LNG must be pumped from one location to another. Industry objectives include development of cost-effective, reliable, lower negative pump suction head pumps that do not cavitate during LNG fueling. LNG pumps are also needed for L/CNG operations (where LNG liquid is pumped to high pressure, then vaporized and dispensed as CNG). Improved LNG fuel dispenser systems capable of providing leak-free, publicly accessible fueling are also needed.

In the area of LNG supply, there is a need for small-scale LNG liquefiers that can economically produce LNG at a cost comparable to larger-scale LNG facilities. In utility peak shaving operations, LNG is produced in plants with 30,000 to 100,000 gallons per day capacity. Small-scale liquefiers in size ranges more suitable for regional fleet needs of 10,000 to 30,000 gallons per day need to be demonstrated and they can also play a role in renewable methane recovery.

Benefits

- More convenient fueling options for fleet and individual users; and
- Lower cost fueling equipment encouraging a greater number of increasingly small fueling stations attractive for investors, operators and users.

Renewable Methane for Vehicles

Substantial domestic sources of renewable methane exist currently in landfill gas, wastewater treatment plants, and other digester plants. This number could expand in the future through expanded use of digesters processing waste material or through purpose-built biomass gasification plants that produce methane. These options provide a renewable and sustainable resource that can extend conventional natural gas supplies. Applying these renewable methane resources to the transportation market can have the additional – and substantial – benefits of reducing imported crude oil while also substantially reducing GHG emissions.

There is a key need to develop cost-effective and reliable clean-up systems to enable the use of this resource as a vehicle fuel. This includes the removal of CO_2 and water as well as other trace gases and contaminants – particularly siloxanes that can damage natural gas engines and compressors.

There is a need for close integration of renewable methane clean-up systems with CNG or LNG fueling stations to minimize the footprint, energy requirements, and capital cost.

Benefits

- Reduced emission of greenhouse gases (CO_2 and methane in particular).

Safety, Codes, and Standards

Safety is a critically important consideration for CNG and LNG fueling stations, on-board fuel storage systems, and vehicles. National and international coordination is required with codes and standards making organizations to harmonize requirements and maximize knowledge from experiences in different markets. This includes organizations such as American National Standards Institute, National Fire Protection Association, Compressed Gas Association, Society of Automotive Engineers, American Society of Mechanical Engineers, International Standards Organization, and Federal regulations within DOT, EPA and others.

Products and systems need to be tested and certified to appropriate national and industry standards. Studies should be conducted to assess in-use fuel storage and fueling stations to monitor the long-term behavior and integrity of new advanced technology materials and other equipment. The results of such studies then need to be brought to the codes and standards making organizations to insure that the best practical practices are allowed and written into future code revisions.

Certification, training, and education programs are needed to aid personnel involved with vehicle conversion and maintenance to use best practices for installation and servicing of natural gas vehicle fuel storage and engine technology.

Benefits

- Coordinated regulation and industry-recognized codes and standards making NGVs and NGV fueling safer, more reliable and more commonplace.

Next Generation Technology Development

Pursue the technology base development and design of next-generation vehicle and infrastructure solutions for natural gas in the transportation sector.

Develop an ultra-high efficiency natural gas commuter vehicle that would meet the needs of users for clean intra-city transportation. The goal is to achieve over 60 mpg and 300 mile driving range. Fuel storage would be tightly integrated into the vehicle design.

Develop auxiliary power units (APUs) that can enable fleet customers – including gas utilities to meet federal and local requirements for anti-idling. APUs can provide energy and emission reduction benefits to a broad range of fleet customers. Natural gas utilities work trucks, in particular, would benefit from advanced APUs that provide power at remote field work sites.

Investigate options for high-efficiency, cost effective natural gas to hydrogen fueling stations and NG-derived high-pressure hydrogen delivery systems.

Study catalytic and other approaches for improved management (e.g., formation-reduction, capture, conversion and storage) of selected combustion byproducts (carbon monoxide, carbon dioxide and oxides of nitrogen) and methane that can degrade air quality.

