TECHNOLOGY

LEVERAGING NATURAL GAS TO REDUCE GREENHOUSE GAS EMISSIONS

SUMMARY REPORT

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

June 2013

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This report is a summary of:

Leveraging Natural Gas to Reduce Greenhouse Gas Emissions, which provides an overview of natural gas production, the climate implications of expanded natural gas use, potential uses and benefits in key sectors, and related infrastructure issues.

The full report is available at:
http://www.c2es.org/publications/leveraging-natural-gas.

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EXECUTIVE SUMMARY

Recent technological advances have unleashed a boom in U.S. natural gas production, with expanded supplies and substantially lower prices projected well into the future. Because combusting natural gas yields fewer greenhouse gas emissions than coal or petroleum, the expanded use of natural gas offers significant opportunities to help address global climate change. The substitution of gas for coal in the power sector, for example, has contributed to a recent decline in U.S. greenhouse gas emissions. Natural gas, however, is not carbon-free. Apart from the emissions released by its combustion, natural gas is composed primarily of methane (CH_4), a potent greenhouse gas, and the direct release of methane during production, transmission, and distribution may offset some of the potential climate benefits of its expanded use across the economy.

This report explores the opportunities and challenges in leveraging the natural gas boom to achieve further reductions in U.S. greenhouse gas emissions. Examining the implications of expanded use in key sectors of the economy, it recommends policies and actions needed to maximize climate benefits of natural gas use in power generation, buildings, manufacturing, and transportation (Table ES-1). More broadly, the report draws the following conclusions:

- The expanded use of natural gas—as a replacement for coal and petroleum—can help our efforts to reduce greenhouse gas emissions in the near- to mid-term, even as the economy grows. In 2013, energy sector emissions are at the lowest levels since 1994, in part because of the substitution of natural gas for other fossil fuels, particularly coal. Total U.S. emissions are not expected to reach 2005 levels again until sometime after 2040.
- Substitution of natural gas for other fossil fuels cannot be the sole basis for long-term U.S. efforts to address climate change because natural gas is a fossil fuel and its combustion emits greenhouse gases. To avoid dangerous climate change, greater reductions will be necessary than natural gas alone can provide. Ensuring that low-carbon investment dramatically expands must be a priority. Zero-emission sources of energy, such as wind, nuclear and solar, are critical, as are the use of carbon capture-and-storage technologies at fossil fuel plants and continued improvements in energy efficiency.
- Along with substituting natural gas for other fossil fuels, direct releases of methane into the atmosphere must be minimized. It is important to better understand and more accurately measure the greenhouse gas emissions from natural gas production and use in order to achieve emissions reductions along the entire natural gas value chain.

TABLE ES-1. Sector-Specific Conclusions and Recommendations

POWER SECTOR
It is essential to maintain fuel mix diversity in the power sector. Too much reliance on any one fuel can expose a utility, ratepayers, and the economy to the risks associated with commodity price volatility. The increased natural gas and renewable generation of recent years has increased the fuel diversity of the power sector (by reducing the dominance of coal). In the long term, however, concern exists that market pressures could result in the retirement of a significant portion of the existing nuclear fleet, all of which could be replace by natural gas generation. Market pressures also could deter renewable energy deployment, carbon capture and storage, and efficiency measures. Without a carbon price, the negative externalities associated with fossil fuels are not priced by society, and therefore there will be less than optimal investment and expansion of zero-carbon energy sources.
Instead of being thought of as competitors, however, natural gas and renewable energy sources such as wind and solar can be complementary components of the power sector. Natural gas plants can quickly scale up or down their electricity production and so can act as an effective hedge against the intermittency of renewables. The fixed fuel price (at zero) of renewables can likewise act a hedge against potential natural gas price volatility.

TABLE ES-1. Sector-Specific Conclusions and Recommendations—continued

BUILDINGS SECTOR
It is important to encourage the efficient direct use of natural gas in buildings, where natural gas applications have a lower greenhouse gas emission footprint compared with other energy sources. For thermal applications, such as space and water heating, onsite natural gas use has the potential to provide lower-emission energy compared with oil or propane and electricity in most parts of the country. Natural gas for thermal applications is more efficient than grid-delivered electricity, yielding less energy losses along the supply chain and therefore less greenhouse gas emissions. Consumers need to be made aware of the environmental and efficiency benefits of natural gas use through labeling and standards programs and be incentivized to use it when emissions reductions are possible.
MANUFACTURING SECTOR
The efficient use of natural gas in the manufacturing sector needs to be continually encouraged. Combined heat and power systems, in particular, are highly efficient, as they use heat energy otherwise wasted. Policy is needed to overcome existing barriers to their deployment, and states are in an excellent position to take an active role in promoting combined heat and power during required industrial boiler upgrades and new standards for cleaner electricity generation in coming years. For efficiency overall, standards, incentives, and education efforts are needed, especially as economic incentives are weak in light of low natural gas prices.
DISTRIBUTED GENERATION
Natural gas-related technologies, such as microgrids, microturbines, and fuel cells, have the potential to increase the amount of distributed generation used in buildings and manufacturing. These technologies can be used in configurations that reduce greenhouse gas emissions when compared with the centralized power system as they can reduce transmission losses and use waste heat onsite. To realize the potential of these technologies and overcome high upfront equipment and installation costs, policies like financial incentives and tax credits will need to be more widespread, along with consumer education about their availability.
TRANSPORTATION SECTOR
The greatest opportunity to reduce greenhouse gas emissions using natural gas in the transportation sector is through fuel substitution in fleets and heavy-duty vehicles. Passenger vehicles, in contrast, likely represent a much smaller emission reduction opportunity even though natural gas when combusted emits fewer greenhouse gases than gasoline or diesel. The reasons for this include the smaller emission reduction benefit (compared to coal conversions), and the time it will take for a public infrastructure transition. By the time a passenger fleet conversion to natural gas would be completed, a new conversion to an even lower-carbon system, like fuel cells or electric vehicles, will be required to ensure significant emissions reductions throughout the economy.
INFRASTRUCTURE
Transmission and distribution pipelines must be expanded to ensure adequate supply for new regions and to serve more thermal loads in manufacturing, homes, and businesses. Increased policy support and innovative funding models, particularly for distribution pipelines, are needed to support the rapid deployment of this infrastructure.

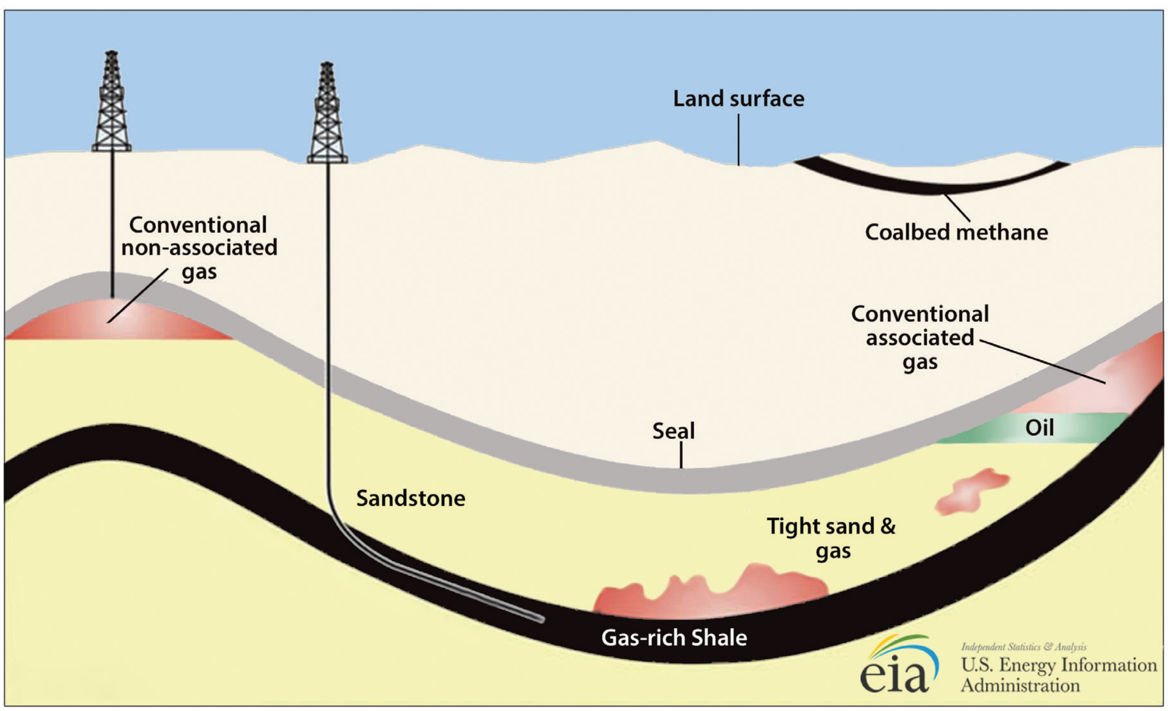
NATURAL GAS PRODUCTION

Natural gas is a fossil fuel found in several different types of geologic formations. It can be produced alone from reservoirs in natural rock formations or be associated with the production of other hydrocarbons such as oil (Figure 1). With relatively recent advances in seismic imaging, horizontal drilling, and hydraulic fracturing, U.S. natural gas is increasingly produced from unconventional sources such as coal beds, tight sandstone, and shale formations where the resources are not concentrated or in permeable rock. These unconventional sources require advanced technologies for development and production and typically yield much lower recovery rates than conventional reservoirs. Shale gas extraction, for example, differs significantly from conventional extraction methods. Wells are drilled vertically and then turned horizontally to run within shale formations. A slurry of sand, water, and chemicals is then injected into the well to increase pressure, break apart the shale to increase permeability, and release the natural gas. This technique is known as hydraulic fracturing or "fracking."

Supply, Demand, and Shifting Market Shares

Technological advances have dramatically increased the amount of natural gas resources that can be economically recovered. Since 1999, proven reserves of natural gas in the United States have increased every year, and production has rapidly increased, driven mostly by shale gas advancements (Figure 2). Reserve estimates represent nearly 100 years of domestic demand at current levels of consumption.

