

What is the Role of Fuels in a Decarbonized Future? What is the Potential Role for Gas Utilities?

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ABSTRACT

To meet long-term climate goals, the world and the United States will need to eliminate net greenhouse gas emissions, including in the buildings, industrial, and transportation sectors. Electrification will play a large role, but some applications will be difficult to electrify. The end-uses needing the most attention to develop carbon-free fuels are long-distance airplanes, high-temperature industrial processes, ships, trucks, and trains. Residential and commercial buildings will also need some decarbonized fuels, particularly in cold climates. Fuels that are largely decarbonized, such as biofuels, hydrogen, and synthetic natural gas, are available in limited or pilot quantities today, but availability is scaling up. Prices for these alternatives are high now but will generally decline over time. Even with these declines, decarbonized fuels are likely to be about three times more expensive at the wholesale level than natural gas is today. These high prices will improve energy efficiency economics. Energy efficiency can reduce the amount of fuel and electricity needed and is a key part of fuel decarbonization strategies. Decarbonization will have profound effects on local gas utility business models. Gas utilities will need to modify their business models, serving remaining markets while potentially entering complementary markets.

Introduction

To meet long-term climate goals, the world and the United States will need to eliminate net greenhouse gas emissions, including in the buildings, industrial, and transportation sectors. Electrification will play a large role, but some applications will be difficult to electrify, such as high-temperature industrial heat, space heating in cold regions during cold waves, and long-distance trucks, planes, ships, and trains. These end-uses can potentially be served by decarbonized fuels such as hydrogen and biogas. This paper reviews these hard-to-electrify sectors, the availability and economics of decarbonized fuels to serve these uses, and the role of energy efficiency to help address logistical and economic challenges. We conclude with a discussion on how the need to decarbonize will affect natural gas utilities and what potential roles they can play in providing fuels and services to these markets.

Decarbonized Fuels

There are several fuels that have zero or near-zero net carbon emissions. In the United States, the most widely used fuel for buildings is natural gas. Low-carbon alternatives include biogas (sometimes called renewable natural gas if it is cleaned to be similar in composition to natural gas) and hydrogen. Biogas is approximately carbon neutral. Biogas from landfills and waste digesters can reduce emissions because the combustion products are a less-potent greenhouse gas than the methane that is emitted from these sources. And for biogas derived from plants, carbon is removed from the atmosphere as plants grow, approximately offsetting emissions from fuel production and combustion. Hydrogen is often produced from natural gas

but can also be produced via electrolysis using carbon-free electricity such as from renewable energy. Hydrogen produced from natural gas is not carbon free (sometimes called “gray” hydrogen), but hydrogen produced from renewable energy is carbon free (often called “green” hydrogen). Green hydrogen can also be converted to other fuels such as synthetic natural gas (chemically similar to natural gas so it can be used in pipes and burners designed for natural gas) and ammonia.

There are also decarbonized alternatives to liquid fuels. Some cars and trucks operate on biodiesel, which is made from vegetable oils. Many buildings are heated with #2 oil, which is nearly identical to diesel fuel. With proper cleaning (e.g., to remove glycerin), biodiesel can be used in oil burners, although at concentrations above about 50% biodiesel, adjustments to burners are needed to maximize efficiency (Spencer 2021). Some buildings are heated with propane, which is shipped in liquid form as LPG. The Gas Technology Institute (GTI) and others are working on several possible paths to renewable LPG (Littlewood et al. 2021). There are also alcohols made from plants (ethanol and methanol) and synthetic fuels that are made from hydrogen and recaptured carbon dioxide. We discuss the availability and cost of these largely decarbonized fuels below.

Hard-to-Electrify Energy End-Uses

Electricity can provide energy for most U.S. applications by the 2040s, but it will likely not be able to meet all needs in certain sectors, such as for high-temperature industrial processes and long-distance airplanes. In this section we estimate the need for alternate fuel sources for seven applications. We find a need for about 9 quadrillion Btus (quads) of fuels in 2040 across these seven applications, which is less than 10% of total current U.S. energy use. Our analysis of fuel needs is based on projected U.S. energy use in 2040 in the Reference Case of the U.S. Energy Information Administration’s (EIA’s) *2022 Annual Energy Outlook*. In the sections below, we discuss fuel needs for each of the seven applications, listed in order from highest to lowest fuel need. We also discuss energy efficiency opportunities and potential decarbonized fuels for each of these applications. Our estimates are highly approximate; they are illustrated in figure 1 and detailed in Table 1 at the end of this section. These estimates assume widespread electrification where electrification is technically possible. We briefly discuss the economics of some of these applications below.

Airplanes

Air travel is a major energy use and is projected to continue growing. Electric planes are in development and will perhaps be able to make trips up to about 500 miles. Beyond that, the weight of the batteries substantially restricts the size of loads, although electric motors can continue to be used as part of hybrid electric/fuel aircraft (Bowler 2019). Data from the Bureau of Transportation Statistics (2022) indicate that in the first 10 months of 2021, 87.5% of U.S. flight miles were on flights of more than 500 miles.

