Clean Energy Brief: Natural Gas in Minnesota

The Health, Safety, and Economic Impacts of Using Natural Gas to Power Minnesota Buildings

February 2020
Prepared by Melissa R. Partin
on behalf of Fresh Energy

Fresh Energy

fresh-energy.org freshenergytoday freshenergy

Executive Summary

A strong and growing body of evidence suggests that using natural gas to power buildings poses significant health, safety, and economic risks. These risks are avoidable and can be prevented by moving building fuel sources to electricity. Shifting toward renewable energy will reduce air pollutants, improve health, and save lives, while at the same time saving money for consumers and the state of Minnesota.

Natural Gas

- A flammable fossil fuel occurring naturally underground.
- Primarily composed of methane, a greenhouse gas 84 times more powerful than carbon dioxide.
- Is imported to Minnesota; none is produced locally.
- Used for industrial processes, electric power generation, and to **power residential and commercial buildings.**

Use in Buildings

- Powers residential and commercial furnaces, water heaters, clothes dryers, and cooking appliances.

Safety Risks

- Accounts for the majority of buildings' greenhouse gas emissions, which are responsible for climate change.
- Exposes consumers to pollutants linked to serious health risks, including:
  - Decreased lung function
  - Asthma attacks
  - Nervous system damage
  - Heart attacks and strokes
  - Cancer
  - Death
- Can lead to life-threatening carbon monoxide leaks.
- Relies on pipeline infrastructure with explosion risk.

Reliability Concerns

- Service can be interrupted by pipeline accidents and loss in pressure in the system.

Economic Risks

- Decreased costs and improved performance of renewable energy sources mean new resources directed toward natural gas infrastructure will be wasted investments and result in increased consumer costs later.
- Natural gas is projected to lose its economic advantage relative to clean energy within 15 years.

75% **68%**

Buildings powered by natural gas in the Midwest

62%

Residents regularly exposed to dangerous levels of pollutants from natural gas stoves

43% **35%**

Minnesota residents reporting natural gas cooking as an asthma trigger

Since 2005, natural gas pipeline incidents in Minnesota have led to:

77 incident reports

15 injuries

3 deaths

$59M in property damage

Every year in Minnesota, carbon monoxide poisoning from fossil fuels causes:

287 emergency room visits

29 hospitalizations

12 deaths

2,180

Customers lost natural gas service during dangerously cold weather in 2019

30%

Projected increase in natural gas per unit delivered fuel cost in the Midwest as a result of declining costs of renewable energy sources

15 years until economic advantage of gas disappears

Overview

Natural gas is a flammable gas that is used as a fossil fuel. It consists largely of methane and other hydrocarbons and occurs naturally underground, often in association with petroleum. In the United States, natural gas is used for industrial processes, electric power generation, and in residential and commercial buildings to power heating, cooking, and other appliances.

Americans tend to think of natural gas as a relatively clean and inexpensive fuel source for heating and powering buildings. While it's true that natural gas is currently cheap to produce, it's far from clean and accounts for the majority of greenhouse gas emissions from buildings. It also poses significant health and safety risks. What's more, recent trends suggest its economic advantage relative to clean energy technology, such as wind and solar, will disappear over the next 15 years.[1-3]

Decisions about whether to continue to invest in natural gas infrastructure should take into account how the consumption of gas in our buildings impacts the health, safety, and pocketbooks of Minnesotans.

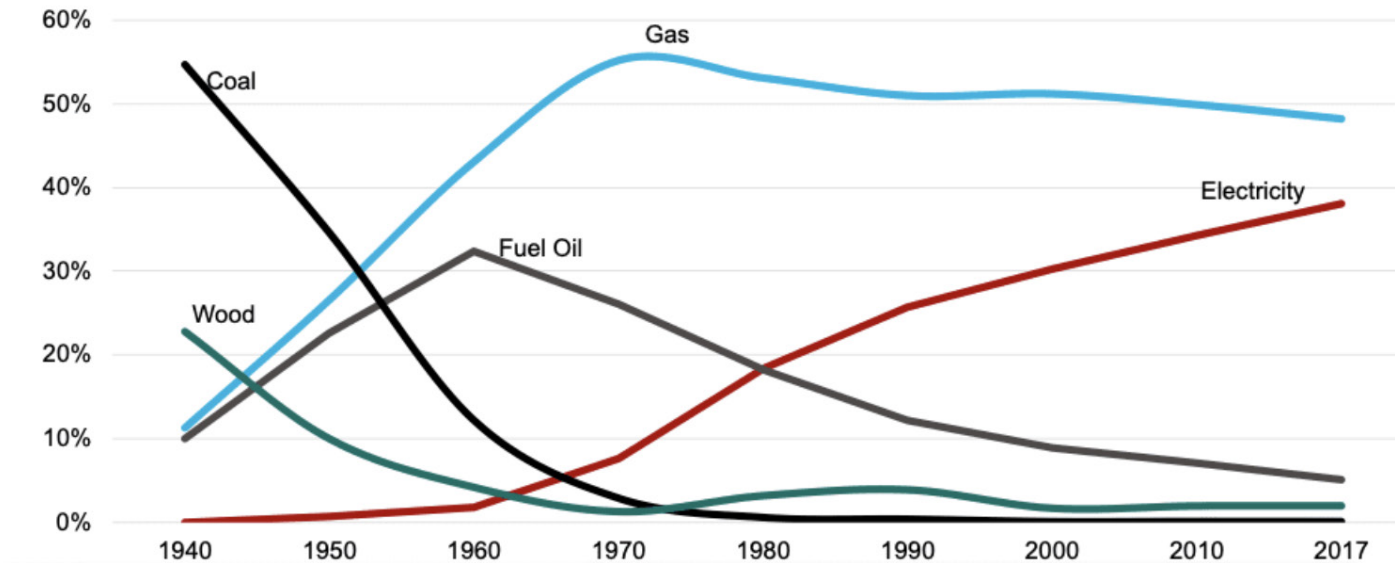
To inform these decisions, this report summarizes available information on the effects of using natural gas to power buildings, as well as residential and commercial appliances. This report draws upon health, safety, reliability, and economic data available for the United States and for Minnesota in particular.

