American Gas FOUNDATION

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OPPORTUNITIES FOR REDUCING GREENHOUSE GAS EMISSIONS THROUGH EMERGING NATURAL GAS DIRECT-USE TECHNOLOGIES

Executive Summary

An American Gas Foundation Study Prepared by:

Enovation Partners

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Founded in 2013 by energy practice leaders from top management consulting firms. Enovation Partners was created to bring innovative thinking and analytics to an increasingly complex energy and infrastructure sector, and to deliver exceptional results. In August 2019, Enovation's consulting team joined Roland Berger, a leading global strategy consultancy, and now serves an expanded base of clients in the US and internationally to help accelerate the energy transition.

Executive Summary

A. Key Take-Aways

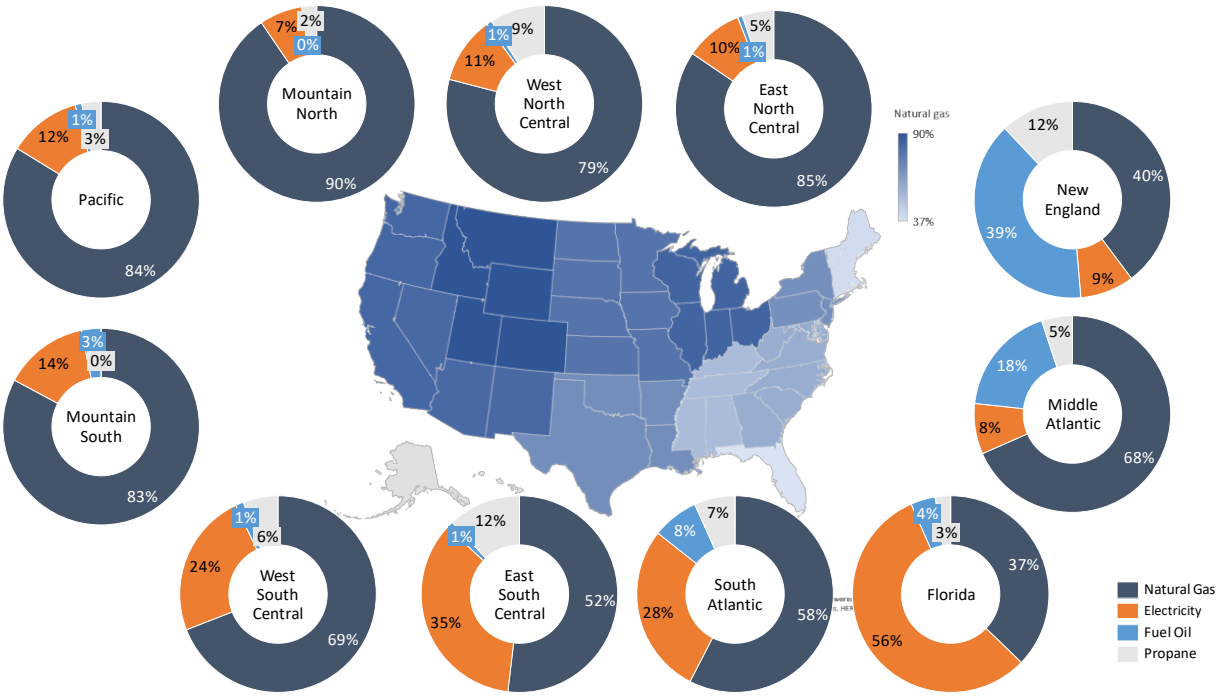
This study demonstrates how widespread adoption of emerging natural gas direct-use technologies can contribute significantly to achieving public goals of deep reductions in greenhouse gas (GHG) emissions in the U.S. residential sector, with much lower costs than other options under consideration. It's low hanging fruit that should be a core element considered for any responsible emissions reduction plan.