These longer flights will require about 3.2 quads of energy in 2040 in the EIA reference case. More-efficient engines and airframes, operational improvements, and changes in travel can reduce this further; Greene and Plotkin (2011) estimate 32% potential savings by 2035. In the longer run, remaining energy could perhaps come from hydrogen. For example, Airbus (2022) is developing several hydrogen-fueled planes. In the nearer term, biofuels and synthetic fuels might be used.

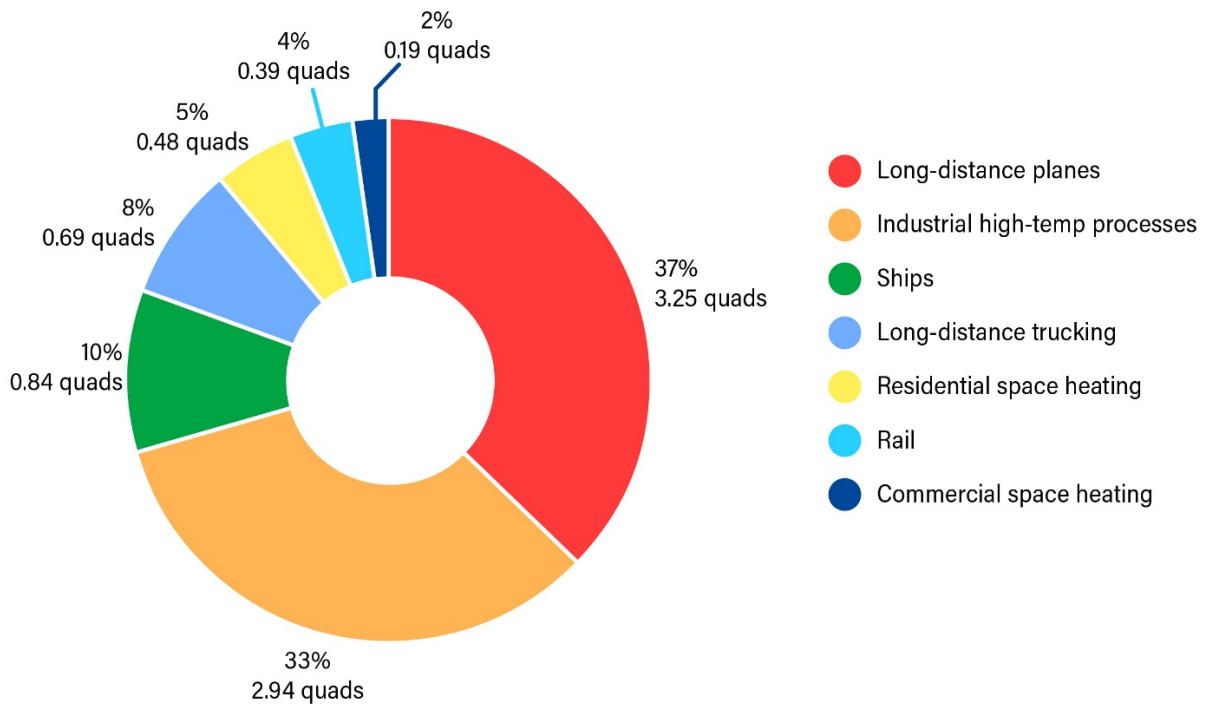


Figure 1. Distribution of fuel needed in a fully electrified U.S. economy based on projected 2040 energy consumption. Source: ACEEE analysis with details in table 1.

Industrial Processes

Industry uses heat for melting, drying, and aiding chemical transformations. Heat pumps can provide much of this heat, but they cannot handle applications that require particularly high temperatures. Zuhldorf et al. (2019) find that industrial heat pumps might be able to serve processes needing temperatures as high as 280° C (526 F); McMillan et al. (2021) estimate that about 30% of industrial heating needs exceed this temperature.

These higher temperature loads will require about 2.9 quads in 2040 in the EIA reference case. This fuel need can be reduced by implementing efficiency measures ranging from reducing steam leaks, to improved industrial processes that use no or less high-temperature steam (e.g., infrared heating, ultraviolet curing), to changing to products that need less heat (e.g., substituting engineered lumber for steel where possible).

Industry is often located in clusters; in many cases, the fuel needed can be provided by hydrogen from regional hydrogen networks. Such a network now exists in Louisiana and eastern Texas, and expansion has been proposed for Houston (KPMG 2021). The recent federal infrastructure bill provides co-funding for seven “hydrogen hubs” across the United States (DOE 2022). However, hydrogen is presently produced mostly from natural gas. In the long term, to decarbonize, this hydrogen production will largely need to be converted to electrolysis using carbon-free electricity.

This discussion covers only fuels that are burned and does not include hydrocarbons that are used as raw materials to produce such goods as plastics and many chemicals, because in these other applications, the carbon is commonly incorporated into products and not released into the air.