How is Natural Gas Used in Buildings?

Natural gas is used to power residential and commercial appliances, including furnaces, water heaters, clothes dryers, and cooking appliances. Between 1950 and 1970, households began to transition from coal as a heat source to natural gas. Today, even though natural gas remains the primary fuel source, its use has been declining while demand for electricity has been increasing.[4]

Percentage of US households by primary heating fuel

1940-2017

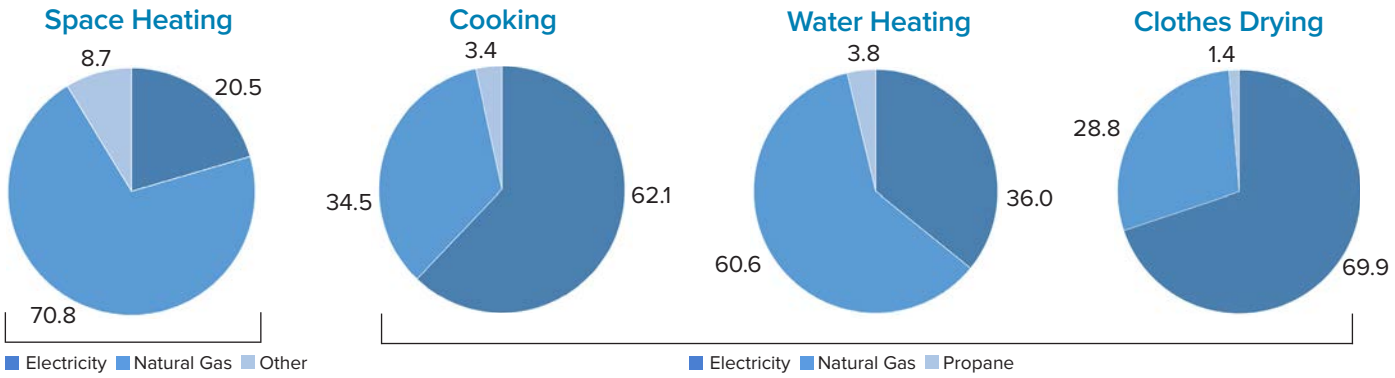


Source: Census Bureau 2018

In residential buildings in the Midwest, natural gas is the most common fuel source used for residential space and water heating, but electricity is the most common fuel source for clothes dryers and cooking.