- U.S. residential natural gas emissions can be reduced by 24 percent through the advancement of more efficient emerging technologies, with average net savings (negative costs) of $51 per metric ton of CO_2 equivalent ("ton" or "MT" as used in this report). With higher levels of incentive support for emerging technologies, GHG emissions can be reduced by 40 percent, at the modest average cost of $66 per ton.
- No technological miracles are required. The natural gas direct-use technologies modeled in this study are either available now or are expected to roll out to market within three years.
- No policy mandates were assumed, e.g., bans of specific technologies or required levels of GHG emission reductions. The savings can be achieved by offering cost-effective incentives and allowing customers to make choices. Customers can consider the superior resiliency and comfort of highly efficient natural gas equipment in their buying decisions. Incentives can be removed once the gas technologies have achieved economic scale and equipment costs are competitive on their own.
- Higher direct-use efficiencies on the demand side can be complemented by increased use of carbon-neutral biogas and hydrogen (collectively "renewable gas") on the supply side, plus continued reductions in methane emissions along the gas delivery chain, to produce very deep cuts to residential GHG emissions from natural gas usage
- In the long-term world of deep decarbonization, direct use of natural gas and renewable gas can serve more intense energy uses more efficiently and effectively than all-electric solutions, which may be technically feasible but are much costlier and can require vast amounts of new infrastructure.
- There is no "one size fits all" solution to reducing GHG emissions. This study demonstrates how natural gas can be a core component of an integrated approach for achieving U.S. emissions reduction goals while providing options that allow gas utilities and their customers to choose what works best in their circumstances (resource base, types of energy demands, demographic mix).

B. Role of Natural Gas in Meeting Residential Energy Needs

Natural gas contributes more to meeting energy needs than many people realize. Maybe that's because furnaces, heat pumps and water heaters are out of sight and out of mind, just doing their job. Nonetheless, 58 percent of U.S. homes have natural gas service. Natural gas currently meets 68 percent of total U.S. residential space and water heating demands. That market share varies widely by region, as shown in Figure 1. Natural gas delivers more than 83 percent of annual heating energy to households in the East North Central, West North Central, Mountain North, Mountain South and Pacific regions. Replacing all that gas energy with electricity would require vast investments to increase production and delivery capacity. Meanwhile, the gas infrastructure to meet those demands is already in place. It can be a very valuable set of assets for delivering clean energy.

Figure 1 Natural Gas Share of Total Residential Energy Consumption for Space and Water Heating in 2018[1]



This report focuses on space heating, water heating and clothes drying in the residential sector. Space and water heating together account for 91 percent of residential gas consumption. Clothes drying amounts to less than 1 percent of gas use but has some impactful emerging technology. Cooking adds another 3 percent but has no major energy efficiency technologies for the residential market. The remaining demand is attributable to hot tubs, fireplaces, patio warmers and a variety of smaller volume uses. Due to their lower level of materiality, the GHG emissions reduction potential in these smaller direct uses was not assessed.

While emerging natural gas direct-use technologies offer step function gains in efficiency, natural gas direct-use efficiency has continued to improve in recent years. Innovations such as efficient burner

[1] Sourced from EIA.

designs and heat recapture technologies have successfully penetrated the market and delivered energy and emissions savings. Improvements in complementary technologies that reduce energy demands (tighter building envelopes, better insulation, smarter controls etc.) have also cut into residential gas consumption. Figure 2 shows the declining trend in natural gas consumption per household, with the trend in total residential natural gas consumption falling slowly while gas customer count grows robustly.

Figure 2 Trends in Total U.S. Residential Weather Normalized Natural Gas Consumption vs. Gas Customer Count (Source: American Gas Association)

