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DECARBONIZING MINNESOTA'S NATURAL GAS END USES

STAKEHOLDER PROCESS SUMMARY
AND CONSENSUS RECOMMENDATIONS

Co-convened by the Great Plains Institute (GPI) and
Center for Energy and Environment (CEE)



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July 12, 2021

Dear Reader,

This letter accompanies and provides further context for the July 2021 report, issued by the Great Plains Institute (GPI) and Center for Energy and Environment (CEE), titled “Decarbonizing Minnesota’s Natural Gas End Uses: Stakeholder Process Summary and Consensus Recommendations.”

In the fall of 2019, GPI and CEE convened a broad group of stakeholders to explore and develop recommendations around decarbonizing Minnesota’s natural gas end uses. The stakeholder group met regularly over the course of 18 months, ultimately issuing a report describing the stakeholder process, findings, and consensus recommendations.

In 2021, just before publication of the stakeholder report, the Minnesota legislature passed, and Minnesota Governor Walz signed into law, a robust package of energy legislation. That package of legislation included new statutes that pertain to some of the stakeholder group’s recommendations. In fact, several stakeholders, outside of their role in the process, played key roles in shaping and passing that legislation. Below is a brief and high-level description of relevant legislation and how it relates to recommendations of the stakeholder group. The following is intended to provide context and is not an endorsement of any specific legislation.

NATURAL GAS INNOVATION ACT (NGIA)

NGIA establishes a regulatory framework for natural gas and dual-fuel utilities to implement and recover their costs for programs that reduce or avoid greenhouse gas emissions from customers’ use of natural gas. “Innovative resources” eligible for inclusion in a natural gas utility “innovation plan” include biogas; carbon capture; ground-source district energy; energy efficiency measures that go beyond the State’s Conservation Improvement Program (CIP); hydrogen or ammonia produced using carbon-free electricity; renewable natural gas; and strategic electrification, including cold-climate air source heat pumps. NGIA defines the content of innovation plans to be filed with the Minnesota Public Utilities Commission (Commission) and criteria for the Commission to consider when approving, modifying, or rejecting innovation plan proposals. When filing an innovation plan, a utility is required to also submit a “utility system report and forecast,” detailing infrastructure characteristics, projected capital and fuel investments, carbon emissions, and incentive programs with respect to fossil gas. This data will equip the Commission to evaluate a utility’s innovation plan in the context of its other planned investments and activities in fossil gas.

Innovation plan filings are optional for natural gas utilities and recoverable costs are limited in proportion to the operating revenue of the utility filing the innovation plan. NGIA also requires the Commission to open several proceedings to consider how to implement the provisions of NGIA as well as, notably, a docket by August 1, 2021, to evaluate changes to natural gas utility regulatory and policy structures needed to meet or exceed the State’s greenhouse gas reduction goals.

Several provisions of the NGIA bill align closely with recommendations included in the stakeholder report. Recommendation #20 of the stakeholder report, stating that Minnesota's regulatory agencies should develop a framework to allow gas utilities to invest in and recover costs for fuels and technologies to decarbonize their system, aligns closely with provisions included in NGIA around utility investments in innovative resources and the associated innovation plans. Recommendation #20, as well as the broader stakeholder report and the associated modeling, may be informative for regulators, utilities, and stakeholders in developing and reviewing utility innovation plans and innovative resource investments.

Additionally, recommendation #16 of the stakeholder report advises that the Commission initiate a process to explore potential changes to the gas utility regulatory and policy structures to support decarbonization targets. This recommendation aligns with the provision in the NGIA bill for a Commission proceeding to align natural gas utility regulation with state greenhouse gas and renewable energy goals. Recommendation #16 provides further detail regarding key topics and considerations for the Commission proceeding. Therefore, though the NGIA takes the important step of establishing the regulatory proceeding, the conveners of the group believe that recommendation #16 may be useful to regulators, parties, and utilities in further framing and scoping the proceeding.

ENERGY CONSERVATION AND OPTIMIZATION ACT (ECO)

The ECO legislation expands Minnesota's existing CIP, the State's longstanding utility energy efficiency program administered by the Minnesota Department of Commerce (Department), to include load management and efficient fuel-switching, while protecting traditional energy efficiency. ECO increases utilities' ability to offer additional efficient choices for customers and support local job opportunities, as well as increases the amount of money investor-owned utilities must spend on energy efficiency improvements for under-resourced households. The ECO bill allows for utilities to invest in efficient fuel-switching through the program when the fuel-switching improvement: results in a net reduction in the amount of source energy consumed for the end use; results in a net reduction of statewide greenhouse gas emissions; passes cost-effectiveness tests approved by the Department; and improves the utility's system load factor.

The stakeholder group identified energy efficiency and efficient fuel-switching as key strategies for decarbonizing Minnesota's natural gas end uses, regardless of the path taken to achieve decarbonization. As such, ECO aligns closely with and supports several recommendations of the stakeholder group, as well as the associated modeling. Recommendation #10 of the report calls for increased building shell efficiency work in the state. Recommendation #11 calls for increased deployment of air source heat pumps, a highly efficient heating and cooling technology, in the residential sector. Recommendation #15 of the report recommends strategies to reduce energy burden, including energy efficiency and weatherization for low-income households. Recommendation #18 of the stakeholder report, which recommends that decision makers allow fuel-switching through CIP, aligns closely with the efficient fuel-switching provisions of ECO. Finally, recommendation #19, which urges state regulators to re-evaluate the methodology used to determine source energy, informs the types of fuel-switching permitted through ECO.

Each of the recommendations listed above and others included in the report, along with the report modeling and discussion may provide further guidance and support for the implementation of ECO.

MINNESOTA EFFICIENT TECHNOLOGY ACCELERATOR (META)

META enables a nonprofit organization with extensive experience implementing energy efficiency programs in Minnesota and conducting efficient technology research in the state to seek approval from the Department of Commerce to implement a program to accelerate the availability and reduce the cost of emerging and innovative efficient technologies and approaches through strategic initiatives with technology manufacturers, equipment installers, and other key actors in the supply chain. META will address market barriers that often slow down commercialization and deployment of beneficial technologies, ensuring that efficient technology is available and affordable for Minnesota's businesses and households. The benefits of META include cost-effective energy savings for Minnesota utilities, bill savings for Minnesota utility consumers, and new opportunities for a skilled and equitable workforce – while avoiding unnecessary utility infrastructure and significant greenhouse gas emissions.

The stakeholder report as well as the associated modeling describe the importance of technological advancements and accelerated market deployment of emerging efficient technologies. The speed of technological advancements and market deployment will be a key driver of the overall costs and ultimate success of decarbonization. Several stakeholder recommendations speak to specific areas where market acceleration will be especially important. Recommendation #10 describes the need to support innovation in building shell energy efficiency research, development, and deployment. Recommendation #11 supports significant advancements in air-source heat pump deployment for the residential sector, noting specific market considerations. Recommendation #13 calls for reducing barriers to deployment of all-electric and dual-fuel solutions for rooftop units. Each of these recommendations and the modeling discussed in the report may be informative for META activities in the future.

All legislation mentioned above will require new or updated cost-effectiveness practices to evaluate different energy resource options. Coordinating and aligning Minnesota's cost-effectiveness practices across these initiatives, and perhaps in other utility regulatory processes, will help to ensure a cohesive approach to energy policy and decarbonization of natural gas end uses.

CEE and GPI, as the conveners of the stakeholder process, celebrate Minnesota's progress toward advancing the stakeholder group's consensus recommendations and hope that the detailed recommendations included in the process report, as well as the modeling and discussion, provide valuable context and considerations for implementation of the important legislation noted above.

Sincerely,

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¹ Erica Larson joined the advisory committee to represent CenterPoint Energy in March 2021 after Nick Mark changed jobs.

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Unless otherwise noted, graphics in the modeling section of this report were developed by E3.

USAGE OF THIS REPORT

This document summarizes the process, non-consensus discussion points, and consensus recommendations of the Decarbonizing Minnesota's Natural Gas End Uses initiative. The viewpoints stated in the non-consensus discussion portions of this document have been anonymized. No view should be attributed to any specific individual or organization. Moreover, the recommendations captured in this document represent consensus at the time this report was published and should not be used to constrain any party's advocacy efforts in the future.

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ABOUT THE CO-CONVENERS

Great Plains Institute: A nonpartisan, nonprofit organization, GPI is transforming the energy system to benefit the economy and environment. Working across the US, we combine a unique consensus-building approach, expert knowledge, research and analysis, and local action to find and implement lasting solutions. Our work strengthens communities and provides greater economic opportunity through creation of higher paying jobs, expansion of the nation's industrial base, and greater domestic energy independence while eliminating carbon emissions. Learn more at www.betterenergy.org.

Center for Energy and Environment: CEE is a clean energy nonprofit with special expertise in energy efficiency that stretches back nearly 40 years. CEE provides a range of practical and cost-effective energy solutions for homes, businesses, and communities to strengthen the economy while improving the environment. More information is available at www.mncee.org.

QUESTIONS ABOUT THIS REPORT

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GLOSSARY

Biogas. “Gas produced by the anaerobic digestion of biomass, gasification of biomass, or other effective conversion processes.”⁴

Carbon capture. “The capture of greenhouse gas emissions that would otherwise be released into the atmosphere.”⁵

Carbon-neutral. A fuel that has no net lifecycle greenhouse gas emissions.

Carbon-free. A fuel that does not emit greenhouse gases into the atmosphere during its production and use.

Decarbonization. The process of reducing and eventually eliminating greenhouse gas emissions on a timeframe in alignment with the latest recommendations from the United Nations Intergovernmental Panel on Climate Change.

District energy. “A heating or cooling system that is solar thermal powered or that uses the constant temperature of the earth or underground aquifers as a thermal exchange medium to heat or cool multiple buildings connected through a piping network.”⁶

Equity. See the meaning given in this group’s consensus guiding principles, which are included in the process section of this report.

Greenhouse gas emissions. “Emissions of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride emitted by anthropogenic sources within Minnesota and from the generation of electricity imported from outside the state and consumed in Minnesota, excluding carbon dioxide that is injected into geological formations to prevent its release to the atmosphere in compliance with applicable laws.”⁷

Lifecycle greenhouse gas emissions. “The aggregate greenhouse gas emissions resulting from the production, processing, transmission, and consumption of an energy resource.”⁸

Lifecycle greenhouse gas emissions intensity. The “lifecycle greenhouse gas emissions per unit of energy delivered to an end user.”⁹

⁴ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021), online, accessed June 30, 2021, http://wdoc.house.leg.state.mn.us/leg/LS92/1_2021/HF0006.1.pdf.

⁵ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

⁶ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

⁷ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

⁸ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

⁹ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

Power-to-hydrogen. The use of electricity generated by a carbon-free resource to produce hydrogen.¹⁰ The modeling included in this report assumes hydrogen that has been produced with wind energy to achieve decarbonization by 2050.

Renewable natural gas. “Biogas that has been processed to be interchangeable with, and that has a lower lifecycle greenhouse gas intensity than, natural gas produced from conventional geologic sources.”¹¹ The modeling included in this report assumes renewable natural gas that is carbon-neutral to achieve decarbonization by 2050.

Synthetic methane or synthetic natural gas. Methane that has been synthetically produced. For the purposes of this report and the associated modeling, we assume it has been produced using a carbon-neutral process to achieve decarbonization by 2050.

¹⁰ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

¹¹ Minn. H.F.6 art. 8, sec. 20, subdivision 1 (2021).

I. Executive Summary

BACKGROUND

Natural gas is an important source of energy in Minnesota that has historically provided affordable and reliable heat to homes and businesses through the state's extreme winters, as well as fuel for industrial processes. Today, natural gas is used to heat over 63 percent of Minnesota homes and it is the primary fuel for high-heat industrial processes.¹² However, natural gas usage also contributes significant amounts of greenhouse gas emissions, and those emissions are increasing. As a result of significant economic, policy, and technology changes that have occurred since 2005, the electric system continues to decarbonize. Meanwhile, natural gas emissions from Minnesota's residential, commercial, and industrial sectors have increased substantially in the same time period. Much of this increase is driven by increased natural gas consumption. As the electric system continues to decarbonize, natural gas emissions will likely eclipse emissions from the electric sector.

The United Nations Intergovernmental Panel on Climate Change (IPCC) says that to avoid the most severe and irreversible consequences of climate change, we must limit warming to no more than 1.5 degrees Celsius. To do so, global greenhouse gas emissions must fall by 45 percent from 2010 to 2030 and reach net-zero emissions by 2050.¹³ Accordingly, Minnesota and several other states have established goals to achieve significant greenhouse gas emissions reductions by 2050.

The timeframe for action to curb the worst effects of climate change is short, yet energy infrastructure changes take time and require careful planning to ensure reliability and affordability. Given the complex challenges of addressing emissions from Minnesota's natural gas end uses, the Great Plains Institute (GPI) and Center for Energy and Environment (CEE) convened a stakeholder group over 18 months to explore pathways and develop potential solutions to drastically reduce or eliminate these greenhouse gas emissions.¹⁴ This report documents the stakeholder process, scenario modeling that was completed to support the process, and the group's final consensus recommendations.

¹² "Primary Space Heating Types in Minnesota Homes," Center for Energy and Environment, published on Tableau, November 19, 2020, <https://public.tableau.com/profile/center.for.energy.and.environment#!/vizhome/PrimarySpaceHeatingTypesinMinnesotaHomes/SpaceHeatingEnergyFlow>.

¹³ "Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments," IPCC (blog), accessed April 23, 2021, <https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/>.

¹⁴ While transportation is also a natural gas end use, the current amount of natural gas used for transportation in Minnesota is extremely small compared to use in buildings and industry, therefore this process did not consider decarbonization of natural gas used for transportation.

PROCESS

In fall of 2019, GPI and CEE recruited a broad mix of stakeholders to participate in a series of conversations about decarbonizing Minnesota’s natural gas end uses. The participants included natural gas and electric utilities, utility regulators, natural gas consumers, clean energy advocates, clean energy implementers, environmental advocates, consumer advocates, workforce advocates, and state and local governments. The process was designed to accomplish the following objectives:

- Build a shared understanding among stakeholders of the current situation of natural gas end uses in Minnesota, including the characteristics of the existing natural gas system and utility business models, emerging technology options, and consumer and environmental considerations.
- Develop a set of shared guiding principles for effectively assessing decarbonization options for natural gas end uses, in consideration of the wide variety of perspectives and opinions on this matter.
- Develop a handful of possible natural gas end-use decarbonization scenarios for the purposes of exploring how Minnesota should approach this challenge, and to facilitate an understanding of the challenges, opportunities, and potential actions associated with each scenario.¹⁵
- Develop one or multiple shared visions of what is needed to help Minnesota meet its aggressive decarbonization goals with respect to natural gas end uses.

The stakeholder group met for 15 meetings from November 2019 to April 2021. Each meeting included participation from the stakeholder group, facilitation by GPI and CEE, and presentations by subject matter experts from within or outside the group. All meetings were five and a half hours in length, with the first three meetings in-person and the rest held virtually due to the COVID-19 pandemic.

To help guide the process, GPI and CEE also facilitated regular meetings of an advisory committee made up of representatives from CenterPoint Energy and Xcel Energy (Minnesota’s two largest natural gas utilities), Fresh Energy (a leading clean energy advocacy organization), and the City of Minneapolis (Minnesota’s most populous city).

SCENARIO MODELING AND PATHWAY TO 2050 DISCUSSION

It became clear during the stakeholder meetings that considering how to decarbonize natural gas end uses in Minnesota is an endeavor that requires planning around an uncertain future. In response, the advisory committee hired Energy and Environmental Economics, Inc. (E3) to

¹⁵ GPI and CEE had originally proposed an additional objective to “identify research needs and form technical committees to pursue research as warranted, including a possible statewide potential study to better understand and compare emerging low-carbon technologies and fuels that may be options for cost-effectively meeting our carbon emissions reduction goals.” Due to funding limitations, this was not pursued, however the scenario modeling described later in this report partially addressed this.

model a handful high-level scenarios for decarbonizing natural gas end uses by 2050 in Minnesota.¹⁶ The purpose of the scenario modeling was to give the stakeholder group a structured way to discuss an uncertain future in light of many complexities and interdependencies that would be difficult to understand without modeling tools. Given limited financial resources to support modeling, the advisory committee asked E3 to produce a slide deck with modeling results rather than a written report. The modeling process and results are detailed further in the scenario modeling section of this report.

Stakeholders also discussed whether there was consensus for or against a general pathway to decarbonizing Minnesota's natural gas end uses based on the modeling results. These spirited and important discussions surfaced different perspectives within the group about what that pathway should be and even whether any pathway should be chosen at this point in time.

Some stakeholders in this group felt strongly that Minnesota must choose a path and begin taking action to pursue that path immediately to avoid the worst impacts of climate change. Other stakeholders felt just as strongly that choosing a path now could limit innovation that may be needed to achieve decarbonization of Minnesota's economy by 2050. While stakeholders agreed that multiple pathways could achieve carbon neutrality by 2050, some felt that only certain pathways would enable achieving carbon-negative emissions after 2050, as determined necessary by the IPCC and International Energy Agency¹⁷ to avoid the worst impacts of climate change.

Despite these different perspectives, all stakeholders agreed that decarbonizing natural gas end uses will require immediate investments in research, development, and deployment of energy efficiency, electrification, renewable natural gas, and hydrogen, though there was disagreement about how best to deploy those resources in the buildings sector. Most importantly, all stakeholders agreed that there are several strategies ready for deployment today, as described in the consensus recommendations section of this report.

CONSENSUS RECOMMENDATIONS

Over the course of several discussions, all stakeholders came to agreement that achieving Minnesota's greenhouse gas emissions reduction goals will require an immediate, definitive departure from the state's current trajectory of natural gas use in buildings and industry, and toward a pathway that will lead to a significant amount of decarbonization of natural gas end uses. While there is ongoing debate about what exactly the new pathway should look like, the group's consensus recommendations lay out what can and must be done now to begin developing any successful pathway. In addition, several recommendations include actions that will help to resolve disagreement about what the pathway should look like. A summary version of each consensus recommendation is listed below. A more detailed version of each

¹⁶ More information about E3 is available at <https://www.ethree.com/about/overview/>.

¹⁷ International Energy Agency, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, (June 2021), https://iea.blob.core.windows.net/assets/405543d2-054d-4cbd-9b89-d174831643a4/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.

recommendation, as well as the rationale for each recommendation, is included in the consensus recommendations section of this report.

Recommendations 1-15 are not targeted at a specific actor because the group was either unsure of who would be best suited to implement the recommendation or felt that many different actors must collaborate to successfully implement it. The group acknowledges that more work is needed to develop and refine the implementation details for these recommendations.¹⁸

Recommendations 16-25 are specifically targeted at the Minnesota Public Utilities Commission, Minnesota Department of Commerce, and Minnesota Pollution Control Agency in recognition of the important and vital role that these regulatory agencies will need to play in decarbonizing Minnesota's natural gas end uses.

Recommendations 1 and 2 express strategies that are broadly applicable to all other recommendations and all sectors of the economy:

1. Ensure equity and equitable engagement are thoroughly incorporated into all efforts, initiatives, and research to decarbonize Minnesota's natural gas end uses.¹⁹
2. Conduct education and outreach for all Minnesotans to increase awareness and understanding of what they need to do to advance decarbonization of natural gas end uses.

Recommendations 3 through 6 all seek to better understand decarbonization options and impacts to support wise decision-making in the near term:

3. Assess options for deploying district energy systems to support natural gas end-use decarbonization.
4. Conduct two studies, paired with stakeholder engagement, to better define the various natural gas end uses for (1) the large commercial sector and (2) the industrial sector, and match decarbonization technologies to those end uses.
5. Explore opportunities for infrastructure investments that can provide lower- or zero-carbon energy, such as hydrogen or renewable natural gas, to industrial and large commercial customers.
6. Conduct a workforce impact study around the three decarbonization scenarios that this group explored. The study should transparently account for impacts on the number of jobs, the types of jobs, and worker compensation, including both wages and benefits.

Recommendations 7 through 9 seek to ensure Minnesota maintains and builds a robust workforce with family-sustaining jobs as natural gas end uses are decarbonized:

¹⁸ At the time of writing this report, GPI and CEE are actively fundraising to support a second phase of stakeholder engagement in which these implementation details can be developed and refined.

¹⁹ The group's consensus guiding principles, which are included in the process section of this report, further define what is meant by equity here.

7. Improve gas and electric utility workforce reporting requirements, including reporting for utility contractors and programs sponsored or administered by utilities.
8. Address energy sector workforce gaps that need to be addressed regardless of the pathway to decarbonizing natural gas end uses.
9. Ensure Minnesota's workforce has the training and expertise necessary to support decarbonization of natural gas end uses.

Recommendations 10 through 15 are targeted at ensuring Minnesota's homes and small businesses are retrofitted to support decarbonization while also attending to affordability, health, and safety:

10. Advance building shell efficiencies well beyond the current trajectory.
11. Significantly advance air-source heat pump deployment for the residential sector, including multifamily housing.
12. During any building envelope retrofits, take the opportunity to address health and safety considerations.
13. For existing buildings with rooftop units, reduce barriers to deployment of all-electric and dual-fuel solutions.
14. Address split incentives that pose barriers to implementing energy efficiency and technology adoption.²⁰
15. Develop policies, programs, and actions to reduce and maintain energy burden below 6 percent for all Minnesota households, to both lessen existing inequities in energy burden and ensure that the costs of the transition are not borne disproportionately by the most under-resourced Minnesotans.

Recommendation 16 is especially important to carry forward this group's work, as it would allow the stakeholder group discussions to continue in a public format where a factual record can be developed and decisions can be made and enforced based on that record:

16. The Minnesota Public Utilities Commission should initiate a process to evaluate opportunities and considerations for changes to gas utility regulatory and policy structures needed to support cost-effective and equitable achievement of the state's economywide greenhouse gas reduction goals and net-zero greenhouse gas emissions by 2050.

Recommendations 17 through 24 lay out a series of regulatory actions that are necessary to support decarbonization of natural gas end uses:

²⁰ A split incentive occurs when the costs and benefits of adopting an energy efficiency or electrification technology are asymmetrically split between two parties, such as a renter and property owner.

17. The Minnesota Department of Commerce should review and update as needed the Conservation Improvement Program (CIP) cost-effectiveness framework to ensure that it is aligned with state decarbonization goals.
18. Decision makers should modify CIP to allow fuel switching and load management that enables the adoption of highly efficient decarbonization technologies.
19. The Department of Commerce should re-evaluate the methodology used to determine source energy from electric generation, to ensure it reflects the current mix of a utility's electric generation resources.
20. Minnesota's regulatory agencies, in consultation with utilities and stakeholders, should develop a framework that requires and/or incentivizes gas utilities to integrate fuels and technologies to achieve decarbonization.
21. Minnesota's regulatory agencies should implement regulatory reforms to prioritize utility procurement of natural gas and decarbonized gaseous fuels from producers that have adopted management practices to reduce greenhouse gas emissions across the entire process chain.
22. Minnesota's regulatory agencies should implement regulatory reforms to prioritize leakage reduction strategies across utility-owned and operated infrastructure systems, including storage and distribution facilities.
23. Minnesota's regulatory agencies should implement mechanisms to advance research, development, and deployment of innovative clean technologies to reduce greenhouse gas emissions across the natural gas supply chain.
24. The Minnesota Public Utilities Commission should require electric utilities to consider electric load and peak impacts resulting from natural gas decarbonization scenarios in their integrated resource plans and integrated distribution plans.

Finally, recommendation 25 seeks to equitably address the complex challenge of managing the costs of decarbonization:

25. Implement a stakeholder process to consider potential changes to gas and electric rate design and utility financing mechanisms to support an affordable and equitable transition to a decarbonized energy system.

In taking action now to advance these recommendations, Minnesota has an opportunity to achieve its greenhouse gas emissions reduction goals by 2050 and become a leader among similar cold climate states that will need to address many of the same challenges.

II. Background

Greenhouse gases, including carbon dioxide and methane, trap heat. Over the past 150 years, human activities—primarily extracting and burning fossil fuels for power and heat—have increased the amount of greenhouse gases in Earth’s atmosphere, warming the planet.²¹ Since the industrial revolution, the Earth’s temperature has increased by about one degree Celsius on average. However, some parts of the planet have experienced greater changes.²² According to the Minnesota Pollution Control Agency, “in the Twin Cities, annual average temperatures increased by [1.8° Celsius] from 1951 to 2012, which was faster than both national and global rates of increase.”²³

Current levels of warming have resulted in more extreme and frequent weather events, rising sea levels, diminishing Arctic sea ice, and other, localized impacts. The Intergovernmental Panel on Climate Change says that to avoid the most severe and irreversible consequences of climate change, we must limit warming to no more than 1.5 degrees Celsius. To do so, global greenhouse gas emissions must fall by 45 percent from 2010 to 2030 and reach net-zero emissions by 2050. This scale of emissions reductions will involve major mitigation efforts across all sectors of the global economy and in all areas of the planet.²⁴ These efforts could have significant economic and socioeconomic impacts, and therefore must be pursued thoughtfully.

Buildings and industry contribute significant amounts of greenhouse gases. In the United States, industry contributes about 22 percent of total national greenhouse gas emissions, mostly from burning fossil fuels on-site for energy. Commercial and residential buildings contribute about 13 percent of total greenhouse gas emissions, primarily from burning fossil fuels on-site for space heating, water heating, cooking, and clothes drying.²⁵ Because natural gas is relatively inexpensive and plentiful in the United States, it is increasingly the fossil fuel of choice for industry and buildings and is therefore a major driver of emissions in those sectors.

Natural gas emits greenhouse gases into the atmosphere through combustion and leakage. Combustion emissions, primarily in the form of carbon dioxide, occur when natural gas is burned and typically make up the majority of emissions associated with natural gas use. Natural gas leakage also contributes to greenhouse gas emissions in the form of methane. Natural gas

²¹ “Sources of Greenhouse Gas Emissions,” US Environmental Protection Agency (EPA) (website), last modified April 14, 2021, <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions>.

²² Alan Buis, “A Degree of Concern: Why Global Temperatures Matter,” NASA’s Global Climate Change Website, June 19, 2019, <https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/>.

²³ “Effects of Climate Change in Minnesota,” Minnesota Pollution Control Agency (website), December 21, 2018, <https://www.pca.state.mn.us/air/effects-climate-change-minnesota>.

²⁴ “Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments,” IPCC (blog), accessed April 23, 2021, <https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/>.

²⁵ “Sources of Greenhouse Gas Emissions,” EPA (website), last modified April 14, 2021, <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions>.

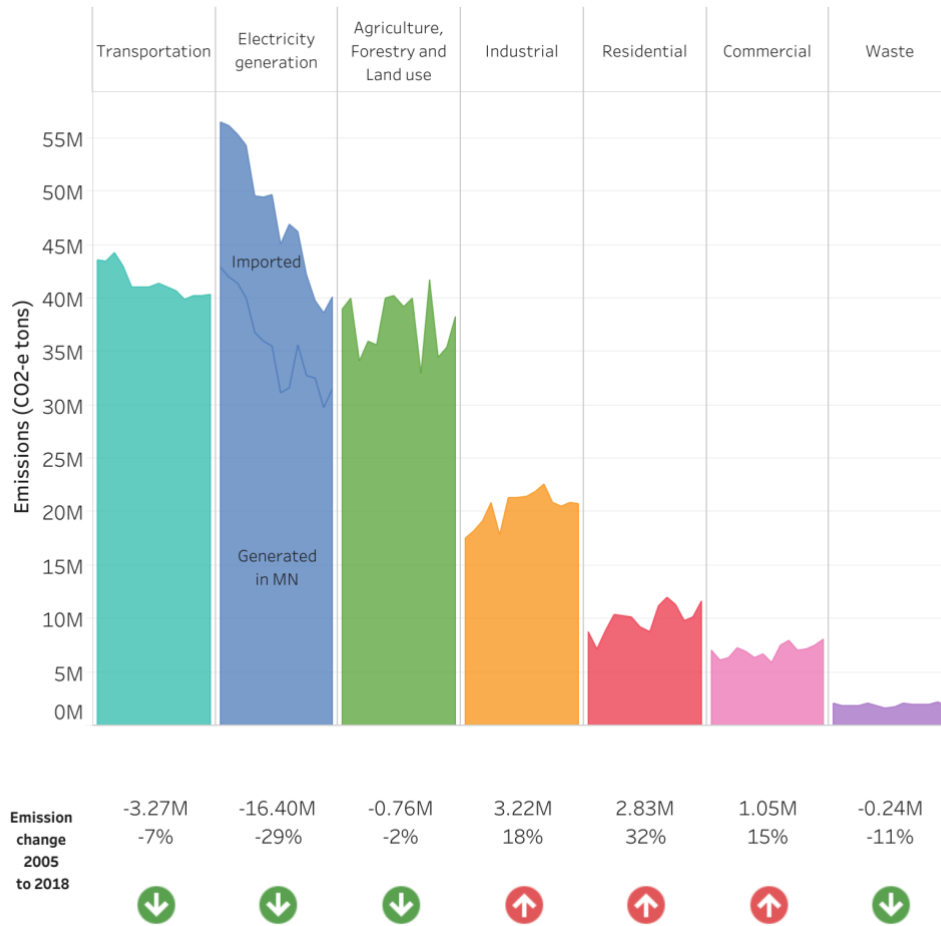
is almost entirely made up of methane, which—while it remains in the atmosphere for less time than carbon dioxide—is a potent greenhouse gas with a warming potential between 28 and 86 times that of carbon dioxide.²⁶ During the production, transmission, distribution, and use of natural gas, some amount of it leaks into the atmosphere. The majority of methane leakage from the natural gas industry occurs during production, processing, and transmission, upstream from the local distribution system that delivers natural gas to buildings and industry in Minnesota. However, a non-trivial amount of leakage also occurs within local natural gas distribution systems from storage facilities, distribution pipes, and other infrastructure.

In Minnesota, 2018 greenhouse gas emissions from buildings and industry contributed nearly the same amount of emissions as the state’s electric system.²⁷ Unlike the electric sector, which has experienced significant reductions in emissions since 2005 as a result of economic, policy, and technology changes, emissions from Minnesota’s buildings and industry have increased substantially in the same time period. As the electric system continues to decarbonize, natural gas emissions will likely eclipse emissions from the electric sector. Figure 1 illustrates emissions trends in Minnesota by sector. The residential, commercial, and industrial sectors reflect emissions from Minnesota’s buildings and industrial processes, mainly from natural gas use but also from propane and fuel oil. Importantly, while buildings and industry use electricity, the emissions from that electricity use are captured in the electricity generation category.

²⁶ G. Myhre, D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura, and H. Zhang, *Anthropogenic and Natural Radiative Forcing*, in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (Cambridge and New York: Cambridge University Press, 2013), https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf. Greenhouse gases differ both in their radiative efficiency (how much energy they absorb, thus warming the Earth) and their atmospheric lifetimes. Global warming potential (GWP) is an accepted metric to compare the warming impact of one ton of any non-carbon dioxide greenhouse gas to one ton of carbon dioxide, over a chosen period of time. The Intergovernmental Panel on Climate Change estimates that the GWP of methane is between 84-86 over a 20-year period, and between 28-34 over a 100-year period.

²⁷ “Greenhouse Gas Emissions Data,” Minnesota Pollution Control Agency (website), accessed June 9 2021, <https://www.pca.state.mn.us/air/greenhouse-gas-emissions-data>.

Figure 1. Emissions trends in Minnesota by sector

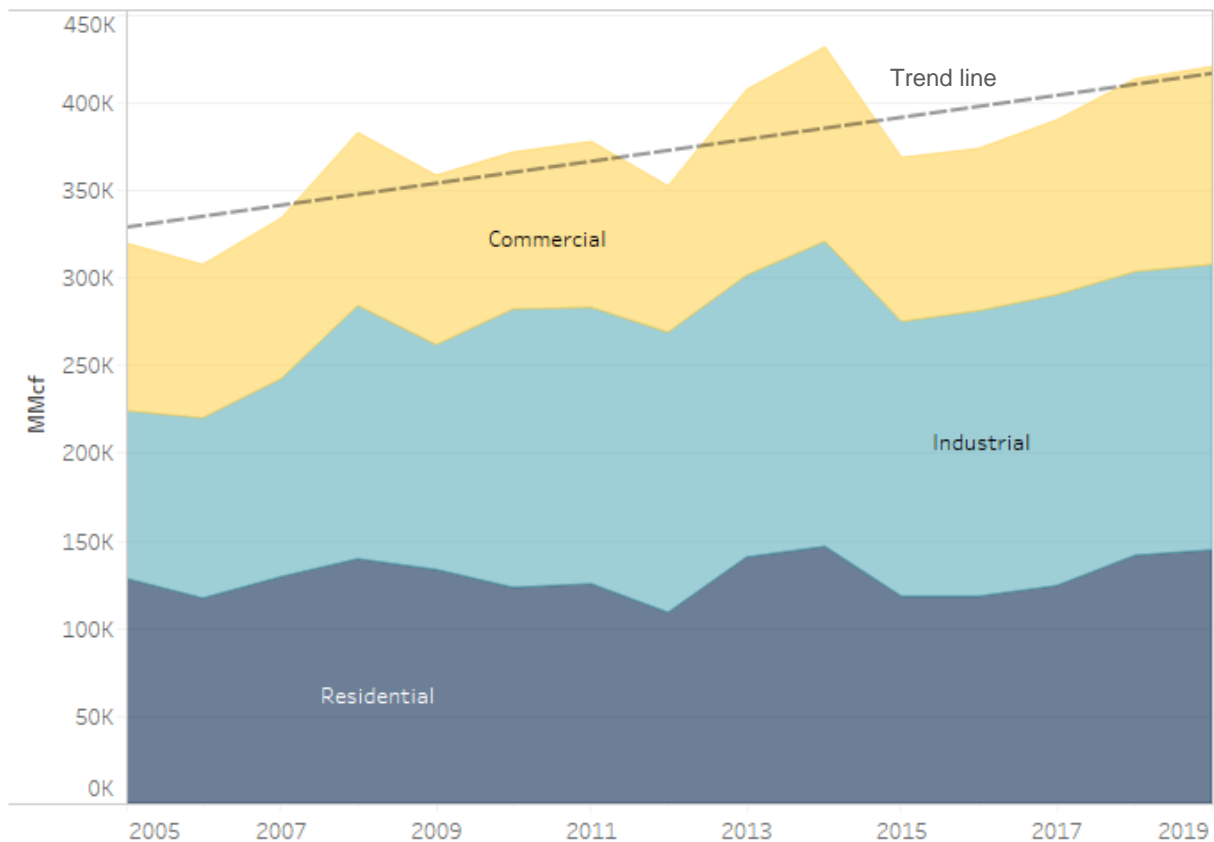


Republished from “Greenhouse Gas Emissions Data,” Minnesota Pollution Control Agency (website), accessed May 19, 2021, <https://www.pca.state.mn.us/air/greenhouse-gas-emissions-data>.