Fuels used and end uses in Midwest homes

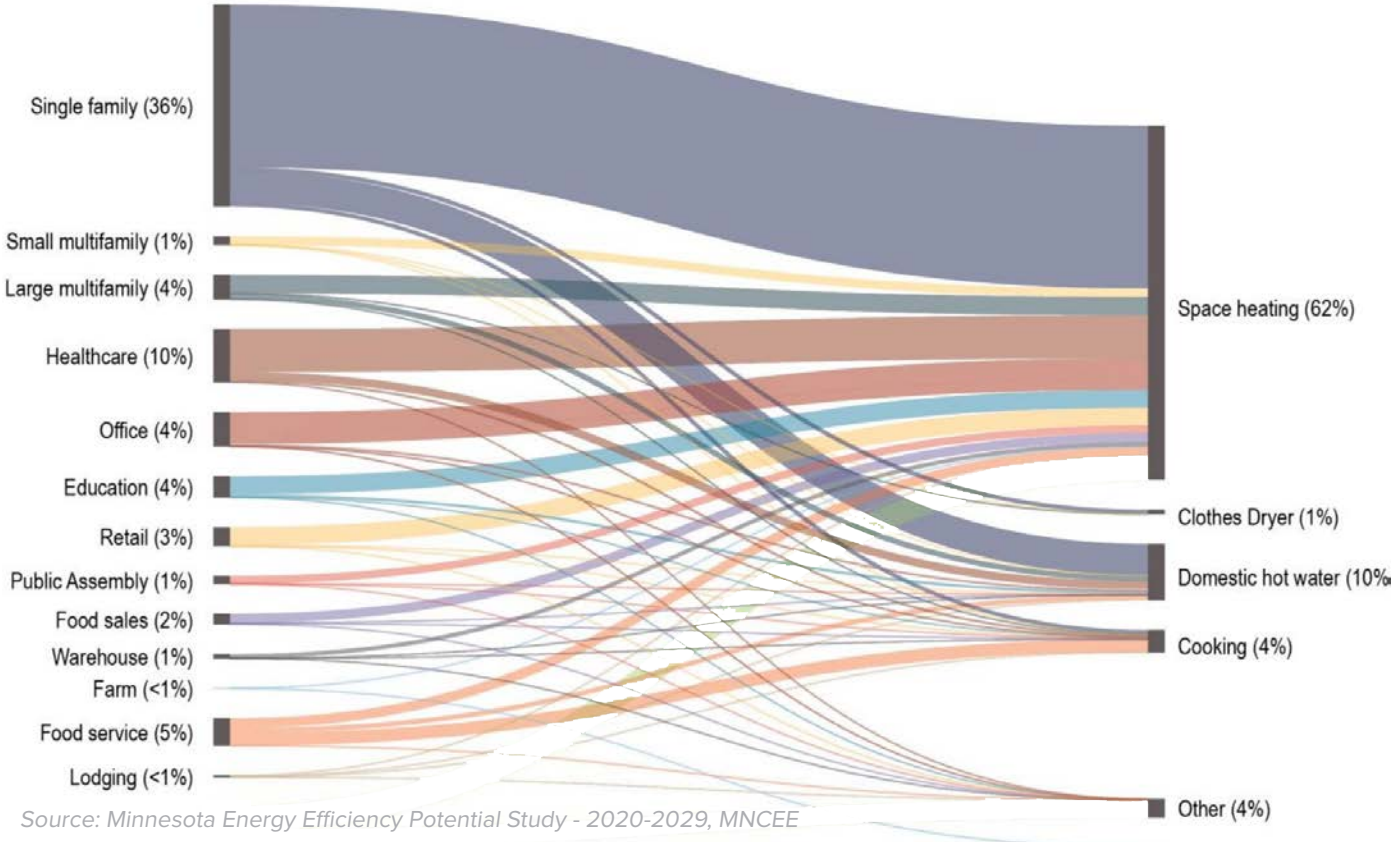
2015



Source: 2015 Residential Energy Consumption Survey

In Minnesota, natural gas is relied on heavily for space and water heating in both commercial and residential buildings.[7]

Minnesota natural gas consumption by building type and end use



Source: Minnesota Energy Efficiency Potential Study - 2020-2029, MNCEE

Is Natural Gas Safe?

Gas appliances and fuel-burning heating devices can generate a variety of air pollutants, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAH), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOC), and particulate matter (PM_{10}, $PM_{2.5}$).

Health Impacts

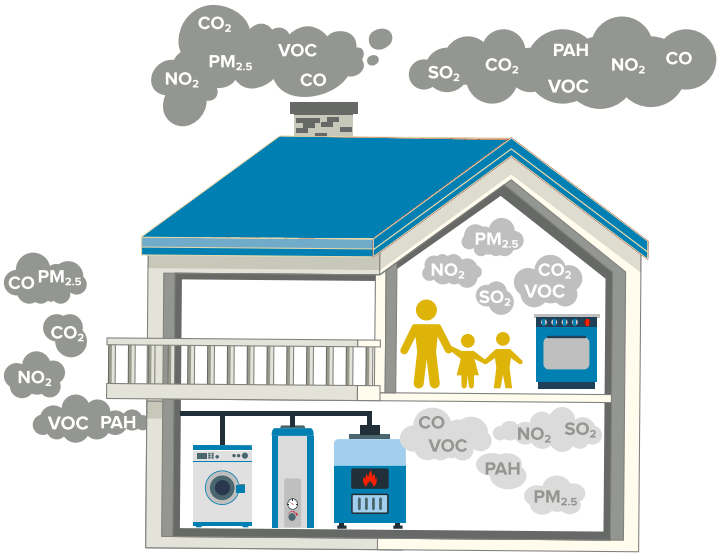
Apart from carbon monoxide, there are no official indoor air quality standards for these pollutants in the United States, and studies have shown that indoor concentrations for some of them routinely exceed established ambient air quality standards.[9] In 2015, Canada recognized the considerable health risks of nitrogen dioxide exposure from sources like cooking and heating and in turn established a residential indoor air quality standard for it.[49] One recent study estimated that 62% of residents using natural gas stoves are regularly exposed to nitrogen dioxide levels that exceed these standards.[10]