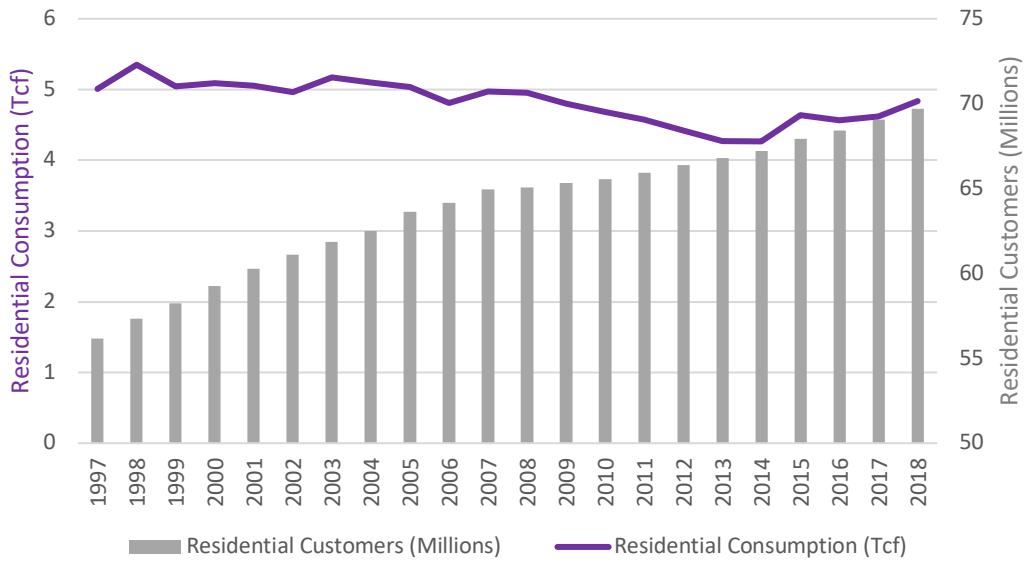
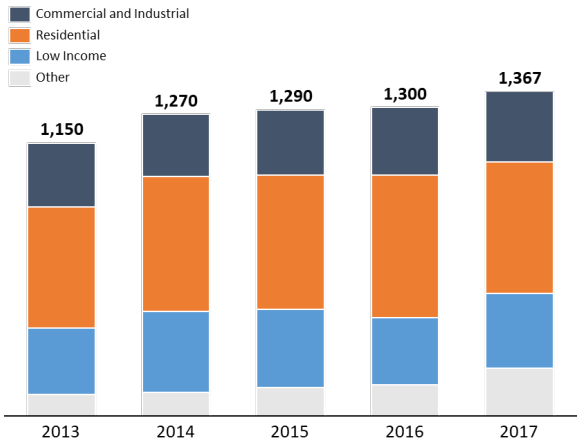


Figure 3 Natural Gas Utility Investments in Energy Efficiency Programs (Millions)[2]



The historical penetration of more efficient heating and water heating technologies was accelerated by the efforts of natural gas utilities. Their investments in energy efficiency programs, which typically take the form of incentive payments to customers who buy more efficient equipment and other forms of energy efficiency support, has grown steadily over the years (See Figure 3). Given the ambitious GHG emission reduction targets that have been adopted in many states, and the relatively low cost of achieving such reductions through more rapid adoption of more efficient direct-use technologies, that upward trend for natural gas utility spending on energy efficiency programs is expected to continue.

[2] Consortium for Energy Efficiency. State of the Efficiency Program Industry: Budgets, Expenditures, and Impacts 2018. http://www.cee1.org/annual-industry-reports, posted May 2019.

C. Innovation in Natural Gas Direct-Use Technologies

The pace of innovation in more efficient natural gas direct-use technologies has been accelerating in recent years. A predecessor study to this study, conducted for the American Gas Association in 2018, identified more than 120 different technology innovations that could significantly improve gas end use efficiency. These technologies are in various places along the research, development and demonstration spectrum. Some are still in the laboratory or early development. Some are in demonstration and almost ready for market. Some are ready for market but not yet penetrated.

These emerging natural gas direct-use technologies are quite diverse, as shown in list of identified technologies in the Appendix of the 2018 report.[3] Research facilities operated by several prominent gas industry players and universities or government agencies[4] will play important roles in developing, testing and commercializing these technologies.

The 2018 study concluded that, on a per customer basis, energy savings from deploying the most promising natural gas emerging technologies could reduce household natural gas consumption and GHG emissions by 20-45 percent, depending on the technology. That conclusion is broadly consistent with the findings below from this study.