As noted above, the primary driver of increased emissions in Minnesota’s buildings and industries is natural gas. From 2005 to 2019, natural gas consumption in Minnesota’s residential, commercial, and industrial sectors increased by 32 percent overall. Figure 2 depicts Minnesota’s natural gas consumption in buildings and industry from 2005 to 2019.²⁸

²⁸ Natural gas consumption in buildings varies significantly with weather. Weather variability may explain the year-to-year ups and downs in natural gas consumption.

Figure 2. Natural gas consumption in Minnesota (residential, commercial, and industrial)



Adapted from *It All Adds Up: Emissions from Minnesota's Natural Gas Consumption*, Center for Energy and Environment, accessed April 23, 2021, <https://www.mncee.org/it-all-adds-emissions-minnesotas-natural-gas-consumption>.

Despite the emissions associated with its consumption, natural gas is an important source of energy in Minnesota that provides affordable and reliable heat to homes and businesses through the state's extreme winters. Today, over 63 percent of Minnesota homes are heated with natural gas.²⁹ Natural gas is also an important fuel for many of Minnesota's largest businesses.

The timeframe for action to curb the worst effects of climate change is short, yet energy infrastructure changes take time and require careful planning to ensure reliability and affordability. While Minnesota has made progress towards decarbonizing its electric system, it has not contributed the same level of effort towards decarbonizing the natural gas system.

²⁹ "Primary Space Heating Types in Minnesota Homes," Center for Energy and Environment, published on Tableau, November 19, 2020, <https://public.tableau.com/profile/center.for.energy.and.environment#!/vizhome/PrimarySpaceHeatingTypesinMinnesotaHomes/SpaceHeatingEnergyFlow>.

Given the complex challenges of addressing emissions from Minnesota’s natural gas end uses, GPI and CEE initiated a stakeholder process in fall of 2019 to explore pathways and develop potential solutions to drastically reduce or eliminate those greenhouse gas emissions.³⁰ This report documents the stakeholder process, scenario modeling conducted to support the process, and the group’s final consensus recommendations.

³⁰ While transportation is also a natural gas end use, the current amount of natural gas used for transportation in Minnesota is extremely small compared to use in buildings and industry, therefore this process did not consider decarbonization of natural gas used for transportation.

III. Process

This section of the report describes the process that stakeholders followed to discuss decarbonizing Minnesota natural gas end uses and reach consensus on the recommendations presented in this report.

In fall of 2019, GPI and CEE began recruiting participants for a year-long process of monthly discussions around decarbonizing Minnesota's natural gas end uses,³¹ with the intention of creating space to discuss the challenge and fostering honest conversation about potential decarbonization strategies. In particular, the process sought to explore the following topics:

- The range of possible fuel and technological options, including consideration of their scalability, cost, and carbon mitigation potential, to meet Minnesota's heating and process loads that are currently fueled by natural gas.
- The role of natural gas utilities and existing distribution infrastructure in a decarbonized economy, including ways in which existing distribution infrastructure may be an asset for decarbonization (e.g., for end uses that are difficult to electrify, integration of renewable natural gas and hydrogen, and long duration energy storage).
- Potential changes in the current regulatory model or utility business model, for both gas-only and combined electric and gas utilities, that would enable decarbonization of natural gas end uses by 2050 while maintaining financially healthy utilities, reliable service, and affordable energy costs for all customers, particularly low- and moderate-income customers.
- Equity and workforce impacts that might result from various natural gas decarbonization strategies.

OBJECTIVES

GPI and CEE designed the overall stakeholder engagement process to accomplish the following objectives:

- Build a shared understanding among stakeholders of the current situation of natural gas end uses in Minnesota, including the characteristics of the existing natural gas system and utility business models, emerging technology options, and consumer, workforce, and environmental considerations.
- Develop a set of shared guiding principles for effectively assessing decarbonization options for natural gas end uses, in consideration of the wide variety of perspectives and opinions on this matter.
- Develop a handful of possible natural gas end-use decarbonization scenarios for the purpose of exploring how Minnesota should approach this challenge, and to facilitate an

³¹ This process focused on end uses in residential and commercial buildings, and in the industrial sector. While transportation is also a natural gas end use, the current amount of natural gas used for transportation in Minnesota is extremely small compared to use in buildings and industry.

understanding of the challenges, opportunities, and potential actions associated with each scenario.³²

- Develop one or multiple shared visions of what is needed to help Minnesota meet its aggressive decarbonization goals with respect to natural gas end uses.

Importantly, developing consensus recommendations was not a requirement of the process, but rather an option that was left open for the group to consider. As described later in this report, the group did ultimately reach consensus on a list of recommendations.

ADVISORY COMMITTEE

To help guide the process, GPI and CEE recruited and facilitated an advisory committee made up of representatives from Minnesota's two largest natural gas utilities, one of its leading clean energy advocacy organizations, and its most populous city. The advisory committee met regularly throughout the entire process to advise on process structure, timeline, and meeting content. It also funded the group's scenario modeling (see page 14) and agreed to the modeling assumptions by consensus.

The following individuals participated in the advisory committee:

- Dr. Margaret Cherne-Hendrick, Fresh Energy
- Luke Hollenkamp, City of Minneapolis, Sustainability Division
- Erica Larson, CenterPoint Energy³³
- Dr. Sydnie Lieb, Xcel Energy
- Nick Mark, CenterPoint Energy³⁴
- Nick Martin, Xcel Energy

PARTICIPANTS

The stakeholders who participated in this process represent a broad mix of perspectives important to decarbonizing natural gas end uses, including natural gas and electric utilities, utility regulators, natural gas consumers, clean energy advocates, clean energy implementers, environmental advocates, consumer advocates, workforce advocates, and state and local governments. While the COVID-19 pandemic limited participation for some organizations, many were able to continue participating. The following individuals participated in this process and agreed to the consensus recommendations on behalf of their organization unless otherwise noted:

³² GPI and CEE had originally proposed an additional objective to "identify research needs and form technical committees to pursue research as warranted, including a possible statewide potential study to better understand and compare emerging low-carbon technologies and fuels that may be options for cost-effectively meeting our carbon emissions reduction goals." Due to funding limitations, this was not pursued, however the scenario modeling described later in this report partially addressed this.

³³ Erica Larson joined the advisory committee to represent CenterPoint Energy in March 2021 after Nick Mark changed jobs.

³⁴ Nick Mark participated on the advisory committee on behalf of CenterPoint Energy until March 2021, at which point he changed jobs. He now works for Xcel Energy.

- Adam Zoet, Minnesota Department of Commerce*
- Adway De, Minnesota Department of Commerce*
- Alexis Troschinetz, Clean Energy Resource Teams
- Bree Halverson, BlueGreen Alliance
- Caroline Arkesteyn, Ever-Green Energy
- Carolyn Berninger, Minnesota Center for Environmental Advocacy
- Erica Larson, CenterPoint Energy
- Ethan Warner, CenterPoint Energy
- Frank Kohlasch, Minnesota Pollution Control Agency*
- Gary Thaden, Minnesota Mechanical Contractors Association
- Jim Phillippo, Minnesota Energy Resources Corporation*
- Katherine Teiken, Minnesota Housing*
- Kevin Lee, BlueGreen Alliance
- Kevin Pranis, LIUNA Minnesota and North Dakota
- Luke Hollenkamp, City of Minneapolis, Sustainability Division
- Dr. Margaret Cherne-Hendrick, Fresh Energy
- Max Kieley, Minnesota Office of the Attorney General, Residential Utilities Division*
- Nick Mark, CenterPoint Energy³⁵
- Nick Martin, Xcel Energy
- Nina Axelson, Ever-Green Energy
- Shane Stennes, University of Minnesota
- Dr. Sydnie Lieb, Xcel Energy

** Individuals marked with an asterisk participated as observers only, which means they provided information to support discussions, but were not asked to agree to the final recommendations.*

MEETINGS

GPI and CEE convened stakeholders for 15 meetings from November 2019 to April 2021. Each meeting included participation from the stakeholders listed above, facilitators from GPI and CEE, and external experts from within or outside the group as noted below. All meetings were five and a half hours in length, with the first three meetings in-person and the rest held virtually due to the COVID-19 pandemic. A brief list of the topics covered at each meeting and guest presenters is provided below.

Meeting 1 (November 6, 2019 – Minneapolis, MN)

- Began to build a shared understanding of the current landscape for decarbonizing natural gas end uses, the motivating factors for this initiative, and the goals and desired outcomes for the process.
 - *Presentation by Audrey Partridge, Center for Energy and Environment*
- Collected an initial set of stakeholder observations about the current state of the natural gas system in Minnesota, with an eye towards decarbonization.

³⁵ Ibid.

- Began identifying guiding principles that could provide boundaries to support a productive process (refined in subsequent meetings).

Meeting 2 (January 10, 2020 – Minneapolis, MN)

- Built a shared understanding of how natural gas consumption contributes to greenhouse gas emissions and other pollutants.
 - *Presentation by Dr. Margaret Cherne-Hendrick, Fresh Energy: Emissions and pollutants associated with natural gas.*
- Built a shared understanding of the breakdown of natural gas end uses across Minnesota, including from the perspective of the state and different sized cities.
 - *Presentation by Adam Zoet, Minnesota Department of Commerce: Characterizing natural gas end uses across Minnesota.*
 - *Presentations by Luke Hollenkamp, City of Minneapolis and Abby Finis, Great Plains Institute: City-level perspectives on natural gas end uses and emissions impacts.*
- Refined guiding principles through facilitated discussion.

Meeting 3 (February 14, 2020 – Minneapolis, MN)

- Checked in and collected feedback on the process we are following as a group.
- Built a shared understanding of recent work on natural gas decarbonization in other states, as well as considerations for Minnesota:
 - *Presentation by Dan Aas, E3: Summary of recent E3 research on decarbonizing natural gas end uses, including strategies, insights from California, New York, and Xcel Energy's IRP, and key considerations for Minnesota.*
- Discussed certainties and uncertainties around decarbonizing natural gas end uses and identified knowledge gaps that the group would like to explore further.

Meeting 4 (March 13, 2020 – Virtual)

- Built a shared understanding of how the natural gas system currently works.
 - *Presentation by John Heer, CenterPoint Energy: Overview of the natural gas system.*
- Build a better understanding of current utility decarbonization strategies.
 - *Presentation by Erica Larson and Amber Lee, CenterPoint Energy: What is CenterPoint doing and planning around decarbonization strategies?*
 - *Presentation by Lauren Wilson, Xcel Energy: What is Xcel Energy doing and planning around decarbonization strategies?*
- Discussed the certainties and uncertainties around natural gas end-use decarbonization that were drafted at the previous meeting.

Meeting 5 (April 10, 2020 – Virtual)

- Built a shared understanding of the current state and future potential for energy efficiency and geothermal technologies to help decarbonize natural gas end uses.
 - *Presentation by Carl Nelson and Jon Blaufuss, Center for Energy and Environment: Insights from the 2020-2029 Minnesota Energy Efficiency Potential Study.*
 - *Presentation by Audrey Schulman and Zeyneb Magavi, Home Energy Efficiency Team (HEET): The GeoMicroDistrict, a novel path to building electrification.*
 - *Presentation by Nina Axelson, Ever-Green Energy: District energy decarbonization trends—emerging opportunities for geexchange and beneficial electrification.*
- Discussed opportunities, challenges, questions, and conclusions with respect to energy efficiency and geothermal technologies as strategies to decarbonize natural gas end uses.

Meeting 6 (May 8, 2020 – Virtual)

- Checked in on the overall process, reviewed content covered to date, and identified key takeaways and questions at this point.
- Prioritized and discussed the most important uncertainties around decarbonizing natural gas end uses, with attention to the group’s Guiding Principles.
- Discussed and identified the factors that stakeholders would like to use to understand and evaluate technologies and approaches for decarbonizing natural gas end uses.

Meeting 7 (June 12, 2020 – Virtual)

- Built a shared understanding of the current state and future potential for electrification to help decarbonize natural gas end uses.
 - *Presentation by Franz Litz and Jessi Wyatt, Great Plains Institute: Midcontinent Power Sector Collaborative—Buildings decarbonization road map summary and modeling outputs.*
 - *Presentation by Joshua Quinnell and Alex Haynor, Center for Energy and Environment: Recent research, opportunities, and challenges for cold climate air-source heat pumps.*
- Discussed opportunities, challenges, questions, and conclusions with respect to electrification as a strategy to decarbonize natural gas end uses.

Meeting 8 (July 17, 2020 – Virtual)

- Built a shared understanding of the current state and future potential for alternative gaseous fuels to help decarbonize natural gas end uses.
 - *Presentation by Tom Cyrs, World Resources Institute: Role of biogas and RNG in decarbonization—opportunities and drivers.*
 - *Presentation by Dr. Jennifer Kurtz and Michael Peters, National Renewable Energy Laboratory (NREL): Hydrogen research at NREL.*

- Discussed opportunities, challenges, questions, and conclusions with respect to alternative gaseous fuels as a strategy to decarbonize natural gas end uses.

Meeting 9 (August 14, 2020 – Virtual)

- Introduced the E3 team to this group and built a shared understanding of E3's modeling capabilities and scope for this project.³⁶
 - *Presentation by Niki Lintmeijer, Dan Aas, Gabe Mantegna, and Charles Li, E3: scenario examples and how modeling works; possible Minnesota scenario narratives.*
- Discussed and sought consensus on three natural gas end-use decarbonization scenarios that the group collectively wanted to see modeled.

Meeting 10 (September 16, 2020 – Virtual)

- Built a shared understanding of workforce and equity opportunities and challenges.
 - *Presentation by Kevin Lee, BlueGreen Alliance: Natural gas workforce.*
 - *Presentation by Ben Passer, Fresh Energy: Equity considerations in the natural gas system.*
- Discussed opportunities, challenges, questions, and conclusions with respect to workforce and equity considerations around decarbonizing natural gas end uses.

Meeting 11 (November 13, 2020 – Virtual)

- Built a shared understanding of the scenario modeling results.
 - *Presentation by Niki Lintmeijer, Dan Aas, Gabe Mantegna, and Charles Li, E3: decarbonization of natural gas end uses, final results.*

Meeting 12 (January 29, 2021 – Virtual)

- Discussed the biggest benefits/opportunities and drawbacks/risks for each of the three scenarios, based on the modeling results.
- Identified the most important certainties and uncertainties that the modeling results indicate to inform the group's development of recommendations.
- Discussed whether there was consensus for one or more preferred pathways to decarbonization.

Meeting 13 (February 26, 2021 – Virtual)

- Discussed how the recent cold weather induced natural gas price spike impacts this group's work.
- Reviewed, discussed, and refined draft recommendations being developed by the subgroups (see more on subgroups below). Sought to identify clarifying questions and feedback.

³⁶ E3 was hired by the advisory committee to conduct scenario modeling for the stakeholder group. Additional details are included in the modeling section of this report.

Meeting 14 (March 26, 2021 – Virtual)

- Reviewed and refined the consensus recommendations.

Meeting 15 (April 16, 2021 – Virtual)

- Reviewed and refined this report.

GUIDING PRINCIPLES

In the initial meetings of the process, GPI and CEE asked stakeholders to jointly develop a set of consensus guiding principles. The principles were intended to declare what the stakeholders in this process collectively aspired to achieve or maintain through decarbonizing Minnesota's natural gas end uses. They were used to guide the group throughout the entire process, including exploring strategies and scenarios for decarbonization of Minnesota's natural gas end uses, as well as developing the final recommendations included in this report. The guiding principles are meant to be taken together, as a balanced package, and not individually. In addition, these principles may be useful as a framework for future discussions around decarbonizing natural gas end uses in Minnesota.

1. Affordability

- a. Keep space heating and water heating affordable for all Minnesota residents, particularly in under-resourced communities that experience the highest energy burden (share of household income spent on all types of energy costs).
- b. Keep space heating, water heating, and process loads affordable for Minnesota businesses.

2. Equity

- a. Ensure that the decarbonization of natural gas end uses is done in a way that reduces current inequities and does not create new inequities, in terms of costs and benefits.
- b. Ensure that the benefits of the transition—in terms of emissions benefits, economic benefits, public health benefits, and energy affordability benefits—are experienced among Minnesotans, especially workers, under-resourced communities, Black, Indigenous, and people of color communities, and communities in Greater Minnesota.
- c. Ensure that all Minnesotans have the ability to adopt technologies and fuels that decarbonize natural gas end uses affordably and effectively.

3. Environment

- a. Work toward practical, scalable, timely solutions to achieve reductions in greenhouse gas emissions and other pollutants.
- b. Maintain urgency in line with Minnesota's established greenhouse gas reduction goals as well as leading climate science from the United Nations Intergovernmental Panel on Climate Change.

4. Economy

- a. Ensure that decarbonization of natural gas end uses in Minnesota supports economic development and innovation throughout the state.

- b. Manage disruption and create opportunities with regard to businesses, workforce, communities, and infrastructure.

5. System Considerations

- a. Tailor metrics of success to be specific to Minnesota's current and future climate, economy, energy system, and other unique characteristics.
- b. Consider system impacts and unintended consequences for both gas and electric to ensure a cost-effective transition to utilize current assets strategically and avoid unnecessary expense.
- c. Develop a portfolio of solutions that improves upon the current situation (with attention to these principles) and is capable of meeting Minnesota's diverse end-use needs.
- d. Consider the different conditions and priorities of local communities in developing solutions.

SUBGROUPS

To support the development of draft recommendations, GPI and CEE established subgroups around the following four topics:

- Residents and small businesses
- Large commercial and industrial
- Utility and regulatory
- Workforce and economic development

The subgroups were open for anybody from the larger stakeholder group to join and, in addition, the subgroups could recruit others from outside the stakeholder group to inform their thinking.

These subgroups were tasked with developing draft recommendations to be brought back to the larger group for consideration, seeking to adhere to the following criteria:

- Develop recommendations that have a high likelihood of earning consensus amongst the larger group.
- Fulfill the group's guiding principles as much as possible.
- Be as specific as time and consensus will allow.

Importantly, all four subgroups were also asked to address equity in developing their recommendations. The recommendations could take whatever form the subgroup felt was appropriate, including policy or regulatory changes or simply calling attention to unresolved questions that all parties agreed should be resolved at some point in the future.

LOCAL GOVERNMENT ADVISORY GROUP

GPI and CEE sought to engage local government representatives beyond the City of Minneapolis in this process, however many potential participants were unable to commit to the all-day meetings due to resource limitations both before, and especially during, the COVID-19 pandemic. In response, GPI and CEE convened an advisory committee for two meetings during the process to elicit feedback from local governments, including on the consensus recommendations.

This committee included representatives from the following local governments: Hennepin County, City of Hutchinson, Metropolitan Council, City of Northfield, City of Rochester, City of St. Louis Park, and City of St. Paul. Additionally, GPI and CEE presented draft recommendations to and collected input from participants in the Community Energy Network, which is made up of more than two dozen cities across Minnesota working to advance clean energy in their communities.

GPI and CEE would like to thank these committee participants for their time and thoughtful feedback.

IV. Scenario Modeling

Discussing how to decarbonize natural gas end uses in Minnesota is an endeavor that requires planning around an uncertain future. The stakeholder group initially approached this challenge by identifying and prioritizing a list of uncertainties that should be taken into account to develop informed recommendations. These uncertainties included the pace of innovation and deployment for decarbonization technologies and fuels, how policy changes might influence that pace, and how those technologies and fuels might interact with one another and the energy system as a whole. However, those uncertainties were complex and interdependent. In addition, participants had very different assumptions about how those uncertainties might unfold over time. It quickly became clear that, to have a robust discussion, the group would need a more structured way to think about how the future might unfold.

In response, the advisory committee pooled funding to hire Energy and Environmental Economics, Inc. (E3) to model a handful of different high-level scenarios for decarbonizing natural gas end uses by 2050 in Minnesota.³⁷ The purpose of the scenario modeling was to give the stakeholder group a structured way to discuss an uncertain future in light of many complexities and interdependencies that would be difficult to understand without modeling tools. Given limited financial resources to support modeling, the advisory committee asked E3 to produce a slide deck with modeling results rather than a written report.

Importantly, E3 conducted the modeling at the direction of the advisory committee, which was facilitated by GPI and CEE. The modeling assumptions were agreed to by consensus of the committee members. Since the purpose of this process was to explore decarbonization of natural gas end uses, all modeling scenarios were constrained to achieve full decarbonization of Minnesota's current natural gas end uses by 2050 from 2018 emissions levels. For the purposes of the modeling, full decarbonization meant that each scenario used a combination of carbon-free and net-zero emissions energy sources and no carbon-positive energy resources by 2050. E3 also provided a sensitivity for each scenario showing an 80 percent reduction in emissions by 2050.³⁸

This section of the report describes the following:

- How the modeling was conducted in collaboration with the stakeholder group
- A narrative of the modeling results (the full results and assumptions are attached to this report)
- The stakeholder group's discussion of the results

It is critical that anyone reading this report understands that scenario modeling looking decades into the future is inherently limited. The goal of conducting this modeling was not to predict the future; it was to develop a handful of different scenarios for how the future might unfold and to

³⁷ More information about E3 is available at <https://www.ethree.com/about/overview/>.

³⁸ The decision to target full decarbonization for all three scenarios, with an 80 percent sensitivity, was a modeling construct designed to compare the impacts of different pathways to a common 2050 goal.

use those scenarios as a tool for discussion and decision-making amongst the stakeholder group. Accordingly, while the advisory committee agreed to the modeling assumptions and found the results valid based on those assumptions, it did not agree that the modeling by itself should determine any particular course of action. Therefore, the modeling that is described below should be understood as a tool that informed the stakeholder group's thinking in developing recommendations; it did not directly determine any recommendations.

Modeling Process

E3, with facilitation support from GPI and CEE, used the following high-level process to develop three natural gas end-use decarbonization scenarios and analyze the impacts of those scenarios on the gas system, the electric system, and customer bills:

1. **Scenario development:** the full stakeholder group developed and agreed on high-level future scenarios.
2. **Scenario refinement:** the advisory committee refined the scenarios, including the final modeling assumptions for each.
3. **Modeling:** E3 conducted modeling for each scenario, using the agreed upon assumptions and the following tools:
 - a. **PATHWAYS:** An E3 economywide scenario framework that models gas and electricity consumption levels by sector, as well as supply curves for decarbonized gaseous fuels.
 - b. **RESHAPE:** An E3 load scenario tool that assesses hourly and peak load impacts from electrification of natural gas end uses.
 - c. **Electric and natural gas revenue requirement tools** that estimate incremental electric and gas infrastructure costs, utility rates and bill impacts for residential, commercial, and industrial customers.
4. **Draft results:** E3 presented draft modeling results to the advisory committee for feedback and refinement.
5. **Final results:** E3 presented final results to the full stakeholder group.

Scenario Development

At the August 2020 stakeholder meeting, after a series of meetings focused on various decarbonization technologies and approaches (as described in the process section of this report), E3, GPI, and CEE worked with the stakeholder group to identify three future natural gas decarbonization scenarios that would meet the following criteria:

- **Relevant:** should be designed to provide insights to the key questions and concerns this group has been discussing.
- **Challenging:** should make important dynamics more visible and raise questions about our current thinking and assumptions.
- **Plausible:** should be logical and fact-based, while acknowledging that what is plausible may not be probable or preferable.

- **Clear:** should be accessible to the group, memorable, and distinct from one another.³⁹

To support discussion towards agreement on a final set of three scenarios (described in the next section of this report), E3 presented the following six draft scenario options to help structure the discussion and also left open the option for the group to create additional scenarios if desired.⁴⁰ These draft scenarios varied in their reliance on different technology and fuel options to achieve decarbonization of natural gas end uses in Minnesota. Some scenarios were considered bookend options, designed to push the limits of reliance on either decarbonized gaseous fuels or electrification to achieve decarbonization, while others included a mix of decarbonized gaseous fuels and electrification. All scenarios were designed to achieve their described state by 2050.

1. **High electrification:** Most homes switch to air-source heat pumps or ground-source heat pumps. New buildings are constructed to be all-electric. Industry is electrified where possible. Buildings achieve high levels of energy efficiency through retrofits. Likely trade-offs include higher upfront consumer investments but lower ongoing fuel costs, relatively higher consumer disruption through retrofits, and high electric system peak demands in winter.
2. **High decarbonized gas I:** Most homes keep their gas connection. Gas supply consists of hydrogen blended into the gas system and paired with in-state and out-of-state renewable natural gas, as well as substantial amounts of synthetic methane. Heating efficiency is improved by deploying gas-fired heat pumps. Likely trade-offs include lower upfront consumer investment costs but higher ongoing fuel costs, lower consumer disruption, and potential competition for the supply of renewable natural gas.
3. **High decarbonized gas II:** Most homes keep their gas connections. Gas supply consists of dedicated hydrogen pipelines where viable, paired with in-state and out-of-state renewable natural gas, as well as synthetic methane. Likely trade-offs include lower upfront consumer investment costs but higher ongoing fuel costs, higher consumer disruption due to in-house adjustments needed to accommodate hydrogen, the need for a large hydrogen supply from electrolysis powered by renewable energy, and potentially expensive pipeline adjustments to accommodate hydrogen.
4. **Hybrid systems:** Most homes both keep their gas connection and adopt an air-source heat pump. Homes are heated with a combination of electricity and decarbonized gas, reserving gas usage only for the coldest days of the year. New buildings are constructed to be all-electric. Gas supply consists of limited amounts of hydrogen blended into the

³⁹ These criteria are adapted from Adam Kahane, *Transformative Scenario Planning: Working Together to Change the Future* (San Francisco: Berrett-Koehler Publishers, Inc., 2012).

⁴⁰ These scenarios, including the trade-offs noted, reflect what E3 presented to the stakeholder group at the August 2020 stakeholder meeting. They do not reflect discussion among the group or consensus that the trade-offs are valid or comprehensive. For more information on stakeholder perspectives around trade-offs, please see the modeling discussion section of this report.

gas system and renewable natural gas from in-state and out-of-state biomass, as well as synthetic methane. Buildings achieve relatively high levels of energy efficiency through retrofits. Likely trade-offs include higher upfront consumer investments but lower ongoing fuel costs, relatively high consumer disruption due to retrofits, lower reliance on electric system peak than the high electrification scenario, and potential for significant gas rates increases due to low usage while maintaining the same infrastructure.

5. **Partial electrification:** Half of homes convert to air-source heat pumps and half retain their gas connection. Newer buildings with better shell efficiency are prioritized for electrification, leaving older buildings to keep their gas connection. New buildings are constructed to be all-electric. Gas supply consists of hydrogen blended into the gas system and renewable natural gas from in-state and out-of-state biomass, as well as synthetic methane. Likely trade-offs include needing to structure the transition neighborhood-by-neighborhood based on housing stock, the potential for inequitable impacts based on socioeconomic conditions of different neighborhoods, and a relatively high electric system peak in winter due to electrifying half of all homes.
6. **District systems:** Existing district energy systems convert and expand to collective geothermal and biomass combined heat and power systems. Collective heat networks are expanded where possible. Electrification relies on ground-source heat pumps. Likely trade-offs include higher upfront consumer investments but lower ongoing fuel costs, investment in new infrastructure but lower electric system peak impacts compared to a high electrification scenario, and the need to strategically deploy different types of district systems based on building type and geography.

After building a shared understanding of these draft scenarios, facilitators from GPI, CEE, and E3 broke up the larger stakeholder group into three smaller groups to discuss these options and identify the top three scenarios that they wanted to see modeled. The facilitators then reconvened the breakout groups to consolidate options and reach consensus on a final set. Upon reconvening, stakeholders generally agreed upon two bookend scenarios—high electrification and high decarbonized gas—as well as a third intermediate scenario that would utilize both electrification and decarbonized gas. The group then further discussed the preferred set of parameters for the intermediate scenarios. Those details are listed below, along with the final decisions on parameters for the scenario modeling.

- **Hybrid versus partial electrification:** Several stakeholders saw value in both the hybrid and partial electrification scenarios, of which the key difference was how a transition to decarbonization was managed. In the hybrid scenario, Minnesota would move towards a system where individual homes would have electric heating with decarbonized gas backup; in the partial scenario, whole communities would choose to become either all-electric or to use decarbonized gas for heating. Notably, part of this discussion focused on whether the transition to a decarbonized energy system should be directed by the state (a top-down model of decision-making) or by individual communities (a bottom-up model). The group ultimately selected the hybrid electrification scenario because it was more likely to occur, but acknowledged that the partial electrification scenario was worth consideration in the future.

- **Hydrogen for industry:** Upon reconvening, all three breakout groups had selected the high decarbonized gas I scenario, in which hydrogen is blended into the gas system, rather than the high decarbonized gas II scenario, in which dedicated hydrogen pipelines deploy pure hydrogen at higher volumes, since hydrogen can only be mixed into the existing gas system to a certain percentage⁴¹ before gas system upgrades and consumer end-use retrofits are required.⁴² However, two of the breakout groups had requested that the high decarbonized gas scenario I be modified to include dedicated hydrogen pipelines for industry. This request was based on the assumption that high-heat industrial processes will be difficult if not impossible to electrify, and that industrial gas demand could support the necessary investment in dedicated hydrogen infrastructure.

The group weighed the fact that this would create asymmetry among the scenarios in how natural gas for industry would be decarbonized—in all scenarios, high-heat industrial processes would use a form of decarbonized gas. This modification would mean that only the high decarbonized gas scenario would benefit from dedicated hydrogen for industry, even though it could arguably be deployed in all scenarios. However, stakeholders ultimately agreed to this modification because they felt that the asymmetry would allow for a useful comparison of options for the industrial sector.

- **District systems:** Stakeholders also disagreed about how to consider district systems within the three scenarios. While district systems can provide efficiencies that could reduce electric system peak and provide reliable heating even on the coldest days of winter, there was uncertainty about how widely these systems could be deployed without significant additional analysis of costs and scalability, which was out of scope and budget for the E3 modeling project. Ultimately, participants agreed that it would be helpful for E3 to provide high-level findings about the implications of district systems using electric ground-source heat pumps so the group could determine if further research would be warranted. Therefore, E3 included a high-level sensitivity of geothermal loop district systems but did not include it as a full fourth scenario. Further research would be needed to identify the actual potential for these systems in Minnesota.

Following discussion of these details, stakeholders reached consensus on three scenarios: high electrification, hybrid electrification (later renamed electrification with gas backup for clarity), and

⁴¹ M.W. Melaina, O. Antonia, and M. Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, Technical Report NREL/TP-5600-51995 (Golden, CO: National Renewable Energy Laboratory, March 2013), <https://www.nrel.gov/docs/fy13osti/51995.pdf>. Additional research is needed to determine the amount of hydrogen that can be mixed into the gas system before embrittlement occurs. The National Renewable Energy Laboratory states that mixing hydrogen into the gas system at concentrations less than 5–15 percent does not significantly increase risks associated with utilization of the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network.

⁴² In addition to pipe embrittlement, there are other considerations that may limit mixing hydrogen into the natural gas system such as impacts to end-user equipment.

high decarbonized gas with dedicated hydrogen for industry. Stakeholder also reached consensus on an additional high-level sensitivity analysis of district systems and a sensitivity on all three scenarios targeting 80 percent decarbonization of natural gas end uses.

Final Scenarios and Assumptions

After the stakeholder group reached consensus on the final three scenarios, the advisory committee worked with E3 to refine the assumptions for a reference case and each of the scenarios. The group sought to make each scenario as relevant, challenging, plausible, and clear as possible, given currently available information and modeling budget limitations. The reference case and resulting scenarios are described below, followed by a list of the key assumptions in table 1, and finally a description of key discussion topics among the advisory committee. The reference case and scenarios all target the year 2050. More information on the modeling assumptions is included in the E3 modeling results slide deck attached to this report.

- **Reference case:** Heat pump adoption follows a linear trend based on historical adoption rates, making up 24 percent of space heater sales by 2050. Half of all buildings achieve high levels of energy efficiency through retrofits. No industrial electrification occurs. The gas distribution system continues to supply conventional natural gas. The electric system fully decarbonizes by 2050 (this parameter is the same for all scenarios).
- **High electrification:** Almost all buildings switch to all-electric and are heated with air-source heat pumps or ground-source heat pumps, relying on electric resistance heating for backup. Buildings achieve high levels of energy efficiency through retrofits. New buildings are constructed to be all-electric. Industry is electrified where technically viable, and otherwise fueled by decarbonized gaseous fuels (hydrogen, biogenic methane, and synthetic methane).
- **High electrification with gas backup:** Buildings are heated primarily by air-source heat pumps, but keep their gas connection to utilize gas for backup heat during the coldest hours of the year, with natural gas gradually replaced by a blend of biomethane, synthetic natural gas, and hydrogen. Buildings achieve high levels of energy efficiency through retrofits. New buildings are constructed to be all-electric. Industry is electrified where technically viable, and otherwise fueled by decarbonized gaseous fuels (hydrogen, biogenic methane, and synthetic methane).
- **High decarbonized gas:** Buildings continue to be heated primarily by gaseous fuels, with natural gas gradually replaced by a blend of biomethane, synthetic natural gas, and hydrogen. Buildings achieve high levels of energy efficiency through retrofits. Industry is supplied with dedicated hydrogen produced using renewable electricity.⁴³

⁴³ The E3 modeling assumed that off-grid onshore wind would be built to supply electricity for hydrogen (and synthetic methane) production. Additional details are included in the appendix to the modeling slide deck, attached to this report.