Residents regularly exposed to dangerous levels of pollutants from natural gas stoves

Air quality standards for these pollutants exist because exposure to them has been linked to serious health risks, including cancer, decreased lung function, worsening asthma, chronic obstructive pulmonary disease and heart disease symptoms, nervous system damage, delayed neurodevelopment in children, and premature death.[9,11-12] While a variety of sources (including outdoor air pollution, building materials, and cigarette smoking) can increase indoor accumulations of these pollutants, gas heating and cooking devices are the primary sources of indoor accumulations of both nitrogen dioxide and carbon monoxide.[9]

The adverse health impacts of indoor nitrogen dioxide accumulations are also well established.[9] Numerous studies have shown that nitrogen dioxide from gas heating and cooking can increase airway responses to irritants and allergens;[13-15] exacerbate symptoms associated with chronic obstructive pulmonary disease,[15-16] asthma,[14-15, 17-18] and heart disease;[19-20] and may adversely affect the mental development of children.[20-21]

How do gas appliances in our buildings affect our air and health?



Gas stove burners release combustion pollutants directly into buildings when lit.

Gas furnaces and water heaters vent combustion pollutants through chimney or wall ducts into the outside air, where they contribute to ambient air pollution. Faulty equipment and poor ventilation can cause pollutants to accumulate indoors.

NO_2 (Nitrogen dioxide): Decreases lung function, particularly in children and individuals with chronic respiratory diseases.[13-16] Causes asthma attacks.[14-15, 17-18] Worsens heart disease symptoms.[19-20]

CO (Carbon monoxide): Causes flu-like symptoms at low concentrations. At high concentrations can cause heart attacks and death.[9,22-23]

CO_2 (Carbon dioxide): A greenhouse gas that causes climate change and health effects associated with air pollution, high pollen counts, temperature extremes, fires, and floods.[8]

VOC (Volatile organic compounds): Can cause flu-like symptoms, decrease lung function, and damage the nervous system.[12] Some VOC cause cancer.[12]

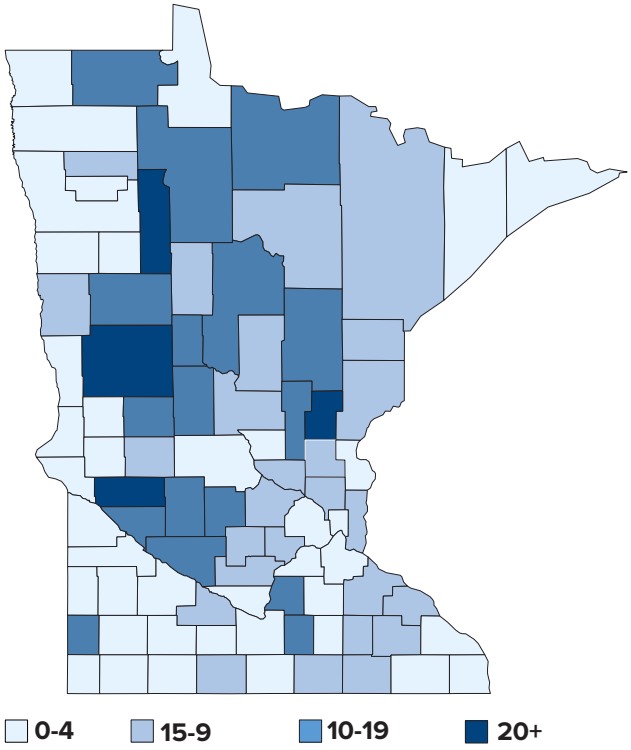
$PM_{2.5}$ (Fine particulate matter): Decreases lung function, worsens asthma, and can cause heart attacks and strokes.[12]

SO_2 (Sulfur dioxide): Worsens asthma and heart disease symptoms and increases chance of respiratory infections.[11]

PAH (Polycyclic aromatic hydrocarbons): Causes bronchitis, worsens heart disease and asthma symptoms, may affect fetal development, and can cause lung cancer.[9]

Other studies have shown that carbon monoxide poisoning resulting from improperly installed, ventilated, operated, or maintained gas appliances and heating devices can lead to health complications ranging from temporary flu-like symptoms to cardiac morbidity and death.[9,22-23] Every year, roughly 21,000 people visit an emergency room, 2,300 are hospitalized, and 438 die of unintentional, non-fire related carbon monoxide poisoning in the United States.[24] Carbon monoxide poisoning incidents result in over $1.3 billion in acute medical expenses and lost earnings annually.[25]

Age-adjusted carbon monoxide poisoning emergency room admission rates per 10,000 population, by county, *2015-2017*



In Minnesota between the years 2012 and 2017, carbon monoxide poisoning led to 1,725 emergency room visits, 175 hospitalizations, and 74 deaths.[26] Carbon monoxide poisoning in Minnesota is more common in men and the elderly, and occurs more frequently in the winter months when fuel-burning heaters are heavily used.[26] Although emergency room admissions related to carbon monoxide poisoning are generally rare (an average of 5.5 per 10,000 in the state of Minnesota as a whole between 2015-2017) some counties, including Clearwater, Swift, Kanabec, and Ottertail, had rates more than three times greater than the statewide average during this time period.