FIGURE 1: Geologic Formations Bearing Natural Gas



Source: Energy Information Agency, "Schematic Geology of Natural Gas Resources," January 2010. Available at: http://www.eia.gov/oil_gas/natural_gas/special/ngresources/ngresources.html

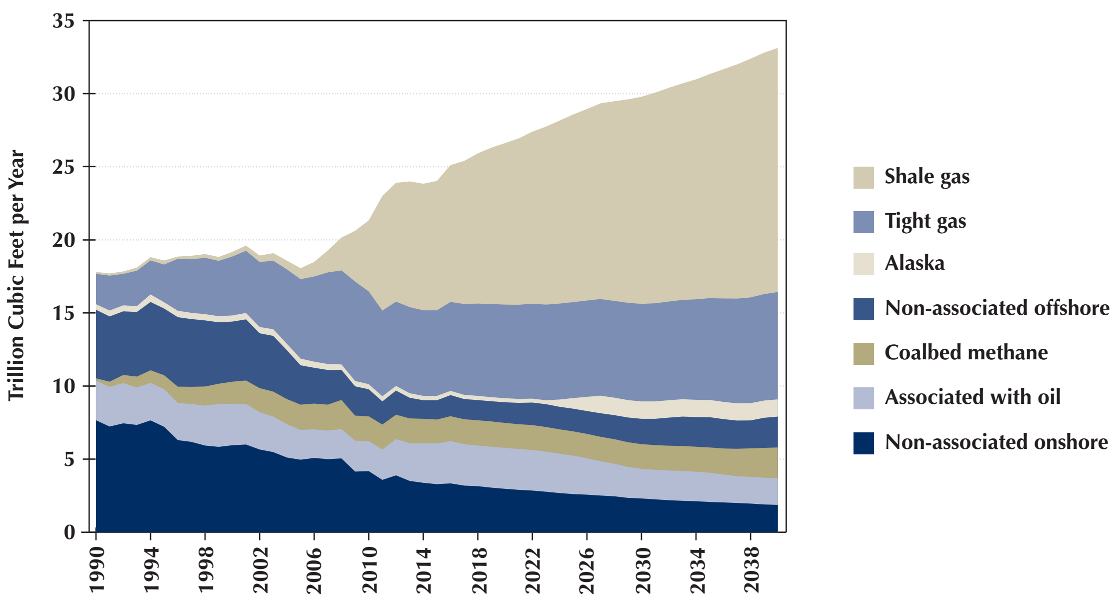
In 2011, natural gas constituted approximately 27 percent of total primary energy consumption in the United States. Recent increases in demand have been driven by the power sector, where demand has grown since 2000 at an annual average rate of 3.5 percent. In the industrial sector demand declined from 2000 to 2008 because of increased efficiency and the economic slowdown but has been increasing since 2008. Natural gas demand from homes and businesses has remained relatively flat since 2000. Use of natural gas in the transportation sector has grown over the same timeframe, but still remains relatively small compared to other sectors.

The growing domestic supplies of natural gas and the resulting lower prices come at a time when the medium- and long-term outlook prices of petroleum and coal are expected to rise. Natural gas is already displacing some coal use in power generation and could overtake petroleum to be the most widely used fuel in the United States within a decade or two. In the coming years, natural gas will exhibit a variety of price tensions, manifestations of the different market, technological, and societal forces that will drive—and be driven by—its future use.

GREENHOUSE GAS EMISSIONS AND REGULATIONS ASSOCIATED WITH NATURAL GAS PRODUCTION

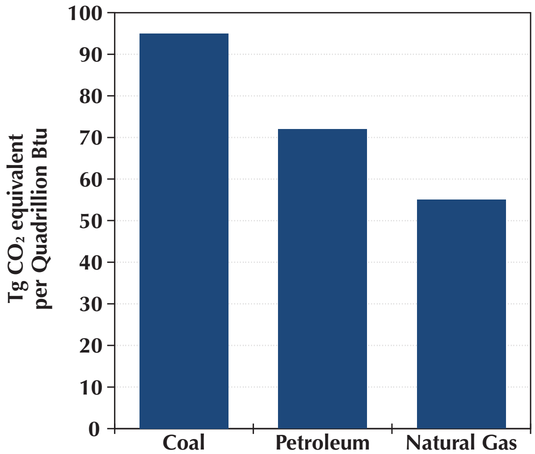
Natural gas extraction and use leads to greenhouse gas emissions through both combustion and direct release into the atmosphere. Natural gas has a lower carbon intensity that other fossil fuels, releasing approximately 50 percent less carbon dioxide (CO_2) than coal and 33 percent less than oil when combusted (Figure 3). However, when natural gas is directly released into the atmosphere (see below), it has a higher impact on the atmosphere's ability to trap heat. Methane, the main component of natural gas, is much more potent than CO_2 at increasing the atmosphere's heat-trapping ability, but remains in the atmosphere a much shorter time (a little more than a decade). Averaged over a 100-year time frame, the warming potential of methane is about 21 times stronger than that of CO_2.[1] However, in a 20-year time frame, it is 72 times more potent.[2] Thus, a critical element of an effective strategy for meeting climate goals while increasing natural gas use is to minimize the direct release of methane into the atmosphere.

FIGURE 2: **U.S. Dry Natural Gas Production, 1990 to 2040**



Source: Energy Information Administration, "Annual Energy Outlook 2013 Early Release" December 2012. Available at http://www.eia.gov/forecasts/aeo/er/executive_summary.cfm

FIGURE 3: CO_2 Emissions from Fossil Fuels



Source: Environmental Protection Agency, Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011. 2013. Chapter 3 and Annex 2. Available at: http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Notes: CO_2 content for petroleum has been calculated as an average of representative fuel types (e.g., jet fuel, motor gasoline, distillate fuel) using 2011 data.

This graphic does not account for the relative efficiencies of end-use technologies.

Direct Release of Methane: Leakage and Venting

As the relative climate benefits of substituting natural gas for other fuels are assessed, it is important to understand the implications of methane emissions—leakage and intentional venting. In natural gas systems, methane can leak into the atmosphere from production wells, processing facilities, storage facilities, and transmission and distribution pipelines. Methane is also sometimes vented to the atmosphere intentionally, either for operational or safety reasons at the wellhead or to reduce pressure from equipment and pipelines. Where possible, this methane is burned (or "flared"), which prevents it from entering the atmosphere directly but still releases CO_2 into the air.

Methane emissions are important, yet not well understood. In recent years, greenhouse gas measurement and reporting requirements have drawn attention to the need for more accurate data. This uncertainty can be seen in the revisions that have accompanied sector emission estimates. Just recently, for example, the Environmental Protection Agency (EPA) revised downward the estimated level of methane emissions attributable to production of natural gas. In 2010, it estimated that about 58 percent of methane emissions in the natural gas system came from production. This year, EPA reduced that number to 37 percent. A major reason for this revision was a change in EPA's assumption about emission leakage rates. Based on EPA's greenhouse gas inventory data, the assumed leakage rate for the overall natural gas system was revised from 2.27 percent in 2012 to 1.54 percent in 2013.[3] Independent studies have estimated leak rates ranging from 0.71 to 7.9 percent.[4,5,6] EPA and others are trying to better understand the extent and sources of leakage.

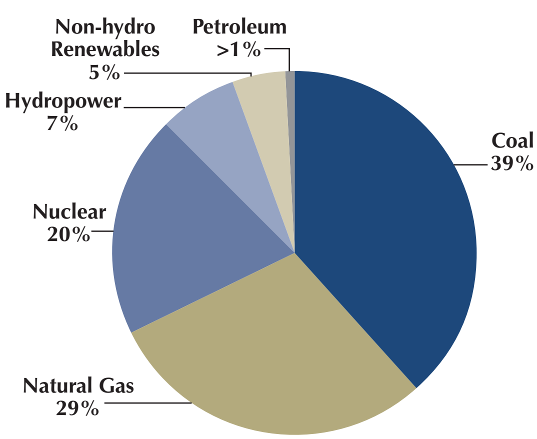
Updated rules governing the direct release of methane are being developed at the state and federal levels. Of particular note, in August 2012, EPA released new air pollution standards for natural gas operations —"green completion requirements" for hydraulically fractured and refractured wells. Hydraulically-fractured natural gas wells must now at least flare the excess methane (not vent it), and beginning in 2015, they must also collect it. While the "green completion" regulations are expected to reduce methane emissions from natural gas wells, concern has been expressed that the regulations do not apply to on-shore wells that are not hydraulically fractured, existing hydraulically fractured wells until such time as they are refractured, or oil wells, including those that produce associated natural gas. However, geologic and market barriers may limit the applicability of this type of rule to other sources of natural gas.

POWER SECTOR

In 2012, natural gas was used to generate 29 percent of electricity in the United States (Figure 4), and the fuel offers a number of advantages for power generation. Natural gas can provide baseload, intermediate, and peaking electric power, essentially able to meet all types of electrical demand. It is an inexpensive, reliable, dispatchable source of power that is capable of supplying firm backup to intermittent sources such as wind and solar. Natural gas power plants can be constructed relatively quickly, in as little as 20 months. However, even though combustion of natural gas produces lower greenhouse gas emissions than combustion of coal or oil, natural gas does emit a significant amount of CO_2. Finally, natural gas-fired power plants must be sited near existing natural gas pipelines, or else building new infrastructure may significantly increase their cost.

With its low price, the increasing stringency of EPA air regulations, and the ultimate likelihood of a carbon-constrained future, natural gas has become the fuel of choice for power generation by U.S. utilities. From 2003 to 2012, the share of primary energy consumption from coal for electricity generation dropped from 53 percent to 37 percent, while the share fulfilled by natural gas grew from 14 percent to 29 percent (Figure 5). Between 2012 and 2040, the U.S. electricity system will need 340 gigawatts of new generating capacity (including combined heat and power additions), given rising demand for electricity and the planned retirement of some existing capacity, and natural gas-fired plants will account for 63 percent of these cumulative capacity additions.[7] The substitution of coal for natural gas in the power system has yielded significant reductions in CO_2 emissions from the sector (Figure 6). It is important, however, that a focus on natural gas not stand in the way of a diverse fuel mix, most notably, the continued development and utilization of zero-carbon energy sources.