Ships

Ships often travel long distances. While electricity can be used for short trips (e.g., an electric container ship is now operating in Norway), as with planes, the weight of batteries impinges on the amount of cargo that can be carried. Smil (2019) discusses some of the issues involved. We estimate that decarbonized fuels might be needed for as much as 90% of shipping, which would require about 0.8 quads of energy in 2040 for U.S. domestic shipping plus decarbonized fuel provided in U.S. ports for international shipping. Again, efficiency can be improved; the International Maritime Organization now requires that new ships be designed to meet Energy Efficiency Design Index requirements, which look at both energy use and carbon emissions (Marine Insight 2019). Shell and Deloitte (2020) discuss an array of efficiency opportunities, including hull streamlining, propulsion design, improved lubricants, speed optimization, weather-routing, just-in-time arrivals, pooling demand, wind technology, and port optimization. To supply the energy needed to move these more-efficient ships, alternative fuels are being explored, including biodiesel, ethanol, methanol, hydrogen, ammonia, and synthetic fuels (EAFO 2019). Shell and Deloitte (2020) think green hydrogen and green ammonia (typically made from green hydrogen) have higher applicability than the other options. Hy2gen has announced two projects to produce green ammonia for use as a shipping fuel, one in Quebec, and one in Norway. Both will use hydroelectric power to produce hydrogen via electrolysis and then convert it to ammonia (Atchison 2022).

Long-Distance Trucks

Electric trucks can serve most trucking needs. The exception is for long-distance runs of more than about 500 miles. Beyond about 500 miles, the cost and weight of additional batteries will generally make fuel cell trucks a better option (Nadel and Huether 2021). Electric trucks and buses are already available for purchase; tractor-trailers that can go long distances on a single charge are scheduled for sale in 2022 and 2023 (including one with a 500-mile range). To maximize range, they include a variety of efficiency improvements. Operational improvements, such as those enabled by information and communication technologies, can improve efficiency further (Mersky 2021). Fuel cell trucks using hydrogen are also being developed (Nadel and Huether 2021). Census data indicate that about 13% of heavy-truck miles are in trips of 500 miles or more (Davis and Boundy 2021). If these trips use hydrogen or other decarbonized fuels, about 0.7 quads of fuel will be needed in 2040.

Buildings on Very Cold Days

Previous research has found that cold-climate heat pumps can supply heat in very cold weather (down to about 5°F [-15°C] and sometimes lower) (Nadel 2018). New highly efficient homes can function with minimal back-up electric resistance heat. For example, Efficiency Vermont has worked on projects that function down to -25°F (-32° C) with only a small electric heating coil (Efficiency Vermont undated).

However, it is difficult to make an existing house (building shell) that efficient. Field studies by the Center for Energy and the Environment found that in metro Minneapolis, cold-climate heat pumps can reduce winter energy use by 65% on average, with the remaining energy coming from a backup gas furnace (Schoenbauer 2017). A subsequent field study on a new well-insulated home found the heat pump provided 98% of the heat, with the electric resistance

backup providing 2% of the heat needed during the study period (Schoenbauer 2018). For less-efficient older houses, while backup electric resistance heat could be used, in cold climates this would often require extensive, expensive grid upgrades; backup fuel-based heating may be a better option.

EIA's Residential Energy Consumption Survey (EIA 2018) estimates that 60% of U.S. residential heating is in cold climates (shown in figure 2). If we assume that existing homes in cold climates need some type of fuel backup, accounting for 20% of their heating demand (allowing for the fact that Minnesota is colder than the cold climate average), 0.5 quads of fuels will be needed for residential heating. While some homes may need fuels for cooking and other end-uses, energy efficiency home upgrades can substantially reduce the amount of fuel needed for space heating.

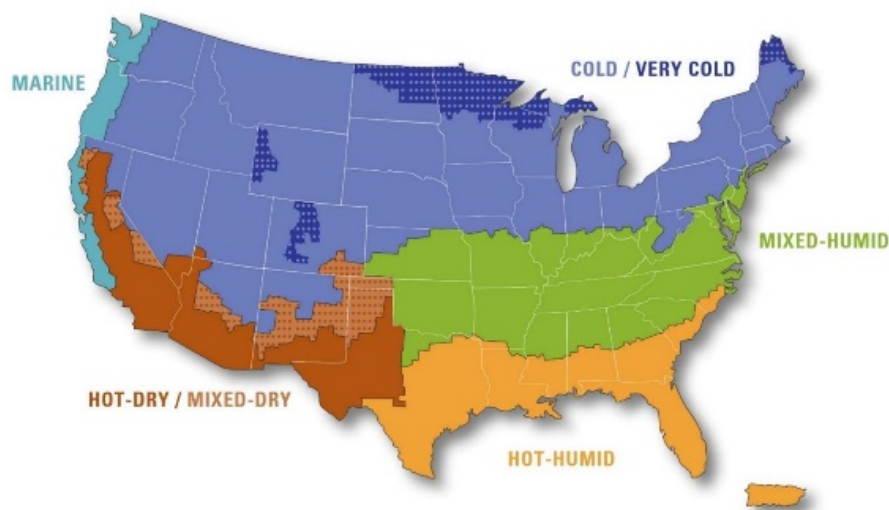


Figure 2. Climate regions. Source: DOE (undated).