Every year in Minnesota, carbon monoxide poisoning from fossil fuels causes:

287 Emergency room visits
29 Hospitalizations
12 Deaths

The elevated rates of carbon monoxide poisoning in these counties could result from piped natural gas or delivered propane use. The relative contribution of each type of fuel to the observed rates is unknown. Data from the U.S. Census Bureau suggests that the percentage of households in these counties relying on natural gas for heating fuel ranged from 49 in Clearwater County to 70 in Kanabec County between 2014-2018.[27]

Some demographics are more vulnerable to the adverse health effects resulting from natural gas-generated air pollutants in buildings than others. Children and the elderly are more at risk, in part because they spend a greater fraction of their time indoors.[15] Children are particularly vulnerable because their organs and nervous systems are still developing. Rural, low-income, and minority residents are more vulnerable to the adverse health effects of using natural gas in buildings because they are more likely to use unvented gas cooking and heating appliances and to use gas stoves as a supplemental heat source.[5,28] One study of public housing residents found that more than half either had a gas stove without mechanical exhaust or reported using a gas stove to heat their apartment.[29]

Individuals with chronic respiratory and heart disease are more vulnerable to the adverse effects resulting from using natural gas-fueled appliances in buildings because natural gas combustion pollutants can worsen symptoms associated with heart disease, asthma, and other respiratory diseases.[9] In Minnesota, gas cooking was reported as an asthma trigger by 35% of children and 43% of adults participating in the 2015 Minnesota asthma callback survey, making it the third and the fourth most commonly reported trigger for children and adults with asthma in the state, respectively.

43% **35%**

Minnesota residents reporting natural gas cooking as an asthma trigger

Replacing gas stoves with electric or induction ranges[30] and/or achieving proper ventilation[31-32] can reduce concentrations of pollutants generated by natural gas-combusting appliances and thus reduce the health risk. However, surveys suggest that at most only one-third of households with gas cooking appliances routinely use their exhaust fan or range hoods while cooking, and only 35% have exhaust fans that properly vent to the outside.[33-34] Given the low compliance with proper ventilation in United States households, even when equipment is available, the best option for reducing adverse health effects associated with gas cooking and heating may be to replace gas appliances with electric.

Risk of Explosions

In addition to contributing to the health risks associated with indoor air pollution described above, gas appliances depend on a pipeline infrastructure that poses safety risks, including injury, death, and hardship resulting from leaks, explosions, and interrupted service. Every year in the United States, there are about 240 natural gas pipeline incidents. Roughly half of these incidents involve gas transmission pipelines that primarily transport gas from gathering systems to refining, processing, or storage facilities, and the other half involve distribution pipelines that deliver fuel to consumers.[35] Since 2005 in the United States, natural gas pipeline incidents resulted in 860 injuries, 195 deaths, and more than $4.2 billion in property damage.[35]

In Minnesota, we experience an average of five incidents each year along the 35,075 miles of natural gas pipeline in the state.[35-36] Since 2005, there have been 77 natural gas pipeline incidents (29 involving transmission and 48 involving distribution lines) in Minnesota—a total that is slightly higher than the national average of 71 per state over this same time period.[35]

Since 2005, natural gas pipeline incidents in Minnesota have led to:

77 incident reports
15 injuries
3 deaths
$59M in property damage

The 77 natural gas incidents occurring in Minnesota since 2005 have led to three deaths, 15 injuries, and more than $59 million in property damage.[35] Not included in these damage estimates are the public costs associated with health expenses, loss of shelter and wages, and long-term disability resulting from physical and psychological trauma,[37] which are not reported to the federal government, but are likely to be substantial.

One recent Minnesota incident illustrates just how devastating pipeline accidents can be. On the morning of August 2, 2017, Minnehaha Academy, a private high school in Minneapolis, experienced a natural gas explosion that occurred when contractors were moving gas piping on the campus. The explosion killed two school employees and injured nine others (including the school soccer coach, who lost a leg in the explosion), resulted in an estimated $30 million in property damages and led to significant additional costs associated with five lawsuits filed by staff and family members of those killed and injured in the incident.

Last year, Minnesota experienced four pipeline explosions: one in Pequot Lakes that hospitalized a restaurant owner with severe burns,[38] one in Paynesville that leveled a home,[39] and two in Saint Paul (one on Payne Avenue that leveled a home and killed the occupant,[40] and another that destroyed a house and badly burned an elderly resident).[41] In addition to the above pipeline-related deaths, two Dakota County residents were killed in a suspected propane-related explosion in the past year.[42] These statistics suggest that, although pipeline incidents and delivered fuel explosions occur relatively infrequently, they can be extremely dangerous and costly when they do.