FIGURE 4: U.S. Electricity Generation by Fuel Type, 2012



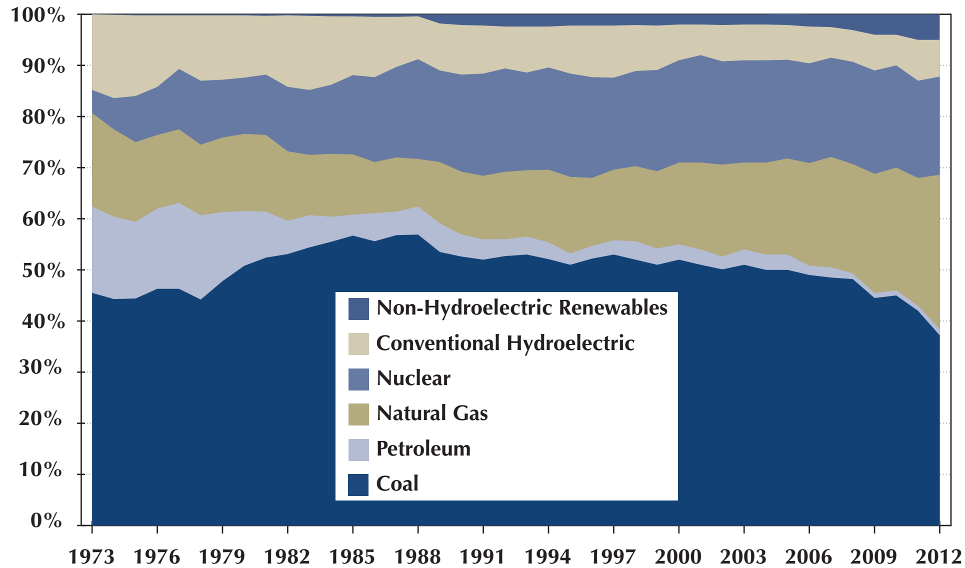
Source: Energy Information Administration, "March 2013 Monthly Energy Review. Table 7.2b. Electricity Net Generation: Electric Power Sector," Available at: http://www.eia.gov/totalenergy/data/monthly/#electricity

Low-Carbon and Zero-Carbon Fuels Are Important

There is concern that the current availability of inexpensive natural gas-fired power generation may dampen initiatives that encourage zero-carbon energy production and greater energy efficiency across all sectors. Policies such as a price on carbon and incentives for renewable and nuclear generation are needed to encourage supply and demand for these zero-carbon energy sources. Policies are also needed to encourage continued development of carbon capture and storage technologies and deployment of energy efficiency technologies.

Recently, the increased use of natural gas to replace coal-dominated electricity generation has increased the diversity of the fuel mix. But rising natural gas use may threaten the overall diversity of the fuel mix in the long term if it replaces electricity from retiring nuclear generators and hinders the emphasis on efficiency or the development of wind, solar, and other low- and zero-carbon energy technologies, such as carbon capture and storage. In the near term, the current low price of natural gas may add to the competitive challenges faced by renewable energy capacity additions in some regions. However, natural gas and renewables can have a complementary relationship in electricity generation. The ability of natural gas generation to cycle up or down almost instantaneously counterbalances the variability of wind and solar, while the fixed fuel price of wind power (fixed at zero) provides a hedge against the potential price volatility of natural gas. Accordingly, low natural gas prices could help facilitate an increase in renewable energy in some regions. In order for this mutually beneficial relationship to flourish, carefully designed policy that allows the addition of both sources to the grid in a complementary fashion must come into play and be encouraged by public utility commissions.

FIGURE 5: U.S. Electricity Generation by Fuel Type, 1973 to 2011



Source: Energy Information Administration, "Electricity Net Generation: Total (All Sectors). Table 7.2a," March 2013. Available at: http://www.eia.gov/totalenergy/data/monthly/#electricity

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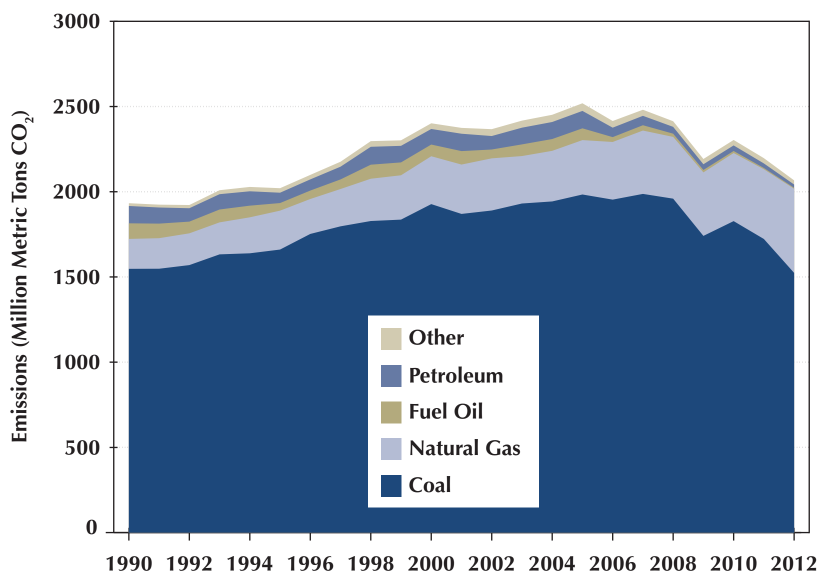
FIGURE 6: U.S. Power Sector Emissions, 1990 to 2011



Source: Energy Information Administration, "Monthly Energy Review," Table 12.6, March 27, 2013. Available at: http://www.eia.gov/forecasts/archive/aeo11/index.cfm

BUILDINGS SECTOR

In the buildings sector, natural gas and electricity have long been the dominant fuel sources, with electricity use growing more rapidly in the last 25 years due in large part to the proliferation of home and office electronics. Natural gas use often provides a means to increase a building's efficiency and decrease its emissions profile because the source-to-site efficiency of the fuel-delivery system together with the site efficiency of a particular appliance often make natural gas more efficient on a full-fuel-cycle basis than similar appliances that use electricity, propane, or oil.

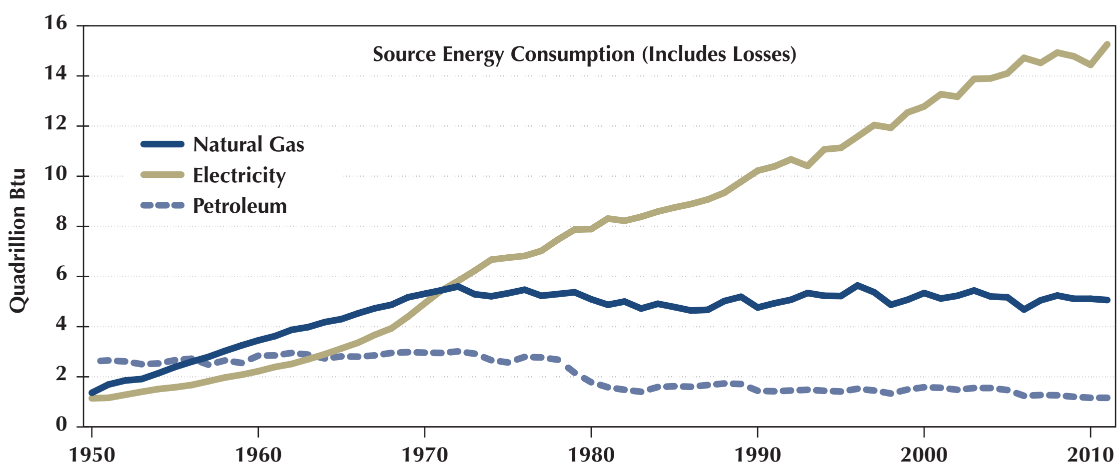
Natural gas can increase the overall efficiency of consumer energy use by two routes: Equipment with lower full-fuel-cycle efficiency can be replaced with more efficient natural gas equipment (and natural gas-powered equipment can be upgraded), and natural gas can be used for electricity generation on site where the resulting heat can be captured and used.

While a building's energy use depends on its location and climate, the predominant use of energy in the residential and commercial sectors nationwide is for thermal applications—space and water heating, clothes drying, and cooking appliances. The full-fuel-cycle efficiency of thermal appliances used in buildings varies dramatically depending on whether they are powered by natural gas or electricity from the grid. In most cases (and in most parts of the country), natural gas models are more efficient in terms of performing more work using less primary energy than electric appliances where an electric resistance element is used.

The efficiency of an appliance has two components, the efficiency of the appliance during operation and the efficiency of the production of the fuel that powers it. This is known as the full-fuel-cycle efficiency of an appliance, a combination of the source-to-site efficiency of the system and the site efficiency of an appliance. Source-to-site efficiency is a measure of the energy requirements to bring energy to the consumer including production, processing, transmission, and (in the case of electricity) generation. The site efficiency of an appliance is its end-use efficiency. The generation of electricity incurs substantial losses. About three times the amount of primary energy is required for every unit of electricity delivered to a consumer. On average, the source-to-site efficiency of grid-delivered electricity is about 32 percent, meaning that about 32 percent of the energy contained in fuels used to generate electricity actually ends up being useful electricity that can power appliances and other equipment. In contrast, the source-to-site efficiency of natural gas, which also incurs some losses in its production, processing, and transmission, averages 92 percent;[8] that is, 92 percent of the energy contained in extracted natural gas is useful energy that can directly fuel appliances.