To serve these fuel needs, what the gas industry calls renewable natural gas (RNG — biofuel that has been refined to be similar to natural gas) is perhaps the most likely solution, but supplies are limited (as discussed below). Hydrogen and synthetic natural gas made from hydrogen are other options. In dense areas such as cities, these fuels can often be provided via gas distribution networks, either existing networks or new networks for hydrogen (because hydrogen can corrode some current pipes and current networks are sometimes too leaky to accommodate hydrogen). This fuel would be used only on the coldest days of the year, and therefore more analysis is needed on the economics of maintaining gas distribution networks for use only on cold days. In areas where maintaining distribution networks is not feasible, bottled compressed RNG, bioLPG, or biodiesel might be used. Because the fuel will not be used often, tanks might require only annual refills.¹

¹ Many natural gas utilities are promoting use of gas-fired heat pumps, which at a typical efficiency of about 140%, reduce fuel use by about one-third relative to a 95% efficient furnace ($[(140\%-95\%)/140\%]$). These would decrease decarbonized fuel use relative to our calculations if used just to back up electric heat pumps but would increase decarbonized fuel use relative to a scenario where most homes use electric heat pumps as their primary source of heat.

Similarly, in the commercial sector, several projects using large-scale heat pumps illustrate the usefulness of a fuel backup for cold days. St. John (2022a), discussing very large buildings in New York City, quotes experts who estimate that with current technologies, fuel will be needed for about 20% of energy use. A recent ACEEE study on electrifying commercial buildings notes several examples of projects where heat pumps supply about 90% of heat, with the remainder from gas (Nadel and Perry 2020). These buildings are not as large nor as land-area constrained as New York City. If we assume this 10% applies on average to U.S. commercial space heating (plus some other uses, minus efficiency savings), about 0.2 quads of fuel will be needed. This fuel will be supplied in ways similar to those used in the residential sector, but larger commercial buildings are more likely to use piped gas.²

Railroads

Some U.S. railroads are electrified, most are not. Blaze as cited in Marsh (2021) estimates that 15-30% of U.S. rail lines can be electrified cost effectively. If we take the midpoint of this range and apply it to railroad energy use in the EIA reference case, we will need about 0.4 quads of fuel. Greene and Plotkin (2011) discuss a variety of ways to reduce train energy use, including more-efficient engines, hybrid engines (similar to a hybrid car), regenerative braking, lighter railcars, and improved operations and maintenance. Decarbonized fuel to serve remaining loads might include hydrogen and, for short and medium distances, batteries. Hydrogen-fueled trains have been demonstrated in Europe (Patel 2021) and General Motors and Wabtec Locomotives

Table 1. Calculations of Annual Fuel Needed

Item	Annual Energy Use (quads)	% Needing Fuels	Explanation	Annual Fuel Needed (quads)	% of Total	Notes
Long-distance planes	3.7	87.5%	Over 500 miles	3.25	37%	% over 500 miles from Bureau of Transportation Statistics 2022.
Industrial high-temp processes	9.8	30%	Temperatures over 280 C	2.94	33%	280 C from Zuhldorf et al. 2019. McMillan et al. 2021 find 27% of process heat needs at 300 C and up so we estimate 30% at 280 C.
Ships	0.9	90%	Rough guess	0.84	10%	Short-distance shipping can be electrified but most cannot -- see Smil 2019
Long-distance trucking	5.3	13%	Over 500 miles	0.69	8%	13% for classes 7 & 8 from Census as cited in Nadel and Huether 2021. This does not include small additional use for classes 3-6 but this is likely to be offset by the fact that regional hauls are increasing and long-distance hauls as a percent of the total are declining.
Residential space heating	3.9	12%	Cold climate per RECS * 20%	0.48	5%	Per RECS, 60% of gas, oil and propane heating energy use in areas designated "cold climate." (EIA 2018). In Metro Minneapolis on average cold climate heat pumps reduced winter energy use 65% (Shoenbauer 2017), we raise to 80% as Minneapolis is colder than average for the cold climate area
Rail	0.5	78%	Midpoint of 15-30% range estimated by Blaze and cited in Marsh 2021	0.39	4%	
Commercial space heating	1.9	10%	Per case studies in Nadel & Perry 2020	0.19	2%	
Total				8.79	100%	

Note: Annual energy use is for 2040 from EIA 2022.

² As with residential heating, use of gas heat pumps would change our numbers (see footnote 1).

recently announced a fuel cell engine partnership (Wayland 2021). BNSF and Wabtec have recently piloted a long-haul battery-electric locomotive (Trains 2021).

Economics of Decarbonized Fuels

While there is great uncertainty, most estimates indicate that the price of decarbonized fuels will be substantially higher than the price of fossil natural gas today. Projections are that renewable natural gas, green hydrogen and synthetic natural gas will be much more expensive than fossil gas, as shown in table 2. Biogas is projected to be about 6-8 times more expensive, green hydrogen 7–13 times more expensive and synthetic natural gas 8–16 times more expensive. For the latter two, price is expected to decline over time to the low ends of the ranges. As of this writing (June 2022), wholesale natural gas is nearly \$8 per million Btus, but even if this price proves to be the average for the next two decades, and further assuming that higher natural gas prices do not affect hydrogen prices, then green hydrogen and synthetic natural gas in 2040 will still cost about 2.7-3.4 times more than natural gas.

This higher fuel price will affect the relative economics of electric heat pumps versus natural gas; it will also improve energy efficiency economics. For example, analysis by Nadel and Fidali (2022) on a nationally representative sample of more than 3,000 homes now using gas, oil, or propane heat finds that electric heat pumps will have the lowest lifecycle costs in 58% of the homes analyzed, hybrid systems (electric heat pumps with fuel backup) will have the lowest lifecycle costs in 23% of homes (all in cold climates), gas furnaces or boilers will minimize lifecycle costs in 12% of the homes (particularly in multifamily buildings), and gas heat pumps will minimize lifecycle costs in 7% of the homes analyzed (mostly in cold climates).