Table 1. Detailed Scenario Assumptions

Sector	Parameter	Reference	High Electrification	Electrification with Gas Backup	High Decarbonized Gas + H2 for Industry
Buildings (residential + commercial)	Overall efficiency	1% for gas and 1.5% for electricity (annually)	Reference + extra building shell upgrades + fuel switching efficiency		Reference + extra building shell upgrades + efficiency from gas-fired HPs
	Building shell efficiency	50% of homes have high efficiency shells in 2050 (high efficiency shell = 29% savings in space heating service demand)	100% of homes (residential) have high efficiency shells in 2050		
	Building electrification (heat pump sales share)	Linear adoption trend from historical sales of heat pumps (24% of space heater sales are heat pumps by 2050)	100% sales of heat pumps by 2035 <ul style="list-style-type: none"> • 80% ccASHP • 20% GSHP • Electric resistance backup 	<ul style="list-style-type: none"> • 100% sales by 2035 of ccASHP with gas furnace backup for non-new construction natural replacements • All-electric new construction with 80% ccASHP and 20% GSHP 	<ul style="list-style-type: none"> • Reference for electric HPs • Gas-fired HPs (20% of sales) • Gas in new construction
Industry	Economic growth	1.9%	Reference		
	Efficiency	1% for gas and electricity (annually)	1.5% annual efficiency in both gas and electricity + efficiency from fuel switching		
	Electrification / fuel switching	None	Low + medium temperature heat: 50% of gas consumption electrified (after efficiency)		Low temperature heat: 20% of gas consumption electrified (after efficiency)
Gaseous fuels	Gas fuel blend in 2050	100% natural gas	100% renewable natural gas (RNG) (used mainly for industry): <ul style="list-style-type: none"> • 93% from biomass and synthetic natural gas • 7% hydrogen blended 		100% RNG in <u>buildings</u> : <ul style="list-style-type: none"> • 93% from biomass and synthetic natural gas • 7% hydrogen blended 100% (dedicated) <u>hydrogen in industry</u>
Electr-icity	Electricity sector emission intensity	Zero-carbon generation by 2050 <ul style="list-style-type: none"> • With sensitivity in gradual change towards 2050 	Reference		

Notes: Complete assumptions, including capital cost assumptions for domestic water heating, cooking, and clothes drying, are detailed in the appendix of the modeling slide deck attached to this report. Across sectors and scenarios, E3 assumed a 100-year global warming potential for methane.

The advisory committee discussed many of these assumptions at length, seeking to find consensus among participants about how to make each scenario as accurate, realistic, and useful as possible to ensure durability of the modeling results. Below, we describe some of the key discussion points about these assumptions.

- **Building shell energy efficiency:** E3 used data from the Minnesota Energy Efficiency Potential Study⁴⁴ and the Minnesota Technical Reference Manual⁴⁵ to estimate that building shell efficiency upgrades would result in a 29 percent reduction in energy consumption. E3 assumed that by midcentury 100 percent of homes would have received building shell upgrades. Some stakeholders thought that the 29 percent reduction in energy demand was conservative since higher levels of building shell efficiency will become increasingly cost-effective as energy costs increase. Other stakeholders believed that 100 percent deployment was too aggressive. The group determined that the assumptions represented the best available data and that, in practice, a conservative estimate on energy savings and aggressive estimate on deployment may cancel each other out.
- **New construction:** Stakeholders acknowledged that building codes for new construction will become more efficient over time. However, there was not an agreed upon way to model how quickly or in what ways building codes would change. Therefore, new construction was assumed to be built based on today's building codes. Stakeholders agreed that this assumption was highly conservative and heating loads could be reduced for new construction if building codes are updated and become more efficient. Some committee members would like to see buildings codes progress to zero-energy standards, however this was not a consensus point.
- **Weather assumptions:** Minnesota winter temperatures vary from year to year, resulting in variable demands on the state's energy systems for heating. The group agreed that it was important for the modeling to consider average winter temperatures, as well as extreme winter temperatures. E3 modeled peak winter loads for a 1-in-2 year winter (relatively moderate in temperature) and a 1-in-40 year winter (extremely cold temperatures), which the advisory committee found acceptable.⁴⁶
- **Synthetic natural gas:** Synthetic methane, using a carbon-free process, is a new technology that is not yet commercialized. Additionally, synthetic methane creates a potent greenhouse gas, where it does not otherwise exist. If synthetic methane were to leak, either during its production or delivery, then its emissions reduction benefits would be reduced. Some stakeholders expressed concerns about the resource and

⁴⁴ Center for Energy and Environment, *Minnesota Energy Efficiency Potential Study: 2020-2029* (December 4, 2018), https://www.mncee.org/sites/default/files/report-files/MN-Potential-Study_Final-Report_Publication-Date_2018-12-04_0.pdf.

⁴⁵ Minnesota Department of Commerce, *State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs*, version 3.0 (January 10, 2019), <https://mn.gov/commerce-stat/pdfs/mn-trm-v3.0.pdf>.

⁴⁶ Modeled conditions may not reflect regulatory requirements for system design. Minnesota's regulated gas utilities design their systems for 1-in-100 winter events.

that all the modeled scenarios rely on varying amounts of synthetic methane. However, other stakeholders noted that other technologies and fuels included in the modeling are emergent and not yet commercialized.

Modeling Results

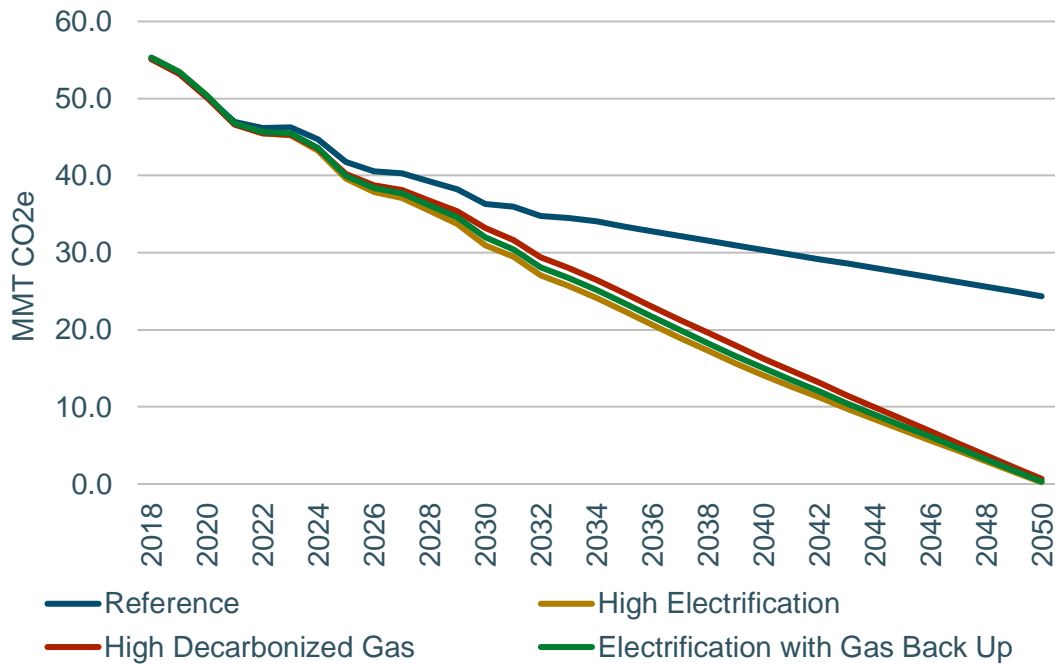
This section describes the E3 scenario modeling results. As noted above, the goal of conducting this modeling was not to predict the future; it was to develop a handful of different scenarios for how the future might unfold and to use those scenarios as a tool for discussion and decision-making amongst the stakeholder group. Moreover, while the advisory committee agreed to the modeling assumptions and found the results valid based on those assumptions, it did not agree that the modeling by itself should determine any particular course of action. Both the advisory committee and the larger stakeholder group have expressed a range of diverse perspectives about the modeling results. That discussion is captured separately in the modeling discussion section of this report, which follows this results section.

Greenhouse Gas Emissions

All three scenarios achieved 100 percent decarbonization by 2050, with a similar emissions reduction trajectory across scenarios as shown in figure 3. E3 performed a high-level analysis of electricity sector emissions based on in-state generation, assuming a 100 percent clean grid by 2050, mostly achieved through a linear trajectory from today. In addition, the advisory committee asked E3 to look at the impact of accelerated decarbonization of the electric sector, such that it might achieve more aggressive reductions in the near term.⁴⁷ This resulted in greater emissions reductions in 2035 for all three scenarios, with the greatest impact occurring in the high electrification scenario, as illustrated in figure 4.

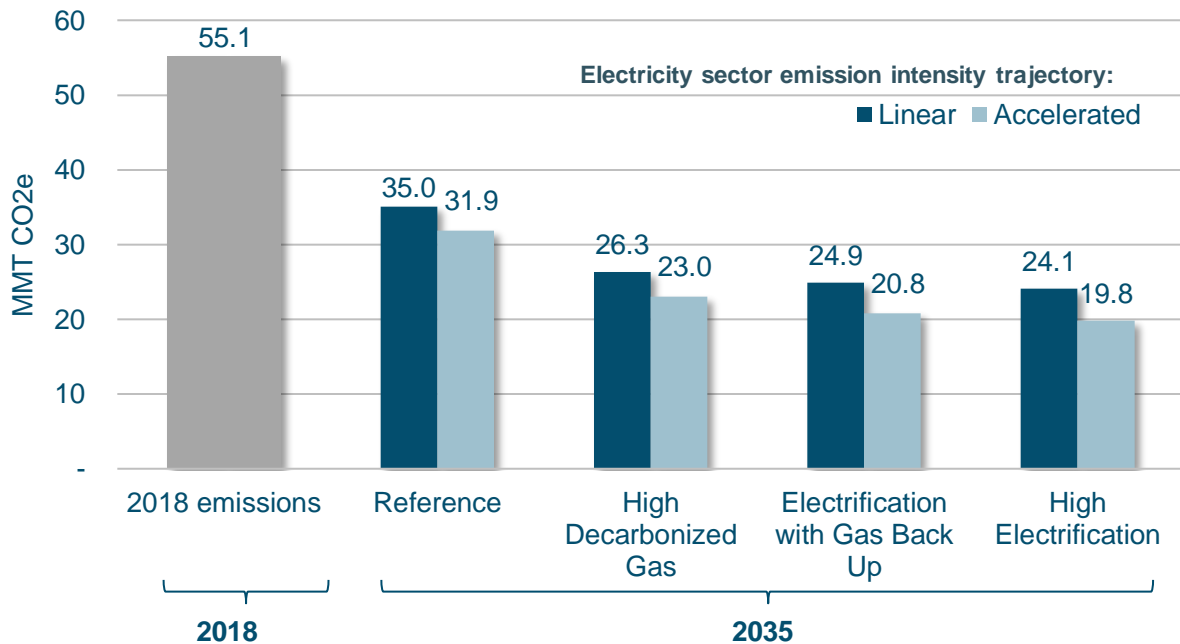
⁴⁷ In the linear decline scenario for electric sector emissions, E3 used the CO₂ intensity forecast through 2034 from Xcel Energy's latest proposed integrated resource plan, then a linear decline from 2034 to zero in 2050. For all other Minnesota utilities, in this scenario E3 assumed a linear decline from actual reported CO₂ intensity in 2018 to zero in 2050. For the accelerated decline scenario for electric sector emissions, E3 used the same trajectory for Xcel Energy, but assumed other Minnesota utilities would start at their reported CO₂ intensity in 2018 but follow a faster decline similar to Xcel Energy until 2034, then linear 2034-2050. See slide 68 of the modeling results slide deck attached to this report. Neither scenario assumes full decarbonization of electricity by 2035. Importantly, only the linear decline scenario was used to assess energy system and economic impacts.

Figure 3. Greenhouse gas (GHG) emission reductions per scenario



Note: GHG emissions are based on emissions from natural gas and electricity for buildings and industry, emissions from natural gas for compressed natural gas vehicles, and emissions from pipeline & distribution usage (including fugitive emissions). Fugitive emissions are estimated based on US Environmental Protection Agency (EPA) reported CH4 emissions by CenterPoint & Xcel Energy and account for ~0.1% of throughput (EPA Flight database). The reference case shows emissions with assumed GHG reductions in the electricity sector (linear).

Figure 4. GHG emissions from end-use sectors: 2018 vs. 2035

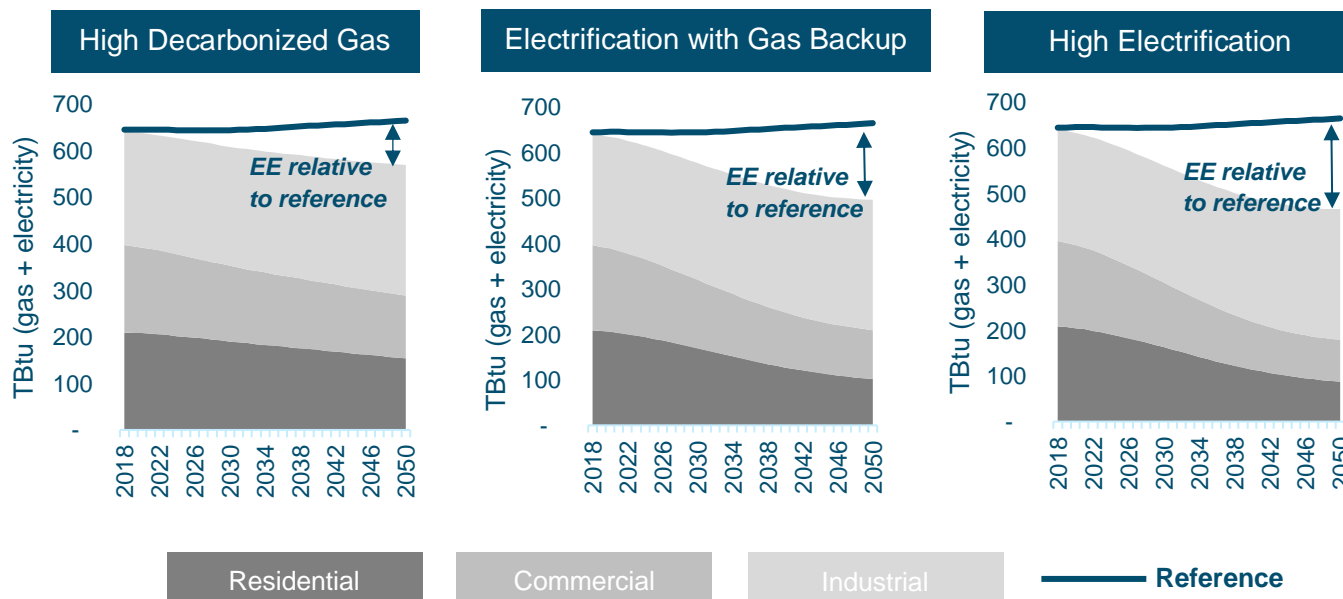


Impact of Energy Efficiency on Overall Consumption

Looking at the reference scenario alone, consumption of both gas and electricity between today and 2050 is expected to increase as a result of population growth, economic growth, and expansion of the gas system.⁴⁸ However, this increase in consumption is expected to be offset by continuous energy efficiency improvements, resulting in 2050 levels of both gas and electricity consumption that are roughly the same as today.⁴⁹

The three scenarios assume the efficiency levels of the reference case, plus achievement of 29 percent reduction in heating demand across all buildings on average. In addition, the two electrification scenarios achieve additional efficiency by switching from gas heating to electric heat pumps, which are more efficient overall, while the decarbonized gas scenario achieves additional efficiency from gas-fired heat pumps, which are more efficient than furnaces or boilers. These scenario-specific energy efficiency gains beyond the reference case are illustrated in figure 5.

Figure 5. Final energy consumption and energy efficiency effects in each scenario relative to reference case



Note: Sources and assumptions are listed in the appendix of the E3 modeling results slide deck attached to this report.

⁴⁸ The modeling assumed population growth of 0.44 percent and economic growth of 1.9 percent, based on estimates of the Minnesota State Demographic Center and the US Energy Information Administration's Annual Energy Outlook 2020.

⁴⁹ The modeling assumed building energy efficiency improvements of 2 percent per year for electricity until 2034 and 1 percent per year thereafter, 1 percent per year for industrial electricity use, and 1 percent per year for gas use in all sectors.

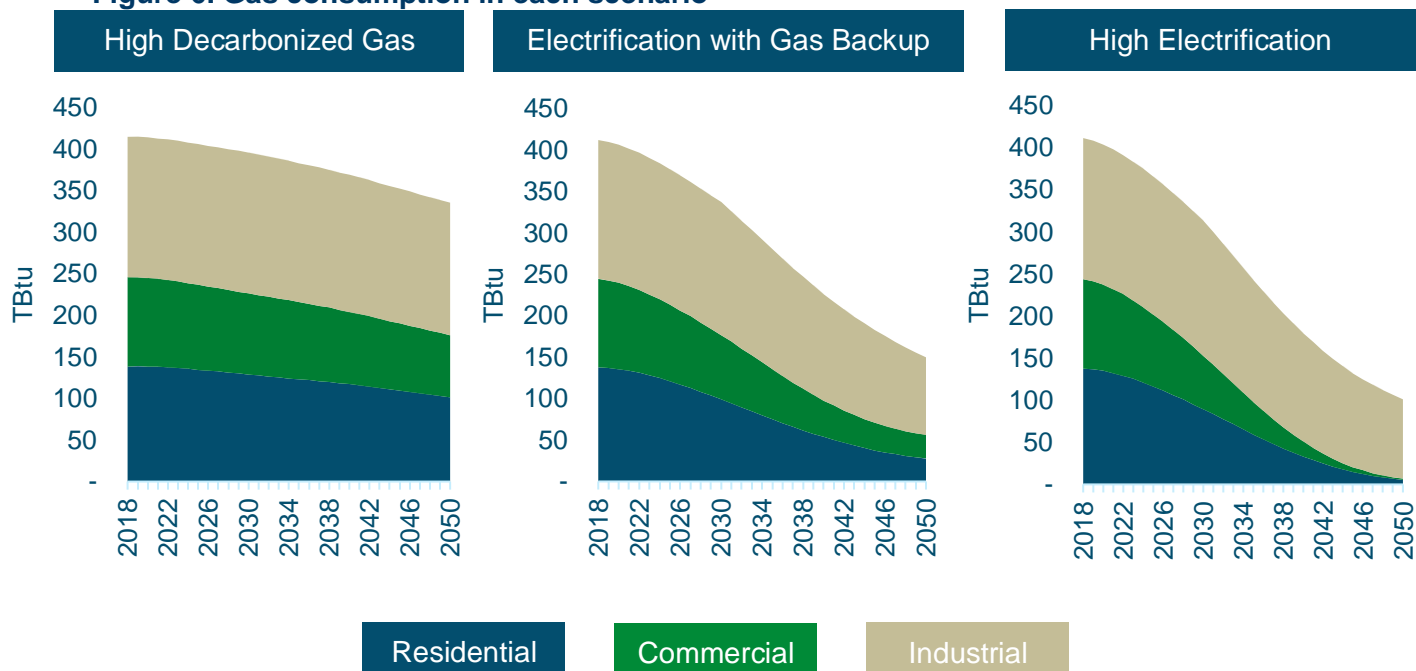
Gas Sector Impacts

GAS CONSUMPTION

Each of the three decarbonization scenarios resulted in a decline in consumption of gaseous fuels by 2050, though the rate and magnitude of decline varies.⁵⁰ These declines, illustrated in figure 6, are as follows:

- The high decarbonized gas scenario showed a slight decline in gas consumption driven mostly by increased building shell energy efficiency, as well as efficiency gains from switching to gas-fired heat pumps.
- The electrification with gas backup scenario showed a steep decline in gas consumption for both the residential and commercial sectors, while industrial gas use is slightly lower than today. Importantly, this scenario retains gas consumption in 2050 to provide backup heat during the coldest hours of the year in the residential and commercial sectors—making up 24 percent of the annual residential heating load.
- The high electrification scenario nearly eliminates gas sales in the residential and commercial sectors by 2050, while industrial gas use is slightly lower than today.

Figure 6. Gas consumption in each scenario



⁵⁰ In all scenarios, geological natural gas is phased out by 2050, replaced by a combination of carbon-neutral or carbon-free hydrogen, biogenic methane, and synthetic methane.

DECARBONIZED GASEOUS FUELS

As illustrated in figure 6, all three decarbonization scenarios assume some amount of gaseous fuel consumption in 2050. This gas consumption is supplied by a combination of biomethane, hydrogen, and synthetic natural gas, which are collectively referred to as decarbonized gaseous fuels throughout this report. To model supply of these decarbonized gaseous fuels, the E3 team utilized an in-house biofuels optimization module that determined the most cost-effective way to convert biomass into biofuel across all sectors under two different outlooks that account for different levels of competing demand in the transportation sector:⁵¹

- A conservative outlook that assumed that all cellulosic feedstocks of biomass would be more cost-effectively used to produce liquid fuels, such as renewable diesel or jet fuel due to higher prices and carbon intensities for these fuels, leading to a heavier reliance on synthetic natural gas in buildings and industry.
- An optimistic outlook that assumed only as much competition for renewable liquid fuels as was modeled in the Minnesota Transportation Pathways study, in which some cellulosic feedstocks (mainly corn stover) are left over for production of biomethane that could be used in buildings and industry.⁵² As a result, the optimistic outlook has a more moderate reliance on synthetic natural gas.

These two outlooks are illustrated in figures 7 and 8 below. Importantly, the module assumed that Minnesota would use its population-weighted share of the national supply of waste biomass, which would correspond to about 25 percent of Minnesota waste biomass in 2050 given the state's disproportionately high biomass supply. The module also excluded demand from Minnesota electric generators.

⁵¹ 2050 demand for renewable diesel in Minnesota corresponded to about 80 percent of 2016 transportation diesel demand in alignment with the moderate mitigation scenario in the Minnesota Pathways to Decarbonization Transportation Study: Minnesota Department of Transportation, *Pathways to Decarbonizing Transportation in Minnesota*, (August 2019), <https://www.dot.state.mn.us/sustainability/docs/pathways-report-2019.pdf>.

⁵² Minnesota Department of Transportation, *Pathways to Decarbonizing Transportation in Minnesota* (August 2019), <https://www.dot.state.mn.us/sustainability/docs/pathways-report-2019.pdf>.

Figure 7. Conservative outlook for supply of decarbonized gaseous fuels

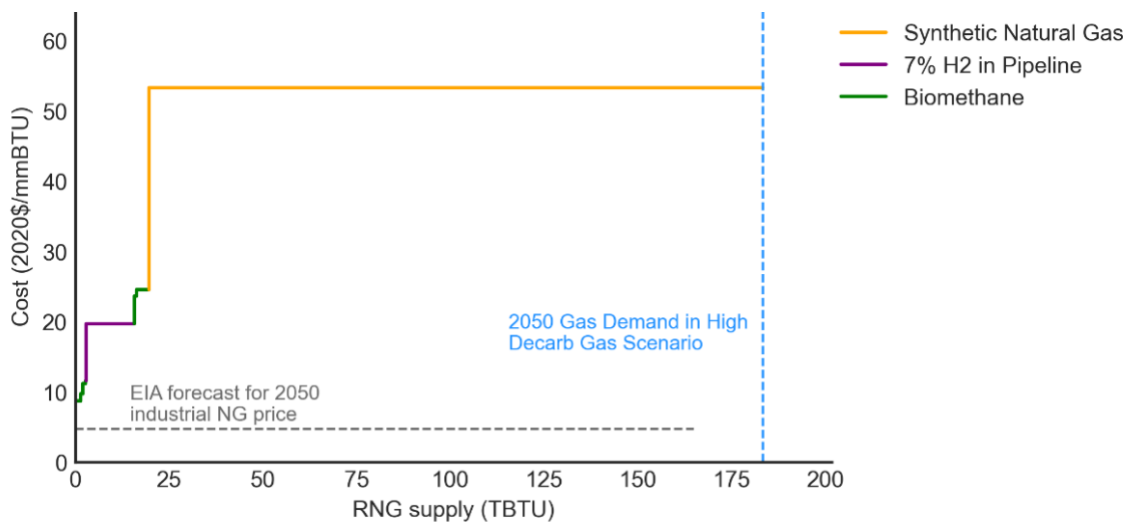
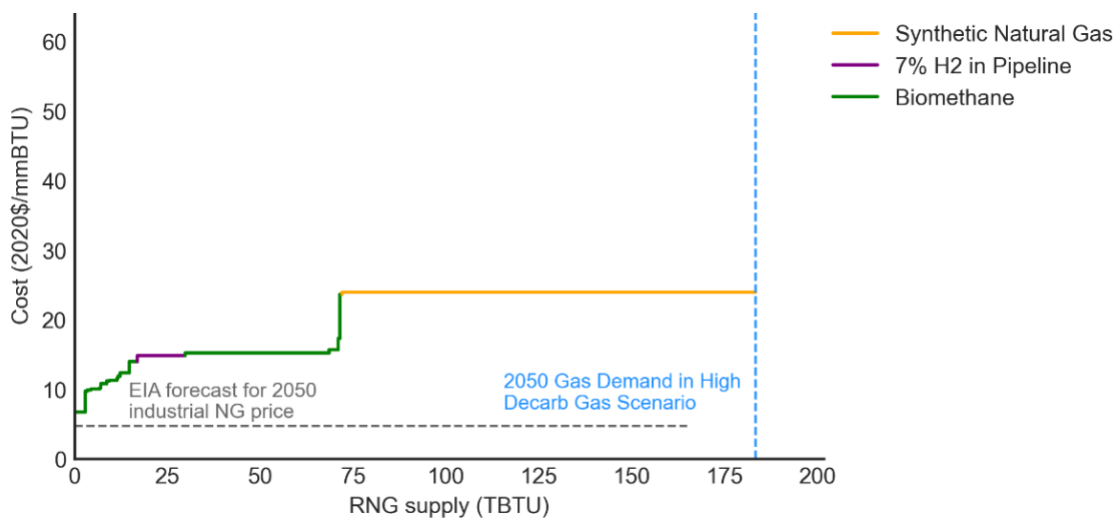


Figure 8. Optimistic outlook for supply of decarbonized gaseous fuels



To understand how the gas blend would change over time in each of the scenarios, E3 modeled the gas blend in 2030 and 2050 based on an average of the conservative and optimistic supply outlooks. By 2030, all three scenarios showed that 8 to 10 percent of residential, commercial, and industrial gas use is supplied by a mix of hydrogen, biomethane, and synthetic natural gas. By 2050, natural gas is fully replaced by decarbonized gaseous fuels, with remaining gas volumes mostly concentrated in the industrial sector. The 2030 and 2050 gas blends are illustrated in figures 9 and 10 below. Notably, the high decarbonized gas scenario utilizes hydrogen blended into the gas system as well as dedicated hydrogen supply for industry, resulting in a much higher supply of hydrogen in that scenario.

Figure 9. Gas commodity blend in 2030 for each scenario

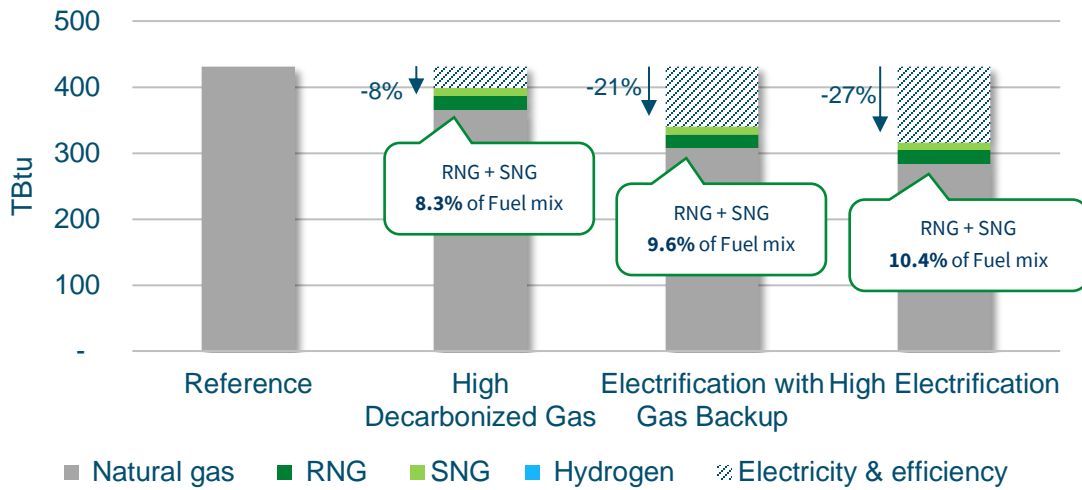
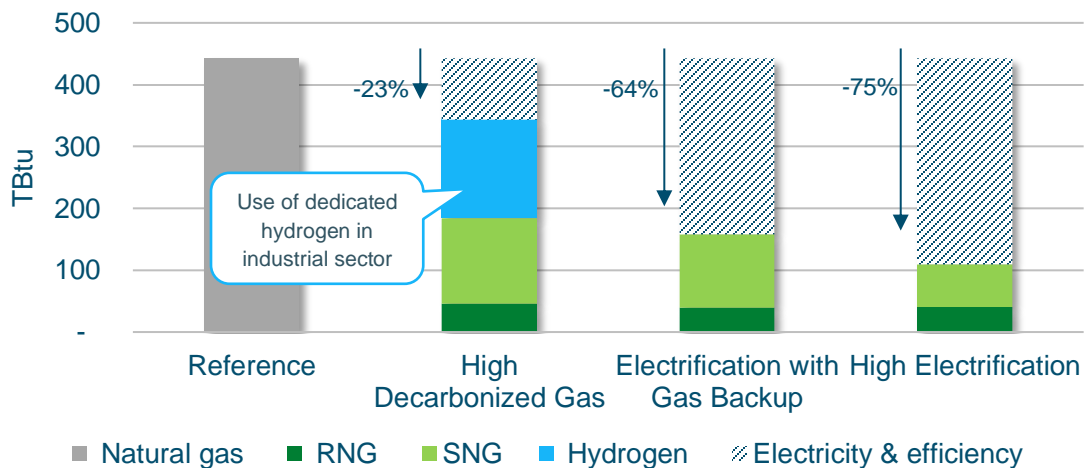
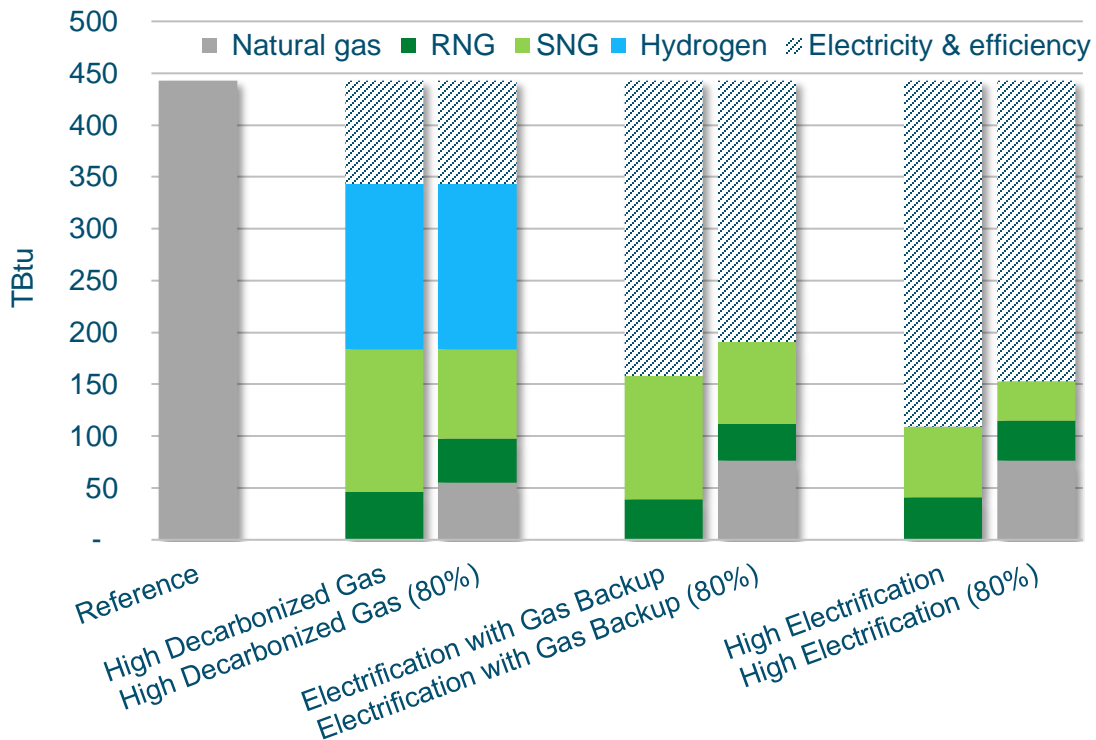


Figure 10. Gas commodity blend in 2050 for each scenario



Finally, the modeling considered what the gas commodity blend would look like if natural gas end uses reached 80 percent reduction of greenhouse gases instead of complete decarbonization. This resulted in a 2050 fuel blend where natural gas still plays an important role and mainly displaces synthetic natural gas, which is more costly than biomethane and hydrogen to produce. This is illustrated in figure 11.