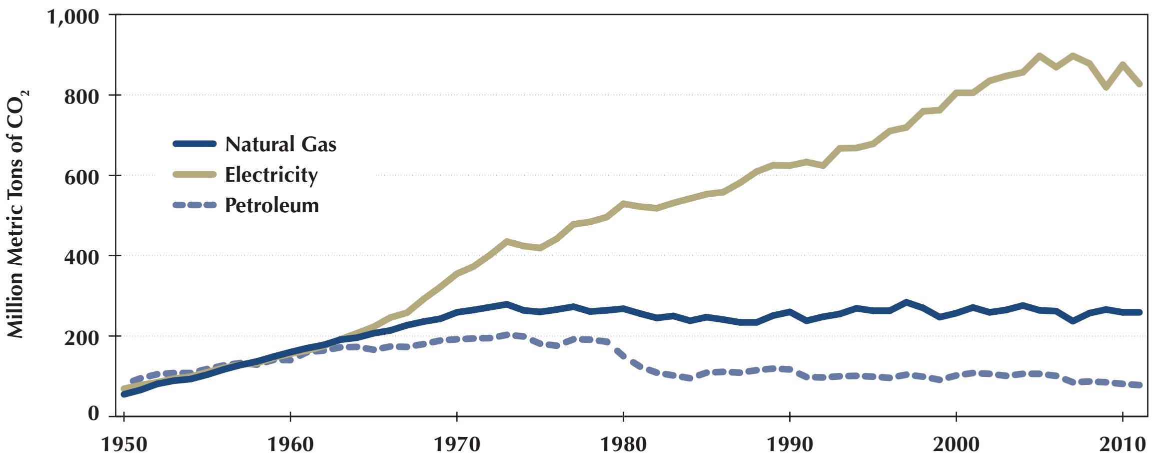
The full-fuel-cycle efficiency and the associated greenhouse gas emissions provide the appropriate

FIGURE 7: Primary Energy Consumption, 1950 to 2010



Source: Energy Information Administration, "Today in Energy," March 6, 2013. Available at: http://www.eia.gov/todayinenergy/detail.cfm?id=10251

FIGURE 8: **Residential Carbon Dioxide Emissions from Energy Consumption, 1950 to 2010**



Source: Energy Information Administration, "Today in Energy," March 6, 2013. Available at: http://www.eia.gov/todayinenergy/detail.cfm?id=10251

metrics with which to evaluate greenhouse gas emissions from building energy use. When full-fuel-cycle efficiency is considered for storage tank water heaters, for example, natural gas-powered models are about 75 percent efficient and electric resistance models are about 30 percent efficient. In fossil fuel-heavy electricity grids, these inefficiencies represent greenhouse gas emissions whose production was not associated with any actual usable power or heating capacity; consequently, the emissions associated with this wasted energy are much greater for electric than for natural gas model appliances. Switching from electric resistance water heaters to natural gas offers substantial emissions savings in an area that constitutes a significant share of overall energy usage in buildings.

Natural gas also plays a role in the greater efficiency of buildings through its use in distributed generation systems: CHP systems, fuel cells, and microturbine technologies. All of these technologies allow electricity to be produced on site, thus avoiding distribution losses and potentially utilizing the waste heat to serve a building's thermal loads. These technologies are discussed in a later section.

Usage Trends: Natural Gas Versus Electricity

Currently, the use of grid-supplied electricity by residential and commercial buildings is growing while direct natural gas consumption remains relatively flat. The growth in total (primary) energy consumed by buildings has been three times greater than the growth in electricity actually used on site, a consequence of the energy required to generate, transmit, and deliver electricity (Figure 7). If natural gas were to satisfy some of the growing electricity demand instead, dramatically less primary energy would be consumed to provide the same amount of on-site energy. In addition to primary energy saved, substantial emissions would be avoided through the decrease in energy required in electricity production and distribution, as emissions from the electricity system constitute a significant portion (74 percent) of buildings-related CO_2 emissions (Figure 8).

Barriers to Increased Use of Natural Gas in the Buildings Sector

Despite the large differences between the full-fuel-cycle efficiencies of electricity and natural gas model appliances, barriers exist to the expanded use of natural gas in buildings, both commercial and residential. First, not all buildings have access to natural gas. Second, for those that do, the occupants or owners often are not aware of the greater full-fuel-cycle efficiency and lower emissions of natural gas appliances or of the cost savings that can be achieved over the life of an appliance. Third, while natural gas appliances can be less expensive to operate, these models often have higher up-front costs than electric models. In the case of non-owner-occupied buildings (where the building developer often does not benefit from the monthly savings from efficient appliances), developers must assess their ability to recoup higher up-front costs through their rental income.

Policy Support for Increased Natural Gas Access and Use

Policy support, including aligned incentives, the provision of accurate information about full-fuel-cycle efficiencies and greenhouse gas emissions, and innovative funding models for new infrastructure, can help overcome the barriers to increased natural gas access and utilization in the buildings sector. In addition, developers should be encouraged to consider natural gas infrastructure and building design that facilitates direct use of natural gas. Innovative funding models are emerging that can make expansion of natural gas distribution networks economical for utilities and consumers. Some states have been active in experimenting with new mechanisms, and additional policies could make expansion of service possible in more jurisdictions.

Aligning incentives is particularly important, as consumers and developers seeking to minimize up-front cost often do not realize that operating costs and environmental costs may be much higher for electric appliances. In addition, although current energy efficiency programs aim to reduce greenhouse gas emissions from appliances and buildings in two important ways—by setting standards and efficiency labeling programs—these standards are based solely on site efficiency, which is reflected in the energy and cost savings identified on efficiency labels. But efficiency labels based only on site efficiency do little to educate consumers about the total energy needed to power appliances and the greenhouse gases associated with that energy and, as such, often steer consumers toward electric appliances even if a natural gas appliance may be more efficient overall and produce fewer greenhouse gas emissions. It is important, therefore, that the source-to-site efficiency of an appliance also be taken into consideration, and in regions with fossil fuel-dominated grid electricity, natural gas appliances should be encouraged. The Department of Energy is evaluating how to implement full-fuel-cycle efficiency appliance standards and will work with the Federal Trade Commission on product labels that take full-fuel-cycle efficiency into consideration.

MANUFACTURING SECTOR

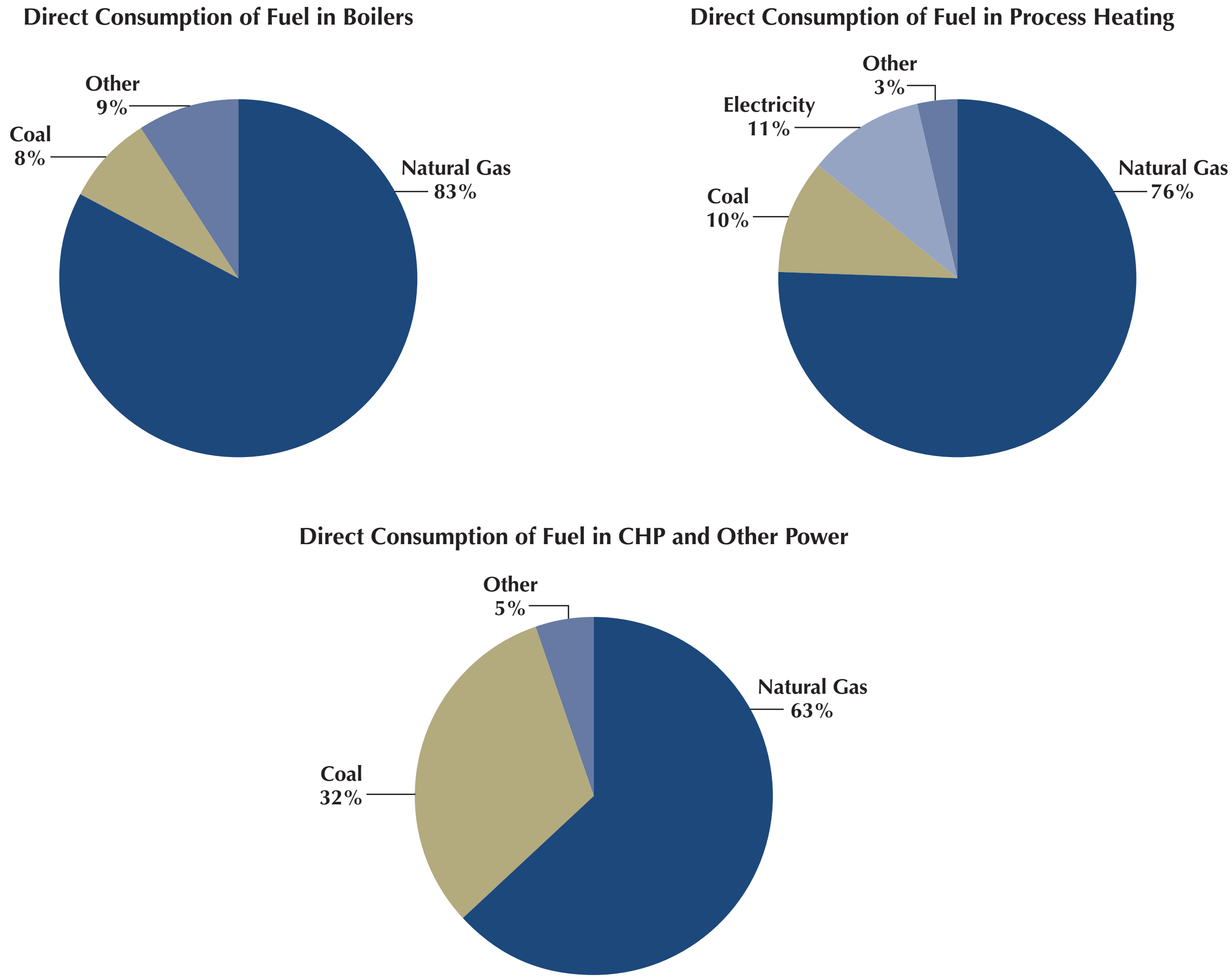
Natural gas is used in the manufacturing sector for on-site electricity generation (fueling boilers and turbines); for process heat to melt glass, process food, preheat metals, and dry various products; and for CHP systems (Figure 9). Natural gas is also used as a material input itself—as a feedstock—to make products such as fertilizers, chemicals, and plastics. In 2010, natural gas supplied 30 percent of the U.S. manufacturing sector's direct energy use.[9] With relatively low and expected stable prices, natural gas demand in this sector is expected to significantly grow, by 16 percent between 2011 and 2025.