Table 2. Projections of the Wholesale Price per Million Btus for Natural Gas and Decarbonized Fuels

Fuel	2030	2040	2050
Biogenic renewable natural gas	\$14-18	\$16-21	\$14-19
Hydrogen (green)	32	21	18
Synthetic natural gas	40	26	21
Fossil natural gas	2.50	2.80	2.50

Source: ICF estimates in NYC 2021. We should note that a recent study by the firm E3 (2022) for the state of Massachusetts estimated slightly higher hydrogen prices.

While decarbonized fuels can help address climate change, their use will likely be limited if less-expensive fossil gas is widely available. Policies, such as a price on greenhouse gas emissions, might be able to drive this shift. For example, comparing the 2050 prices of fossil gas and hydrogen in table 2 and applying the carbon dioxide emissions of natural gas, a carbon price of \$293 per tonne of CO₂ equivalent would make the fossil and synthetic gas price the same.³ At \$7.70 per million Btus (the June 2022 price), the needed carbon price is “only” \$195 per tonne. In another approach, Colorado has adopted a “clean heat standard” that requires gas distribution utilities to cut emissions by 4% by 2025 and by 22% by 2030, with more-ambitious cuts to come in later years. The bill identifies several of what it terms “clean heat resources” that can be used

³ (\$18 H price -2.5 NG price) / 52.1 kg/mBtus * 1000 kg/tonne. We use “tonne” to indicate a metric tonne.

to achieve the targets, such as energy efficiency, electrification, and green hydrogen (Henchen and Overturf 2021). Other policy approaches to decarbonize the gas sector are likely to emerge in coming years as many states and gas utilities proceed in their work on this issue.

Availability of Decarbonized Fuels

Another issue is availability of decarbonized fuels. Biogas is now produced from landfills and food and agricultural waste (e.g., manure and crop wastes). It can potentially be produced from garbage, sewage waste, logging residue, and energy crops. Figure 3 illustrates a “high scenario” estimate for decarbonized fuel availability by 2040 that was prepared by ICF (2019) for the American Gas Foundation. This figure shows various types of biogas as well as some green hydrogen (labeled P2G). This full potential includes some controversial biogas sources such as municipal solid waste and energy crops; depending on how these controversies are resolved, the available supply may not be as high as these estimates. For example, Borgeson (2020) argues that the ICF estimates are too high.

To put these resources in perspective, the high scenario includes nearly enough gas to serve current residential demand for natural gas, as shown by the dotted line at the top of the figure. But much of this gas will be needed in other sectors; recall that the residential sector accounts for only 5% of the total fuel demand in figure 1. Figure 1 shows a need for about 9 quadrillion Btus of energy from fuels each year. Figure 3 shows availability of about 4.5 quadrillion Btus of energy from the fuels listed. The remaining fuel supply will likely need to come from additional hydrogen-based fuels, which, as shown in table 2, are more expensive than biofuels.

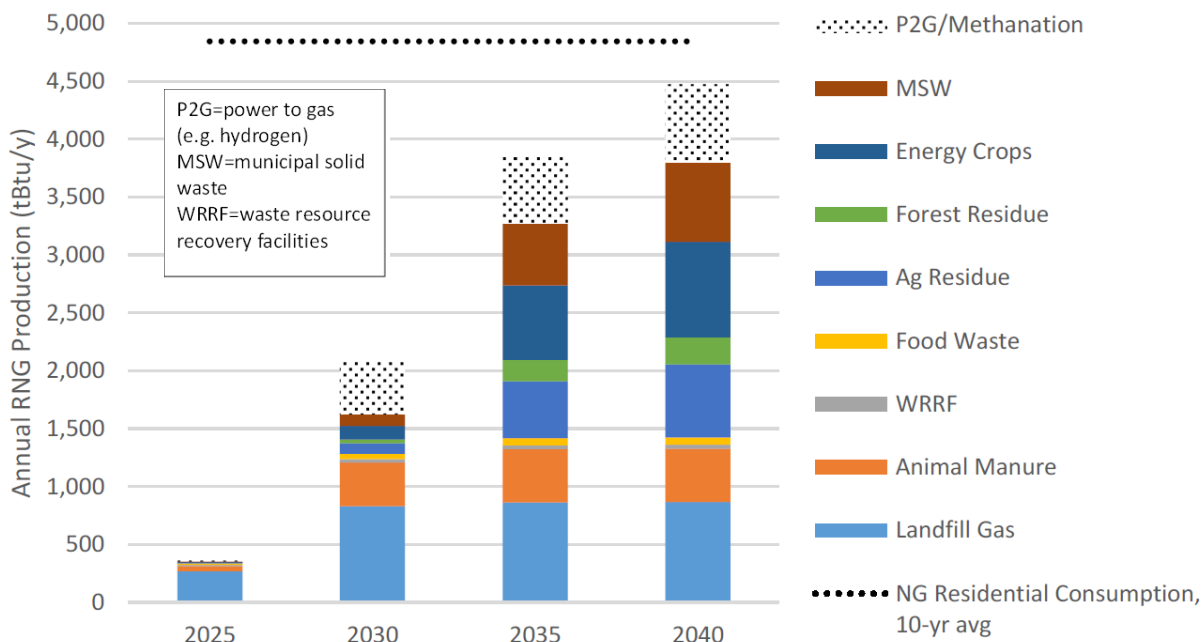


Figure 3. Annual renewable natural gas production in a potential high-resource gas scenario. Source: ICF 2019.