Figure 11. Gas commodity blend in 2050 for each scenario if GHG reductions are limited to 80 percent



Electricity Sector Impacts

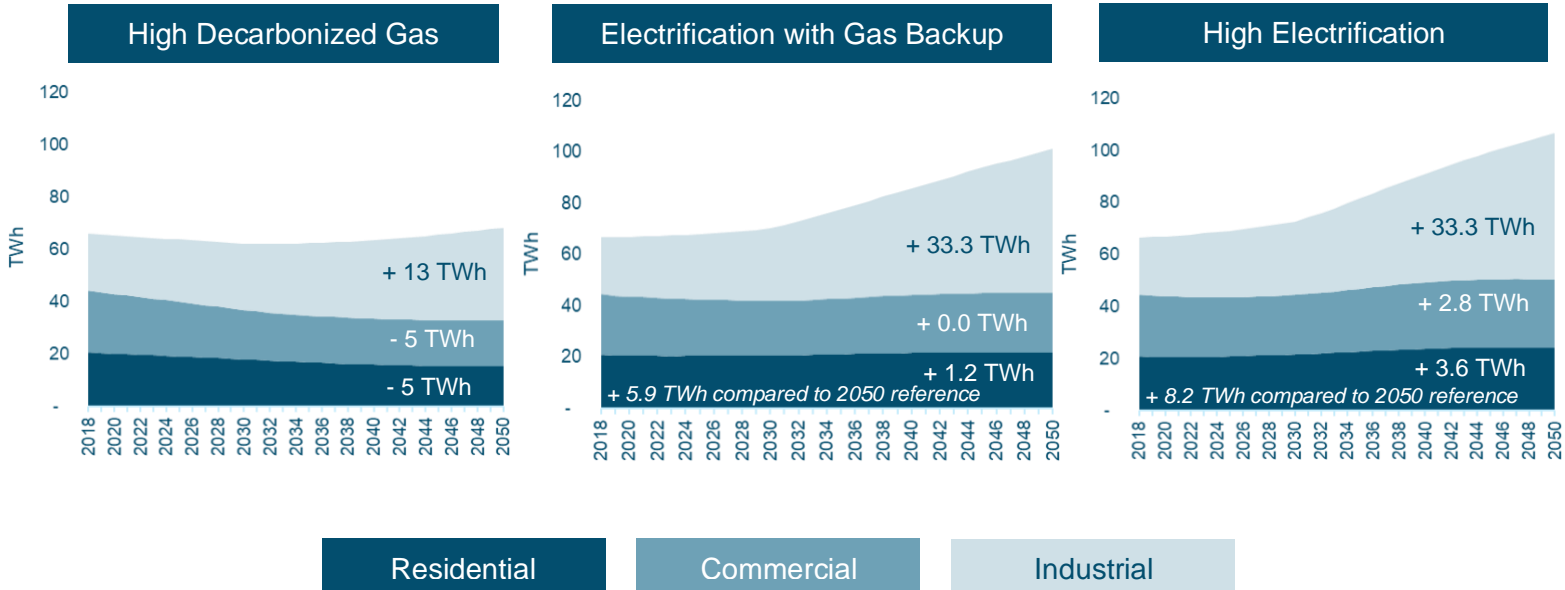
ELECTRICITY CONSUMPTION

As gas consumption decreases in each of the three decarbonization scenarios by 2050, electricity consumption increases, though the increase in all cases is primarily driven by industrial electrification and muted by energy efficiency measures that are included in all scenarios (i.e., increases in residential and commercial load are largely offset by efficiency that is assumed also to occur in the reference scenario). Electricity consumption impacts in each of the scenarios, illustrated in figure 12 below, are as follows:

- In the high decarbonized gas scenario, overall electricity load increases by around 4 percent compared to today, primarily due to electrification of low temperature heat industrial processes. For this scenario, electricity consumption declines in both the residential and commercial sectors.
- In the electrification with gas backup scenario, overall electricity load increases by 52 percent compared to today, with the bulk of that growth due to industrial electrification, while load in buildings increases only slightly, with electrification driven load growth offset to a significant extent by energy efficiency.
- Electricity consumption in the high electrification scenario is very similar to that of the electrification with gas backup scenario, with an overall increase of 59 percent. Due to assumed energy efficiency, the greatest impacts of high electrification on the

electric system are not in overall consumption (terawatt hours or TWh), at least for the residential and commercial sectors, but on electric system winter peak demand (gigawatt or GW), as explained in the following section.

Figure 12. Electricity consumption in each scenario

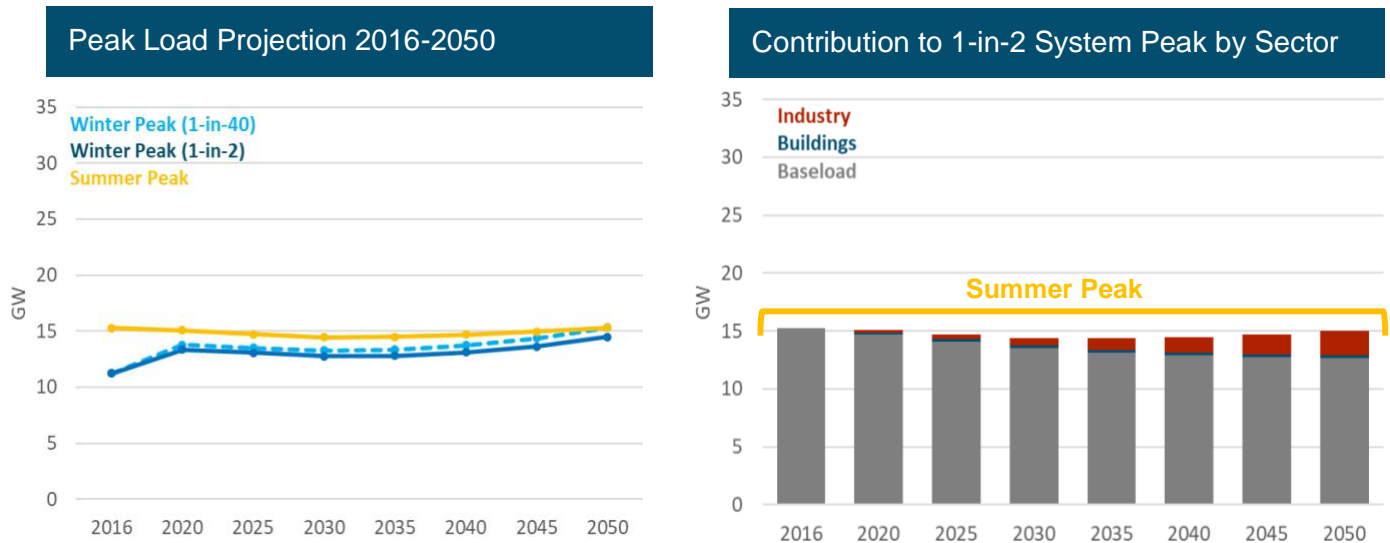


ELECTRIC SYSTEM PEAK

Electric utility systems are designed to serve peak load, which is currently around 15 gigawatts in the summer months in Minnesota. This peak is mainly driven by residential and commercial air conditioning. However, Minnesota’s building heat load, which represents both space and water heating, is mainly supplied by natural gas today and has a large peak in winter due to the state’s cold climate. Electrifying the state’s building heat load will impact the electric system peak. The modeling assessed the extent of impacts to electric system peak for each of the three scenarios. Since the building heat load peak changes year-over-year due to customer energy usage changes in response to temperature, the E3 team modeled electric peak impacts based on an average winter peak that occurs once every two years, and an extreme winter peak that occurs once every 40 years.

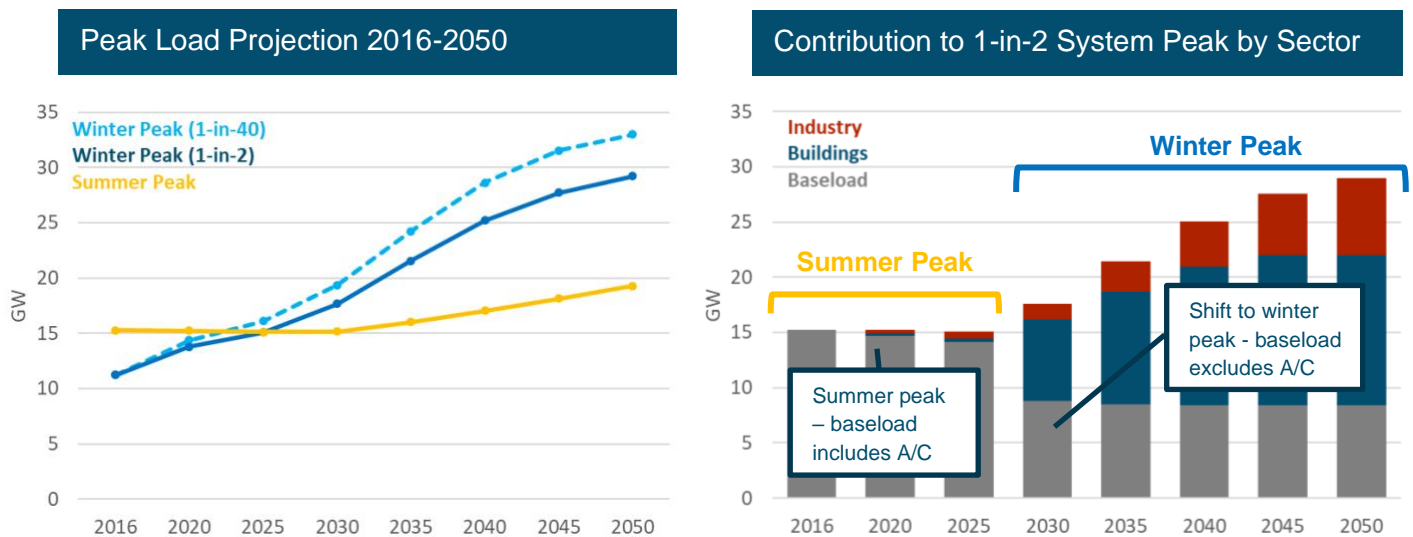
While the high decarbonized gas scenario shows a limited increase in electricity consumption as described above, it primarily relies on decarbonized gaseous fuels to meet the building heat load, keeping Minnesota’s electric system peak load about the same in 2050 as it is today. This is illustrated in figure 13.

Figure 13. Electric peak impacts of high decarbonized gas scenario



The high electrification scenario—which transitions nearly all of Minnesota’s building heat load to electric heat pumps and backup electric resistance heating—shows the greatest impact to the state’s electric system peak in 2050, shifting it to winter before 2030 and nearly doubling it compared to the current summer peak. This is illustrated in figure 14.

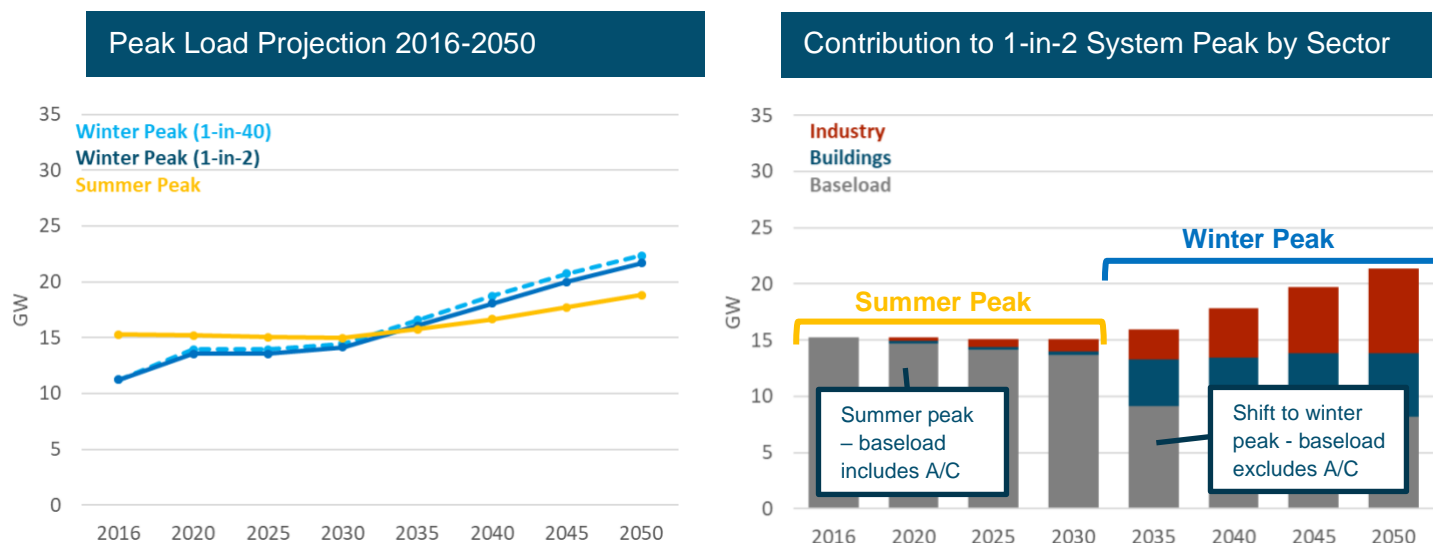
Figure 14. Electric peak impacts of high electrification scenario



The electrification with gas backup scenario also shifts the peak from summer to winter, but the increase in the peak is significantly lower than the high electrification scenario. This is because the electrification with gas backup scenario is designed to use the gas system as backup to provide peak heat demand during cold days. The resulting impact to peak is illustrated in figure

15. Comparing figures 14 and 15 illustrates the effect of maintaining a gas backup heating source on electric system peak: even though electricity by 2050 delivers the bulk of annual heating, relying on a gas backup heating source on the coldest days of the year lowers winter peak electric demand and delays the switch from summer to winter peaking by nearly a decade.

Figure 15. Electric peak impacts of electrification with gas backup scenario



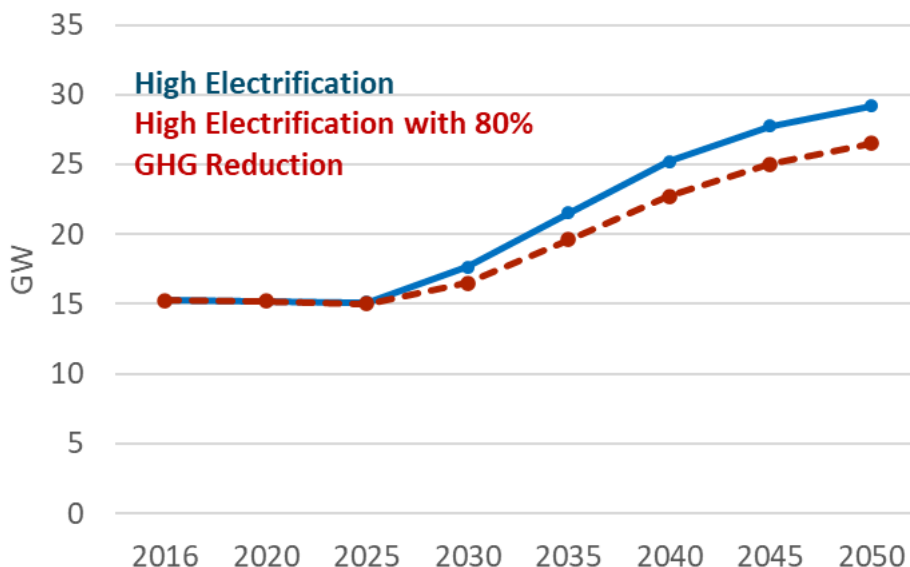
Importantly, impacts to the electric system peak by 2050 as a result of electrification are largely dependent on the advancement of cold climate air-source heat pump technology. Air-source heat pumps on the market today vary in their ability to operate in cold temperatures. For the high electrification scenario, the E3 modeling utilized an average of performance expectations across different heat pumps available today to determine electric system peak impacts.⁵³ However, if air-source heat pumps become better able to operate in colder temperatures, and if building shell improvements are adopted by customers faster than assumed in the modeling, fully electrified buildings will need to rely less on electric resistance heating, reducing the electric system peak in the high electrification scenario.

Finally, the modeling considered what electric system peak impacts would look like under the high electrification scenario if greenhouse gas reductions were limited to 80 percent rather than full decarbonization. This resulted in 20 percent lower heat pump adoption than the high electrification scenario that reaches full decarbonization. As a result, peak load would be 10 percent smaller than in the full decarbonization scenario as building heat loads contribute to

⁵³ Single-family homes and commercial buildings were assumed to have an integrated central system with an electric ASHP and gas furnace/boiler, with the latter designed to turn on at temperatures below 3F, serving the coldest 5 percent of heating hours. Multifamily homes were assumed to have a mini-split or packaged terminal electric ASHP installed in one or more rooms, separate from an existing gas furnace/boiler that turns on at temperatures below 20F, serving the coldest 20 percent of heating hours. Complete air-source heat pump assumptions are included in the modeling results slide deck attached to this report.

roughly half of the system peak load in 2050, with the other half driven by industrial electrification. This difference is shown in figure 16.

Figure 16. Electric system peak load impacts of the high electrification scenario if GHG reductions are limited to 80 percent



Economic Impacts

GAS SYSTEM ECONOMIC IMPACTS

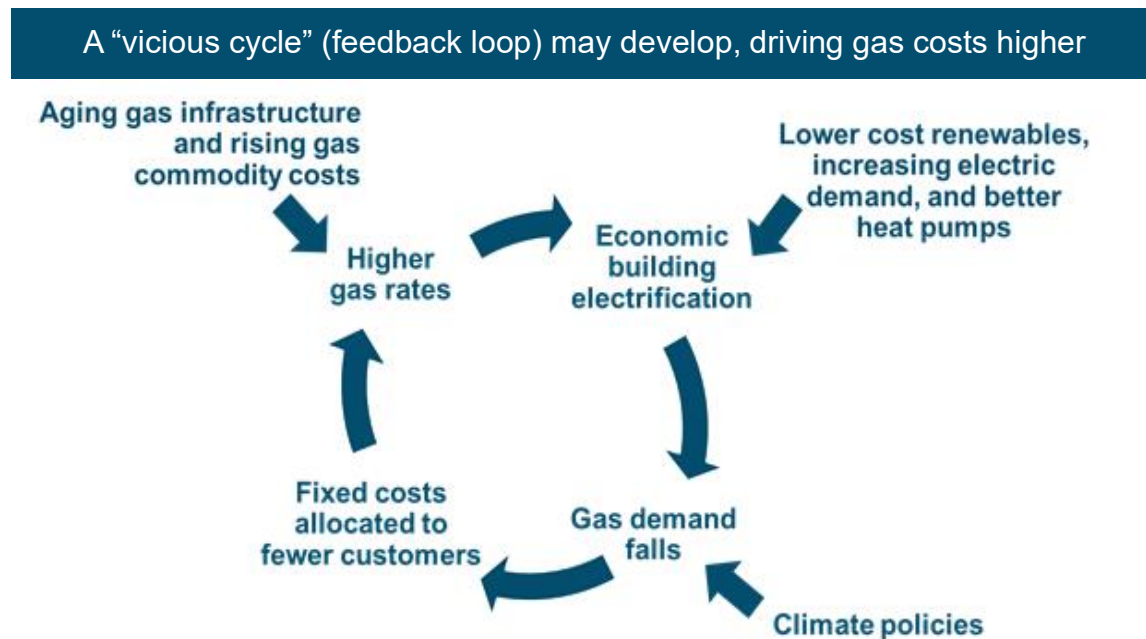
Gas rates are likely to increase under any decarbonization scenario, due to commodity costs and infrastructure costs. Decarbonization of the gas system would require blending carbon-neutral or carbon-free gaseous fuels—including biomethane, synthetic methane, and hydrogen—into the system. The costs of these fuels are expected to remain much higher than the current costs of geological natural gas, thereby increasing the commodity costs of gas to achieve decarbonization.

In addition to procuring fuel, gas utilities build and maintain gas system infrastructure and recover the costs of that infrastructure from customers. The infrastructure costs are recovered through a volumetric delivery charge as well as through fixed charges divided among customers. Under this structure, stable or increasing system costs divided over lower gas sales or fewer customers will result in increased gas rates for remaining gas customers.

The mechanism of increasing customer costs is most notable under an electrification scenario, assuming electrification does not lead to a cost reduction of the gas system. As shown in figure 17 below, a feedback loop may occur where electrification and increasing gas commodity costs to customers leads to lower gas demand and could encourage existing customers to leave the gas system entirely. Fewer customers on the gas system would increase the share of system costs paid by the remaining customers and could create a feedback loop by encouraging more customers to leave the system. Importantly, the gas system costs allocated to fewer customers

could burden those least able to leave the gas system, such as renters and low-income customers.

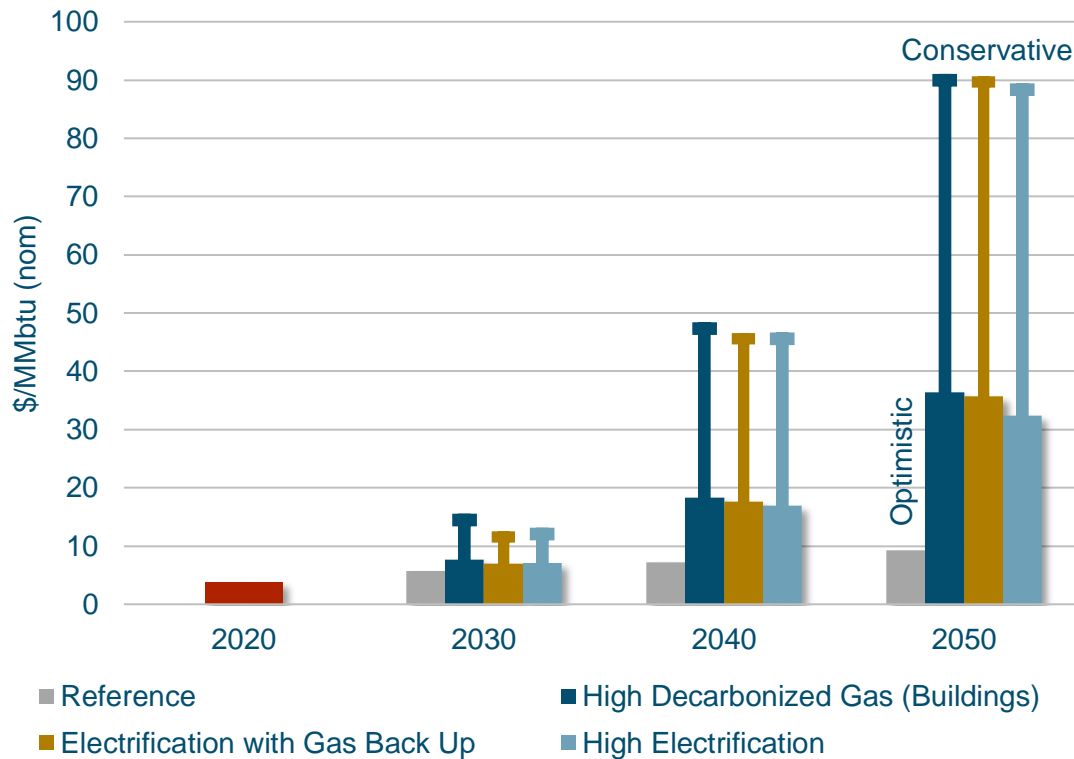
Figure 17. Possible impacts of decarbonization on gas rates



Republished with permission from E3, California Energy Commission: “The Challenge of Retail Gas in California’s Low-Carbon Future” (2020).

As noted above, carbon-neutral and zero-carbon gaseous fuels are expected to be costly and their future supply is uncertain. The costs of these fuels are assumed to increase as the supply of cheaper forms of these fuels is fully utilized. Additionally, because renewable natural gas and carbon-free hydrogen are emerging fuels and not yet deployed at scale, there is a high degree of uncertainty about the future costs for those fuels. Figure 18 below illustrates the commodity costs of decarbonized gaseous fuels for each scenario modeled over time. In the high decarbonized gas scenario, the commodity cost estimates only apply to buildings. Industrial customers experience separate and lower commodity costs because of the assumed dedicated hydrogen for industry.

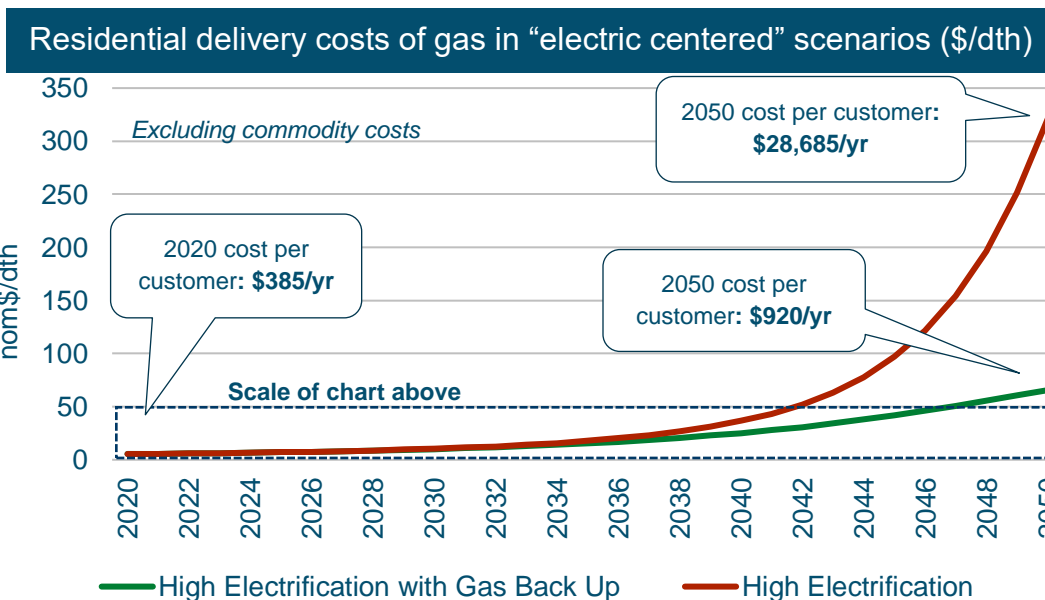
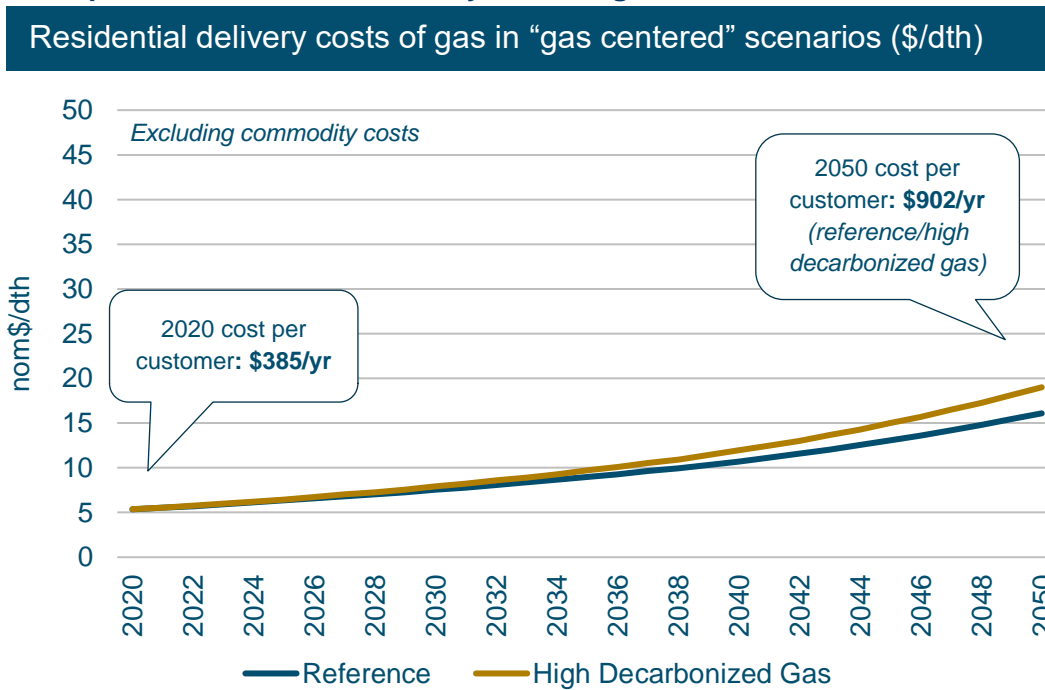
Figure 18. Average annual commodity costs of gas per scenario (\$/dht)



Note: The optimistic and conservative outlooks noted in this chart reflect different levels of competing demand in the transportation sector, as described in the gas sector impacts subsection above. The conservative outlook assumed that all cellulosic feedstocks of biomass would be more cost-effectively used to produce liquid fuels, leading to a heavier reliance on synthetic natural gas in buildings and industry. The optimistic outlook assumed only as much competition for renewable liquid fuels as was modeled in the Minnesota Transportation Pathways study, in which some cellulosic feedstocks (mainly corn stover) are left over for production of biomethane that could be used in buildings and industry.

Under current rate structures, customer delivery rates increase as sales volumes and the number of customers decline. Especially in an electrification scenario, the volumetric delivery costs associated with natural gas rates would increase as households switch to electric space and water heating and all-electric appliances, causing equity challenges for those customers unable to electrify. This effect is mitigated in the electrification with gas backup scenario, as all existing customers remain connected to the gas system. This means that the costs of the gas system continue to be spread over a large number of customers, mitigating impacts on the delivery component of gas bills. Figure 19 illustrates changes in the delivery portion of residential gas rates under a high gaseous fuels decarbonization scenario compared to a high electrification decarbonization scenario. Note that figure 19 assumes an unmanaged transition with no gas system cost reductions and no changes to rate structure or design to mitigate rate increases.

Figure 19. Impacts on residential delivery costs of gas

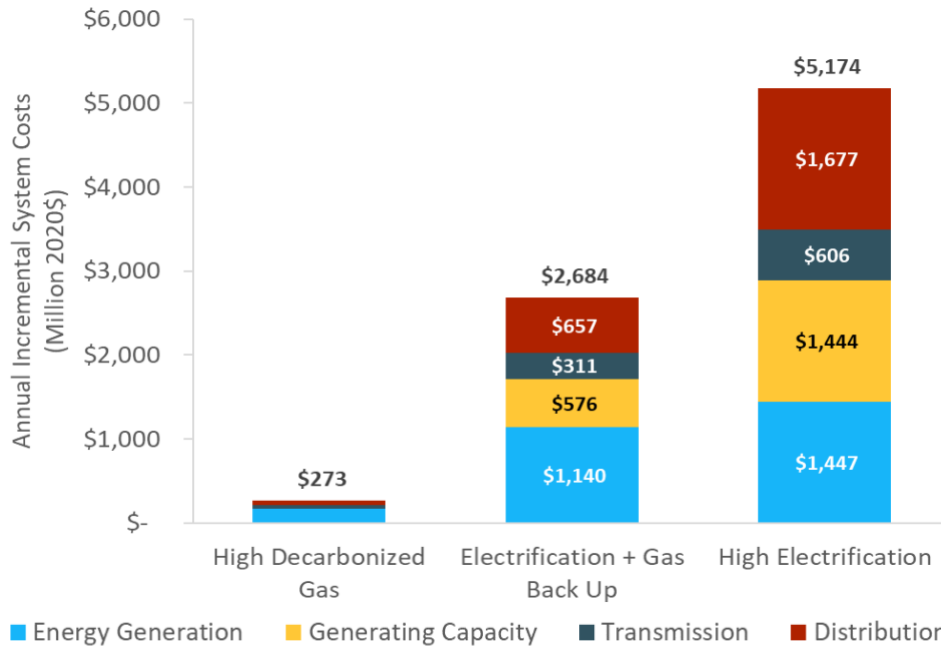


ELECTRIC SYSTEM ECONOMIC IMPACTS

In a high electrification decarbonization scenario, increased electric loads drive additional electric system costs, primarily for meeting additional winter peak capacity needs but also for incremental transmission and distribution system upgrades necessary to meet peak demands. Pairing air-source heat pumps with a backup gas heating source can significantly reduce incremental electric system costs by avoiding additional electric transmission and distribution infrastructure, generation, and storage resources as a result of lower system peak impacts.

Figure 20 depicts the incremental electric system costs associated with the three different decarbonization scenarios modeled.