Benefits

- Breakthrough technology making natural gas a competitive fuel in more applications; and
- Reduced consumption of imported petroleum.

Impact of RD&D on Vehicle Owners and Fleet Customers

Successful conduct of the RD&D initiatives proposed in this plan will provide a range of benefits to individual and fleet vehicle owners and operators, and fueling station operators. Benefits include:

- Reduced purchase and operating costs for natural gas vehicles;
- A wider choice of competitive natural gas vehicle options;
- Cost-effective compliance with environmental and safety requirements, including lower-cost carbon emission reductions;
- More cost-effective options for vehicle fueling; and
- Greater market acceptance of renewable methane as an alternative and sustainable transportation fuel.

Impact of RD&D on the U.S. Natural Gas Industry

For the U.S. natural gas industry and its customers, the new and improved products, processes, systems and materials resulting from the RD&D initiatives proposed in this plan will, in broad terms, help to make natural gas an integral part of the U.S. transportation market. The RD&D portfolio provides a way to simultaneously:

- Spur wider adoption of current and early-market-entry natural gas vehicle and infrastructure technologies;
- Develop advanced, next-generation gas-based systems whose characteristics will make them even more attractive in a low-carbon energy future;
- Enhance use of domestic natural gas resources and renewable methane, offsetting the nation's reliance on imported petroleum; and
- Generate technologies that may result in new domestic job creation to produce new products for export to the global market for NGVs and related equipment.

Successful execution of this RD&D portfolio will help ensure long term vitality of natural gas as a vital alternative energy option in the transportation market.

Key Trends and Challenges

Energy cost is a concern for fleet operators in particular, including natural gas utilities. High-fuel-use fleets such as transit buses, delivery trucks, refuse trucks and other medium and heavy-duty vehicles consume substantial amounts of fuel on an annual basis.

These fuels are almost exclusively gasoline and diesel, with a growing proportion of this being imported from outside of the United States. This growing dependence has left the United States vulnerable to supply disruptions. There is an explicit recognition of this fact and a desire within public policy to diversify the transportation market fuel mix.

Another key trend is a concern over GHG emissions. The transportation sector and electricity production are the top sources of GHG emissions in the U.S. A shift to natural gas can provide an estimated 23 to 29 percent reduction compared to conventional liquid fuels. This benefit can be substantially enhanced through the expanded use of renewable methane as a transportation fuel.

The growing interest in "advanced technology" solutions in the vehicle sector – such as hybrid vehicles, hydrogen fuel cell vehicles, and plug-in hybrid electric vehicles – necessitates continued investment in natural gas technology to keep

this important domestic resource as a key vehicle fuel option – particularly for high-fuel-use fleet vehicles.

Expanded use of NGVs, particularly coupled with increasing domestic supplies, can provide large societal benefits. Cost-effective home and business refueling options can provide a reliable local fueling infrastructure until larger public fueling stations are built and offer a long term option for convenient refueling as the fueling infrastructure matures.

Performance Targets

Table 10 lists estimated performance targets for transportation solutions developed through the RD&D initiatives proposed in this plan. Natural gas vehicles are an important element to the nation's approach to reduce GHG emissions and significantly reduce the consumption of imported petroleum. While replacing gasoline and diesel vehicles and equipment accomplishes these goals, it does not reduce transportation energy consumption. Gasoline vehicles are roughly equivalent and diesel vehicles are roughly 10 percent more efficient than natural gas vehicles. Energy savings are important for the associated benefits it brings: GHG emission reductions, cost savings and conserving finite fuel resources. In the case of NGVs, these benefits are all realized except for energy savings. Moving away from imported petroleum to domestic natural gas supplies is a key national security issue. Currently, there are well over 100 years of domestic natural gas reserves. This plan would increase domestic demand by approximately 6 percent while averaging more than 20 million metric tons of GHG reductions compared to business as usual.
Further, natural gas, as a transportation fuel, is projected to be half the price of gasoline or diesel both near and long-term. That means this plan is projected to save vehicle owners and operators hundreds of millions of dollars each year.