Fatal 2019 explosion in Payne Avenue in Saint Paul. Photo by Leila Navidi, Star Tribune

Soccer coach Bryan Duffey, Photo by Glen Stubbe, Star Tribune

Is Natural Gas Reliable?

Because Minnesota has no natural gas production plants or wells, the natural gas we use is provided by production plants in other states and Canada, which is transported to and within the state by pipeline. Consumer access to natural gas for heating and cooking can be interrupted by pipeline incidents, such as those described above, or by a loss in pressure in the pipeline system, caused by inadequate supply for higher than anticipated demand levels during heat waves and cold snaps.

2,180

Customers lost natural gas service during dangerously cold weather in 2019

In the past year, Minnesota experienced several interruptions in natural gas service that affected thousands of residents and businesses during extreme cold. For example, in November 2019 the entire town of Paynesville (about 1,400 households) lost gas service after a construction crew hit a gas main line.[43] In the same month, a loss of pressure occurred in Shakopee during a cold snap, causing about 600 CenterPoint Energy customers to lose service for 24 hours.[44] To divert fuel to schools and residences during this low pressure event, farms with grain dryers had their service turned off, which resulted in costly harvest delays.[45] Between January 28 and February 1, 2019, when temperatures fell as low as -56 degrees Fahrenheit during the polar vortex, about 180 Xcel Energy customers lost service in Princeton, Hugo, and surrounding areas due to a loss of pressure in the system.[46] Xcel tried to prevent the low pressure from spreading by asking customers to turn down their thermostats to 63 degrees during the cold snap, but only about two-thirds complied.[46]

To prevent service loss resulting from low pressure in the future, Minnesota utilities have refined their demand modeling and invested in better infrastructure.[46] However, customers will likely still need to curtail natural gas usage to prevent low pressure from spreading in future extreme weather events and can expect fines to be imposed for any failure to comply with curtailment requests.[46]

Should Minnesota Continue to Invest in Natural Gas Infrastructure?

As with its three previous rate cases, CenterPoint Energy proposed an increased annual capital investment of $200 million in the 2019 rate case filing with the Public Utilities Commission.[47] However, recent economic trends call into question the rationale for continued, significant investment in natural gas infrastructure systems.

"Economics increasingly suggest clean-energy is the least-cost option for new grid capacity." [1]

15 years until economic advantage of gas disappears

Wind, solar, and storage power generation sources are already more economic than new gas power plants to build, and are expected to be cheaper than existing gas plants to operate by 2030.[1-2] These trends mean that any new resources directed toward gas pipeline upgrades and expansions now could emerge as wasted investments that will translate to increased consumers costs later. Indeed, one recent study found that continued declines in its demand could lead to natural gas per unit of delivered fuel cost increases of up to 30 percent in the Midwest, and as high as 140 percent in the Southeast.[2]

30%

Projected increase in natural gas per unit delivered fuel cost in the Midwest as a result of declining costs of renewable energy sources

In contrast, electricity prices are much more stable than gas prices and have remained virtually unchanged for the past 50 years.[4] Further, recent studies suggest that shifting to electricity to power buildings could lead to consumer savings in the long run. For instance, a recent study conducted in California estimated that most residents' energy bills would decrease with electrification for space and water heating.[48]

Summary

A strong and growing body of evidence suggests that using fossil fuels to power buildings poses non-trivial public health and safety risks. These risks are avoidable and can be prevented by shifting building fuel sources to electricity. In addition to saving lives and improving health, shifting toward renewable sources of energy to power our buildings is likely to save money over the long run for utility customers and the state as a whole, and to reduce air pollutants responsible for global climate change.