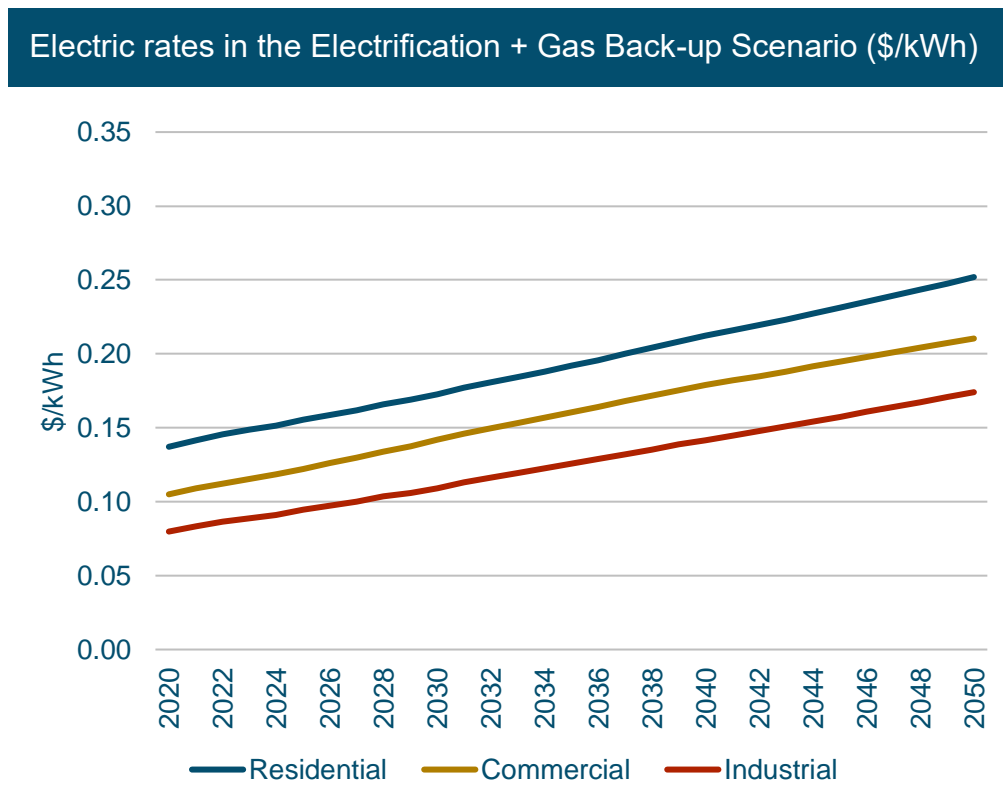
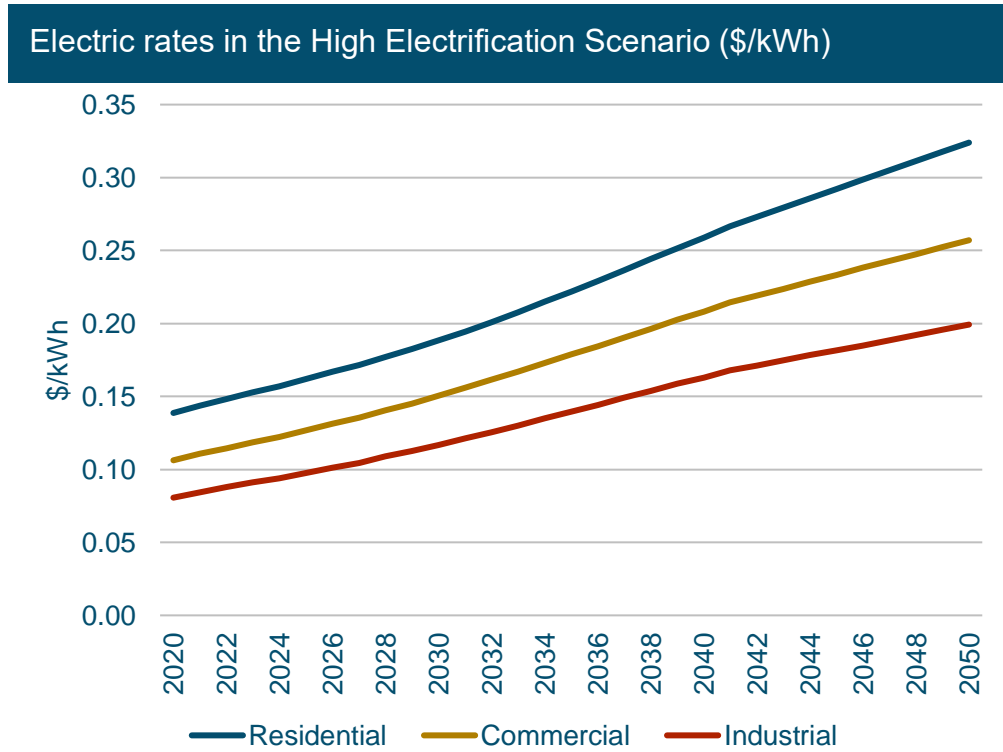
Figure 20. Annual incremental electric system costs relative to reference in 2050



Note: Assumptions for incremental electric system costs can be found in the appendix of the E3 modeling slide deck attached to this report.

Increased electric system costs will drive increases in electric rates. Maintaining a gas backup for space heating, as in the electrification with gas backup scenario, is projected to mitigate the increase in electric rates because it avoids significant generating capacity (winter peak demand), transmission, and distribution system costs. Figure 21 illustrates forecasted electric rates under the high electrification scenario as compared to the electrification with gas backup scenario.

Figure 21. Decarbonization impacts on electric rates



Notes: Rates pictured are in nominal dollars. While the reference case is not shown, electric rates in the reference case are similar to the high electrification scenario as the \$/kWh value is determined by dividing electric system costs by electric system load—the high electrification scenario significantly increases both systems costs and load, while the electrification with gas backup scenario increases load but does not require the same amount of system investment as the high electrification scenario, resulting in lower rates.

Total Incremental Resource Costs

In addition to forecasting the specific impacts to the electric and gas sectors, the scenario modeling considered what the total incremental resource costs would be to build and operate a decarbonized energy system for each of the scenarios in comparison to the reference case. This includes the following costs:⁵⁴

- Those that would be borne by consumers without rebates or other policies to subsidize those costs, such as purchasing and installing an air-source heat pump in the electrification-centric scenarios.
- Those that would be incurred in building electric system generation, transmission, and distribution infrastructure to meet an increase in electricity consumption and peak load due to electrification of natural gas end uses.
- Those that would be incurred to provide decarbonized gaseous fuels, including biomethane, hydrogen, and synthetic natural gas.

Notably, additional gas system infrastructure costs to provide dedicated hydrogen pipelines to the industrial sector are not included.⁵⁵ Costs of the gas system are assumed to follow a similar trajectory to the reference case in all decarbonization scenarios.⁵⁶

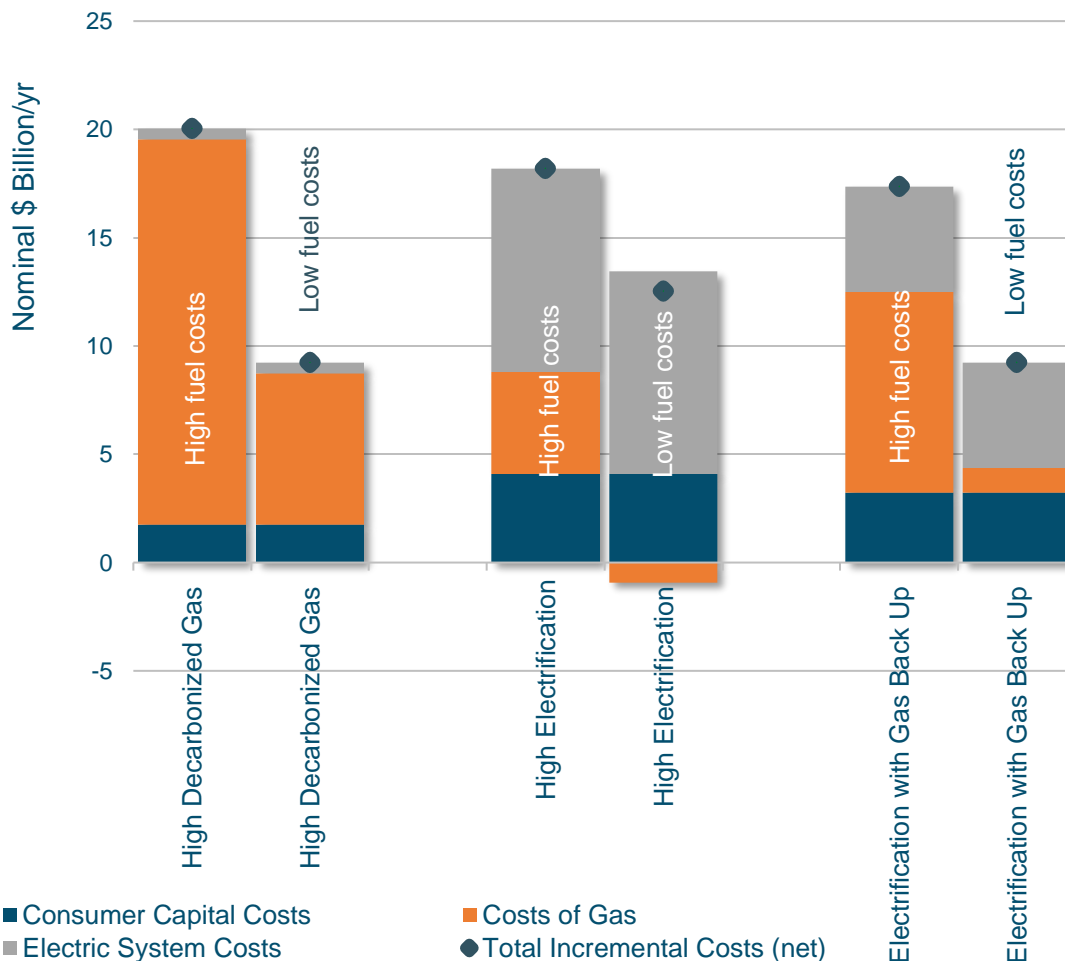
The total incremental resource costs for each scenario in 2050, including costs for all sectors—residential, commercial, and industrial—are illustrated in figure 22. There are two results for each scenario based on the optimistic and conservative outlooks for supplying decarbonized gaseous fuels. Under a scenario where decarbonized gaseous fuels are more expensive, the electrification with gas backup is the most affordable scenario, though the three scenarios are very similar. However, under a scenario where decarbonized gaseous fuels are less expensive, the high decarbonized gas and electrification with gas backup scenarios show similar costs, with the high electrification scenario significantly more expensive.

⁵⁴ Incremental electric and gas system and fuel costs (bullets 2 and 3) are reflected in the electric and gas rates described in previous paragraphs. A complete listing of costs and assumptions is included in the appendix of the modeling slide deck attached to this report.

⁵⁵ Stakeholders acknowledged that gas system infrastructure costs would likely increase to accommodate dedicated hydrogen pipelines (as modeled in the high decarbonized gas scenario), and potentially for interconnection pipelines to biogenic renewable natural gas and synthetic methane sources.

⁵⁶ Gas system costs are based on US Energy Information Administration reports of Minnesota statewide rates and natural gas sales and broken out into rate base, depreciation and operations and maintenance costs. Annual capital expenditures are expected to stay flat in the reference case and high decarbonized gas scenario. In the high electrification and electrification with gas backup scenarios, annual capital expenditures are expected to stay flat, with the exception of capital expenditures for new construction (as these scenarios assume all-electric new construction).

Figure 22. Total incremental resource costs for each scenario in 2050

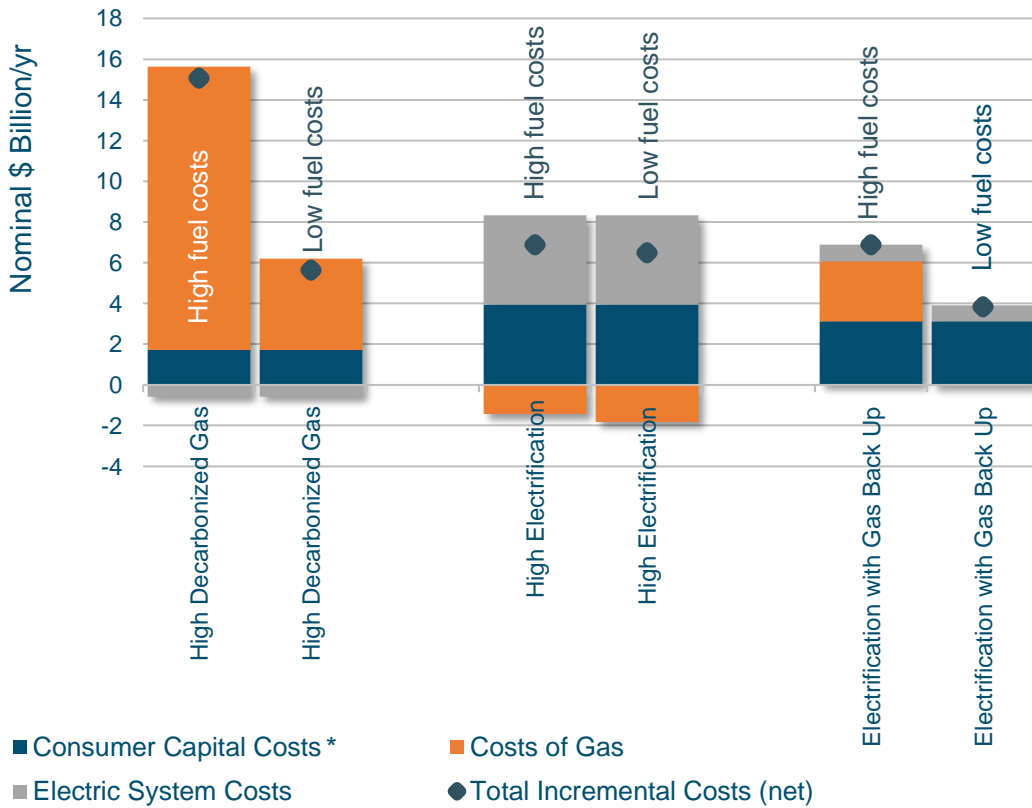


Note: Costs shown are in incremental in comparison to the reference case. Negative values mean that those costs are incrementally lower than the reference case.

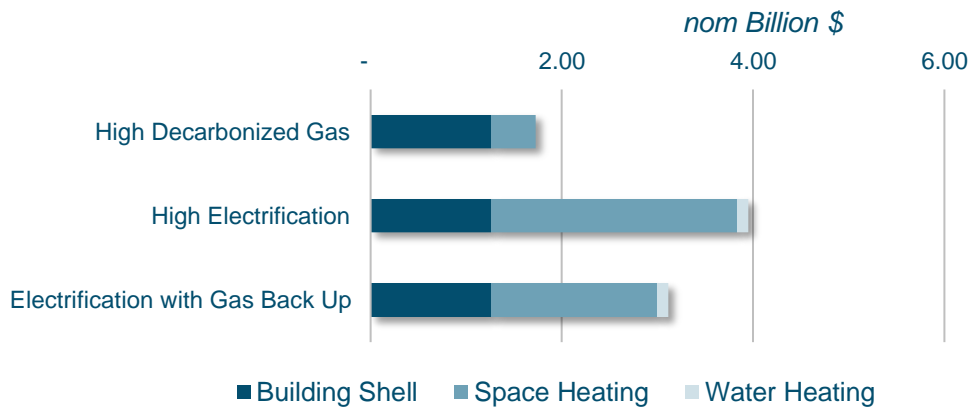
BUILDINGS SECTOR INCREMENTAL RESOURCE COSTS

The scenario modeling also assessed total incremental resource costs for buildings and industry separately. Looking at only buildings (residential and commercial), the electrification with gas backup scenario is the most affordable option regardless of whether decarbonized gaseous fuels are more or less expensive. This is because the electrification with gas backup scenario strikes a more cost-effective balance between infrastructure investments and fuel costs compared to the other two scenarios. For example, incremental resource costs for buildings in the high decarbonized gas scenario vary widely depending on the cost of decarbonized gaseous fuels, while the opposite is true for the high electrification scenario—fuel costs don't have a noticeable impact. These impacts are illustrated in figure 23.

Figure 23. Incremental resource costs for buildings across the three scenarios in 2050 (commercial and residential)



***Breakdown of consumer capital costs (incremental to reference)**

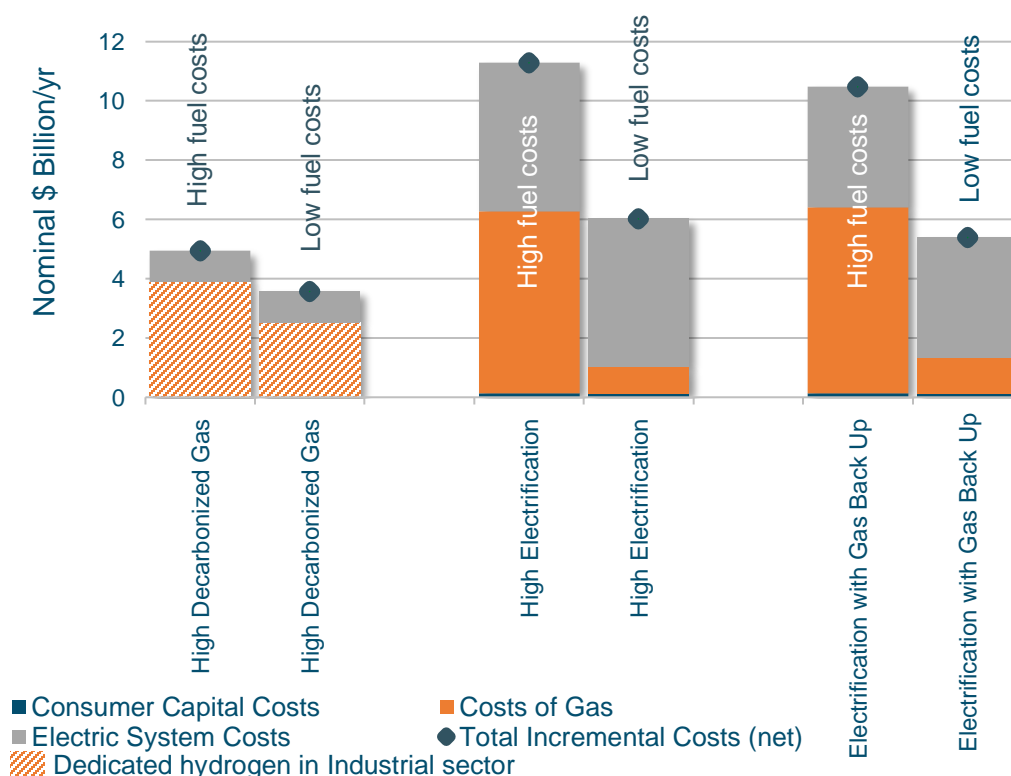


Notes: Costs shown are in incremental in comparison to the reference case. Negative values mean that those costs are incrementally lower than the reference case. Building sector costs show large variation across scenarios depending on gas fuel costs (optimistic/conservative supply curve). The electrification with gas backup scenario could potentially “hedge” for this uncertainty given its lower overall costs in both bookends.

INDUSTRY INCREMENTAL RESOURCE COSTS

The high decarbonized gas scenario is the most affordable for the industrial sector regardless of fuel costs in terms of incremental resource cost. This is illustrated in figure 24. This is due to providing dedicated hydrogen produced by renewable electricity for industry in that scenario and not in the other two, as dedicated hydrogen is assumed to be more cost-effective than providing decarbonized gaseous fuels through the existing gas system.⁵⁷ Importantly, the E3 modeling team acknowledged that further research is required to assess the technical feasibility of industrial infrastructure conversions to accommodate dedicated hydrogen, as well as to assess the costs of converting existing pipelines to dedicated hydrogen pipelines.

Figure 24. Incremental resource costs for industry across the three scenarios in 2050



Note: Lower costs in the high decarbonized gas scenario are the result of dedicated hydrogen for industry.

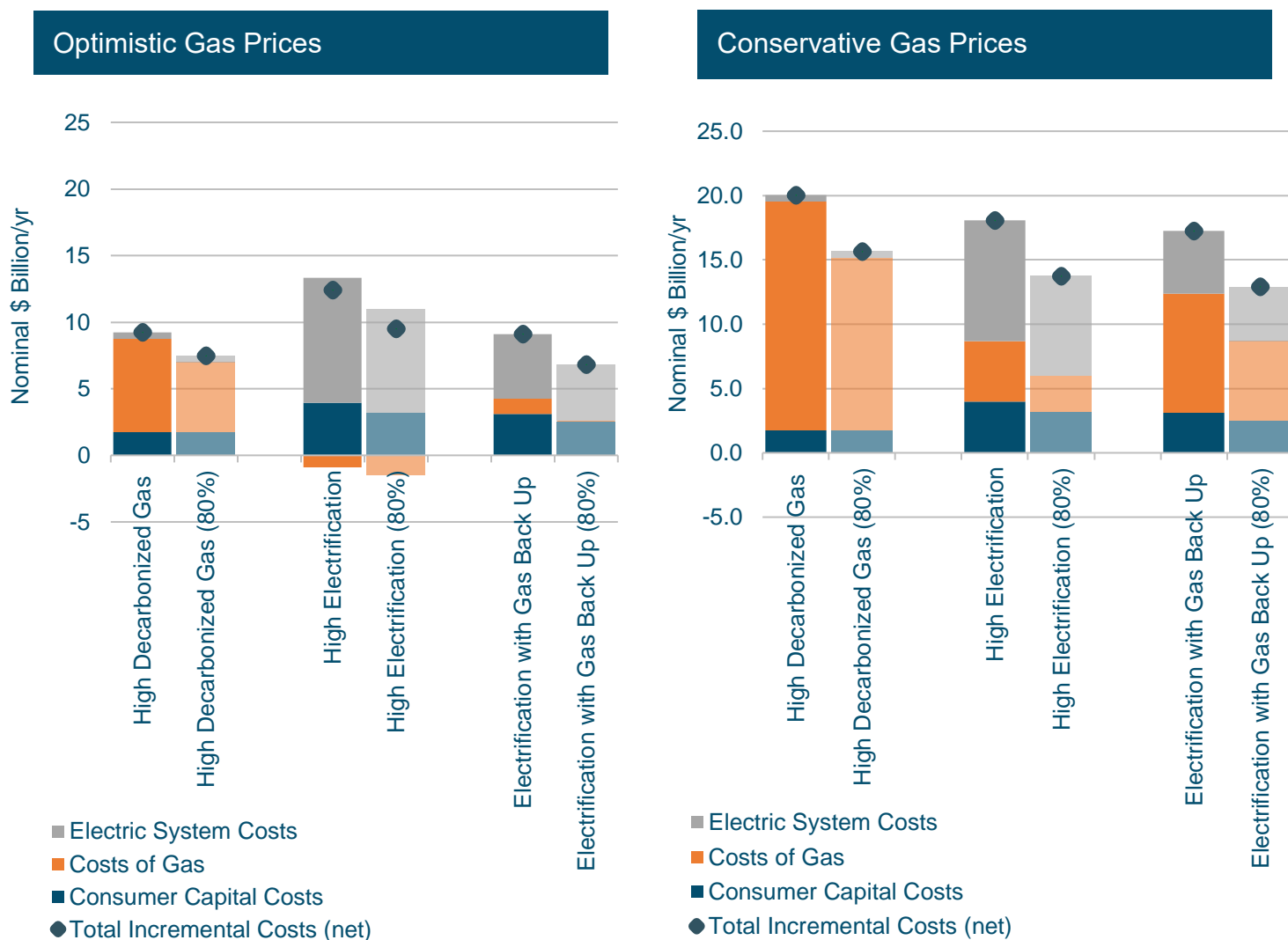
80 PERCENT GHG REDUCTION SENSITIVITY

The modeling also assessed the resource mix and total incremental resource costs if greenhouse gas reductions are limited to 80 percent by 2050, rather than achieving full decarbonization. Under this sensitivity, each scenario maintains some amount of geological

⁵⁷ The E3 modeling assumed that off-grid onshore wind would be built to supply electricity for hydrogen (and synthetic methane) production. Additional details are included in the appendix to the modeling slide deck, attached to this report.

natural gas, which largely offsets the same amount of synthetic methane, compared to the resource mix in the 100 percent emissions reduction. The sensitivity resulted in a general cost reduction for each of the scenarios, though it didn't noticeably change the relative differences in cost between the scenarios.⁵⁸ This is illustrated in figure 25.

Figure 25. Total incremental resource costs in 2050 if GHG reductions are limited to 80 percent



Note: Costs shown are in incremental in comparison to the reference case. Negative values mean that those costs are incrementally lower than the reference case.

⁵⁸ Savings from targeting 80 percent reductions in lieu of 100 percent ranged from \$1.7 billion/year in the optimistic gas prices scenario to \$4.4 billion/year in the conservative gas prices scenario.

District Systems Analysis

As noted above, the stakeholder group was interested in assessing the extent to which district systems could provide efficiencies to reduce electric system peak and provide reliable heating even on the coldest days of winter, though there was uncertainty about how widely these systems could be deployed without significant additional analysis of costs and scalability, which was out of scope and budget for the E3 modeling project.

In response, the E3 team sought to answer the first question about the potential for district systems to reduce peak impacts by conducting a high-level analysis with basic assumptions about district system deployment. The E3 team acknowledged that the results would lack analysis on the second question—locational feasibility of district systems and their thermal sources.

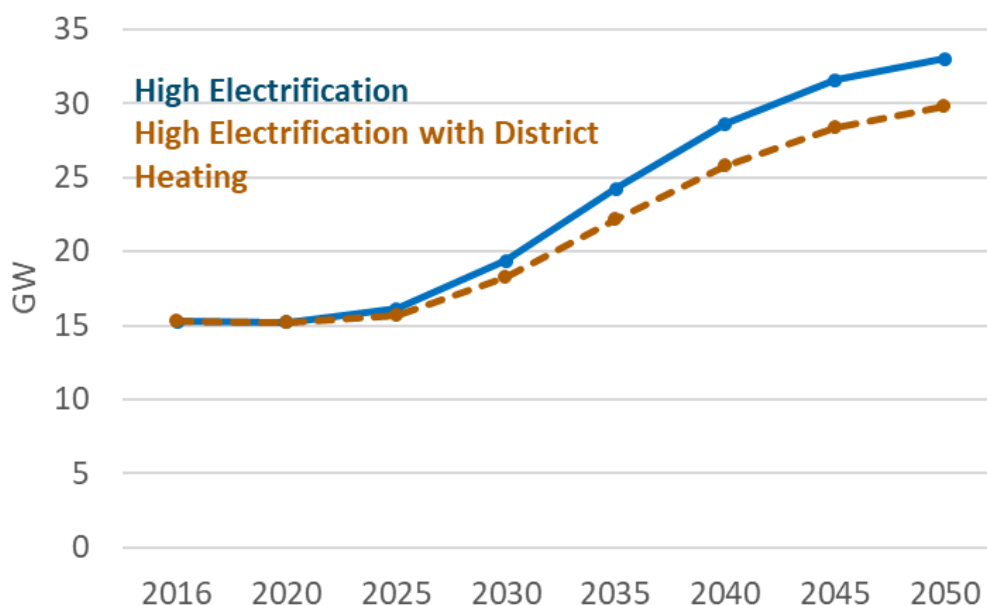
To assess how much the electric peak could be reduced if a percentage of load were served by district systems, the E3 team modified the assumptions of the high electrification scenario, such that district systems are installed for all new construction buildings in Minnesota, leading to a total penetration of 27 percent of buildings by 2050.⁵⁹

The analysis found that installing district systems in new construction—roughly 20 percent of building heating load in 2050—could reduce the 1-in-40 peak load by about 10 percent compared to the normal high electrification scenario, as illustrated in figure 26. This would result in electric system cost savings of about \$1.2 billion per year in 2050.⁶⁰ Moreover, the E3 team noted that this electric system cost savings figure is conservative because it does not take into account commercial and industrial load sharing, in which waste heat from commercial and industrial buildings could supplement the heating needs of nearby homes. This would further reduce electric system peak impacts if those homes were using electricity for heating. However, these cost savings may be partly offset by increased infrastructure investments associated with installing district systems, which are uncertain and warrant additional, location-specific research.

⁵⁹ BaroHappold and HEET, *GeoMicroDistrict Feasibility Study* (July 1, 2019), <https://heet.org/wp-content/uploads/2019/10/HEET-BH-GeoMicroDistrict-Final-Report.pdf>. This analysis assumed that all district systems would be vertical closed loop ground-source heat pump systems and used additional assumptions from the GeoMicroDistrict Feasibility Study conducted by BuroHappold for HEET in Massachusetts. Full assumptions are listed in the modeling slide deck attached to this report.

⁶⁰ Nominal dollars.

Figure 26. 1-in-40 electricity peak reduction impact from district systems



Modeling Discussion

This section of the report describes stakeholder observations and discussion points about the E3 scenario modeling. Importantly, the modeling was not intended to address all the wide-ranging considerations and implications of decarbonizing Minnesota’s natural gas end uses. Rather, it was conducted to help stakeholders think through an uncertain future in a structured way. Similarly, the discussion points captured below are not intended to describe every possible consideration that is pertinent to decarbonizing Minnesota’s natural gas end uses. They are simply meant to capture the group’s discussion that occurred within a limited amount of time.

Moreover, the observations and discussion points described below do not reflect consensus opinions of the stakeholder group. Instead, they represent a wide range of perspectives that stakeholders within the group hold about the modeling results. This discussion provides important context for the modeling results and insight into the multidimensional and interrelated challenges and opportunities associated with the different scenarios.

Notably, despite diverse and in some cases divergent opinions about the meaning of the modeling results, the group reached consensus on recommended actions to begin decarbonizing Minnesota’s natural gas end uses. These are described in the consensus recommendations section of this report.

Discussion of the 80 Percent GHG Reduction Sensitivity

Early on in considering the assumptions and parameters for the E3 modeling, stakeholders discussed the difference between Minnesota’s statutory greenhouse gas emissions reduction goal, which calls for an 80 percent reduction in emissions by 2050, as compared to the latest guidance and science from the Intergovernmental Panel on Climate Change (IPCC), which

recommends net-zero greenhouse gas emissions by 2050.⁶¹ Furthermore, stakeholders discussed that both Minnesota’s statutory emissions reduction goal and the IPCC recommendation refer to economywide emissions and do not indicate emissions targets for specific sectors or industries.

Stakeholders generally agreed that the latest guidance from the IPCC should be the goal for economywide emissions targets. However, some stakeholders indicated that it might be possible, and possibly more economical, to achieve a 100 percent reduction in emissions economywide, while allowing for some greenhouse gas emissions from natural gas end uses. This strategy would require other sectors or industries to achieve net negative greenhouse gas emissions levels.

Ultimately, the group decided to model all decarbonization scenarios for Minnesota’s natural gas end uses to achieve a 100 percent reduction in greenhouse gas emissions by 2050. However, as described above, stakeholders also asked E3 to provide a modeling sensitivity to show the estimated resource mix, energy system impacts, and cost implications of each decarbonization scenario if the scenarios achieved an 80 percent reduction in greenhouse gas emissions by 2050. This sensitivity resulted in lower overall costs in all scenarios, mostly due to the decreased use of synthetic methane. Synthetic methane was estimated to be the most expensive fuel in all scenarios, and lower electric system peak demand.

After reviewing the modeling results, some stakeholders questioned whether the forecasted cost savings of achieving an 80 percent emissions reduction, as opposed to the 100 percent emissions reduction, might be better used for emissions mitigation in other sectors that either have a larger contribution to statewide emissions or where emission reductions might be cheaper. Other group members noted that the latest guidance from the IPCC says that global emissions must be net negative after 2050 to avoid the most severe effects of climate change and that not achieving full decarbonization of natural gas end uses by 2050 would make it much harder to achieve net negative greenhouse emissions thereafter. Additionally, some stakeholders noted that aiming for an 80 percent reduction in emissions by 2050 could reduce investments in innovative decarbonization solutions, limiting Minnesota’s flexibility to respond and adjust to changing technology, costs, and consumer behavior over time.

Importantly, in the near- to mid-term the strategies and actions required to achieve either an 80 percent or a 100 percent emissions reduction in Minnesota’s natural gas end uses are the same. This is why, while the group did not come to agreement about the ultimate emissions goal for natural gas end uses by 2050, they did reach consensus on the robust recommendations of this report.

Discussion of Scenario Opportunities and Challenges

After the November 2020 stakeholder meeting during which E3 presented the modeling results to the group, GPI and CEE asked participants to submit an email stating what they believed to be the most important benefits/opportunities and drawbacks/risks for each of the three

⁶¹ All emissions reduction figures included in this report use a 2005 emissions level baseline.

scenarios. GPI and CEE then consolidated the responses and the group reviewed and discussed them at the January 2021 stakeholder meeting. We have provided below a brief summary of the stakeholder perspectives shared by email and discussed at the January 2021 meeting, as well as in subsequent meetings. Importantly, this section of the report provides a high-level summary of the conversation that took place among the stakeholders—it is not intended to describe every consideration that is pertinent to each of the scenarios.

HIGH ELECTRIFICATION SCENARIO

Electric System

One advantage of the high electrification scenario noted by many stakeholders was that utilities have demonstrated the ability to lower electric system emissions while maintaining reliability. This makes electrification seem an attractive and feasible alternative energy source to natural gas for many. Furthermore, stakeholders stated that many of the decarbonization technologies and strategies required to reduce emissions in the electric system are commercially available and currently in use. However, other stakeholders noted that electric utilities do not currently have the technologies and strategies in place to achieve full decarbonization of the electric system and that additional policy, regulatory support, and technological advancement will be required.

Many stakeholders also noted that a high electrification scenario would require the electric system to grow and evolve significantly, both in terms of generation and grid modernization, to serve new loads for buildings and industry. That growth could be costly and may pose additional challenges for achieving decarbonization of the electric system. One such challenge noted by stakeholders is that building heating loads peak in winter, when renewable electricity generation is the lowest, often for longer periods than batteries can economically support.

Some stakeholders noted that energy efficiency in both existing buildings and new construction can significantly help to mitigate higher peak electric loads resulting from electrification. Additionally, deployment of ground-source heat pumps, geothermal district systems, and advancements in air-source heat pump technology could also help to mitigate peak electric loads associated with building electrification.

Notably, all stakeholders agreed on the following points:

- Electrification as a strategy to decarbonize natural gas end uses requires continued decarbonization of the electric system.
- The electric system would need to evolve and grow to serve new loads.
- Strategies to manage peak electric loads are critical to address the costs and technical challenges of electrification.

Gas System

Stakeholders also discussed gas system challenges associated with the high electrification scenario. Notably, under this scenario use of the gas system would decrease significantly, potentially resulting in stranded natural gas infrastructure assets and requiring new regulatory

mechanisms to recover infrastructure costs.⁶² Regardless of whether stranded assets occur, fewer gas customers or lower sales volumes could increase gas rates.⁶³ Participants noted that without intervention, customers who remain on the gas system may be those who face the greatest barriers to electrification, including people who lack the money or financing tools to change out equipment and invest in energy efficiency improvements, as well as renters and customers who face a split incentive.⁶⁴

All stakeholders agreed that a thoughtful, managed transition for businesses and workers in the gas industry would be necessary to mitigate negative economic and workforce impacts if the state transitioned away from maintaining the current gas system.

Customer Equipment

Several stakeholders noted the benefits of electric heat pumps for space and water heating in buildings, including the following:

- Heat pumps are commercially available today, offering a lower-emissions alternative to natural gas heating equipment.
- Heat pumps are highly efficient.
- Heat pump technology has advanced in recent years and can provide space heating in colder weather, compared to older air-source heat pump models.