Twin Considerations: Expanded Use and the Need for Higher Efficiencies

The increased availability and relatively low and stable prices of natural gas have led to growth in domestic manufacturing, with numerous companies in the United States citing natural gas supply and a stable low price in the announcement of new facilities in the chemicals, plastics, steel, and other industries. As the manufacturing sector expands, it is important to reduce its emissions intensity—the amount of CO_2 emitted per unit of output. Two key strategies for tempering the growth in emissions are to increase the efficiency of industrial boilers and to increase the use of on-site CHP systems.

Replace low-efficiency boilers. Since industrial boilers are replaced infrequently, many older, inefficient boilers are still in use. On average, to replace an older natural gas-fired boiler (efficiency rates of 65 to 75 percent) with a high-efficiency or super-high-efficiency unit (efficiency rates of 77 to 82 percent) can decrease CO_2 emissions by 4,500 to 9,000 tons per year per boiler. Moreover, businesses have an economic incentive to make these replacements, seeing annualized monetary savings as high as 20 percent (given certain assumptions, including 2010 natural gas prices) and a payback period for the new equipment of just 1.8 to 3.6 years. In addition, new regulations have been adopted for the release of air toxins for coal-fired boilers (the EPA's 2012 Maximum Achievable Control Technology standard, known as the Boiler MACT). Replacement of a coal-fired boiler with a high-efficiency natural gas-fired boiler reduces CO_2 emissions

FIGURE 9: Direct Consumption of Fuels in the Manufacturing Sector, 2009



Source: Energy Information Administration, "Manufacturing Energy Consumption Survey," June 2009, Tables 2.2 and 5.2. Available at http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html.

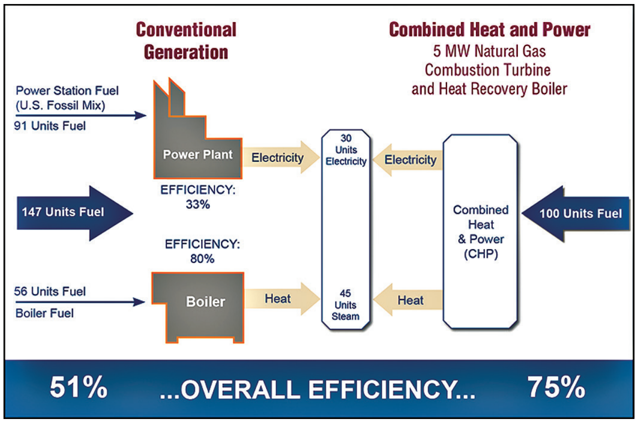
by up to 56 to 59 percent or about 52,000 to 57,000 tons per year per boiler on average.[10]

Increase the use of CHP. Increasing the use of CHP systems—also known as cogeneration—has considerable potential to reduce emissions from the manufacturing sector. CHP systems simultaneously produce both electricity and heat from a single fuel source, and because they use waste heat and avoid transmission losses, they are significantly more efficient than grid electricity (Figure 10). Of the potential new capacity for CHP operations in the United States, 70 percent is at large-scale industrial systems. These systems confer benefits beyond the industrial facility itself, as they can bolster the reliability of the grid overall during extreme weather events and can even serve to replace some of the capacity lost as coal-fired plants retire.

Barriers to the Increased Use of CHP

There are several barriers to the deployment of CHP systems, despite their advantages. Utilities often charge operators of CHP systems standby rates or partial service requirement rates that can reduce the cost savings of these systems. Second, non-standardized interconnect requirements and uncertainty in the application process can lead to additional project costs and delays. Third, utility considerations include perceived risks related to electricity being

FIGURE 10: Combined Heat and Power versus Conventional Generation



On the right, 100 units of fuel are converted into 30 units of electricity and 45 units of useful heat by a single CHP unit; 75/100 = 75 percent efficiency. On the left, 91 units of fuel are converted into 30 units of electricity by a large power plant and 56 units of fuel are converted into 45 units of useful heat by a separate boiler; 75/(91 + 56) = 51 percent efficient.

Source: Environmental Protection Agency, "Efficiency Benefits," 2012. Available at: http://www.epa.gov/chp/basic/efficiency.html.

added to the grid outside of the central power plant (a situation that pertains to any type of distributed generation, including rooftop solar); utilities' lack of control over safety and technical decisions made by CHP operators; and these systems' potential need for backup or partial service power, which could require utilities to make new investments in capacity. Fourth, owners of CHP systems often face additional costs associated with obtaining trained installers and operators, and the cost to retrofit a system to capture the waste heat can be a significant expense (installation is easier and less expensive during new construction or a major redesign). Fifth, an on-site use or nearby buyer must exist for the excess heat or electricity produced. Finally and in some cases most importantly, some electric utility regulations discourage the growth of CHP capacity because a large facility generating its own power can significantly reduce the demand for centrally generated power and can thus increase the per customer cost of electricity for those remaining reliant on the grid.

Policy Support Needed

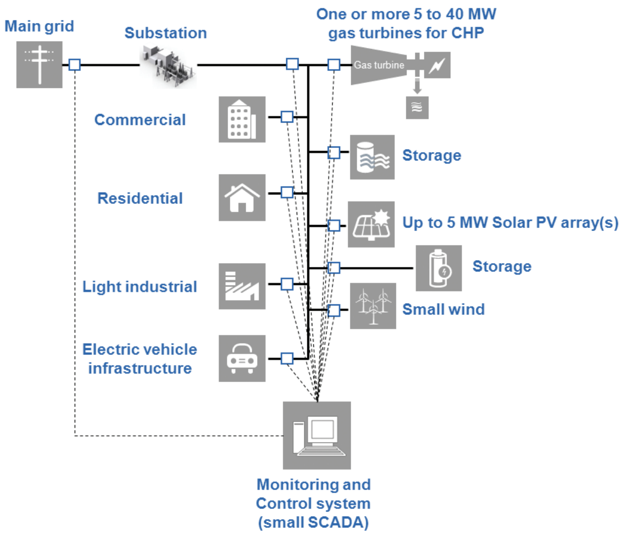
Innovative policy approaches can overcome some of the perceived conflict between utilities and CHP operators. "Decoupling" is one such mechanism. It removes or modifies the link between a volume of utility sales and profits, and it allows room for broader goals such as greenhouse gas reductions and system reliability. A second strategy is a lost-revenue adjustment policy, which compensates utilities —through a charge on customer bills—for revenues lost as a result of effective energy efficiency measures. Promising state-level initiatives include standardizing grid-interconnection guidelines, offering tax incentives, providing individualized education and outreach to operators, and including CHP as a compliance mechanism for a state's clean-energy standard.

DISTRIBUTED GENERATION IN THE RESIDENTIAL AND COMMERCIAL SECTORS

Distributed generation, the production of electricity near where it will be used, helps reduce the greenhouse gas emissions of the power sector when waste heat is captured (as discussed in the previously section) and by diminishing the line losses associated with distribution. Currently, 6.5 percent of electricity in the United States is generated outside of centrally located power plants.

Technologies such as microgrids, fuel cells, microturbines, and residential CHP systems, while not widely used at this point in the United States, can have several advantages over grid-delivered electricity. Key advantages associated with high-efficiency distributed generation include customers' access to waste heat, easier integration of renewable energy sources, lower greenhouse gas emissions, potential improvements to system reliability, and reduced system vulnerability to terrorism and extreme weather because distributed power plants are smaller and more geographically dispersed. While the majority of existing natural gas-powered distributed generation technologies are not as efficient at producing electricity as a centralized power plant, several new types coming on the market are highly efficient. In addition, when distributed generation can capture and use waste heat or better integrate renewable energy, it will be more efficient and emit fewer greenhouse gases than conventional power plants. The following technologies have one or all of these advantages.

FIGURE 11: Microgrid Concept



Individual microgrid elements will vary.

Source: Siemens, "The Business Case for Microgrids," 2011. Available at: http://www.energy.siemens.com/us/pool/us/energy/energy-topics/smart-grid/downloads/The%20business%20case%20for%20microgrids_Siemens%20white%20paper.pdf

Microgrids

A microgrid is a small power system for a group of buildings that consists of one or more electrical generation units operated either in conjunction with or independently from the central power system. Microgrids can more easily integrate renewable sources of electricity with fossil fuel-fired backup power, for example, integrating dispatchable natural gas-fired electricity (or CHP systems) with local renewable power and energy storage (Figure 11).

Fuel Cells

Natural gas-powered fuel cells avoid combustion altogether and use natural gas and air to create electricity and heat electrochemically (Figure 12). Natural gas is converted into hydrogen gas inside a fuel cell, and when the hydrogen passes across the anode of the fuel cell stack, the result is the production of electricity, heat, CO_2, and water. The CO_2 emissions from a fuel cell are a pure stream, making it possible to capture the emissions for use or storage. Fuel cells are available for a wide range of climates, have electrical efficiencies of 40 to 60 percent, and are quiet devices with a fairly small physical footprint.

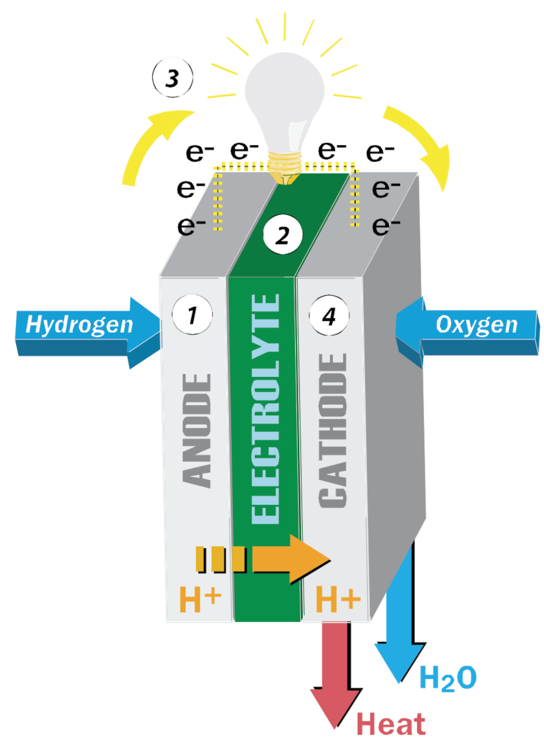
Microturbines

Microturbines are small combustion turbines approximately the size of a refrigerator, with outputs of up to 500 kilowatts (Figure 13). They can be fueled by natural gas, hydrogen, propane, or diesel. In a CHP configuration where waste heat is captured, the combined thermal-electrical efficiency can be as high as 90 percent.