References

1. Teplin C, Dyson M, Engel A, Glazer G. The Growing Market for Clean Energy Portfolios: Economic Opportunities for a Shift from New Gas-Fired Generation to Clean Energy Across the United States Electricity Industry. Rocky Mountain Institute, 2019. https://rmi.org/cep-reports.
2. Dyson M, Glazer G,Teplin C. Prospects for Gas Pipelines in the Era of Clean Energy: How Clean Energy Portfolios Are Reducing US Power Sector Demand for Natural Gas and Creating Stranded Asset Risks for Gas Pipelines. Rocky Mountain Institute, 2019. https://rmi.org/cep-reports.
3. Henchen M and Kroh K. A New Approach to America's Rapidly Aging Gas Infrastructure. Rocky Mountain Institute, January 6, 2019. https://rmi.org/a-new-approach-to-americas-rapidly-aging-gas-infrastructure/.
4. The Impact of Fossil Fuels in Buildings: A fact base. Rocky Mountain Institute, 2019. https://rmi.org/insight/the-impact-of-fossil-fuels-in-buildings/.
5. 2017 American Housing Survey. https://www.census.gov/programs-surveys/ahs.html
6. 2015 Residential Energy Consumption Survey. https://www.eia.gov/consumption/residential/data/2015/
7. Center for Energy and Environment, Optimal Energy and Seventhwave. Minnesota Energy Efficiency Potential Study: 2020–2029. Minneapolis: Center for Energy and Environment, 2018. https://www.mncee.org/MNCEE/media/PDFs/MN-Potential-Study_Final-Report_Publication-Date_2018-12-04.pdf.
8. Luber G, Knowlton K, Balbus J, Frumkin H, Hayden M, Hess J, McGeehin M, Sheats N, Backer L, C. B. Beard CN, Ebi KL, Maibach E, Ostfeld RS, Wiedinmyer C, Zielinski-Gutiérrez E, and Ziska L. 2014: Ch. 9: Human Health. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 220-256. doi:10.7930/J0PN93H5. http://nca2014.globalchange.gov/report/sectors/human-health.
9. World Health Organization. WHO guidelines for indoor air quality: selected pollutants. Copenhagen: WHO Press, 2010. https://www.google.com/search?client=firefox-b-1-d&q=World+Health+Organization.+WHO+guidelines+for+indoor+air+quality%3A+selected+pollutants.+Copenhagen%3A+WHO+Press%2C+2010.+
10. Logue JM, Klepeis NE, Lobscheid AB, Singer BC. Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California. Environ Health Perspect 2014;122:43–50; http://dx.doi.org/10.1289/ehp.1306673
11. Khan RR and M.J.A. Siddiqui MJA. Review on effects of Particulates; Sulfur Dioxide and Nitrogen Dioxide on Human Health. Int. Res. J. Environment Sci 2014; 3(4):70-73. Available online at: www.isca.in, www.isca.me.
12. American Lung Association. Indoor Air Pollutants and Health. https://www.lung.org/our-initiatives/healthy-air/indoor/indoor-air-pollutants/
13. Institute of Medicine. 2000. Clearing the air: Asthma and indoor air exposures. Washington, DC: National Academies Press. https://download.nap.edu/login.php?record_id=9610&page=http%3A%2F%2Fwww.nap.edu%2Fdownload.php%3Frecord_id%3D9610
14. Kanchongkittiphon W, Mendell MJ, Gaffin JM, Grace Wang G, and Phipatanakul W. Indoor Environmental Exposures and Exacerbation of Asthma: An Update to the 2000 Review by the Institute of Medicine. Environ Health Perspect 2015;123:6–20. http://dx.doi.org/10.1289/ehp.13079222015.
15. Environmental Protection Agency. Integrated Science Assessment for Oxides of Nitrogen - Health Criteria. EPA/600/R-15/068 | January 2016 | www.epa.gov/isa
16. Hansel NN et al. In-Home Air Pollution Is Linked to Respiratory Morbidity in Former Smokers with Chronic Obstructive Pulmonary Disease. Am J Respir Crit Care Med 2013; 187(10): 1085-1090. https://doi.org/10.1164/rccm.201211-1987OC
17. Belanger K, et al. Household levels of nitrogen dioxide and pediatric asthma severity. Epidemiology 2013;24(2):320-330. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3686297/
18. Pauline LM et al. 24-h Nitrogen dioxide concentration is associated with cooking behaviors and an increase in rescue medication use in children with asthma. Environmental Research 2017;159:118-123. http://dx.doi.org/10.1016/j.envres.2017.07.052.
19. Dennekamp M et al. Ultrafine particles and nitrogen oxides generated by gas and electric cooking. Occup Environ Med 2001;58:511-516.
20. Peters A, Liu E, Verrier RL, Schwartz J, Gold DR, Mittleman M, Baliff J, Oh A, Allen G, Monahan K, et al. Air pollution and incidences of cardiac arrhythmia. Epidemiology 2000;11:11-17.
21. Vrijheid M, et al. Indoor air pollution from gas cooking and infant neurodevelopment. Epidemiology 2012;23(1):23-32. https://doi.org/10.1097/EDE.0b013e31823a4023.
22. Townsend CL, and Maynard RL. Effects on health of prolonged exposure to low concentrations of carbon monoxide. Occup Environ Med 2002;59:708-714.
23. Mathieu-Nolf M. Poisons in the air: a cause of chronic disease in children. J Toxicol Clin Toxicol 2002;40: 483-489.
24. Sircar K et al. Carbon monoxide poisoning deaths in the United States, 1999 to 2012. American Journal of Emergency Medicine. 2015;33: 1140-1145. http://dx.doi.org/10.1016/j.ajem.2015.05.002.