However, stakeholders also pointed out the limitations of heat pump technology for space heating in cold climates. Even the most advanced and efficient cold climate heat pumps require a backup heating system for most buildings in Minnesota. In the high electrification scenario, backup heat would be supplied by electric resistance heating, which is less efficient and therefore more expensive than heat pump heating. Additionally, as temperatures decrease, so does the efficiency of air-source heat pumps, making them more expensive and energy intensive on the coldest days of the year.

One stakeholder suggested that relying solely on electricity for space heating could improve resiliency for some customers, noting that for people who currently heat with a natural gas furnace, their furnace would fail in the event of either a natural gas or electric service outage.⁶⁵ Others noted that overall resiliency and reliability of the electric system could diminish under the high electrification scenario, reducing reliability at the customer level as well.

⁶² Natural gas infrastructure is long-lived and the costs of the infrastructure are typically recovered over decades through rates. Stranded assets are assets, often infrastructure, that are retired or no longer useful prior to the end of their economic life, which is the period of time over which a utility recovers the costs and earns a rate of return on the asset.

⁶³ Under current rate structures, fixed infrastructure costs of the gas system are divided among customers and gas sales volumes. With fewer customers and sales volumes to spread out system costs, rates could increase for those who remain on the gas system.

⁶⁴ A split incentive occurs when one person or entity is responsible for paying energy utility bills, while another person or entity owns the equipment that uses the energy, such as a renter and property owner. Costs and benefits of adopting an energy efficiency or electrification technology are asymmetrically split between the two parties.

⁶⁵ This is because modern gas furnaces require electricity to operate.

Several stakeholders pointed out that, while there are challenges to electrifying existing heating loads, other building electrification technologies—such as clothes dryers, cooking ranges, and water heaters—are commercialized, effective, and widely available. Additionally, some in-building electric technologies like water heating can be managed to reduce electric system peak demand and even store energy to help integrate renewable energy resources.

Stakeholders acknowledged that one key challenge of the high electrification scenario is that it would require millions of individual decisions and actions, as nearly all homes and businesses would need to be retrofitted and receive new equipment. Finally, participants noted that electrification solutions for many industrial applications are currently limited.

HIGH DECARBONIZED GAS SCENARIO

Gas System

One advantage many stakeholders cited to the high decarbonized gas scenario was that it utilizes the existing natural gas system, which is robust and wide-reaching in Minnesota. Some stakeholders observed that this scenario would require the fewest changes to gas utility operations. These stakeholders noted that incremental investments would be needed primarily for new technology and innovation, but the scenario would not require a wholesale transformation of infrastructure and the utility business model. Therefore, some stakeholders thought the scenario might provide an easier path to decarbonization, compared to the high electrification scenario, with the added benefit of minimal disruption to the existing natural gas workforce.

Other stakeholders, however, believed that this scenario would require a major transformation of gas infrastructure and operations, including construction of renewable natural gas interconnection pipes and dedicated pipes for hydrogen. Additionally, some stakeholders noted that there are few established policy and regulatory mechanisms to enable utility investments in decarbonized gaseous fuels and associated changes to the gas system.

Some participants pointed out that the natural gas distribution system and other in-state infrastructure leaks, though that leakage is relatively small compared to the amount of leakage that occurs during the production and transmission of natural gas. Continued distribution of a methane-based fuel like biogenic renewable natural gas or synthetic methane in the gas system would result in continued methane emissions, posing a challenge to decarbonization.

Decarbonized Gaseous Fuels

All stakeholders acknowledged that a key risk to the high decarbonized gas scenario is that carbon-free hydrogen and carbon-neutral renewable natural gas are emerging fuels for which future costs and availability are uncertain and the markets are immature, especially in Minnesota.⁶⁶ Moreover, some stakeholders expect significant competition for renewable natural

⁶⁶ There are varying estimates of the potential for carbon-neutral renewable natural gas to replace conventional natural gas. In “A Pipe Dream or Climate Solution,” published in June 2020, the Natural Resources Defense Council estimated biogenic RNG to be capable of replacing between 2 to 5 percent of current natural gas throughput in the

gas and hydrogen supplies from other economic sectors, including transportation, agriculture, and electricity generation. Therefore, some stakeholders anticipate demand for those fuels to surpass supply.

Some participants noted that decarbonized gaseous fuels have the potential to support greenhouse gas reductions and other environmental benefits in other sectors of the economy, such as agriculture and waste. Conversely, other participants noted concerns about the potential environmental ramifications of renewable natural gas market growth.

Some stakeholders also noted that hydrogen and renewable natural gas, including synthetic methane, are not inherently carbon-free or carbon-neutral. The emissions intensity of these fuels, which can vary from only slightly lower carbon than natural gas to carbon-negative, is dependent upon the method of production and feedstock. Finally, some stakeholders noted that achieving carbon neutrality by 2050, as opposed to zero carbon emissions, could make it difficult to reduce emissions to net negative levels after 2050.

Group members also discussed the potential for economic development associated with decarbonized gaseous fuels, stating that renewable natural gas and hydrogen can be produced in-state, which would create local jobs and economic activity.

Customer Equipment

Several stakeholders noted that maintaining the gas system and re-fueling it with decarbonized gas may require few customer-level decisions and actions to achieve decarbonization. Rather, the utilities and regulators would be the key decision makers. Customers who currently use natural gas could potentially continue to use the same equipment. This is especially true if the system contained methane-based fuels like biogenic renewable natural gas or synthetic methane. Some stakeholders believed that this could pose an easier path toward decarbonization compared to electrification strategies, which require more customer-level equipment changes.

Other stakeholders stated that maintaining combustion of gaseous fuels in homes and businesses has inherent health and safety risks, including carbon monoxide poisoning, reduced indoor air quality, and risk of explosion. In response, some participants stated that such risks are not significant for well-maintained equipment with proper ventilation.

ELECTRIFICATION WITH GAS BACKUP SCENARIO

Stakeholders acknowledged that the electrification with gas backup scenario shares many of the same opportunities and challenges as the high electrification and high decarbonized gas scenarios. However, the group discussed several unique implications as well, which are described below.

United States by 2040. An American Gas Foundation study prepared by ICF, "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment," published in December 2019, found potential of 6 to 14 percent.

Electric and Gas Systems

Many stakeholders noted that the electrification with gas backup scenario lessens some of the risks of both high gas costs and the costs of building a much larger electric system to accommodate all space heating in the coldest hours of winter. Stakeholders highlighted that the modeling results showed that this scenario would be the lowest cost option. Stakeholders observed that this scenario lowers costs by requiring a smaller electric system build-out compared to the high electrification scenario, largely because of lower winter peak demand as well as avoided transmission and distribution system investments. Similarly, this scenario reduces the costs of decarbonized gaseous fuels by avoiding significant amounts of the most expensive gaseous fuel, synthetic natural gas, as compared to the high decarbonized gas scenario.

Some stakeholders also noted that this scenario would continue to use existing gas system infrastructure, reducing the risk of stranded assets when compared to the high electrification scenario. However, stakeholders also acknowledged that the electrification with gas backup scenario would pose challenges related to recovering gas system costs through volumetric rates, as gas volumes would significantly decline from today's levels.

One participant stated that compared to the high electrification scenario, the electrification with gas backup scenario optimizes the electric system, making it highly efficient in shoulder months with less overbuilding of electric generation to accommodate the high winter peak.

Customer Equipment

Some stakeholders expressed that the electrification with gas backup scenario provides additional resiliency associated with a dual-fuel system at the customer level. However, others noted that the electrification with gas backup scenario requires two types of fuel to function and is therefore vulnerable to an outage of either fuel.

Participants also noted that this scenario provides greater customer choice, which might provide reassurance of heating reliability and ease customer hesitancy around transitioning to a decarbonized system.

Finally, several stakeholders believed that the electrification with gas backup scenario was the most complicated of the scenarios modeled, noting that it would require implementing advanced building controls, which could be vulnerable to human and mechanical error.

DECARBONIZATION ECONOMIC BENEFITS

In addition to the climate benefits of decarbonizing Minnesota's natural gas end uses, stakeholders generally agreed that, regardless of scenario, decarbonization could provide additional economic benefits for the state:

- All decarbonization scenarios modeled would reduce Minnesota's exposure to the volatility of natural gas markets.

- Decarbonized energy sources, whether electric resources or gaseous fuels, can be produced in-state, which could keep more revenue in the state compared to continued use of geological natural gas.⁶⁷
- New economic opportunities, including jobs, could arise from investments in infrastructure build-out, end-use technology change-out, major energy efficiency improvements, and building retrofits.

Choosing a Path to 2050

In the final meetings of the process, stakeholders discussed whether there was consensus for or against a general pathway to decarbonizing Minnesota's natural gas end uses based on the modeling results. It became clear through these spirited and important discussions that there were different perspectives within the group about what that pathway should be and even whether any pathway should be chosen at this point in time.

Despite these different perspectives, all stakeholders agreed that decarbonizing natural gas end uses will require immediate investments in research, development, and deployment of energy efficiency, electrification, renewable natural gas, and hydrogen, though there was disagreement about how best to deploy those resources in the buildings sector. Stakeholders also agreed that there are several strategies ready for deployment today, as described in the consensus recommendations section of this report. The paragraphs below describe the different perspectives shared by stakeholders during discussion about a decarbonization pathway to 2050. Importantly, these discussions focused on the three scenarios that the group modeled, but in reality Minnesota's best path forward likely will not align perfectly to one of these modeling scenarios.

Several stakeholders noted that the high electrification and the electrification with gas backup scenarios share many complementary and overlapping strategies, especially in the near term. Accordingly, stakeholders noted that pursuing either scenario provides flexibility to move from one to the other at a later date if one becomes more attractive or more feasible. Conversely, stakeholders noted that pursuing the high decarbonized gas scenario requires some near-term actions that are incompatible with the other two scenarios. While it is possible to switch from the high decarbonized gas scenario to one of the other scenarios at a later date, it would be more costly and time-consuming to do so, as compared to moving between the other two scenarios.

Some stakeholders, however, expressed concerns about picking a scenario or taking any scenario or strategy off the table. These stakeholders noted uncertainty as a key driver of their concerns, especially given that some of the fuels and technologies in the E3 modeling are emergent with limited cost information. In addition, these stakeholders were concerned that recommending or selecting a path forward today could preclude or discourage decision makers from considering or pursuing a different path if, in the future, a different approach becomes more attractive or feasible.

⁶⁷ Minnesota has no in-state geological natural gas production.

Conversely, several stakeholders voiced concern about not recommending a scenario or set of complementary scenarios. These stakeholders felt that Minnesota should choose a path and begin taking action down that path immediately to avoid the worst impacts of climate change. While stakeholders agreed that all pathways could achieve carbon neutrality by 2050, some felt that only certain pathways would enable achieving carbon-negative emissions after 2050, as determined necessary by the IPCC and International Energy Agency⁶⁸ to avoid the worst impacts of climate change. In addition, some participants worried that presenting all scenarios as equally plausible and attractive is inaccurate and could result in inaction by decision makers or uncoordinated action, which could slow progress toward or increase the costs of decarbonization. Other participants noted that the goal of conducting this modeling was not to predict the future but to serve as a tool for discussion and decision-making amongst the stakeholder group, and that therefore the modeling by itself should not determine any particular course of action.

The consensus recommendations described below include actions that will provide the opportunity to further explore and identify the best path forward for Minnesota.

⁶⁸ International Energy Agency, *Net Zero by 2050: A Roadmap for the Global Energy Sector*, (June 2021), https://iea.blob.core.windows.net/assets/405543d2-054d-4cbd-9b89-d174831643a4/NetZeroBy2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

V. Consensus Recommendations

This section of the report describes what all stakeholders agree can and must be done now to achieve economywide decarbonization in Minnesota by 2050. The group agrees that the following recommendations are necessary regardless of the degree of decarbonization or the exact pathway to decarbonization.

The recommendations are grouped by categories based on the subgroups that developed them, though the groupings should not be taken as restrictive. Stakeholders also identified a set of cross-cutting recommendations that apply to all groupings—these are presented first. The recommendations are numbered for reference purposes only. The numbers do not indicate a ranking or priority. Importantly, the full set of recommendations is intended to be taken as a package.

Recommendations 1-15 are not targeted at a specific actor because the group was either unsure of who would be best suited to implement the recommendation or felt that many different actors must collaborate to successfully implement it. The group acknowledges that more work is needed to develop and refine the implementation details for these recommendations.⁶⁹

Recommendations 16-25 are specifically targeted at the Minnesota Public Utilities Commission, Minnesota Department of Commerce, and Minnesota Pollution Control Agency in recognition of the important and vital role that these regulatory agencies will need to play in decarbonizing Minnesota's natural gas end uses.

Cross-Cutting Recommendations

#1 ENSURE EQUITY IS THOROUGHLY INCORPORATED

Rationale: All energy infrastructure and policy decisions have the potential to impact people unequally and inequitably. Unfortunately, there are many examples of such decisions that have caused adverse impacts on historically marginalized communities. This has occurred and continues to occur because these impacts were not adequately considered and because affected communities were either not consulted or did not have an equal voice in the decision-making process.

Accordingly, through its guiding principles this group agreed that equity must be a priority in the process to decarbonize Minnesota's natural gas end uses. Moreover, the scenario modeling showed that the decarbonization process could have negative impacts on marginalized communities without thoughtful decision-making and active management of the transition.

In addition, stakeholders recognized that they collectively represented many different perspectives, but did not adequately represent Black, Indigenous, and people of color (BIPOC) communities and communities in Greater Minnesota. Therefore, additional efforts must be made

⁶⁹ At the time of writing this report, GPI and CEE are actively fundraising to support a second phase of stakeholder engagement in which these implementation details can be developed and refined.

to engage a more diverse set of stakeholders as these recommendations are carried forward and refined.

Recommendation: All efforts, initiatives, and research to decarbonize Minnesota’s natural gas end uses should include diverse voices and perspectives, including marginalized communities and others who (a) have not been involved regularly in energy planning and decision-making in the past; (b) face disproportionately high energy burden and environmental impacts; and (c) will likely be disproportionately impacted financially or socioeconomically by changes made to achieve decarbonization. All efforts around decarbonizing Minnesota’s natural gas end uses must be done in deliberate, inclusive, and thoughtful ways to accomplish the following:

- a. Ensure that the decarbonization of natural gas end uses is done in a way that reduces current inequities and does not create new inequities, in terms of costs and benefits.
- b. Ensure that the benefits of the transition—in terms of emissions benefits, economic benefits, public health benefits, and energy affordability benefits—are experienced among Minnesotans, especially workers, under-resourced communities, BIPOC communities, and communities in Greater Minnesota, and that such benefits outweigh the costs borne by such persons and communities.
- c. Ensure that all Minnesotans have the ability to adopt technologies and fuels that decarbonize natural gas end uses affordably and effectively.

#2 CONDUCT WIDESPREAD EDUCATION AND ENGAGEMENT

Rationale: Emissions from natural gas end uses in Minnesota buildings and industry contribute substantially to Minnesota’s greenhouse gas emissions. Moreover, emissions from natural gas end uses in Minnesota are increasing, as natural gas consumption in the residential, commercial, and industrial sectors has increased by 32 percent since 2005. Minnesota cannot achieve its statutory greenhouse gas reduction goals without addressing emissions from natural gas end uses in the state. Moreover, given the timeframe of the state’s greenhouse gas reduction goals, as well as the timeframe for greenhouse gas reductions in the Intergovernmental Panel on Climate Change guidance, we must act quickly to address natural gas end-use emissions.

Addressing emissions from natural gas end uses will require action by a wide range of individuals, businesses, and governmental agencies. Therefore, education and engagement of customers, contractors, installers, builders, property owners, and utilities will be critical to support this group’s recommendations related to decarbonization technologies and strategies in a timely manner. Without proper knowledge and awareness, deployment of key decarbonization strategies could be delayed or performed in an ineffective or inefficient way.

Recommendation: Appropriate and relevant education and outreach should be conducted for all Minnesotans, including the general public, all natural gas and electric customers, contractors, installers, the construction community, distributors, regulators, and utilities to increase

awareness and understanding of what they need to do to advance decarbonization of natural gas end uses.⁷⁰ This should include the following:

- a. Education, engagement, and outreach for the residential and small business sector that supports the following key strategies:
 - i. Building envelope measures, including emerging techniques and technologies for achieving deep energy retrofit levels.⁷¹
 - ii. Heat pumps for space conditioning and water heating.
 - iii. Electrification infrastructure and rates, including for other electrified end uses such as electric vehicles and induction cooking.
- b. Education, engagement, and outreach to ensure all relevant actors have the most up-to-date technology capability and cost information, so that they can make informed decisions.

#3 ASSESS OPTIONS FOR DEPLOYING DISTRICT ENERGY SYSTEMS

Rationale: Modern district energy systems can effectively and efficiently use multiple energy sources, including thermal energy trapped in the ground, to heat and cool multiple buildings, as well as transfer waste thermal energy between buildings. For example, waste heat from commercial and industrial buildings can be used to heat nearby residential buildings. Importantly, efficiencies of scale increase when these systems are connected to a mix of different building stock types.⁷² In addition, it may be helpful to further explore other (non-geothermal) district energy systems—prioritizing use cases that maximize coefficient of performance—to support decarbonization, due to the efficiency gains of these systems.

While the scenario modeling was unable to look in-depth at the potential for deploying decarbonized district energy systems in Minnesota, it did show that these systems could significantly reduce electric system costs in the high electrification scenario by reducing peak heating loads. In this way, district energy systems can be thought of as an enabling technology to support decarbonization scenarios. However, there is uncertainty about the installation costs of these systems and whether those costs would be worth the benefits.

More research is needed to identify where these systems can be most effectively deployed to support decarbonization, as well as what is needed to make these systems viable, including policy, business climate, technical expertise, worker training, incentives, and availability for scaled deployment of specific technologies, among other considerations. Such research could also highlight potential benefits, costs, and opportunities of these systems. For example, the

⁷⁰ See also recommendation #6, which speaks specifically to workforce education and training.

⁷¹ Building envelope measures include, but are not limited to: attic air sealing, increased or improved attic and wall insulation, exterior insulation panels, caulk around windows and doors, upgrades to existing windows or additional storm windows, replace old exterior doors, weatherstripping, and caulk around outlets on exterior walls.

⁷² Load diversity (a mix of buildings with different energy use profiles) can be useful for deploying these systems, but is not necessary to make them work.

group discussed how gas utilities could build and operate these systems, though doing so would require new expertise and business models.⁷³ Additionally, geothermal district loop systems have potential workforce retention benefits, repurposing the skills of existing natural gas distribution system workers and businesses, and helping support a just transition.

Recommendation: Assess options for deploying decarbonized district energy systems, including but not limited to the following:

- a. Identifying where decarbonized district energy systems could be most beneficially deployed across Minnesota.
- b. Developing an approach to enable small utilities and district energy systems to address gas end-use decarbonization through customized programs, similar to those considered for large electric and gas utilities, with consideration for low-carbon fuel standards, technology innovation, and deployment on a smaller, localized scale.
- c. Further exploring how expansion of district energy for all sectors could support meeting the guiding principles.

Large Commercial and Industrial Recommendations

#4 STUDY DECARBONIZATION OPTIONS FOR LARGE COMMERCIAL AND INDUSTRIAL END USES

Rationale: Natural gas end uses in large commercial and industrial facilities present special challenges for decarbonization. Those end uses are often highly specialized for a particular business operation or facility and may also require extreme heat. While the E3 scenario modeling considered decarbonization options for large commercial and industrial natural gas end uses, it drew upon high-level assumptions for how those sectors could be decarbonized. Moreover, the modeling was not intended to provide the level of granularity that would be needed for policy makers and natural gas consumers to make wise decisions about how to practically decarbonize natural gas end uses in the large commercial and industrial sectors. Therefore, additional research is needed to better understand and make actionable the decarbonization options for these sectors.

Recommendation: Conduct two studies, paired with stakeholder engagement, to better define the various natural gas end uses for (1) the large commercial sector and (2) the industrial sector, and match decarbonization technologies to those end uses.

⁷³ “Eversource Approved to Build GeoMicroDistrict,” HEET (website), accessed May 19,2021, <https://heet.org/2020/11/16/eversource-approved-to-build-geomicrodistrict>. EverSource, a large natural gas utility in New England, received regulatory approval to build and operate geothermal micro districts in Massachusetts. Eversource is authorized to spend \$10 million for the design, construction, and maintenance of networked geothermal in a densely populated neighborhood, around 100 homes and businesses.

The key question for both studies is: What technologies can achieve decarbonization at the lowest cost for each end use, with attention to the full set of guiding principles developed by this group (carbon intensity, equity, workforce, public health, system dynamics)?

Importantly, the group recommends two separate studies—one for industrial end uses and one for large commercial end uses—because these sectors are unique and have different end uses, challenges, opportunities, and key actors, even though the key question to be answered in each study is the same.

These studies should seek to accomplish the following:

- a. Be technology agnostic, including consideration of the following technologies:
 - i. Energy efficiency
 - ii. New dedicated hydrogen infrastructure for industry (to support hydrogen produced via a low-carbon process)
 - iii. Electrification
 - iv. Carbon capture (all applicable forms)
 - v. Pipeline-delivered (via existing infrastructure) low-carbon gaseous fuels (renewable natural gas, hydrogen, ammonia⁷⁴)
 - vi. Non-pipeline delivered low-carbon gaseous fuels (on-site produced biogas, truck delivered fuels)
 - vii. Geexchange (geothermal, aquifer thermal energy storage, sewer exchange, deep water exchange)
 - viii. District energy systems
 - ix. Other resources and future technologies not listed above
- b. Identify (1) barriers to adoption and implementation of decarbonization technologies, (2) recommended pathways to decarbonization, and (3) policy recommendations to facilitate the transition to decarbonization for the industrial and large commercial sectors. Importantly, the study should also consider how innovation may change which technologies are the best fit for different end uses over time.⁷⁵
- c. Be transparent in how lifecycle carbon emissions and carbon intensity are accounted for. This group suggests accounting for fuel lifecycle⁷⁶ (but not parts and equipment manufacturing) emissions, using existing methodologies and available data.

⁷⁴ Ammonia cannot be blended into the existing gas system, but there is existing ammonia infrastructure.

⁷⁵ For example, the study should not close the door on localized alternatives, such as local methane capture and reuse.

⁷⁶ "Lifecycle Analysis of Greenhouse Gas Emissions under the Renewable Fuel Standard," EPA (website), accessed May 19, 2021, <https://www.epa.gov/renewable-fuel-standard-program/lifecycle-analysis-greenhouse-gas-emissions->

- d. Consider which sectors have higher deployment of combined heat and power (CHP) and what specific decarbonization solutions may be the best fit for CHP applications.

#5 EXPLORE INFRASTRUCTURE INVESTMENT OPPORTUNITIES TO DECARBONIZE THE ENERGY DEMANDS OF INDUSTRIAL CUSTOMERS

Rationale: Currently, the natural gas system in Minnesota is being expanded to bring natural gas to large industrial sites. When gas infrastructure is built out for a large industrial customer, it is also often connected to nearby commercial and residential customers. From a greenhouse gas emissions perspective, extending the system in this way can create near-term benefits for emissions reductions, affordability, reliability, and, by consequence, equity for smaller towns in Minnesota that primarily use propane for space and water heating. However, this practice could also create long-term challenges for decarbonization because it requires investment in infrastructure that may not accommodate a fully decarbonized system. The long-term public interest, therefore, might be better served by investing in infrastructure that can deliver lower- or zero-carbon energy, such as hydrogen or renewable natural gas, to industrial customers. This can help facilitate lower- or zero-carbon alternatives for other types of customers on the system. There may also be areas of Minnesota that would be better served in the long term by investing in electrification infrastructure.

Recommendation: Explore opportunities for infrastructure investments that can provide lower- or zero-carbon energy, such as hydrogen or renewable natural gas, to industrial and large commercial customers.

Workforce Recommendations

#6 STUDY WORKFORCE IMPACTS OF THE THREE DECARBONIZATION SCENARIOS

Rationale: The group's guiding principles include (a) managing disruption; (b) creating family-supporting workforce opportunities; and (c) ensuring that the benefits of the transition are experienced, and negative impacts mitigated, among Minnesota's workers. While the E3 scenario modeling helpfully laid out three viable decarbonization scenarios, it did not assess workforce impacts around those scenarios. Developing a better understanding of the potential workforce impacts for all three scenarios can help to ensure that Minnesota can manage workforce disruptions and create opportunities and benefits for affected workers.

Recommendation: Conduct a workforce study, including modeling and stakeholder engagement, around the three decarbonization scenarios that this group explored. This study should be informed and directed by robust stakeholder engagement to ensure credibility. Moreover, whoever leads the study should work with stakeholders and industry representatives to ensure they are making use of and appropriately interpreting available information. This study should specifically seek to answer the following questions:

[under-renewable-fuel](#). Lifecycle analysis, sometimes referred to as fuel cycle or well-to-wheel analysis, is used to assess the overall GHG impacts of a fuel, including each stage of its production and use. More information on lifecycle emissions analysis is available through the EPA's Renewable Fuel Standard Program.

- a. What raw number of jobs would be created or impacted by each of the scenarios, and what sector would each of those jobs be in?
- b. What would the quality of those jobs and compensation look like under each scenario in comparison to the jobs reduced, displaced, or eliminated?
- c. What would be the demographic and geographic distribution of those jobs?
- d. What would be the workforce impacts on specific sectors, including potential benefits of decarbonization scenarios?
- e. What workforce expertise and skills are needed under each scenario and what kinds of businesses generally provide those?
- f. The timing of the transition should be taken into account to manage workforce disruptions and create opportunities.
- g. How might regulation of sectors change under each of the scenarios, and what impacts to workforce might that have?

#7 IMPROVE GAS AND ELECTRIC UTILITY WORKFORCE REPORTING

Rationale: Currently, utilities are not required to report information about their workforce for most programs and projects. Data about the utility workforce could help to inform and document job creation associated with utility programs and projects, and the demographic and locational makeup of the workers. This information could provide a better understanding of the economic impacts of utility projects and programs and identify opportunities to improve diversity and equity among the utility workforce.

Recommendation: Improve and expand gas and electric workforce reporting requirements among utilities, contractors, and other energy providers, including by implementing the following:

- a. Metrics to better assess equity among jobs in the energy industry, including demographic and geographic distribution of jobs.
- b. Metrics to better assess energy-related jobs funded by ratepayers.

#8 ADDRESS WORKFORCE GAPS

Rationale: All strategies and pathways to decarbonizing Minnesota’s natural gas end uses will require a transition in the energy workforce. Workers will be needed to deploy new technologies and fuels, and to maintain and operate the changing utility system. An adequately sized and skilled workforce will be necessary for a smooth and timely transition to decarbonization. Equitable access to opportunities in the future energy workforce will ensure that the economic benefits of the transition are shared among all Minnesotans.

Recommendation: Address workforce gaps that need to be addressed regardless of the pathway to decarbonizing natural gas end uses, including the following:

- a. Implement the recommendations of the “Minnesota Energy Efficiency Workforce Gap Analysis,” published in February 2019, which includes the following:⁷⁷
 - i. Expand workforce pipelines into the trades, including through expanded use of registered apprenticeship programs.
 - ii. The public workforce system should collaborate with small and mid-sized energy efficiency employers.
 - iii. Increase diversity in the energy efficiency workforce.
 - iv. Local governments should lead by adopting targeted workforce goals, procurement policies, and strategies.
 - v. Utilize effective training models for initial training, as well as ongoing training for advancing technology and techniques.
 - vi. Ensure energy efficiency jobs pay good wages, provide benefits, and offer lifelong training and career pathway opportunities to workers at all levels.
- b. Work towards a more equitable and diverse workforce, in parallel as we work to decarbonize buildings and industry, including consideration of the following:
 - i. The language and policies listed in the BlueGreen Alliance’s *State-Based Policies to Build a Cleaner, Safer, More Equitable Economy*.⁷⁸
 - ii. Apprenticeship utilization in particular may be helpful for increasing diversity in the workforce.

#9 ENSURE WORKERS HAVE THE TRAINING AND EXPERTISE NECESSARY TO SUPPORT DECARBONIZATION

Rationale: Many decarbonization strategies and techniques are new and emerging. Many workers in the current workforce do not have experience and knowledge of these emerging techniques, technologies, and fuels. Workers will need to be trained and build new skills in order to deploy and operate decarbonization strategies for Minnesota’s natural gas end uses.

Recommendation: All relevant actors should work to ensure Minnesota’s workforce has the training and expertise necessary to support decarbonization of natural gas end uses.

As part of this recommendation, the following should be considered:

- a. Relevant actors include but are not limited to the Minnesota Department of Employment and Economic Development, unions, schools, apprenticeship programs,

⁷⁷ *Minnesota Energy Efficiency Workforce Gap Analysis*, Center for Energy and Environment, February 2019, <https://www.mncee.org/sites/default/files/report-files/MN-Energy-Efficiency-Workforce-Gap-3-1-19.pdf>.

⁷⁸ BlueGreen Alliance, *State-based Policies to Build a Cleaner, Safer, and More Equitable Economy – A Policy Toolkit*, July 2020, http://www.bluegreenalliance.org/wp-content/uploads/2020/07/StatePolicyToolkit_Report2020_vFINAL.pdf.

- employers, manufacturers, continuing education providers and networks, and trade allies.
- b. Additional funding may be needed to accomplish this, such as state funded scholarships for new workers and retraining existing workers.
 - c. Workforce programs and funding for such programs should be calibrated to workforce needs, with attention to geographic supply and demand.
 - d. Workforce programs should be designed and delivered to address barriers to participation, including transportation, childcare, and financial barriers.
 - e. Training programs should adhere to Minnesota Department of Labor and Industry standards to ensure the certifications are credible, where applicable.
 - f. Training programs need to emphasize controls optimization for the latest technologies and fuels.⁷⁹
 - g. Ensure continuing education networks and programs provide up-to-date training for the latest technologies.

Residential and Small Business Recommendations

#10 ADVANCE BUILDING SHELL EFFICIENCY

Rationale: Heat loss through the envelope of existing single-family homes is the largest energy efficiency opportunity for buildings in Minnesota. Older homes have approximately 30 percent higher space heating loads than new construction, despite being sized about 50 percent smaller. Lower-income residents are more likely to inhabit older building stock than wealthier residents, thus creating disproportionately high energy use and costs for those least able to pay. Weatherization efforts have successfully delivered cost-effective envelope improvements for decades, but existing weatherized buildings still lag new construction in performance and comfort.

While the scenario modeling showed that decarbonization is technically possible in all scenarios, it assumed that by 2050, all residential and commercial buildings, on average, have a 29 percent reduction in heating demand through building shell efficiency improvements. Notably, there was disagreement among the group about whether this was too low of an assumption, given the possibility of significant advancements in energy efficiency technologies and deployment, or too high given the current pace and extent of building shell efficiency improvements in Minnesota.

⁷⁹ The issue that the group contemplated, which resulted in this consideration being included, was that in order to operate a system under the electrification with gas backup scenario, homes with dual-fuel heating would need to be optimized to only use gas to avoid significant peak impacts on the electric system. This is a different way of operating than today, where systems are optimized for cost unless the customer asks otherwise, in which case the contractor can set up the controls to maximize carbon emissions reductions (by maximizing air-source heat pump operation).

Regardless of the specific target for building shell efficiency in 2050, the group agreed that deeper levels of building shell efficiency can dramatically decrease the costs and improve the performance of air-source heat pumps, another recommended decarbonization strategy for residential buildings.

Recommendation: Advance building shell efficiency well beyond the current trajectory. In implementing this recommendation, consider the following:

- a. To achieve the advanced efficiency levels that are needed, we should continue to support innovation in building shell energy efficiency research, development, and deployment.
- b. Implement measures to achieve building shell efficiency levels necessary for heating systems to operate more effectively and reduce system peaks.
- c. This will require financing mechanisms and a skilled labor workforce, among other things.
- d. Doing all of the above will require a re-evaluation of cost-effectiveness tests (see separate recommendation), since many building shell efficiency measures do not currently pass cost-effectiveness tests.
- e. For new buildings, advance and adopt building codes to ensure a higher standard of energy efficiency.

#11 ADVANCE AIR-SOURCE HEAT PUMP DEPLOYMENT

Rationale: Air-source heat pumps (ASHPs) are a highly efficient decarbonization technology that can provide both space heating and cooling. Air-source heat pumps use electricity to capture heat from ambient air and transfer it into a building to provide heat, or out of a building to cool. Heat pumps provide a decarbonized alternative to heating with natural gas.⁸⁰

In Minnesota's climate, ASHPs typically require a backup heating source for the coldest hours of the year. However, heat pump performance is improving and cold climate heat pumps can operate below -13 degrees Fahrenheit. Air-source heat pumps are a relatively new or novel technology for most residents, contractors, and distributors in Minnesota and are not widely deployed or available throughout the state.

Recommendation: Significantly advance air-source heat pump deployment for the residential sector, while considering the following:

- a. It is currently very unlikely consumers will switch to a new technology at the point of failure. Moreover, for the electrification with gas backup scenario, we want consumers to keep and maintain their existing gas heating appliance. To address

⁸⁰ The emissions intensity of an electric air-source heat pump reflects the emissions intensity of the electric supply providing power, as well as the efficiency of the equipment. Electric air-source heat pumps require carbon-free or carbon-neutral electricity in order to achieve full decarbonization.

- this, consider make-ready programs⁸¹ to enable choosing ASHPs at the point of equipment failure.⁸²
- b. Given Minnesota's climate, programs should be designed to prioritize and incentivize cold climate ASHP models that can operate in colder temperatures.
 - c. It is important that all key actors have up-to-date information and education on ASHPs, and are equipped to serve as educators. This includes manufacturers, distributors, retailers, installers, and end-use consumers. (Also see separate recommendation #2 on education and engagement).
 - d. In a dual-fuel scenario, residential building controls (and the contractors who install and set them up) need to be programmable and programmed to optimize between the ASHP and gas appliance.
 - e. In keeping with the guiding principle to make decarbonization technologies accessible to all Minnesotans, it is important to ensure that ASHP deployment efforts are targeted at all applicable residential buildings, including affordable housing, and other multifamily owner-occupied and rental units.