D. Study objectives: Assessing Opportunities for Achieving Meaningful and Cost-Effective Emissions Reductions through Emerging Natural Gas Technologies

The intent of this American Gas Foundation report is to:

- provide factual information on how faster penetration of more efficient emerging natural gas direct-use technologies could contribute to meeting emissions reduction goals; and to
- compare the volume, timing and cost of such GHG emission reductions to other potential pathways.[5]

The following key questions are addressed in this study:

- How much could U.S. CO_2 emissions be reduced with current and emerging residential direct-use gas technologies by 2050?
- What is the expected unit cost of achieving these reductions?
- What savings or costs would customers see?
- What type and level of financial support would be needed to realize the full benefits of these technologies?

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[3] See pages 28-30 of the 2018 report. https://www.aga.org/globalassets/research--insights/reports/ghg-reduction-pathways_phase-1-report.pdf

[4] For example, Gas Technology Institute, Research and Innovation Center for Energy (owned by Engie), Gas and Heat Institute (Germany), Osaka Gas, Tokyo Gas, Korea Gas, University of California – Irvine, European Research Institute for Gas & Technology Innovation, National Renewable Energy Laboratory, to name a few.

[5] "Pathway" as used in this report is a combination of energy sources and technologies that over time can meet defined goals for reducing GHG emissions.

E. Analytical approach

The study modeled two scenarios with moderate and high levels of penetration of emerging natural gas direct-use technologies for space heating, water heating and clothes drying applications. Within the overall residential sector, natural gas use is mainly concentrated within two end-uses: space heating and water heating. These two end-uses are responsible for 91 percent of all residential sector natural gas consumption. Clothes drying end-use is responsible for less than percent and was also analyzed in both scenarios. The levels of penetration in each scenario were determined by the level of incentives introduced to accelerate the penetration of these technologies and summarized in the Table 1 below.

Table 1 Technology Penetration Levels Achieved by 2050 in Each End-Use[6] (percent of total units installed)

End-Use	Moderate Penetration scenario	High Penetration scenario
Space heating	74% (furnace) 10% (heat pump)	75% (heat pump)
Water heating	64%	92%
Clothes drying	22%	69%

The study results shown in the Introduction section below are attributable to the deployment of emerging natural gas direct-use technologies that are projected to be commercially available before 2023 (listed in the figure below). These technologies were selected from a long list of considered technologies forecasted to be commercially available before 2030. Even greater emissions reductions could be realized through even higher efficiency technologies commercially available after 2030. A high potential of emission reductions also exists in the commercial sector based on our review of the emerging technologies. However, only residential emissions are considered in this study. Overall results in both scenarios are highly sensitive to the levels of incentives provided, first costs and technology cost reduction over time. Additional details on scenario specific assumptions are further discussed in Section 4.2 of the report.

Table 2 Emerging High-Efficiency Natural Gas-Fired Technologies Selected for the Study[7]

End-Use	Moderate Penetration scenario	High Penetration scenario
Space heating	Natural gas furnace (AFUE 97%) Gas absorption heat pump (AFUE 1.4)	Gas absorption heat pump (AFUE 1.4)
Water heating	Gas heat pump water heater (1.3 UEF)	Gas heat pump water heater (1.3 UEF)
Clothes drying	Standard Energy Star certified dryer (CEF 3.49)	Standard Energy Star certified dryer (CEF 3.49)

[6] In addition to equipment turnover forecasted in the Baseline
[7] See additional discussion on technologies considered and selected for the study in Appendix E and F

G. Study conclusions: Less costly, quicker, deeper emission reductions

Less costly. This report concludes that advancing the penetration of emerging natural gas direct-use technologies for major end uses is a more cost-effective way to reduce GHG emissions in the residential sector than other options currently being considered by states and cities. The pathway including natural gas emerging technologies has a much higher volume of accessible low-cost options for GHG emissions reduction.

Quicker. Because these emission reductions can be delivered by equipment in the market now or within three years, and would not require expensive and very time-consuming rebuilding of electric generation, transmission and distribution infrastructure (as would be the case for electrification solutions), they could be achieved earlier than with other options and could, over time, avoid higher cumulative amounts of emissions.