25. Hampson NB. Cost of accidental carbon monoxide poisoning: A preventable expense. Preventive Medicine Reports 3 (2016) 21-24. http://dx.doi.org/10.1016/j.pmedr.2015.11.010.
26. Minnesota Department of Health. https://data.web.health.state.mn.us/web/mndata/co
27. U.S. Census Bureau, American Community Survey five-year estimates 2014-2018. https://www.census.gov/acs/www/data/data-tables-and-tools/narrative-profiles/2018/
28. HH Slack HH, Heumann MA. Use of Unvented Residential Heating Appliances -- United States, 1988-1994. MMWR December 26, 1997;46(51):1221-1224. https://www.cdc.gov/mmwr/preview/mmwrhtml/00050535.htm#00001460.gif
29. Adamkiewicz G et al. Environmental Conditions in Low-Income Urban Housing: Clustering and Associations With Self-Reported Health. Am J Public Health 2014;104:1650-1656. https://doi.org/10.2105/AJPH.2013.301253..
30. Pauline LM et al. Home interventions are effective at decreasing indoor nitrogen dioxide concentrations. Indoor Air 2014; 24(4): 416-424. https://doi.org/10.1111/ina.12085.
31. Singer BC, et al. Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes. Building and Environment 2017;122:215-229. https://doi.org/10.1016/j.buildenv.2017.06.021.
32. Kile ML, et al. A cross-sectional study of the association between ventilation of gas stoves and chronic respiratory illness in U.S. children enrolled in NHANESIII. Environmental Health 2014;13:71. https://doi.org/10.1186/1476-069X-13-71.
33. Klug VL, Lobscheid AB, and Singer BC. Cooking appliance use in California homes: data collected from a web-based survey. Berkeley: Lawrence Berkeley National Laboratory, 2011. https://homes.lbl.gov/sites/all/files/lbnl-5028e-cooking-appliance.pdf.
34. Price PN and Sherman MH. Ventilation Behavior and Household Characteristics in New California Houses. Berkely: Ernest Orlando Lawrence Berkeley National Laboratory, 2006. https://escholarship.org/uc/item/8gx9v5fb
35. Pipeline and Hazardous Materials Safety Administration (2019). https://www.phmsa.dot.gov/
36. American Gas Assossiation. Natural Gas State Profiles: Minnesota Industry Facts. https://www.aga.org/knowledgecenter/facts-and-data/state-profiles-natural-gas?state=MN.
37. David Knutson. November house explosion on St. Paul's Payne Avenue deemed accidental, likely natural gas leak. Pioneer Press. March 8, 2009. https://www.twincities.com/2019/03/08/november-house-explosion-on-st-pauls-payne-avenue-deemed-accidental-likely-natural-gas-leak/.
38. PineandLakes Echo Journal. Owner burned in oven explosion at Tasty Pizza North. Brainerd Dispatch. December 27, 2019. https://www.brainerddispatch.com/news/4840367-Owner-burned-in-oven-explosion-at-Tasty-Pizza-North.
39. Staff Reports. Sheriff: Explosion destroys Paynesville house. SC Times. October 22, 2019. https://www.sctimes.com/story/news/local/2019/10/22/sheriff-explosion-destroys-paynesville-house/4066260002/.
40. WCCO-CBS Minnesota. Minnesota house destroyed in massive explosion. WCCO-CBS Minnesota. November 23, 2018. https://www.cbsnews.com/news/minnesota-house-explosion-today-authorities-investigating-after-home-is-leveled-in-st-paul-2018-11-23-live-updates/.
41. Erin Hassanzadeh. Man Recovering After Being Pulled From Burning Home In St. Paul. April 21, 2019 at 5:46 pm. WCCO-CBS Minneapolis. https://minnesota.cbslocal.com/2019/04/21/possible-house-explosion-st-paul-hall-avenue-baker-street-west/.
42. Brian Suilmann, Theresa Ann Snoeyenbos. Man Severely Injured In Hampton House Explosion Dies. WCCO-CBS Minnesota. February 22, 2019. https://minnesota.cbslocal.com/2019/02/22/hampton-house-explosion-man-dies/.
43. Shelby Lindrud. West-central Minnesota city warming back up after overnight gas outage. Grand Forks Herald. Nov 20th 2019. https://www.grandforksherald.com/business/energy-and-mining/4779896-West-central-Minnesota-city-warming-back-up-after-overnight-gas-outage
44. Mike Hughlett. A second natural gas outage in Twin Cities leaves customers in the cold. Star Tribune. November 12, 2019. http://www.startribune.com/centerpoint-energy-shakopee-power-outage-leaves-600-customers-without-gas/564807842/.
45. Sarah Gannon. Farmers face new challenge, diversion of natural gas. My Fox 47. November 11, 2019. https://myfox47.com/2019/11/11/farmers-face-new-challenge-diversion-of-natural-gas/
46. Minnesota Public Utilities Commission. Staff Briefing Papers for Docket No. G-999/AA-18-374, et al, and Docket No. G-008/M-18- 462. Oct 10, 2019.
47. Minnesota Public Utilities Commission. Staff Briefing Papers for Docket No. G-008/GR-19-524. Dec 5, 2019.
48. Energy and Environmental Economics, Inc. Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts. San Francisco: Energy and Environmental Economics, Inc., 2019. https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf
49. https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-nitrogen-dioxide.htm