Residential CHP

Residential CHP systems are an established technology in Europe and Japan but still rare in the United States. These units provide electric power for a home while also supplying heat for thermal applications or absorption cooling (Figure 14).

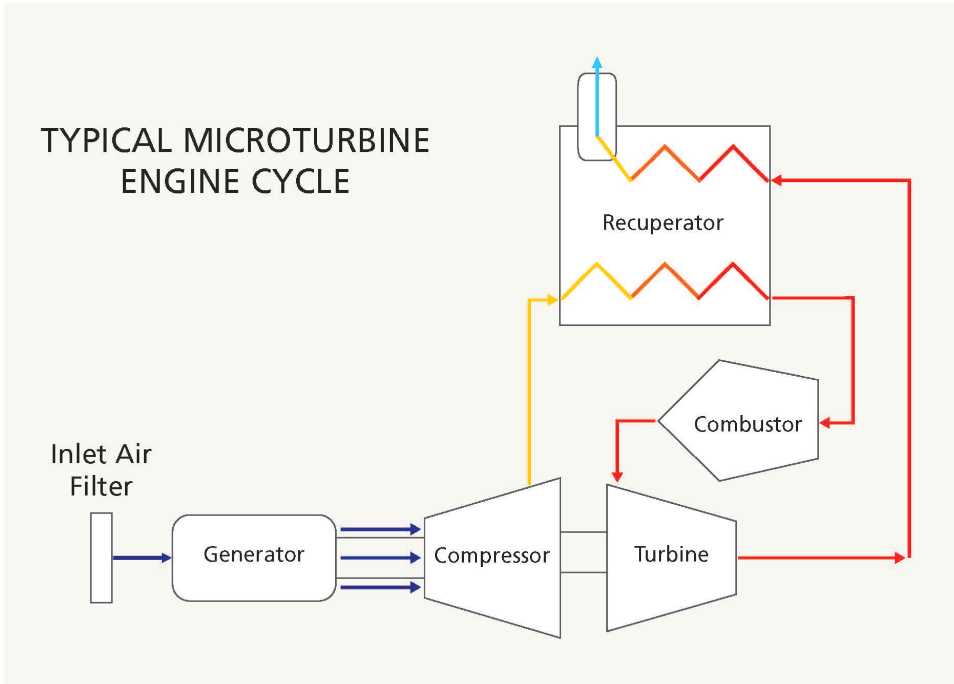
FIGURE 12: Fuel Cell Stack



1) Anode: As hydrogen flows into the fuel cell anode, a catalyst layer on the anode helps to separate the hydrogen atoms into protons (hydrogen ions) and electrons. 2) Electrolyte: The electrolyte in the center allows only the protons to pass through the electrolyte to the cathode side of the fuel cell. 3) External Circuit: The electrons cannot pass through this electrolyte and, therefore, must flow through an external circuit in the form of electric current. This current can power an electric load. 4) Cathode: As oxygen flows into the fuel cell cathode, another catalyst layer helps the oxygen, protons, and electrons combine to produce pure water and heat.

Source: ClearEdge Power

FIGURE 13: Microturbine Schematic



Fuel enters the combustor and the hot gases ejected from the combustor spin a turbine, which is connected to a generator that creates electricity. The exhaust gases transfer heat to the incoming air. A recuperator captures waste heat and helps improve the efficiency of the compressor.

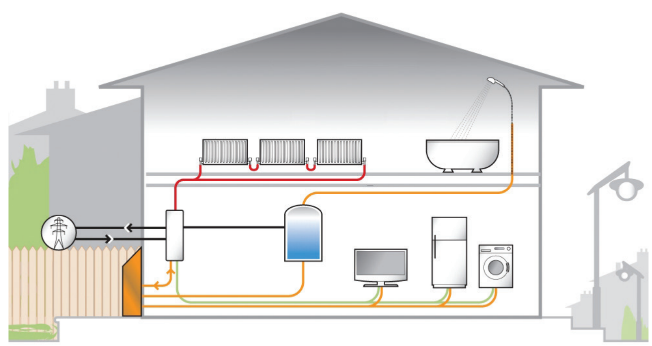
Source: Capstone Turbine Corporation

Barriers to Use and Policies to Encourage Deployment

Despite the climate, energy, and overall financial benefits of distributed generation in the residential and commercial sectors, its use is hindered by higher upfront capital costs and, as discussed above, utility regulations that often do not encourage distributed generation technologies and in some cases actively discourage them. Furthermore, potential customers are often not aware of these technologies' existence, much less their climate benefits.

Some state and federal incentive programs help home- and business-owners with upfront costs. At least 10 states provide financial incentives for distributed generation, and the federal Investment Tax Credit applies to fuel cells, CHP, and microturbines for use in the commercial, industrial, utility, and agricultural sectors. Another important incentive is net metering, which allows customers to sell excess generated power to the grid at retail prices. It is important that net metering apply to all distributed generation technologies. Finally, standard interconnection rules are needed to simplify grid interconnections, and it is important that utilities' unusually high electricity rates for distributed generation systems be rethought and modified to reflect actual costs and benefits.

FIGURE 14: Residential Combined Heat and Power Unit



Residential CHP unit (bottom left outside of house) is capable of supplying hot water and heating as well as electricity to several appliances. Home is still grid connected for any consumption unable to be met by the CHP unit and excess power generated by the unit can be sold back to the electric utility.

Source: Fuel Cell Today

TRANSPORTATION SECTOR

Historically, energy use in the transportation sector has been dominated by petroleum (Figure 15). While transportation accounts for about a third of U.S. emissions, only 3 percent of the vehicles on the road are fueled by natural gas and, of these, the majority are buses and trucks. As in other sectors, substitution of natural gas for petroleum in some parts of the transportation sector may yield important climate benefits as natural gas has lower carbon-intensity than petroleum-based fuels (Figure 16). In addition, fuel substitution could benefit U.S. national security by decreasing our reliance on the global oil market, which is vulnerable to supply shocks and geopolitical uncertainty. The potential climate benefits of using more natural gas in the transportation sector, and passenger vehicles in particular, is much more limited than in other sectors of the economy. The limited potential for passenger vehicles is due to the required infrastructure investments, the relatively slow turnover of vehicle fleets, and the more modest reductions in emissions when natural gas is substituted for petroleum (compared to the benefits of substituting natural gas for coal in other sectors). The greatest potential for fuel substitution in the transportation sector is in medium- and heavy-duty trucks, fleet vehicles, and buses, where a small transition to natural gas has already begun.

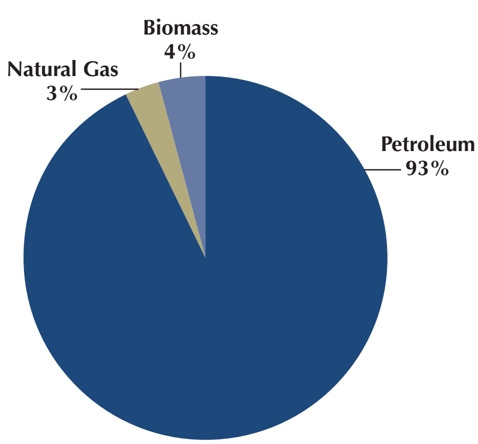
Compressed and Liquefied Natural Gas

The most prominent use of natural gas in vehicles is as compressed natural gas (CNG), most commonly seen in large transportation fleets such as city buses. Some commercial fleets use natural gas-powered trucks, including thousands of trucks at FedEx, United Parcel Service, Waste Management, and AT&T. Liquefied natural gas (LNG) is used primarily as a replacement for diesel fuel in heavy-duty trucks, as they are able to accommodate the hefty storage system required and can use existing fueling infrastructure, currently limited to trucking routes.

Gas-to-Liquids Technologies and Fuel-Cell-Powered Vehicles

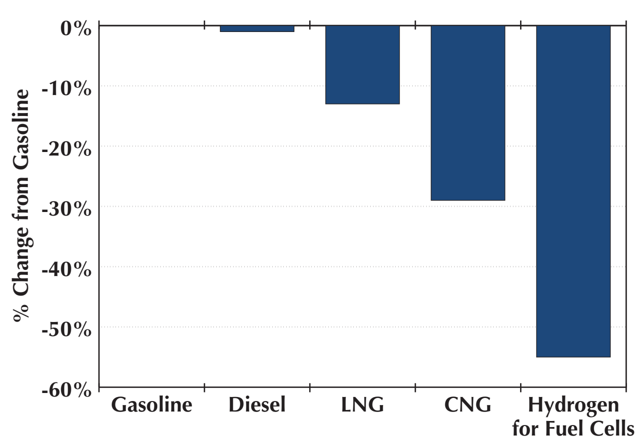
Gas-to-liquids technology is in the early stages of adoption in the United States (though it is used elsewhere in the world). It involves refining natural gas into gasoline or diesel hydrocarbons that can be used in existing vehicles and moved through existing infrastructure. Fuel

FIGURE 15: Energy Sources in the U.S. Transportation Sector, 2010



Source: Energy Information Administration, "Annual Energy Review," Table 2.1e. October 2011. Available at: http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0201e

FIGURE 16: Full Lifecycle, Total Carbon Intensity of Selected Transportation Fuel Options, as a Percentage Reduction from Gasoline