Table 10. RD&D Plan Performance Targets for Transportation

TRANSPORTATION TARGETS	2015	2020	2030
Reduction in Greenhouse Gases (Million Metric Tons CO_2e)			
Natural Gas Engine and Vehicle Technology Fuel Storage Technology Fueling Infrastructure Renewable Methane for Vehicles Safety, Codes, and Standards Next-Generation Technology Development	Each research area contributes to increased market penetration for heavy, medium and light duty vehicles and related equipment. GHG savings represent aggregate benefit for transportation research portfolio.		
Total	**5**	**16**	**40**

Section 8 Research and Funding Approach

Assumptions and Calculation Methodology

The natural gas industry and its stakeholders have developed a research agenda aimed at near, mid and long-term energy, GHG and consumer cost savings.

Proposed full fuel cycle energy savings are accomplished through replacement of existing electric, fuel oil and natural gas fired equipment with more energy efficient natural gas equipment. Energy savings were developed using projected market penetration for high efficiency gas-fired equipment based on natural gas industry high-level estimates, projected likelihood of technical and market success and current market penetration of existing technologies. Different values were assigned for different research areas; for example incremental technology improvements were allocated higher technical probability of success than innovative or "breakthrough" technologies. Where available, established government and industry RD&D program goals were used to forecast market penetration of new technologies. In other cases, engineering judgment based on previous research experience was used to estimate forecasted market penetration.

GHG reductions associated with reduced energy consumption or fuel switching were estimated using nationally recognized multipliers for each energy source and listed as carbon dioxide equivalents (CO_2e) based on the global warming potential (GWP) of each greenhouse gas. GWP is an index that approximates the impact of GHG's such as methane on global warming relative to an equal amount of CO_2.

Most energy and GHG emission savings were generated using national numbers from EIA and other government sources; however, in some instances it was necessary to use regional EIA data. For example, the majority of electric resistance space heating equipment is installed in areas with fewer heating degree days than the national average. Thus the replacement savings per unit are less than the national average and energy savings would be overstated unless regional data were used.

Net energy cost savings were estimated from reduced energy consumption and switching from more expensive fuels (electricity, oil, diesel and gasoline) to less expensive natural gas. All fuel and electricity cost calculations applied published EIA 2009 Annual Energy Outlook cost projections in 2007 Dollars. Net consumer savings represent the present value of future energy cost savings minus the estimated incremental capital cost of new high efficiency equipment. Each research program targets different price points and payback durations based on given market. For instance, the commercial food service market is very price sensitive and thus acceptable payback durations for efficient technologies are lower than the residential market or some other commercial market segments.

Additionally, with pending federal carbon cap and trade legislation, the value of net energy cost savings may be significantly higher. As there are still many questions regarding environmental legislation including the price of carbon and who will pay, this significant potential benefit was not included in the cost-benefit analysis.

Funding Level Estimates

The natural gas industry and its stakeholders have developed a research portfolio for transportation, homes and businesses and industrial applications to promote energy efficiency, GHG emission reductions, and consumer cost savings among other benefits. The funding levels for RD&D portfolios were calculated based on the costs of proposed research, the estimated benefits, and the reasonableness relative to current and historic natural gas research spending.

Table 10. Proposed Funding Requirements for Natural Gas End Use RD&D Initiatives

	Funding ($ millions)		
RD&D Portfolio	**2010**	**2015**	**2020**
Homes and Businesses	109	111	113
Industrial Applications	215	251	287
Transportation	35	40	45
Total	**359**	**402**	**445**

The Gas Research Institute, GRI, as administered by the Federal Energy Regulatory Commission, spent roughly $100 million a year on end use research in the 1990s. Today, California spends nearly 1% of gross gas operating revenues on RD&D, approximately $24 million for 2009-2010. In comparison, the Homes and Businesses research portfolio funding level is estimated to be 0.1% of total expenditures in the residential and commercial sectors. Funding levels are also appropriate given payback, for every dollar spent under this plan there is more than $10 dollars in net consumer energy cost savings.