Role of Energy Efficiency

To bring the demand for fuels and the supply of decarbonized fuels into balance, more energy efficiency will be needed to reduce demand for fuels (the numbers in figure 1 do not include additional energy efficiency beyond business as usual). Increased energy efficiency will make available biofuel resources go further and reduce the amount of expensive hydrogen and synthetic fuels we need. The importance of energy efficiency is illustrated by three recent decarbonization studies, one for Minnesota, one for Maryland, and one national in scope. In the Minnesota study, more energy efficiency is justified by the higher price of low-carbon fuels, as well as increased electricity prices due to the need to address higher winter peaks spurred by increased electrification. The study estimates that at least 29% average energy efficiency savings will be available from more-efficient building shells, plus additional savings from use of more-efficient equipment such as electric and gas heat pumps. The role of these energy efficiency savings is illustrated in figure 4. This shows three scenarios – high decarbonized gas, electrification with gas backup, and high electrification (with electric resistance backup). Under both high and low fuel costs, the electrification with gas backup scenario had the lowest total resource costs (GPI and CEE 2021).

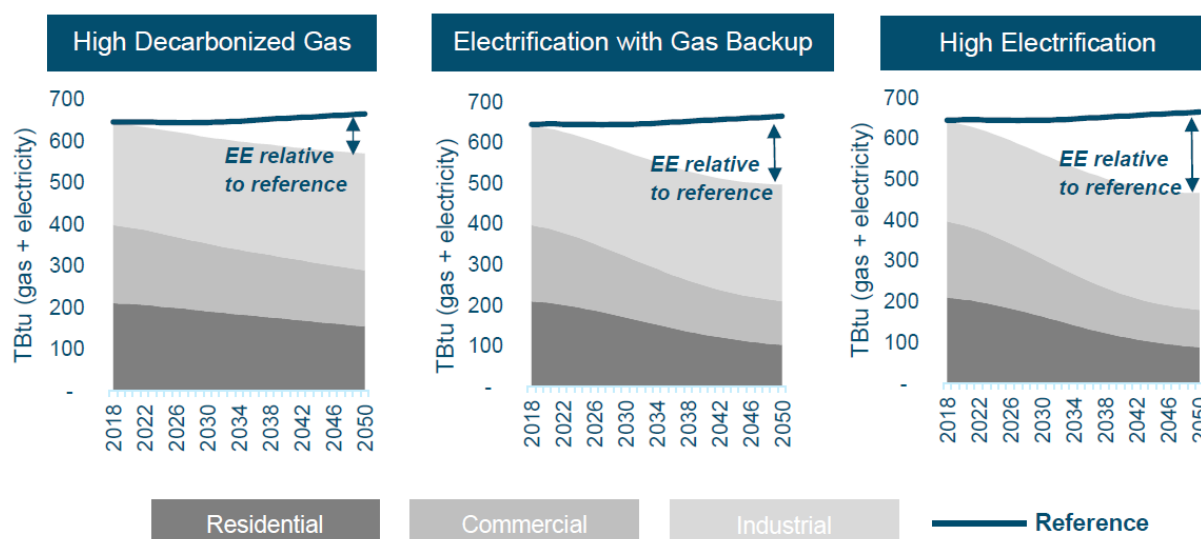


Figure 4. Final energy consumption and energy efficiency effects in the three Minnesota decarbonization scenarios. Source: GPI and CEE 2021.

The Maryland study used similar scenarios. In the first draft of the study, the electrification with gas backup scenario had the lowest cost. Stakeholders suggested increasing the amount of energy efficiency, and once more efficiency was added, the low-cost scenario no longer needed gas backup for most homes (Maryland Commission on Climate Change 2021). Maryland's climate is moderate (~4500 heating degree days), and temperatures rarely get below 5°F. As a result, when energy efficiency is included, a gas backup may generally not be needed. This contrasts with the cold Minnesota climate (more than 7000 heating degree days), where a backup is useful for very cold days.

The national study, published by the American Gas Association (AGA), shows four pathways for decarbonizing gas use – one emphasizing gas efficiency, one emphasizing

decarbonized gas, one emphasizing hybrid electric-gas heating, and one mixing the three approaches. In these scenarios, gas demand reduction ranges from 27% to 52%, with the highest reductions in the hybrid and mixed cases. Figure 5 illustrates the mixed case.