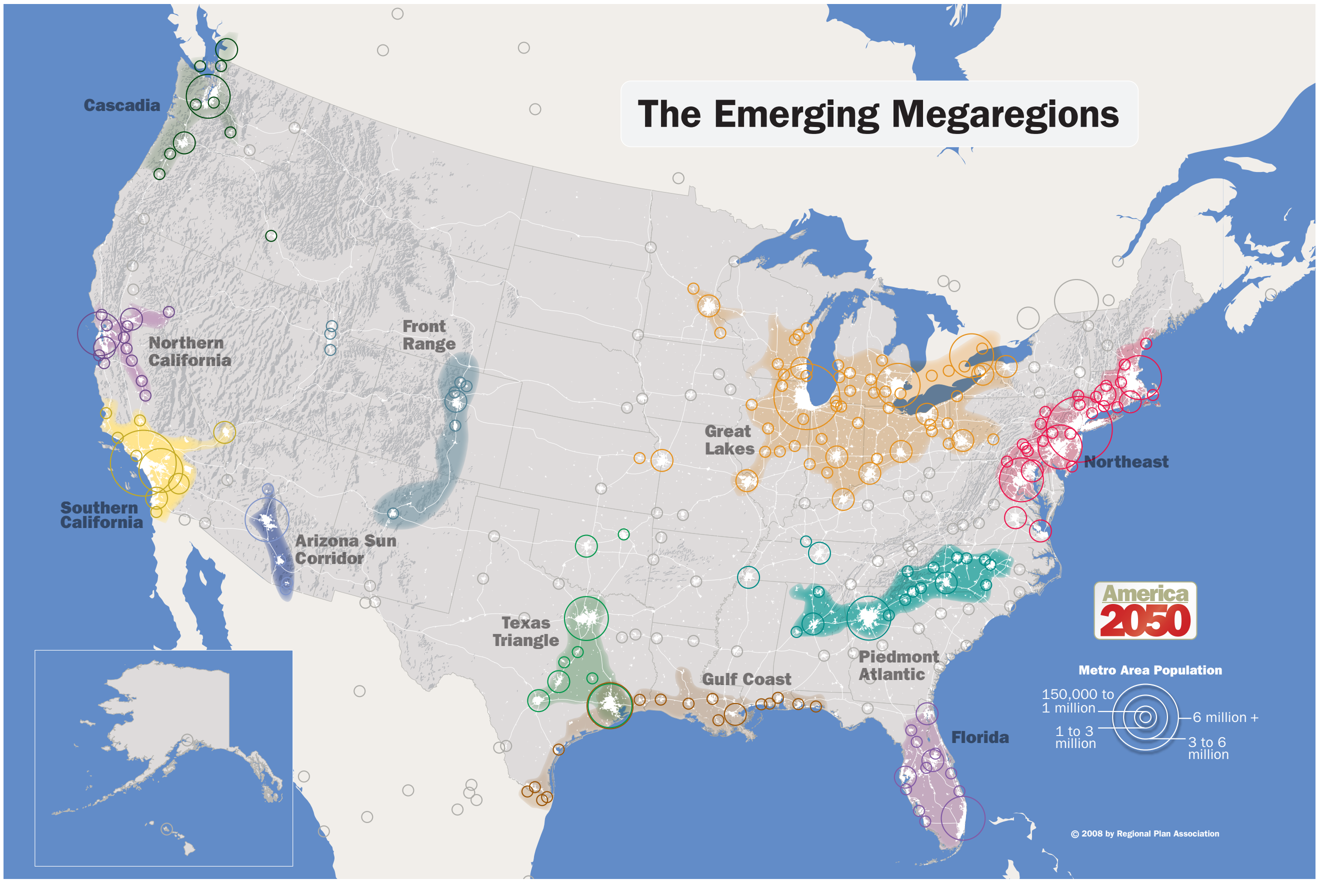


Source: California Air Resources Board, "Proposed Regulation to Implement the Low Carbon Fuel Standard," March 5, 2009. Table ES-8. Available at: http://www.arb.ca.gov/fuels/lcfs/030409lcfs_isor_vol1.pdf

Notes: The carbon intensities compared above were calculated specifically for California's Low Carbon Fuel Standard program using the GREET model.

Results from the GREET model rely on the assumptions included in the model. Other models may use other assumptions and yield different results. Models are useful for insights, but their results depend on the assumptions made.

FIGURE 17: Emerging Megaregions with High Tractor-Trailer Usage



Source: Regional Plan Association, "Maps," 2012 Available at: http://www.america2050.org/maps

cells, another technology, produce electricity through an electrochemical process and release heat, water, and far lower emissions of greenhouse gases and other pollutants than does gasoline combustion. Fuel cells are fueled by hydrogen, and the most common source of hydrogen today is natural gas.

Barriers to the Increased Use of CNG and LNG in Vehicle Fleets

Barriers to the increased use of compressed or liquefied natural gas in large fleets and trucks include shorter ranges, lower resale value, and fewer refueling options. The availability problem for fueling infrastructure is self-reinforcing: Limited availability hinders deployment of vehicles, and the paucity of vehicles hinders the development of more expansive infrastructure.

One strategy for overcoming this chicken-and-egg problem is to focus on carefully designed fleets and fueling infrastructure at the municipal level, taking into account types of vehicles, fleet size, and the shape and distance of routes driven. Another approach is to focus on one subset of the high mileage, heavy-duty tractor-trailer industry segment, namely, intercity transport. In intercity regions with areas of high tractor-trailer usage ("Megaregions"), a very small number of public natural gas refueling stations could serve a large percentage of the heavy-vehicle transportation segment (Figure 17).

INFRASTRUCTURE

The transport infrastructure for natural gas is made up of gathering, transmission, and distribution pipelines, linked together in networks (Figure 18). This infrastructure will need to be expanded in order to support increased natural gas use—with its accompanying climate benefits—across the economy. Such expansion will be regionally specific, and the system will need to be able to quickly adapt to prevent bottlenecks and ensure reliable access.

Components of the Natural Gas System

Gathering pipelines transport natural gas from the wellhead to a processing plant, where impurities and water are removed. Transmission pipelines then transport pressurized natural gas to consumer demand centers, often hundreds of miles away (Figure 19). Compressor stations repressurize the gas every 40 to 100 miles along the way. At points along the pipeline, natural gas can be stored to help ensure supply reliability and to modulate the seasonality of natural gas demand. In towns and cities, local distribution companies lower the pressure, add odorant to the gas, and deliver it to homes and businesses.

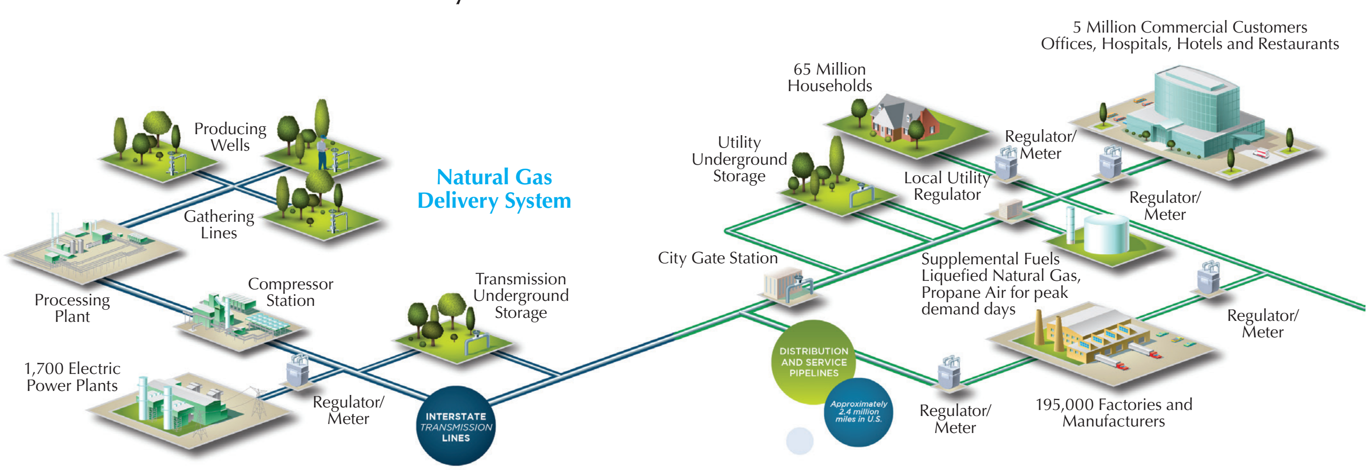
This extensive infrastructure is challenging to maintain. Pipelines are often in remote locations and/or buried underground, and they often cross local, state, and even national boundaries. The responsibility for monitoring and regulating pipelines falls in multiple jurisdictions and many levels of government, which makes maintenance and expansion complicated.

Expansion of Natural Gas Infrastructure

All new supply sources of natural gas will require new infrastructure, and the farther these new sources are from existing transmission pipelines, the more extensive and expensive the new networks will be. New changes in supply and demand are estimated to require that 28,000 to 61,900 miles of new pipelines be constructed in North America by 2030, with a price tag of $108 billion to $163 billion. Additional storage capacity of 371 to 598 billion cubic feet will cost $2 billion to $5 billion.[11] Similarly, local distribution networks will need to be expanded to serve new demand in homes, businesses, and manufacturing facilities, and for vehicle fueling and on-site electricity generation.

The expansion of natural gas infrastructure means more opportunity for the direct release of methane into the atmosphere. As discussed above, methane is a potent greenhouse gas, and its direct release, whether intentional or accidental, may offset some of the climate-related benefits of substituting natural gas for other fossil fuels.