#12 ADDRESS HEALTH AND SAFETY WHILE RETROFITTING BUILDINGS

Rationale: One of the group's guiding principles is to ensure that the benefits of the transition to a decarbonized economy, including public health benefits, are experienced among all Minnesotans. The scenario modeling showed that achieving decarbonization for all three scenarios will require widespread building retrofits to achieve much higher levels of energy efficiency by 2050. The group discussed at length how, if buildings are to be retrofitted in this way, the implementation must be paired with consideration of public health and safety, including indoor air quality, moisture management, and combustion safety for homes keeping their gas connection.

Recommendation: During any building envelope retrofits, take the opportunity to address health and safety considerations such as indoor air quality, moisture management, and combustion safety⁸³ for homes keeping their gas connection.

⁸¹ Make-ready programs are those where the cost and installation of wiring and infrastructure necessary for new technology adoption are subsidized by the utility or a third party.

⁸² Because even cold climate heat pumps will typically require a backup heating source, the equipment failure to target is that of the air conditioner. Heat pumps can replace air conditioners and address a home's full cooling load and then also take on heating load as well.

⁸³ L. Brand, D. Cautley, D. Bohac, P. Francisco, L. Shen, and S. Gloss, Partnership for Advanced Residential Retrofit and NorthernSTAR, *Combustions Safety Simplified Test Protocol Field Study* (Washington, DC: US Department of Energy Office of Energy Efficiency and Renewable Energy, November 2015), prepared for the National Renewable Energy Laboratory on behalf of the US Department of Energy's Building America Program, Office of Energy Efficiency and Renewable Energy, <https://www.nrel.gov/docs/fy16osti/65318.pdf>. Combustion safety is the general term for evaluating gas-fired water heaters, boilers, and furnaces for safe operation.

#13 REDUCE BARRIERS TO DECARBONIZATION OF BUILDINGS WITH ROOFTOP UNITS

Rationale: Many small business spaces are heated, cooled, and ventilated with rooftop units because the units are affordable and conveniently packaged as a single system. Achieving decarbonization of natural gas end uses in the small business sector could be advanced by fully electric or dual-fuel rooftop units. While all-electric and dual-fuel rooftop units are commercially available today, they are not being installed as commonly as gas-fueled rooftop units due to multiple barriers, including costs, awareness, and split incentives.⁸⁴

Near-term solutions include gas and electric dual-fuel/hybrid rooftop units, which are a direct replacement for existing units, and variable refrigerant flow systems, which would require a retrofit of the building HVAC system.

Recommendation: For existing buildings with rooftop units, find ways to reduce barriers to deployment of all-electric and dual-fuel solutions.

#14 ADDRESS SPLIT INCENTIVES

Rationale: One of the group's guiding principles is to ensure that all Minnesotans have the ability to adopt technologies and fuels that decarbonize natural gas end uses affordably and effectively. Moreover, the scenario modeling showed that successfully decarbonizing natural gas end uses will require significant levels of energy efficiency and electrification for residents and businesses. However, this will be more difficult for customer segments that face a split incentive, which occurs when the costs and benefits of adopting an energy efficiency or electrification technology are asymmetrically split between two parties, such as a renter and property owner.

The group acknowledged that many parties are actively working on addressing split incentive barriers, and would like to emphasize the urgency to continue that work.

Recommendation: Address split incentives that pose barriers to implementing energy efficiency and technology adoption, including for the following customer segments:⁸⁵

- a. Single-family renters
- b. Multifamily owners and renters
- c. Small and medium commercial leased spaces

#15 IMPLEMENT STRATEGIES TO REDUCE ENERGY BURDEN

Rationale: One of the group's guiding principles is to ensure that the decarbonization of natural gas end uses is done in a way that reduces current inequities and does not create new inequities, in terms of costs and benefits. Energy burden, which is defined as a percentage of

⁸⁴ This description refers to electric heat pump roof top units. Dual-fuel units include an electric heat pump function as well as a gas heating function.

⁸⁵ The following list is lettered for reference purposes only and does not indicate a ranking or priority.

spending on energy compared to income, is one way to measure inequities in how the costs of our energy systems are allocated to customers. For example, in Minnesota some households contribute as low as 1 percent of their income to energy costs, while others contribute as high as 19 percent.⁸⁶ The Minnesota Department of Commerce considers a contribution of 6 percent or more of income to be an energy burden.⁸⁷

The group's scenario modeling showed that all three decarbonization scenarios will increase energy system costs significantly. Moreover, electrification of space heating in the residential sector, which is a strategy included in all three scenarios, risks increasing gas system costs for customers who do not have the resources or means to electrify. Both the overall increased costs to decarbonize natural gas end uses, as well as the potential for gas system costs to be allocated to fewer customers due to electrification, could significantly exacerbate energy burden for the most vulnerable Minnesotans without policies to protect against this.

Recommendation: Develop policies, programs, and actions to reduce and maintain energy burden below 6 percent for all Minnesota households, to both lessen existing inequities in energy burden and ensure that the costs of the transition are not borne disproportionately by the most under-resourced Minnesotans.⁸⁸ Actions may include, but should not be limited to the following:

- a. Make lessening energy burden⁸⁹ a policy priority of the state.
- b. Implement low-income specific rate designs and regulatory reforms, including financing mechanisms (see recommendation #24).
- c. Prioritize energy efficiency and weatherization for low-income households.
- d. Create grant programs to assist customers in this transition, and fund and scale-up assistance and outreach to increase access to those programs.

⁸⁶ Ana Diaz, "Energy Poverty: What Is It and How Do We Understand It," Citizens Utility Board Minnesota (blog), last modified January 26, 2021, <https://cubminnesota.org/energy-poverty-what-is-it-and-how-do-we-understand-it/>.

⁸⁷ Ibid.

⁸⁸ Fisher, Sheehan, and Colton, *The Home Energy Affordability Gap 2012*, 2nd Series (Belmont, Massachusetts: Public Finance and General Economics, 2013), <http://homeenergyaffordabilitygap.com/>; American Council for an Energy-Efficient Economy, *Understanding Energy Affordability* (September 9, 2019), <https://www.aceee.org/sites/default/files/energy-affordability.pdf>. Researchers define households with a 6 percent energy burden or higher as experiencing a high energy burden. The 6 percent affordability threshold is based on Fisher, Sheehan, and Colton's Home Energy Affordability Gap Analysis. The affordability percentage is based on the assumption that an affordable housing burden is less than 30 percent of income spent on housing, and 20 percent of housing costs should be allocated to energy bills. The American Council for an Energy-Efficient Economy use this methodology and threshold to define high energy burden.

⁸⁹ Defined as percent of spending on energy compared to income.

Utility and Regulatory Recommendations

#16 MINNESOTA PUBLIC UTILITIES COMMISSION PROCEEDING ON NATURAL GAS DECARBONIZATION

Rationale: The Minnesota Public Utilities Commission (Commission) is currently tasked with regulating Minnesota’s investor-owned natural gas utilities in a way that maintains safe, adequate, and efficient services at fair, reasonable rates and is consistent with state policies and the public interest.

Given the importance of natural gas service in Minnesota, the impacts of natural gas use on state greenhouse gas emissions reduction goals, and the effects of climate change on the state, the Commission will likely need to make decisions in the future about how to reduce greenhouse gas emissions from natural gas in a way that balances environmental and health concerns with rates, reliability, safety, and equity.

Many of those decisions will pertain to new ideas and emerging technologies that the Commission has not previously considered. This presents two challenges:

- First, the Commission and Commission staff will need to become knowledgeable about the different decarbonization technologies and strategies in order to assess and determine appropriate utility investments.
- Second, the Commission will need to have a regulatory framework in place that provides for consideration and evaluation of natural gas decarbonization strategies and proposals.

The following recommendation aims to address both the need for additional education and understanding of natural gas decarbonization strategies, as well as the need to develop a regulatory framework for the Commission to evaluate and approve proposals for utility investments in natural gas decarbonization strategies.

Recommendation: By August 1st, 2021, the Minnesota Public Utilities Commission should initiate a process to evaluate opportunities and considerations for changes to gas utility regulatory and policy structures needed to support cost-effective and equitable achievement of the state’s economywide greenhouse gas reduction goals, as defined in section 216.H.02, subdivision 1, and net-zero greenhouse gas emissions by 2050, as determined by the Intergovernmental Panel on Climate Change.

Importantly, the goals cited in the above paragraph are economywide goals that do not dictate a given reduction in use of or emissions from natural gas. There is not yet agreement on or even modeling to determine what amount of emissions reductions are needed from natural gas end uses to achieve the state’s economywide greenhouse gas reduction goals.

The group acknowledges that additional staffing or resources at the Minnesota Public Utilities Commission, Department of Commerce, and Pollution Control Agency may be needed to carry out this recommendation.

This proceeding should seek to accomplish the following:

- a. Establish education to support wise decision-making among stakeholders and regulators about natural gas end-use decarbonization, including the following:
 - i. Understanding of the existing natural gas system.
 - ii. Understanding of emissions sources and operational control of gas supply.
 - iii. Consideration of this group's guiding principles.
- b. Determine whether and what additional reporting and planning is needed from gas and electric utilities to facilitate gas decarbonization, including the following:
 - i. Look at existing requirements on the electric side, including integrated distribution plans (IDPs) and integrated resource plans (IRPs) to determine what could be utilized for the gas side.
 - ii. Consider what reporting and planning/forecasting exercises are needed from gas and electric utilities. This should include supply, demand, weather sensitivity, and utility infrastructure and operations.
 - iii. Consider utilizing information that is already being provided in other Commission dockets and filings to other regulatory agencies.
 - iv. Consider the costs of different decarbonization strategies, as well as the costs to achieve different levels of natural gas decarbonization, and compare these to costs to achieve comparable reductions in other sectors in pursuit of the economywide GHG goals cited above.
- c. Assess whether existing regulatory and/or legislative structures are sufficient to meet Minnesota's established GHG reduction goals and identify reforms if necessary.

NOTE 1: Given the time it takes for long-term planning to influence infrastructure investments, the urgency to reduce greenhouse gas emissions, and potential cost and public health impacts, this process needs to begin as soon as possible.

NOTE 2: The docket should be implemented expeditiously. If needed, consider a phased approach that could begin with one or a series of Commission planning meetings intended to establish common understanding before opening the docket.

#17 UPDATE CIP COST-EFFECTIVENESS FRAMEWORK

Rationale: The Minnesota Department of Commerce (Department) oversees Minnesota's utility energy efficiency program, called the Conservation Improvement Program (CIP). The CIP cost-effectiveness framework is foundational to the program, determining the amount of energy efficiency utilities pursue, as well as the types of programs and measures that utilities include in their CIP portfolio. Energy efficiency is a key strategy for decarbonizing Minnesota's natural gas end uses. As the largest single source of energy efficiency, CIP will play a major role in decarbonizing natural gas emissions in buildings and industry. Therefore, it is important that the CIP cost-effectiveness framework is designed to fully value the benefits CIP provides.

Recommendation: The Department and stakeholders should review and update as needed the CIP cost-effectiveness framework to ensure that it is aligned with state decarbonization goals, including the following:⁹⁰

- a. Cost-effectiveness testing should be redesigned to appropriately value the level of energy efficiency required to achieve decarbonization goals for natural gas end uses in Minnesota. Alternatively, cost-effectiveness testing could solve for the most cost-effective, fuel-neutral decarbonization strategy or resource, comparing decarbonized resources to each other and not to conventional fossil fuels (e.g., natural gas). In either case, more substantial policy changes developed by the Department and stakeholders may benefit from legislative adoption.
- b. Ensure that long-term energy savings and emissions reductions are being fully incorporated and valued through the CIP cost-effectiveness framework.
- c. Ensure that CIP cost-effectiveness tests are symmetrical in terms of the costs and benefits included in each test.⁹¹
- d. The Technical Reference Manual Advisory Committee should prioritize the inclusion of new and emerging building envelope efficiency measures and appliances that can support decarbonization.
- e. The Department should consider prioritizing research projects for the Conservation Applied Research and Development grant program that have the potential to improve the cost-effectiveness of existing and new building envelope efficiency measures for use in Minnesota's climate.
- f. Where possible coordinate cost-effectiveness practices developed through this process elsewhere in the utility regulatory framework, including fuel switching (recommendation #18), natural gas innovative resource plans (recommendation #20), and the Commission proceeding on natural gas decarbonization (recommendation #16).

#18 ENABLE FUEL SWITCHING IN CIP

Rationale: Minnesota's CIP currently prohibits fuel switching. The prohibition was put into place to ensure that utilities not use CIP in order to increase their own sales volumes. Additionally, load management programs and investments that do not save energy are also not allowed through CIP. Fuel switching from natural gas to lower-carbon energy resources will be a key

⁹⁰ This should include any current or future state goals related to emissions reduction in Minnesota's building sector.

⁹¹ A fundamental principle of benefit-cost analyses, according to the National Standard Practice Manual, is to ensure symmetry of costs and benefits. Asymmetrical treatment of benefits and costs associated with a resource can lead to a biased assessment of the resource. To avoid bias, benefits and costs should be treated symmetrically for any given type of impact. For example, if a benefit-cost test includes the utility's full cost to procure the resource, then the test should also include the full range of benefits that the utility receives from the resource.

strategy for decarbonizing Minnesota’s natural gas end uses. Additionally, load management strategies can help manage system costs of using low- or zero-carbon electricity.

Recommendation: Decision makers should modify CIP to allow fuel switching and load management that enables the adoption of highly efficient decarbonization technologies.

In advancing this recommendation, the following should be considered:

- a. Highly efficient decarbonization technologies are those that do the following:
 - i. Result in a net reduction in the amount of source energy consumed for a particular use, measured on a fuel-neutral basis.
 - ii. Result in a net reduction of statewide greenhouse gas emissions over the lifetime of the improvement.
 - iii. Are cost-effective, considering the costs and benefits from the perspective of the utility, participants, and society (see recommendation #17 to update cost-effectiveness tests).
 - iv. Are installed and operated in a manner that increases or does not decrease the customer’s electric utility system load factor.
- b. As part of this recommendation, the Department of Commerce should re-evaluate source energy from electric generation, given the expected electric generation source of the decarbonization technology (see recommendation #19).
- c. As part of this recommendation, gas utilities should be allowed to propose programs to install electric technologies that reduce the consumption of natural gas by the utility’s retail customers as an energy conservation improvement, provided the program meets criteria (i) to (iv) above.
- d. Finally, fuel switching that enables the adoption of highly efficient decarbonization technologies should be included in both electric and gas demand side management potential studies.⁹²

#19 RE-EVALUATE ELECTRIC GENERATION SOURCE ENERGY METHODOLOGIES

Rationale: Certain utility programs, including CIP, compare energy resources based on the total energy from a source perspective. Source energy represents the total amount of raw fuel that is required to operate a particular end use.⁹³ Source energy accounts for all energy lost through production, transmission, and delivery. Conversely, site energy only considers the amount of heat or electricity consumed by the final end-use technology. Currently, when Minnesota

⁹² These studies determine cost-effective potential and expected achievable potential at different levels of program spend of demand-side management for electric and gas utilities. These studies help inform which individual measures are cost-effective and should be included in utility plans, and provide the potential to inform achievement goals for these plans.

⁹³ “The Difference between Source and Site Energy,” EnergyStar (website), accessed April 23, 2021, <https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/difference>.

regulators consider source energy associated with electricity, they assume that the electricity was produced by a combined-cycle natural gas power plant. However, as electric utilities transition to a more diverse and lower-emissions mix of electric generation resources, the current methodology may no longer accurately reflect the source energy of electricity in Minnesota.

Recommendation: For utility programs that consider source energy as a comparison, the Department of Commerce should re-evaluate the methodology used to determine source energy from electric generation to ensure it reflects the current mix of a utility's electric generation resources. Non-combustion-based renewable energy should be considered to have 100 percent efficient production.

#20 REQUIRE AND/OR INCENTIVIZE GAS UTILITIES TO INTEGRATE DECARBONIZATION TECHNOLOGIES AND FUELS

Rationale: The scenario modeling conducted during this process made clear two key considerations: first, some current natural gas end uses, such as high-temperature industrial process heating, will be challenging to electrify; second, even for residential and commercial space heating, there may be affordability and system optimization benefits to maintaining gas backup for the coldest days of the year. In both cases, it will be important to decarbonize the gas backup. For this reason, a regulatory framework is needed for gas utilities to begin integrating low-carbon fuels like RNG and hydrogen into the gas system.

Recommendation: Minnesota's regulatory agencies, in consultation with utilities and stakeholders, should develop a framework that requires and/or incentivizes gas utilities to integrate fuels and technologies to achieve decarbonization. These fuels and technologies should include, but not be limited to: biogas, biogenic renewable natural gas, power-to-hydrogen, power-to-ammonia,⁹⁴ synthetic methane, carbon capture utilization and storage, electrification, district energy systems, and energy efficiency. In advancing this recommendation, the following should be considered:

- a. This framework should include an evaluation of the lifecycle carbon intensity of decarbonization fuels and technologies and prioritization of lower-carbon intensity options, balanced with consideration of the total greenhouse gas reduction potential and costs of those options.
- b. This framework should include some upfront assurance for gas utilities that they can recover the incremental costs of investing in research & development and fuels and technologies to achieve decarbonization, as long as those investments are found to be prudent and in the public interest.
- c. Costs associated with these decarbonization fuels and technologies eligible for recovery should include the following:

⁹⁴ "Power-to-ammonia" means the production of ammonia from hydrogen produced via power-to-hydrogen using a process that has a lower lifecycle greenhouse gas intensity than does natural gas produced from conventional geologic sources. To achieve decarbonization, the ammonia must eventually be produced via a carbon-neutral or carbon-free process.

- i. Implementation and administrative costs, including energy efficiency and electrification program costs.
 - ii. Capital investment in infrastructure for the production, processing, pipeline infrastructure (e.g., interconnection, necessary facility modifications including stations, flanges, compression, etc.), storage, and distribution of a low-carbon fuel or thermal energy.
 - iii. Operating costs.
 - iv. Fuel purchase costs.
- d. The total cost of these investments, as well as the long-term cost impacts throughout the energy system, should be managed to ensure the cost impacts are reasonable and equitably distributed (also see recommendation #25 on transition costs).

#21 REDUCE UPSTREAM METHANE LEAKAGE VIA REGULATORY REFORMS

Rationale: The majority of greenhouse gas emissions associated with Minnesota’s natural gas end uses are carbon dioxide and result from natural gas combustion. However, methane leakage across the natural gas fuel cycle also contributes greenhouse gas emissions.⁹⁵ Methane is an especially potent greenhouse gas with a warming potential between 28 and 86 times that of carbon dioxide.⁹⁶ Therefore, methane mitigation has an outsized effect on the trajectory of climate change. The vast majority of methane leakage occurs upstream, during the production and processing of natural gas, and is outside of the direct control of Minnesota utilities.

Recommendation: Minnesota’s regulatory agencies should implement regulatory reforms to prioritize utility procurement of natural gas and other gaseous fuels from producers that have adopted management practices to reduce greenhouse gas emissions across the entire process chain. For fossil natural gas, this includes production, gathering and boosting, processing, storage, and transmission. For other gaseous fuels, such as renewable natural gas or synthetic

⁹⁵ Audrey Patridge and Rabi Vandergon, *It All Adds Up: Emissions from Minnesota’s Natural Gas Consumption*, Center for Energy and Environment (December 3, 2020), https://www.mncee.org/sites/default/files/report-files/NG-analysis-deliverable_FINAL-%281%29.pdf. Based on CEE’s 2020 “It All Adds Up: Emissions from Minnesota’s Natural Gas Consumption,” methane leakage emissions contributed 16 percent of total lifecycle greenhouse gas emissions associated with Minnesota’s natural gas consumption in buildings and industry.

⁹⁶ G. Myhre, D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura, and H. Zhang, *Anthropogenic and Natural Radiative Forcing*, https://archive.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf. Greenhouse gases differ both in their radiative efficiency (how much energy they absorb, thus warming the Earth) and their atmospheric lifetimes. Global Warming Potential (GWP) is an accepted metric to compare the warming impact of one ton of any non-CO₂ greenhouse gas to one ton of CO₂, over a chosen period of time. The IPCC estimates that the GWP of methane is between 84-86 over a 20-year period, and between 28-34 over a 100-year period.

natural gas, this includes methane leakage in production, processing, storage, and transmission.

#22 REDUCE DOWNSTREAM METHANE LEAKAGE VIA REGULATORY REFORMS

Rationale: While methane leakage on the local distribution utility system and infrastructure is estimated to be far lower than upstream methane leakage, leakage does occur. Leakage on utility-owned distribution infrastructure and storage facilities is an important consideration for how and what fuels utility-owned infrastructure can be used for decarbonization. For methane-based fuels, distribution system and facilities leakage will be a key factor in understanding whether and to what extent those fuels can contribute to greenhouse gas emissions reductions in Minnesota.

Recommendation: Minnesota’s regulatory agencies should implement regulatory reforms to prioritize leakage reduction strategies across utility-owned and operated infrastructure systems, including storage and distribution facilities.

#23 ADVANCE RESEARCH, DEVELOPMENT, AND DEPLOYMENT FOR NATURAL GAS DECARBONIZATION

Rationale: One of the greatest challenges to natural gas decarbonization is availability of affordable substitutes for today’s very low-cost natural gas. Supporting research, development, and deployment efforts for natural gas end-use decarbonization technologies and fuels can help to bring down the cost of these technologies and fuels, making them more competitive with natural gas.

Recommendation: Minnesota’s regulatory agencies should implement mechanisms to advance research, development, and deployment of innovative clean technologies to reduce greenhouse gas emissions across the natural gas supply chain, and to further the development, commercialization, and deployment of innovative clean technologies that benefit Minnesota’s utility customers and help decarbonize Minnesota’s natural gas end uses. Findings of the research should be published and shared publicly to maximize the applicability and impact of the research.

Research, development, and deployment (RD&D) should be focused on innovative clean technologies that:

1. is expected to help to decarbonize Minnesota’s natural gas ends uses;
2. is expected to offer energy-related, environmental, or economic benefits; and
3. is not widely deployed by the utility industry.

This could be accomplished through one or more of the following mechanisms:

- a. An RD&D fund overseen by one of Minnesota’s regulatory agencies, to which utilities and third parties could submit proposals for funding.
- b. A pathway that encourages utilities to make innovative investments, including deploying pilot or demonstration projects, and allows cost recovery and earning a return on those investments.

Additionally, the Minnesota Public Utilities Commission and the Minnesota Department of Commerce should encourage utilities to integrate findings from the RD&D work into their operations and programs.

#24 REQUIRE CONSIDERATION OF NATURAL GAS DECARBONIZATION IN ELECTRIC IRPS AND IDPS

Rationale: The stakeholder group has discussed the potential need to better integrate natural gas end-use decarbonization strategies into electric utility IRPs. This includes electrification technologies that would have significant long-term impacts on the electric generation resources and the electric grid's ability to serve load for the electrification technologies. Issues that need to be further explored include the following:

- a. Expected costs compared to the expected savings on the gas system for all gas utilities within the service territory of the electric utility.
- b. The ability of the existing gas system to provide peak-management services to the electric system.
- c. Comparing the costs and savings from the electric and gas systems to provide the optimal level of electrification technologies to be implemented.
- d. The reliability, resiliency, and redundancy requirements for an expanded electric system that increasingly supports building heating, and for decarbonized carbon gaseous fuels.
- e. How much load management could reduce an electric system peak that may be much higher and occurring in winter, depending on the rate of building electrification.

Recommendation: The Commission should require electric utilities to consider electric load and peak impacts resulting from natural gas decarbonization scenarios in their IRPs and IDPs.

#25 IMPLEMENT A STAKEHOLDER PROCESS TO ADDRESS TRANSITION COSTS AND COST ALLOCATION

Rationale: The scenario modeling conducted during this process indicated that fossil natural gas throughput is likely to decrease in all decarbonization scenarios, creating challenges for gas utility business models, utility workers, communities and customers, particularly low-income customers..

In particular, if the fixed costs of the gas system remain similar to today, but those costs are recovered over fewer customers, gas bills would increase under current rate designs. Without intervention from regulators, this could lead to a situation where wealthier customers would have a greater ability to switch to more cost-effective electric heating (because they own their homes and can afford the upfront cost of switching to all-electric heating), while less wealthy customers would remain on the gas system, paying increasingly higher rates. This would violate the guiding principle to “ensure that the decarbonization of natural gas end uses is done in a way that reduces current inequities and does not create new inequities.”

In order to manage the transition and avoid creating these potential inequities, new rate design methodologies, as well as financing mechanisms may be needed. Moreover, gas rate design is

a complex topic that the group has not explored in detail. More statewide research and discussion is warranted before proposing any specific changes to rate design.

Recommendation: Implement a stakeholder process to consider potential changes to gas and electric rate design and utility financing mechanisms to support an affordable and equitable transition to a decarbonized energy system. In advancing this recommendation, the following should be considered:

- a. The process should address the likelihood of lower fossil natural gas throughput, implications for fixed and variable costs, and ways to maintain customer affordability, equitable energy burden across different customer classes and income levels, and financial viability for gas utilities.
- b. Significant electrification potential may be available at lower costs to serve per kilowatt-hour (kWh) than the average rate class cost to serve per kWh that is currently used to set electric volumetric rates. Providing electric rate options that reflect this lower cost to serve will be necessary to achieve the full adoption of cost-effective electrification by electric customers.
- c. The natural gas system has value as a backup or peak-shaving resource for the electric system. The process should consider how that value should be reflected in both gas and electric customer rates. The process should also explore rate design or policy tools to encourage closer integration of the gas and electric systems to simultaneously become lower carbon.
- d. Given that any transition to electrification of the building sector is likely to happen over time, policy makers should create pathways today to manage these potential costs and to ensure they are equitably shared. This might include consideration of the following options:
 - i. Natural gas customers switching to electricity could pay all or some portion of any stranded costs given the infrastructure was built to serve their original energy needs.
 - ii. It may be appropriate for electric utilities to pay for some natural gas system costs if the additional electricity sales from electrification are sufficiently beneficial to justify that payment.
 - iii. It may be appropriate for electric utilities to pay natural gas utilities for the capacity and demand benefits of backup heating provided by gaseous fuels.
 - iv. Securitization or other utility system financial tools to address transition costs.

VI. Conclusion

Natural gas is an important source of energy in Minnesota that provides affordable and reliable heat to homes and businesses through the state's extreme winters, as well as fuel for industrial processes. However, natural gas usage also contributes significant amounts of greenhouse gas emissions, and those emissions are increasing. As the electric system continues to decarbonize, natural gas emissions will likely eclipse emissions from the electric sector in the coming years.

Given the complex challenges of addressing emissions from Minnesota's natural gas end uses, a broad mix of stakeholders came together for a series of discussions over 18 months to explore pathways and develop potential solutions to drastically reduce or eliminate greenhouse gas emissions from natural gas end uses in Minnesota.

It became clear during the stakeholder discussions that the group would need a structured way to plan around an uncertain future. In response, the group worked with Energy and Environmental Economics, Inc. (E3) to model a handful of high-level scenarios for decarbonizing natural gas end uses by 2050 in Minnesota. The modeling showed that to achieve decarbonization, the state will need a combination of fuels and technologies including increased energy efficiency, electrification, renewable natural gas, and hydrogen. Though the three scenarios modeled are not the only options to decarbonize Minnesota's natural gas end uses, any feasible path will likely include some combination of all of the technologies and fuels modeled.

Through continued technological advancement and market development, the optimal combination of decarbonization technologies and fuels for Minnesota will become clearer. In the near term, aggressive development and deployment of those technologies and fuels, as laid out in the group's recommendations, will set Minnesota up for successful decarbonization of the state's natural gas end uses.

While the stakeholder group did not agree whether full decarbonization of natural gas end uses will be necessary to meet state emissions goals and recent climate guidance from the Intergovernmental Panel on Climate Change, it did agree that substantial emissions reductions are necessary. The group's consensus recommendations lay out what must be done now to achieve those substantial emissions reductions.

In addition, the group acknowledges that some of the non-energy implications of decarbonization, such as workforce and equity implications, may be the most challenging to address, but are equally critical to the ultimate success of Minnesota's decarbonization efforts. Equity and workforce considerations and implications of decarbonization of Minnesota's natural gas end uses require additional deep exploration and study. This exploration should be guided and informed by those individuals and communities who are most likely to be impacted. Despite the challenges, with thoughtful, informed, and intentional work, decarbonization of Minnesota's natural gas end uses can be a process by which we improve equity in our state and provide more and better opportunities to our state's diverse workforce.

As a result of this group's work, Minnesota has an opportunity to take action now that will allow the state to achieve its greenhouse gas emissions reduction goals by 2050. In addition, Minnesota can be a leader among similar cold climate states that will need to address many of the same challenges.

VII. Appendix

Scenario Modeling Results Slide Deck



Energy+Environmental Economics

Decarbonization of Natural Gas End-Uses in Minnesota

Final results

November 13th 2020

Dan Aas
Niki Lintmeijer
Charles Li
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Content

- + Overview
- + Energy consumption & GHG reduction
- + Electricity sector impacts
- + Customer economics: fuel costs & investments
- + District system sensitivity
- + Appendix

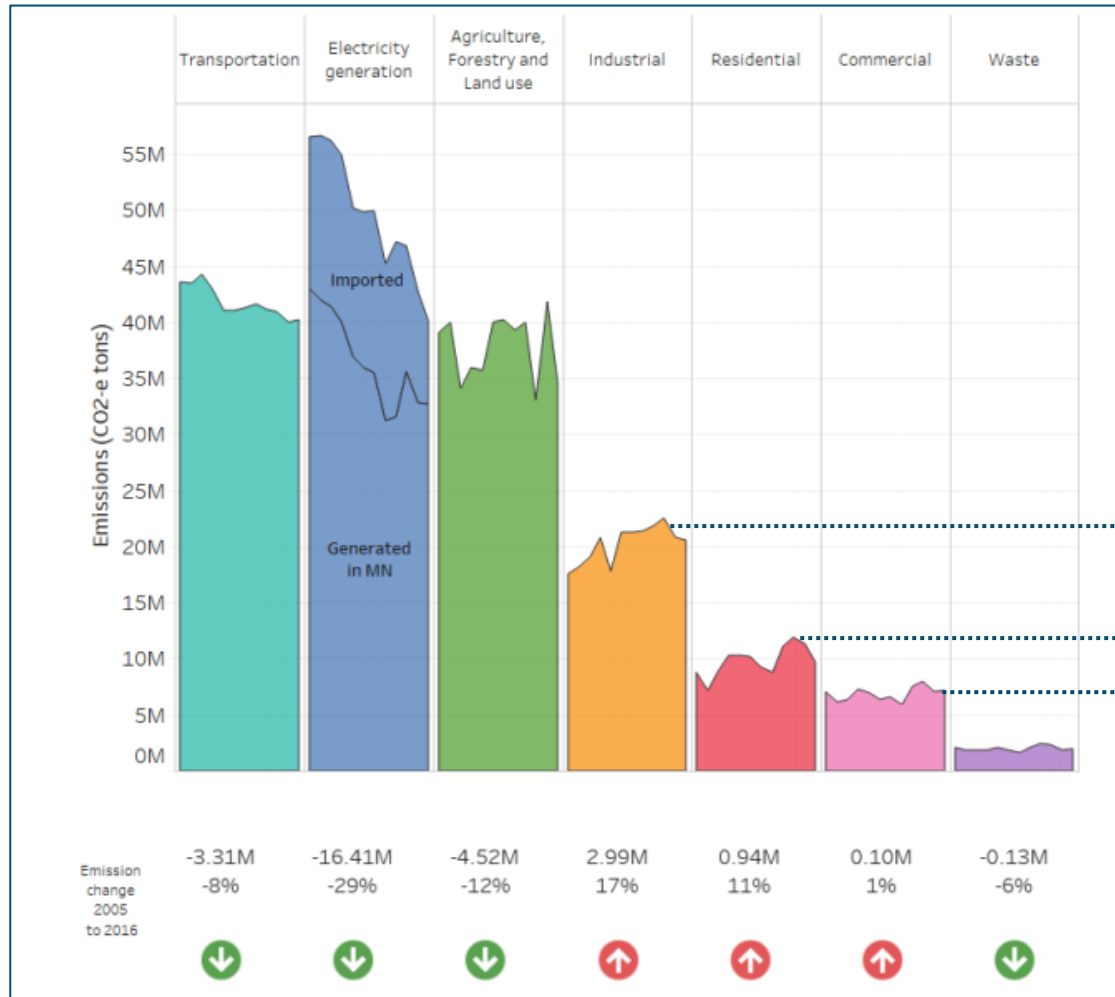


Energy+Environmental Economics

Overview



Minnesota's Next Generation Energy Act requires steep economy-wide emission reductions by 2050



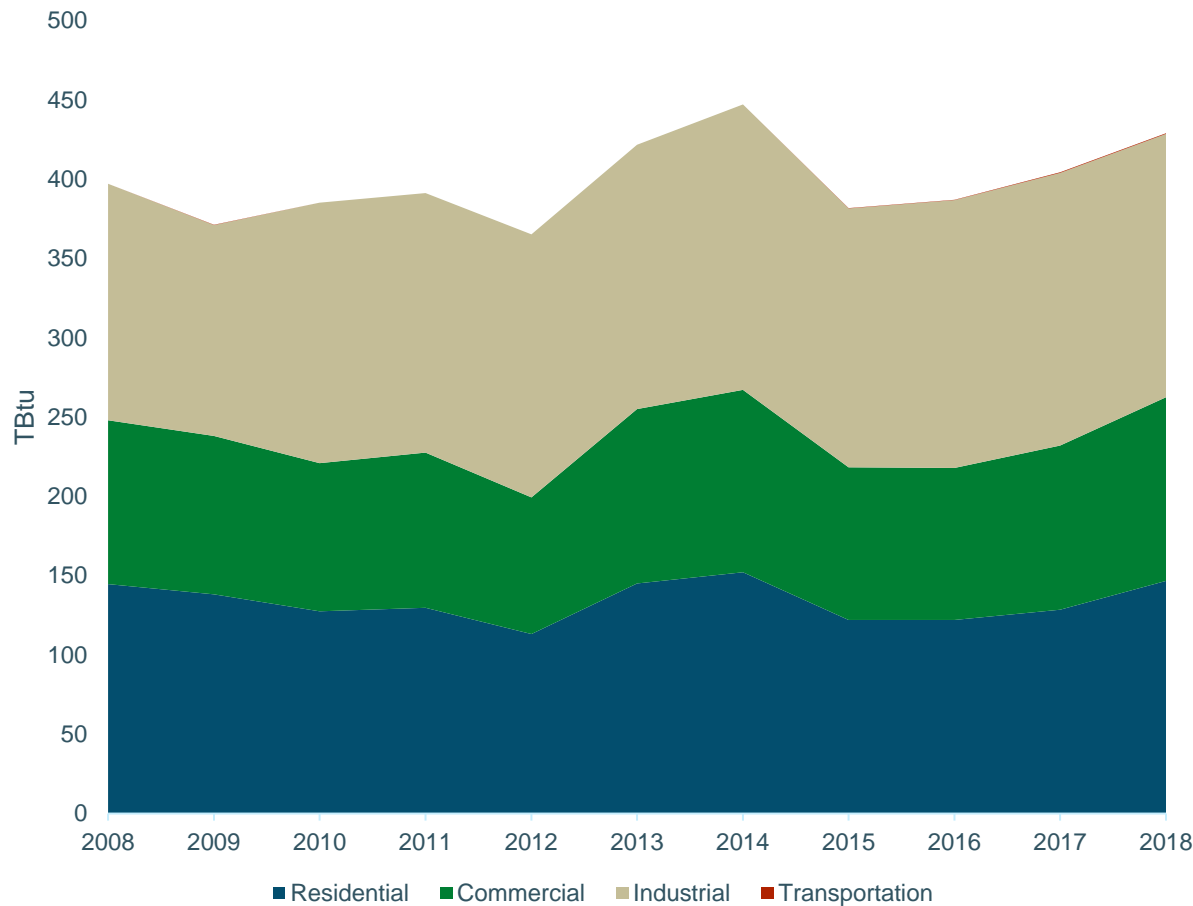
- + The Next Generation Energy Act requires Minnesota to reduce Greenhouse Gases by 80% compared to 2005.
- + This goal calls for strong efforts throughout all sectors of the economy, including Minnesota's end-use sectors where GHGs have shown an upward trend since 2005.