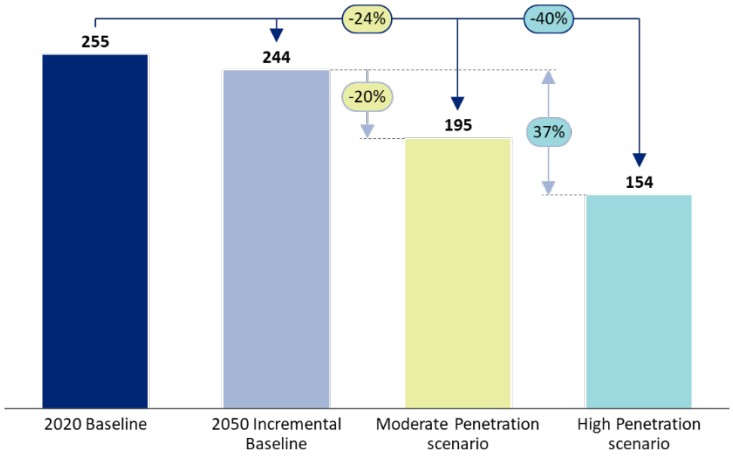
Deeper. A third advantage is that the GHG emissions reductions from emerging natural gas direct-use technologies could be deeper in the near term and medium term (through 2035-2040) in regions where substantial portions of electricity supplies will continue to come from coal or natural gas fired generation. Emissions reductions from reduced natural gas use will all count directly toward emissions reduction goals, while electrification solutions may actually increase GHG emissions in places where the grid has a high carbon footprint that reflects fuel mix and large thermodynamic losses of energy in converting fuel to electricity.

In the longer term, higher natural gas direct-use efficiencies on the demand side can be complemented by increased use of carbon-neutral renewable natural gas and hydrogen on the supply side, plus continued reductions in methane emissions along the gas delivery chain. This natural gas pathway could provide meaningful and cost-effective contributions towards reducing U.S. GHG emissions.

F. Key Findings

Under the High Penetration scenario, the residential sector could reduce overall annual CO_2 emissions by 101 million metric tons/year (MMT/year) by 2050 relative to the 2020 Baseline representing a 40 percent reduction in total residential natural gas emissions. With the Moderate Penetration scenario, 60 MMT of CO_2 or a 24 percent reduction in residential emissions could be reduced relative to the 2020 baseline. The reductions in residential emissions for the two scenarios relative to the Baseline emissions in 2020 and 2050 are shown in Figure 4.

Figure 4 CO_2 Emissions from Residential Natural Gas Use[8] (MMT of CO_2 per year)



In the High Penetration scenario, the 101 MMT of annual CO_2 reductions are achieved at a net cost of $66 per MT of CO_2 reduced. Under the Moderate Penetration scenario, 60 MMT of annual CO_2 reductions are achieved at a net *savings* of $51 per MT of CO_2 reduced. Under either scenario, the CO_2 reductions are significant on a national scale, and at costs per ton that are low relative to other potential options for reducing emissions such as electrification at $572-806 per MT and atmospheric removal of CO_2 at $94-232 per MT[9].

These levels of CO_2 emission reductions are achieved despite the overall increase in number of equipment units in each end-use analyzed. For example, in space heating the total number of equipment units increases by 36 percent from 2020 to 2050, in water heating by 35 percent, and in clothes drying by 53 percent.

From the consumer perspective, the High Penetration scenario achieves considerable savings. Nationally, for an average consumer in 2033 that installs the high-efficiency technology for space heating, water heating, and clothes drying could expect to save $271 each year over the lifetime of the equipment (levelized savings in 2020$).

[8] Emission reduction in High Penetration scenario includes reductions from complementary technologies (e.g. insulation, smart thermostats) in the amount of ~4 MMT of CO_2 per year

[9] Cost estimates are from *Implications of Policy-Driven Residential Electrification, AGA, 2018* study. While the cost estimates are not fully "apples-to-apples" comparison as the scope boundary of the referenced study is different from this report, it nevertheless serves as an important comparison point.

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