FIGURE 18: U.S. Natural Gas System



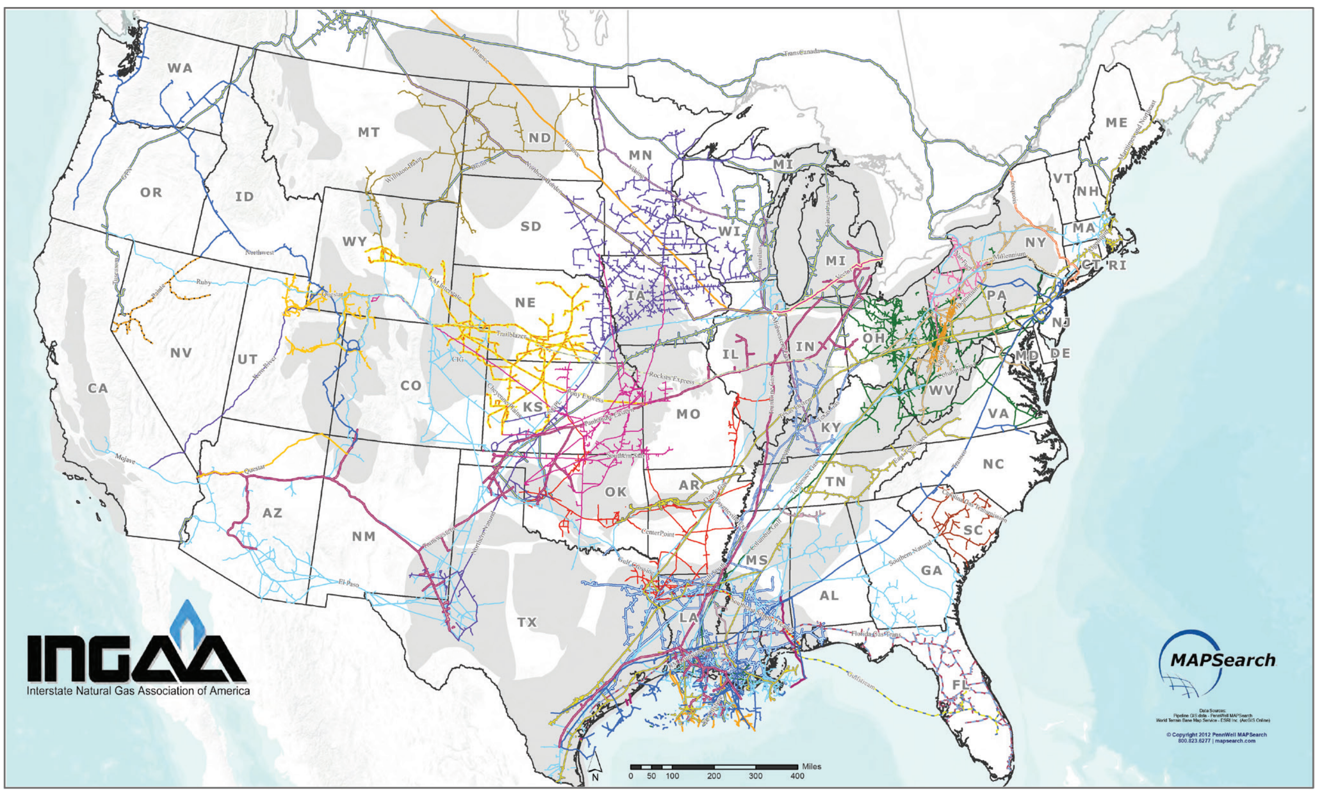
Source: American Gas Association, "About Natural Gas," 2013. Available at: http://www.aga.org/Kc/aboutnaturalgas/Pages/default.aspx

Barriers to Network Expansion and Upgrades

Factors hindering the expansion and upgrading of interstate transmission pipelines and local distribution networks have to do primarily with cost. The owner of a proposed transmission pipeline must fund the construction through equity or debt. For new distribution pipelines in urban areas, challenges include costly repairs of overlaying roads and landscaping, negotiations with holders of surface and subsurface rights-of-way, and public inconveniences. Funding the expansion of local distribution networks typically requires a formal regulatory proceeding (a rate case), and costs can typically be recovered only after the investment is made.

Several state-level regulatory innovations are designed to address these challenges. These include tracker mechanisms that allow rates to change in response to operating costs and conditions, temporary surcharges for partial recovery of program costs, deferred accounting mechanisms, and a rate stabilization method that allows rates to adjust annually for infrastructure replacement and construction. Innovative funding models have also emerged to support the expansion of local distribution networks. Examples include public utilities commissions allowing for dedicated funds for new distribution pipelines, utilities redirecting what would have been ratepayer refunds toward system expansion instead, and states issuing loans or bonds to fund a portion of an expansion project.

FIGURE 19: Interstate Pipelines, 2013



Source: Interstate Natural Gas Association of America and PennWell

CONCLUSIONS

Natural gas plays a role in all sectors of the U.S. economy, constituting 27 percent of total U.S. energy use in 2012. Its prominence is expected to grow as the supply boom unleashed by new drilling technologies continues in coming decades. Expectations of sustained abundance, and correspondingly low and relatively stable natural gas prices are sparking widespread interest in additional ways that this domestic energy resource can replace oil and coal as the major fuel undergirding a growing economy. Indeed, natural gas is projected to displace petroleum as the dominant fuel used in the United States within a few decades.

In these early days of this energy transition, it is imperative to set a course for utilizing this increasingly abundant domestic resource in ways that help meet, rather than aggravate, the challenge of climate change. Substitution of natural gas for other fossil fuels can contribute to U.S. efforts to reduce greenhouse gas emissions in the near- to mid-term, even as the economy grows. At the beginning of 2013, energy sector emissions are at the lowest levels since 1994, in part because of the substitution of natural gas for coal in the power sector. Substitution of natural gas for coal, petroleum, and grid-supplied electricity is underway in other parts of the economy and will bring similar benefits to the climate and air quality. In the buildings sector, for example, a large reduction in emissions is possible through greater direct use of natural gas in an array of more efficient appliances and expanded use of CHP. The manufacturing sector also has a significant opportunity to reduce emissions even as it expands. Manufacturers can increase their consumption of natural gas as feedstock and an energy source, while reducing the emissions intensity of production. Finally, in the transportation sector, natural gas fuel substitution can reduce greenhouse gas emissions when used in fleets and heavy-duty vehicles.

In the long term, however, the United States cannot achieve the reduction in greenhouse gas emissions necessary to address the serious challenge of climate change by relying on fuel substitution to natural gas alone. Low-carbon investment must be dramatically expanded. Zero-emission sources of energy such as wind, nuclear, and solar are critical, as are the use of carbon capture-and-storage technologies at fossil fuel plants and continued improvements in energy efficiency. Given that many renewable energy sources are intermittent, natural gas can serve as a complementary and reliable backup. In addition, because fossil fuels will likely be part of the energy fuel mix for the foreseeable future, carbon capture and storage will need to be deployed. Without a price on carbon emissions, alternative policy support will be needed to ensure optimal investment in zero-carbon energy sources and technologies.

Direct releases of methane into the atmosphere must also be minimized. The primary component of natural gas is methane, which is a very potent greenhouse gas. Total methane emissions from natural gas systems in the United States have improved during the last two decades, declining 13 percent from 1990 to 2011. Nevertheless, given its impact on the climate, especially in the short term, it is important to better understand and more accurately measure the greenhouse gas emissions from natural gas production and use in order to achieve emissions reductions along the entire natural gas value chain.

In the coming years, abundant natural gas will play an increasingly prominent role across all sectors of the U.S. economy. Increased availability of natural gas can yield economic opportunities and lower greenhouse gas emissions. Yet, natural gas is not carbon-free. A future with expanded natural gas use will require diligence to ensure that potential benefits to the climate are achieved.

ENDNOTES

1 Twenty-one is the global warming potential (GWP) used in the calculations associated with the statements involving the CO_2-equivalence of methane emissions. It appears in the Second Assessment Report (1996) of the Intergovernmental Panel on Climate Change (IPCC) and is used by the U.S. Greenhouse Gas Inventory reports prepared by the EPA. Although the IPCC has since updated the GWP for methane (and other non-CO_2 gases), the older value is used to maintain comparability among Inventories.

2 Intergovernmental Panel on Climate Change, "Climate Change 2007: Working Group I: The Physical Science Basis," IPCC Fourth Assessment Report: *Climate Change 2007*, 2007. Available at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html.

3 Bradbury, James, et al., "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems," World Resources Institute, 2013. Available at http://www.wri.org/publication/clearing-the-air.

4 Bradbury, James, et al., "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems," World Resources Institute, 2013. Available at http://www.wri.org/publication/clearing-the-air.

5 Alvarez, Ramon, et al., "Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure," *Proceedings of the National Academies of Science*, February 2012. Available at http://www.pnas.org/content/109/17/6435.

6 Pétron, Gabrielle, et al., "Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study," *Journal of Geophysical Research*, February 2012. Available at http://www.agu.org/pubs/crossref/pip/2011JD016360.shtml.

7 Energy Information Administration, "Annual Energy Outlook," April 15, 2013, Table 9. Available at http://www.eia.gov/forecasts/aeo/data.cfm#summary.

8 Gas Technology Institute, "Source Energy and Emission Factors for Building Energy Consumption 2009," Technical Report, Natural Gas Codes and Standards Research Consortium, American Gas Foundation. Available at http://www.aga.org/SiteCollectionDocuments/KnowledgeCenter/OpsEng/CodesStandards/0008ENERGYEMISSIONFACTORSRESCONSUMPTION.pdf.

9 Energy Information Administration, "Early-release estimates from the 2010 MECS show that energy consumption in the manufacturing sector decreased between 2006 and 2010," March 28, 2012. Available at http://www.eia.gov/consumption/reports/early_estimates.cfm.

10 MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary MIT Study*, June 2011, p. 105. Available at http://web.mit.edu/mitei/research/studies/natural-gas-2011.shtml.

11 ICF International for the Interstate Natural Gas Association of America Foundation, "Natural Gas Pipeline and Storage Infrastructure Projections Through 2030," October 2009. Available at http://www.ingaa.org/File.aspx?id=10509.

This report provides an overview of natural gas production, the climate implications of expanded natural gas use, potential uses and benefits in key sectors, and related infrastructure issues.

The Center for Climate and Energy Solutions (C2ES) is an independent non-profit, non-partisan organization promoting strong policy and action to address the twin challenges of energy and climate change. Launched in 2011, C2ES is the successor to the Pew Center on Global Climate Change.

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

2101 Wilson Blvd., Suite 550
Arlington, VA 22201
P: 703-516-4146
F: 703-516-9551

WWW.C2ES.ORG