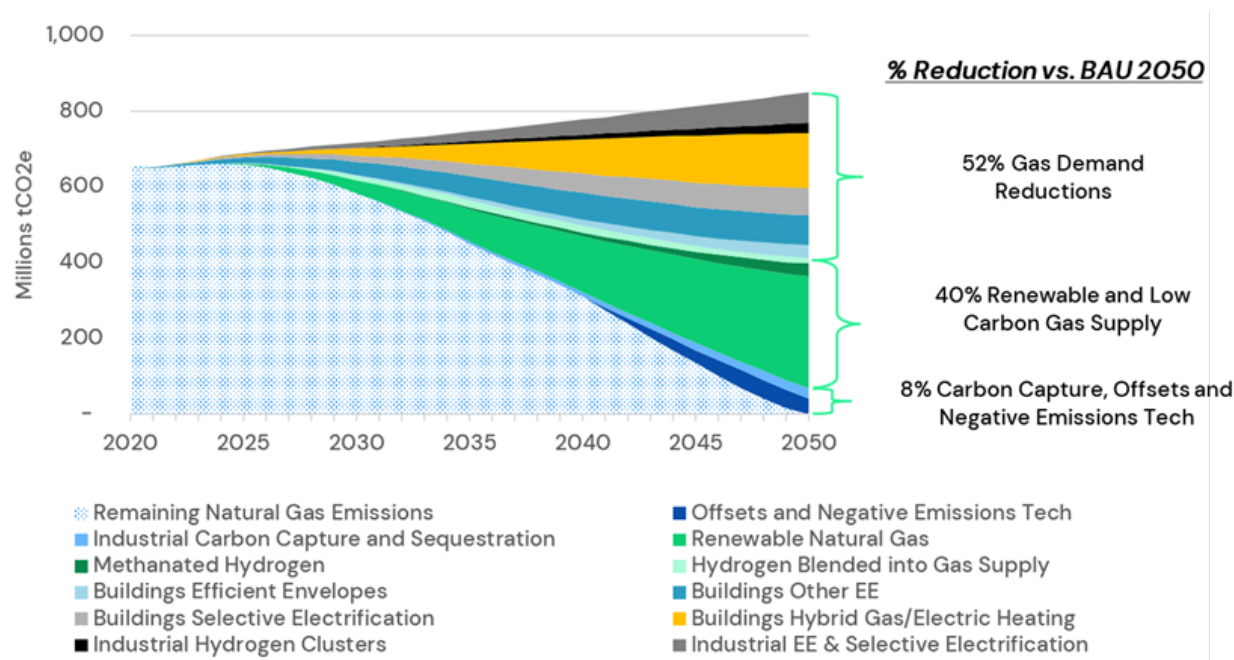


Figure 5. Mixed technology pathway in the AGA study. Source: AGA and ICF 2022.

Possible Roles for Gas Utilities

Gas utilities account for about 13% of U.S. greenhouse gas emissions (AGA and ICF 2022). Most of this is from gas used by their residential, commercial, and industrial customers. Industrial energy use will likely be the largest use of fuels in a decarbonized world, as shown in figure 1. Some of this use is served by local distribution companies and some directly by gas pipeline companies. We anticipate that these companies will generally continue to serve these loads, likely through some combination of hydrogen and natural gas, each in its own pipes. While hydrogen can be mixed with natural gas up to about 20% hydrogen, given the quantity of fuel needed and limited availability of biogas, substantial volumes will need to be provided by pure hydrogen. Companies such as Praxair and Air Products presently operate hydrogen pipelines running between Houston and New Orleans (KPMG 2021). Natural gas utilities might be able to link to such pipelines in their areas to serve their customers, leveraging their expertise in local distribution and established relationships with customers.

Going a step farther, Southern California Gas (SCG) has recently proposed to develop a hydrogen pipeline that would carry green hydrogen generated from renewable power in the California desert to Los Angeles for use in factories, power plants, and heavy transportation. SCG would own the pipeline and contract with other companies to supply the hydrogen (Penrod 2022).

Commercial fuel use will be more limited (see figure 1) but tends to be concentrated in cities and towns. We anticipate that gas utilities will continue to serve these customers, most

likely with some form of decarbonized natural gas (biogas and/or synthetic gas) that can use existing distribution pipes and equipment.

Residential fuel use overall is likely to be larger than commercial use (figure 1), but the cost to serve this load generally varies with density (Guldmann 1980). Many gas distribution system pipes are getting old; utilities and their regulators will need to decide whether to replace or retire these systems. Studies will be needed on the relative economics of replacement versus retirement. The answer will vary from site to site and more generally will vary with climate (replacement is more likely to make sense the colder the climate) and density (replacement is more likely to make sense as density increases). One important factor will be the impact of electrification and energy efficiency on remaining load. As shown by Davis and Hausman (2022), as customers exit the gas system or substantially scale back their use of gas, fixed costs need to be recovered over lower sales, increasing costs to customers. Their results, which are illustrated in figure 6, are based on empirical data on past price responses to changes in gas sales. In particular, care is needed to ensure that if higher-income customers leave the gas system, lower-income customers do not bear a disproportionate burden of higher gas prices. There are also important issues to work through about “duty to serve” before any gas distribution systems can be retired (Henchman and Kroh 2020).

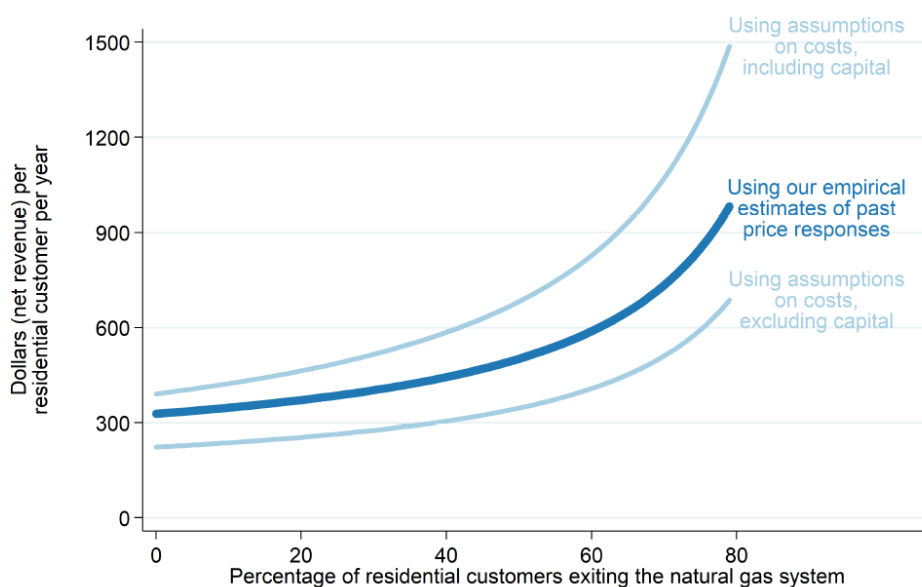


Figure 6. Impact of declining number of customers on gas bills. Source: Davis and Hausman 2022.

Another possible role for gas utilities is being explored by three Massachusetts utilities. They are piloting micro-thermal grids that would serve multiple homes and buildings in a neighborhood using geothermal heat pumps. The geothermal networks could be located in parallel with existing gas pipes, as illustrated in figure 7. Geothermal heat pumps are both more efficient and more expensive than air-source heat pumps and primarily make sense in cold climates. The Massachusetts utilities are each doing a pilot of the concept in dense neighborhoods, seeking to understand the technologies, economics, and consumer interest. If these all align well, the utilities hope to be able to rate-base and earn a return on their investments (St. John 2022).

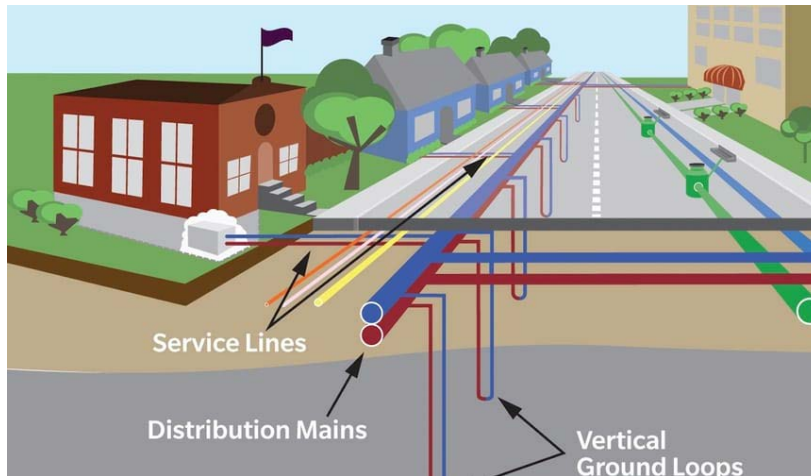


Figure 7. Schematic of a ground-source heat pump thermal network. Source: Eversource as published in St. John 2022b.

In addition, we note that airplanes, long-distance trucks, ships, and railroads will also use fuels, likely including hydrogen (see figure 1 and discussion above). Depending on local needs and the business strategies of individual gas distribution companies, some distribution companies may seek to serve some of these markets, such as providing hydrogen to airports and long-distance truck terminals.

Taken together, local gas distribution companies will see significant changes in their markets and business strategies. With electrification and energy efficiency reducing load, gas sales volumes are likely to decline, and the price will likely increase substantially due to both the reduced volumes and the cost of decarbonized fuels. Gas utilities may place more emphasis on serving large customers and serving neighborhoods with above-average densities, with reduced emphasis, and perhaps even dropping, lower density areas.

Conclusion

The numbers discussed in this paper are highly approximate. Ultimately, electricity can serve most loads, but some fuel will also be needed. The end-uses needing the most attention to develop carbon-free fuels are long-distance airplanes, high-temperature industrial processes, ships, trucks, and trains. Residential and commercial buildings will also need some fuels, particularly in cold climates. Largely decarbonized fuels such as biofuels, hydrogen, and synthetic natural gas are all available in limited or pilot-scale quantities today; availability can scale up in the future. Prices of these alternative fuels are high but will generally decline over time, but even with these declines, decarbonized fuels are likely to be more than twice as expensive at the wholesale level than natural gas is today. These high prices will improve energy efficiency economics. Energy efficiency can reduce the amount of fuel and electricity needed, and it is a key part of gas decarbonization strategies. Decarbonization will have profound effects on local gas utility business models. Industrial and commercial sales will shrink on average but remain prominent. As residential gas distribution systems age, utilities and regulators will need to make decisions about replacement versus retirement. These will be local decisions, likely influenced by climate and density. Gas utilities will need to modify their business models to serve remaining markets while possibly entering complementary markets.

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