Unlike other sectors in Minnesota, GHG emissions in the **Industrial**, **Residential** and **Commercial** sector show an upward trend



Minnesota's end-use sectors rely on natural gas, mainly for space heating and process heating purposes

Natural gas end-use consumption in Minnesota: 2008-2018



- + **Minnesota's natural gas end-use is mostly concentrated in the residential, commercial and industrial sector**
 - Together these sectors consumed 428.5 TBtu of natural gas in 2018
 - In the residential sector, around 80% of consumption is used for space heating purposes
 - In the industrial sector, roughly 1/3 of consumption is used in the chemical industry
- + **Natural gas consumption in the transportation sector is small, but has been increasing over the last few years**



This study investigates opportunities for 100% gas end-use decarbonization through 3 scenarios

Technology focus

High Electrification

- + Almost all buildings switch to ASHPs and GSHPs. Heating is supplied by electricity throughout the entire year. Some features:
 - All-electric for new construction
 - High efficiency through building retrofits
 - Industrial electrification where technically viable

High Electrification with Gas Back Up

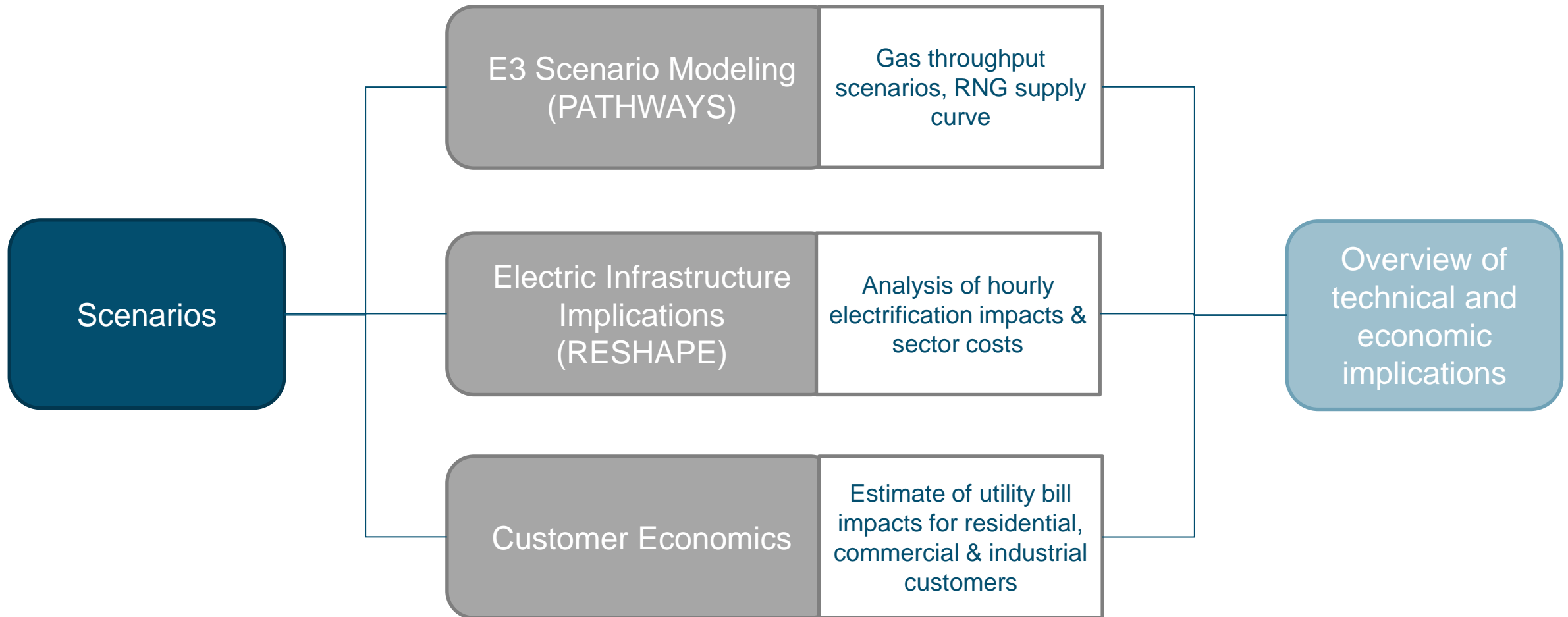
- + Buildings keep their gas connection and are supplied with a heat pump combined with gas furnace that serves as back up in the coldest hours of the year. Some features:
 - All-electric for new construction
 - High efficiency through building retrofits
 - Industrial electrification where technically viable

High Decarbonized Gas *with dedicated hydrogen in industrial sector*

- + Buildings keep their gas connection while natural gas is gradually replaced by RNG. The industrial sector switches to hydrogen. Some features:
 - RNG supplied by biomethane and synthetic natural gas
 - High efficiency through building retrofits
 - Dedicated hydrogen in Industry, 7% hydrogen blend in other sectors



Modeling approach: 3 steps to analyze the impacts of gas end-use decarbonization scenarios





Summary of key findings



100% GHG reduction of natural gas end-uses is feasible in all scenarios, but requires technology commercialization and accelerated implementation.



Costs of gas increase in all scenarios as a result of zero-carbon fuels and higher delivery costs (due to lower consumption levels); emphasis on mitigating the energy burden with customers 'staying behind' is important.



Level of commodity cost increase is highly uncertain and dependent on the availability of and competition for biomass, as well as learning rates of hydrogen and Synthetic Natural Gas (SNG).

Mostly the High Decarbonized Gas scenario shows significant cost uncertainty, as costs heavily depend on competing demands for biofuels, availability of waste-CO2 for SNG, and learning rates for SNG.



High Electrification causes a significant Summer to Winter peak-shift, resulting in high incremental electricity system costs



The Electrification with Gas Back Up decreases electricity system costs by more than half compared to a High Electrification scenario and shows lowest overall resource costs compared to the other scenarios.

At the same time, this scenario is more resilient to variance in commodity costs and therefore shows benefits in risk mitigation compared to a High Decarbonized Gas scenario.



Both 80% sensitivity and district system scenarios result in a decreased electricity system peak of around 10% compared to High Electrification, lowering overall system costs. More research on the costs and feasibility of district systems is required.

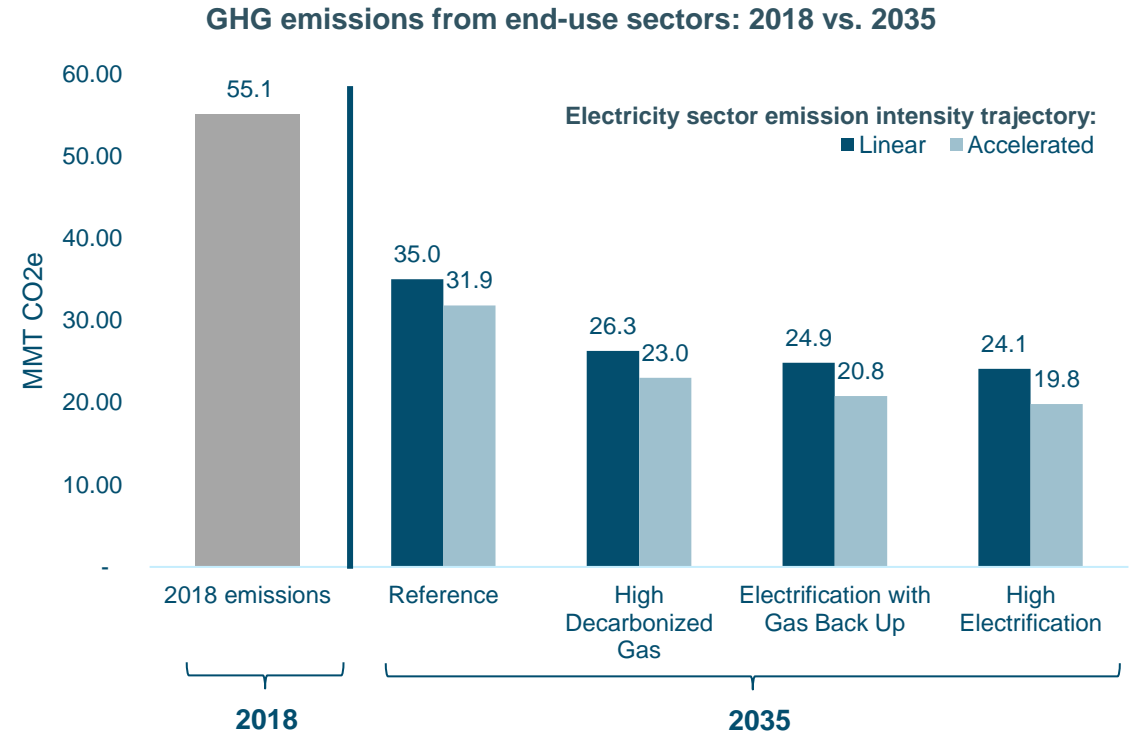
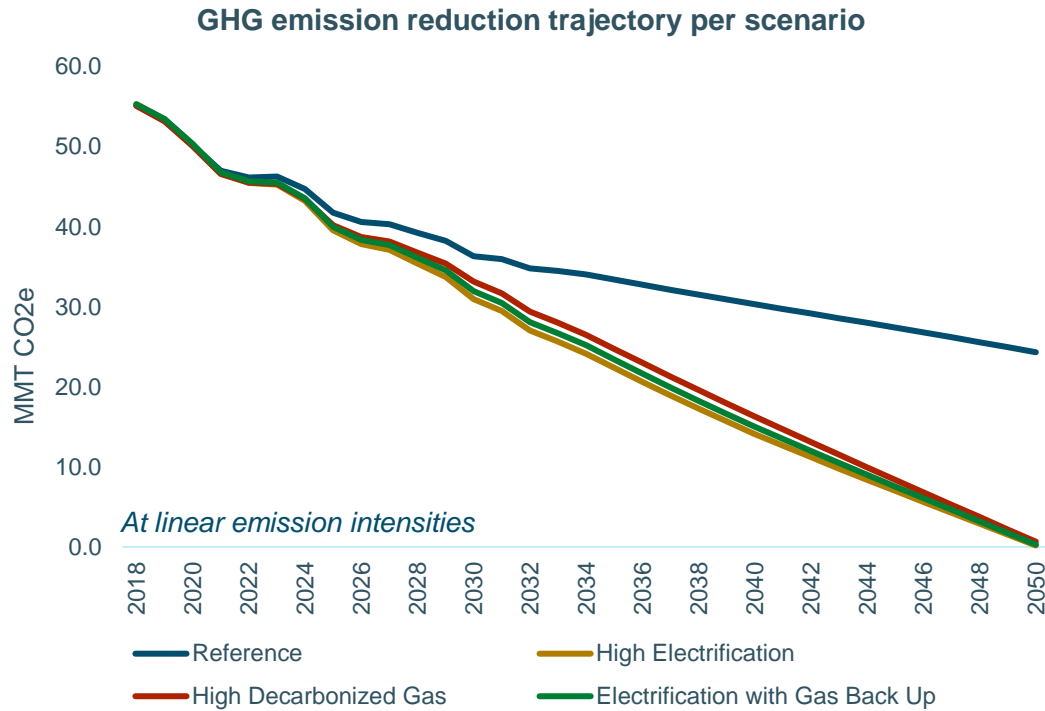


Energy+Environmental Economics

Energy consumption & GHG reduction



All scenarios reach 100% GHG reduction in 2050



- + All scenarios reach 100% decarbonization by 2050; emission reduction trajectory is similar across scenarios, assuming linear electricity emission intensities.
- + Emission trajectory is partly driven by electric sector emission intensities; an ‘accelerated’ track of electricity sector decarbonization mostly benefits the High Electrification scenario.

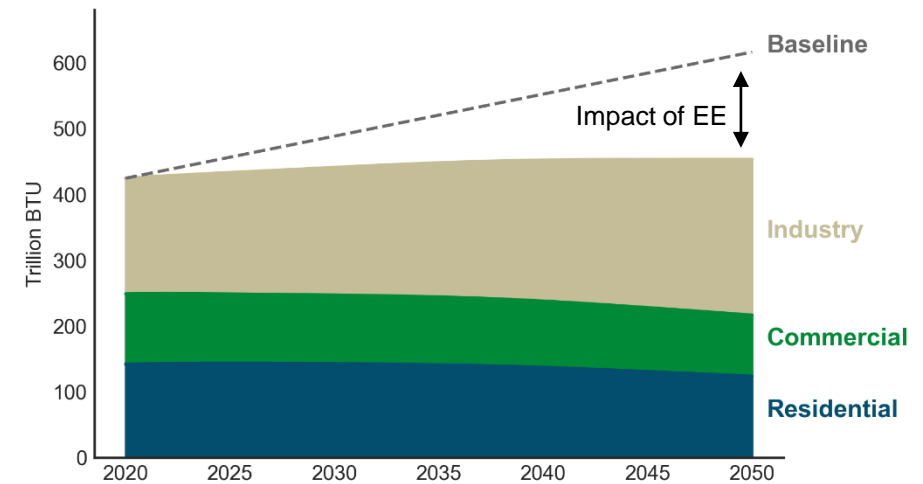
Sources & assumptions: GHG emissions are based on emissions from natural gas and electricity for Buildings and Industry, emissions from natural gas for CNG vehicles, and emissions from pipeline & distribution usage (including fugitive emissions). Fugitive emissions are estimated based on EPA reported CH₄ emissions by CenterPoint & Xcel Energy and account for ~0.1% of throughput (EPA Flight database). The reference case shows emissions *with* assumed GHG reductions in the electricity sector (linear). Emission intensity trajectories for the electricity sector are outlined in the Appendix.



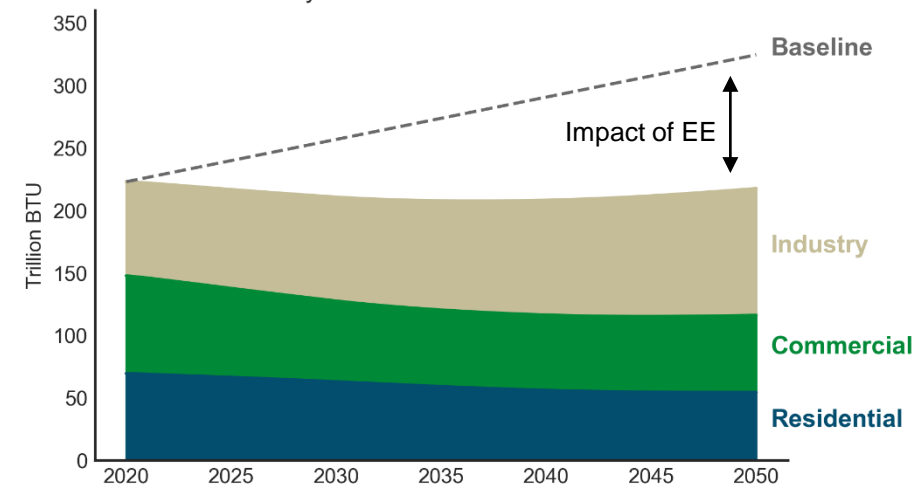
In a Reference scenario, volume increases are offset by steady energy efficiency levels towards 2050

- + Without efficiency or fuel switching, gas volumes are expected to increase as a result of population growth, economic growth and expanded access to gas
 - Population growth: 0.44%
 - Economic growth: 1.9% (industry)
- + In the reference case, load is assumed to decline as a result of continuous efficiency improvements:
 - **2% per year** for electricity to 2034 and **1% per year** thereafter (Buildings)
 - **1% per year** for electricity (Industry)
 - **1% per year** for gas (all sectors)

Gas Demand in Reference Scenario



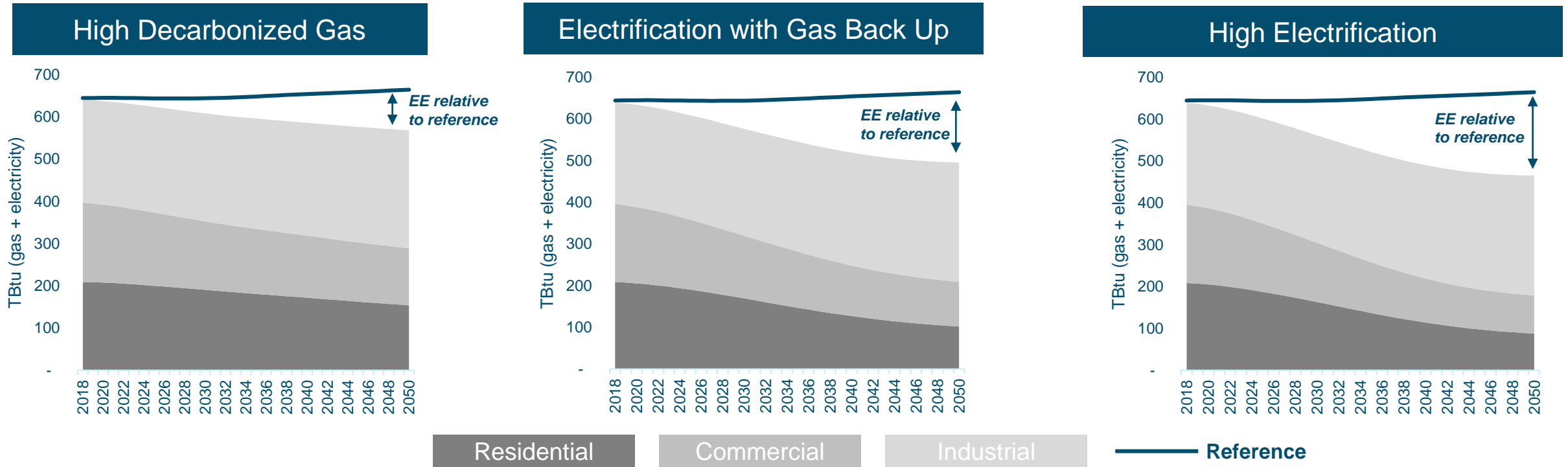
Electricity Demand in Reference Scenario



Sources & assumptions: population growth and economic growth assumptions are based on estimations from the MN State Demography Center and EIA AEO 2020 respectively. Assumptions on energy efficiency are based on historical achievements and statutory (CIP) goals. Efficiency levels are applied to [total sales](#) (includes opt-out customers).



Additional energy efficiency is achieved through extra building shell retrofits and fuel switching



+ All scenarios show additional energy efficiency relative to the reference:

- High Decarbonized Gas: Reference + extra building shell upgrades + efficiency from gas-fired HPs
- Electrification with Gas Back Up: Reference + extra building shell upgrades + fuel switching efficiency
- High Electrification: Reference + extra building shell upgrades + fuel switching efficiency

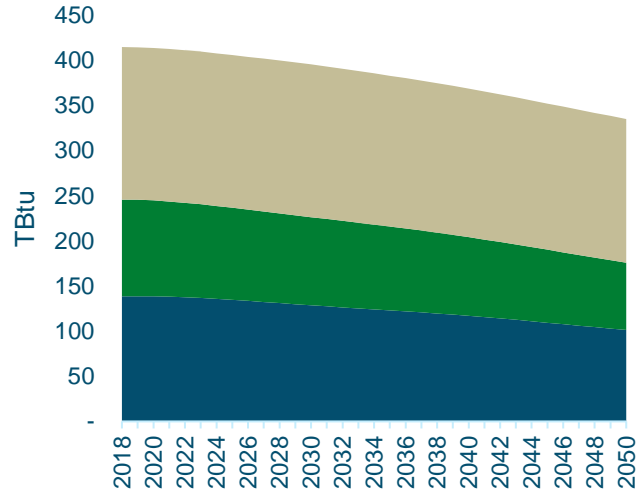
+ Building shell upgrades achieve a 29% reduction in service demand based on current building standards; this represents a substantial improvement over today, but further reductions may be possible in net zero buildings or via deep retrofits

Sources & assumptions: full list of scenario parameters is included in the Appendix.

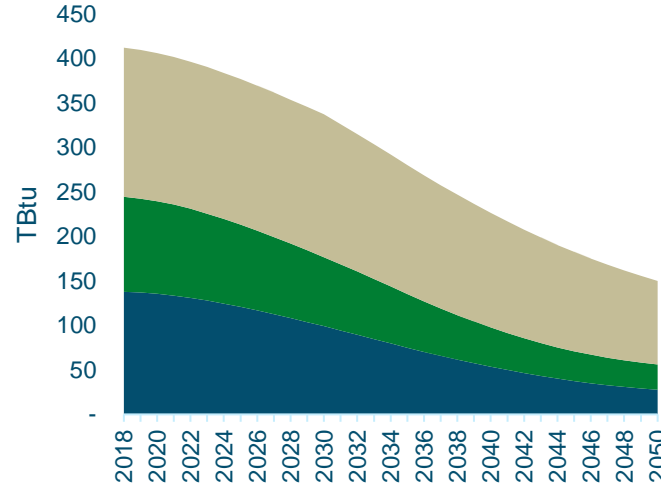


The decarbonization scenarios show a varying decline in gas consumption

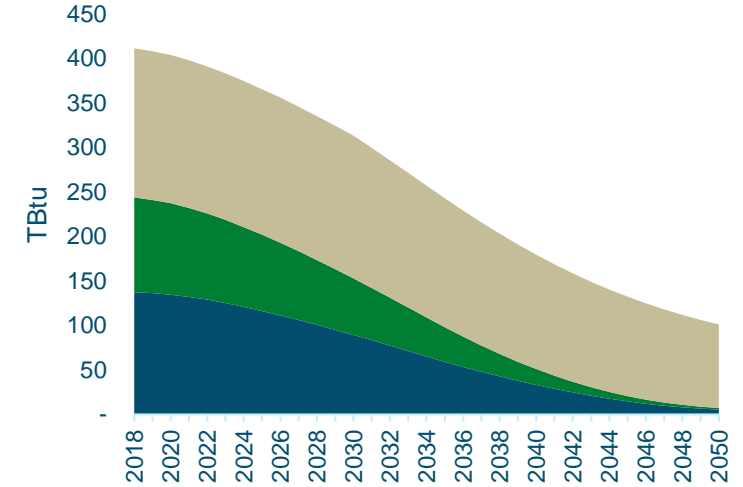
High Decarbonized Gas



Electrification with Gas Back Up



High Electrification



Residential

Commercial

Industrial

- + Overall gas sales declines slightly
- + Sales decline mostly as a result of energy efficiency (and moderate switch to HPs)

- + Gas sales in buildings declines steeply
- + Reliance on gas in coldest hours (24% of residential heating load)

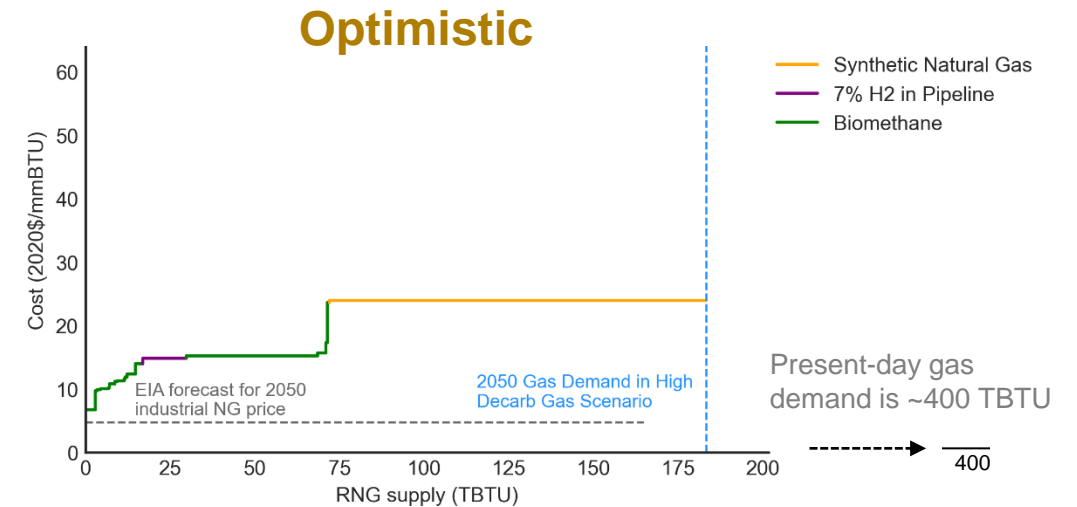
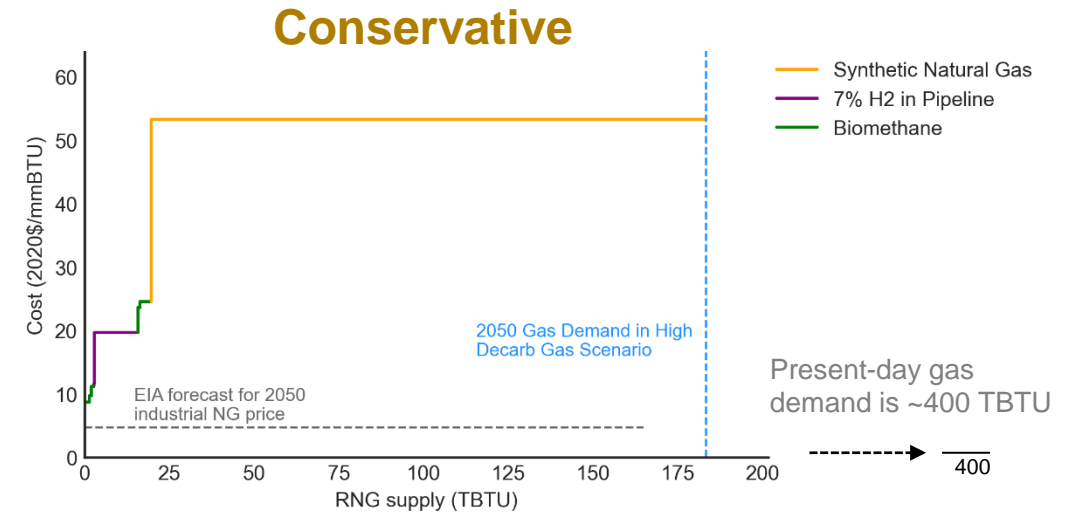
- + Gas sales in buildings sector almost eliminated towards 2050
- + Gas sales dominated by industrial sector in 2050

Sources & assumptions: full list of scenario parameters is included in the Appendix.



The E3 Biofuels Module models two bookends for RNG Supply

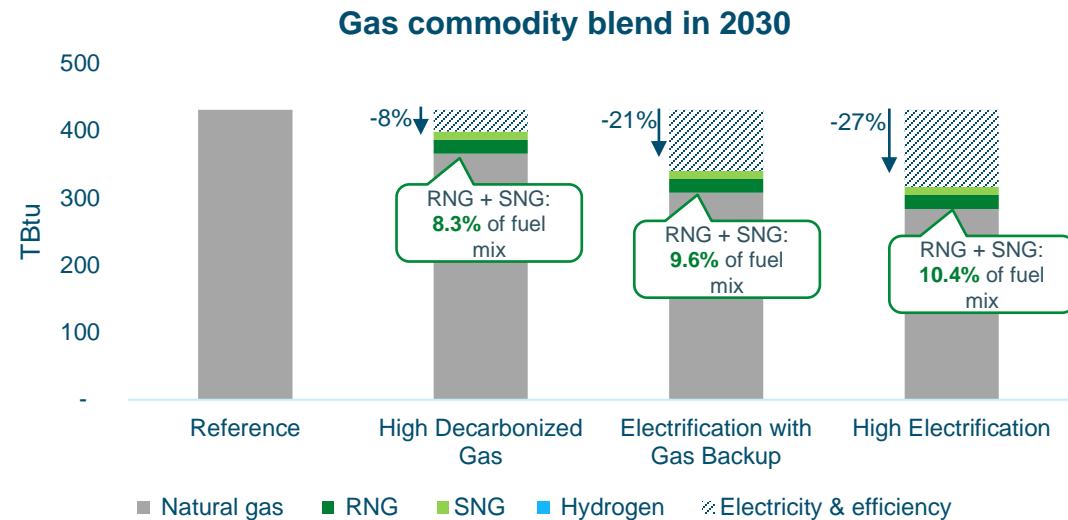
- + RNG Supply Curve assumptions are developed using E3 biofuels optimization module, which determines the most cost-effective way to convert biomass into biofuel across all sectors.
- + Conservative and Optimistic scenarios modeled here represent **two bookends** for the supply of RNG towards 2050
 - + **Conservative** scenario assumes all cellulosic feedstocks would be more cost-effectively used to produce liquid fuels - such as renewable diesel or jet fuel (due to higher prices and carbon intensities for these fuels), leading to a **heavy reliance on Synthetic Natural Gas (SNG)**.
 - + **Optimistic** scenario assumes only as much competition for renewable liquid fuels as was modeled in MN Transportation Pathways study, meaning some cellulosic feedstocks (mainly corn stover) are left over for RNG production, leading to a **moderate reliance on SNG**.



Sources & assumptions: Biomass supply assumptions are developed from the 2016 Billion Ton Report (DOE, 2016), with supplemental landfill gas assumptions from the Renewable Sources of Natural Gas report (American Gas Foundation, 2019). The module assumes MN gets access to its population weighted-share of national feedstocks (in-state feedstocks are used first). The conservative scenario assumes SNG is produced with CO₂ from Direct Air Capture (DAC), the optimistic scenario assumes SNG is produced using waste bio-CO₂ from biofuels. The 7% hydrogen blend is as a percentage of energy content. More background on cost assumptions are included in the Appendix.



Gas composition gradually transitions to RNG and hydrogen

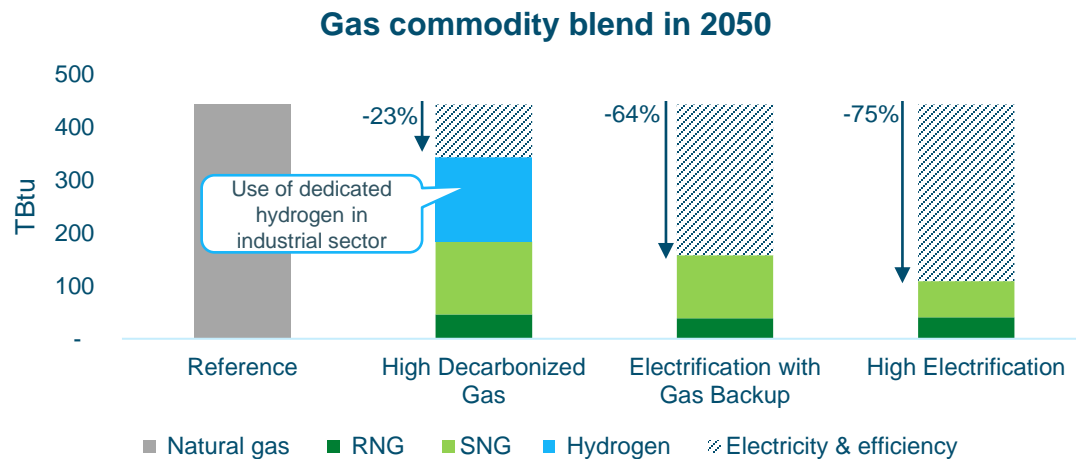


+ In 2030, overall gas sales decline by 8-27% as a result of increased efficiency levels and electrification

- 8-10% of residential, commercial and industrial gas demand is supplied by RNG, consisting of a mix of hydrogen (7% of total), renewable natural gas from biomass and SNG

+ In 2050, natural gas is fully replaced by a combination of RNG and SNG

- Remaining gas volumes are mostly concentrated in the industrial sector, where hydrogen plays a large role in the High Decarbonized Gas scenario
- High Electrification with Gas Back Up uses up to 50 TBtu gas per year to supply heat in the coldest hours

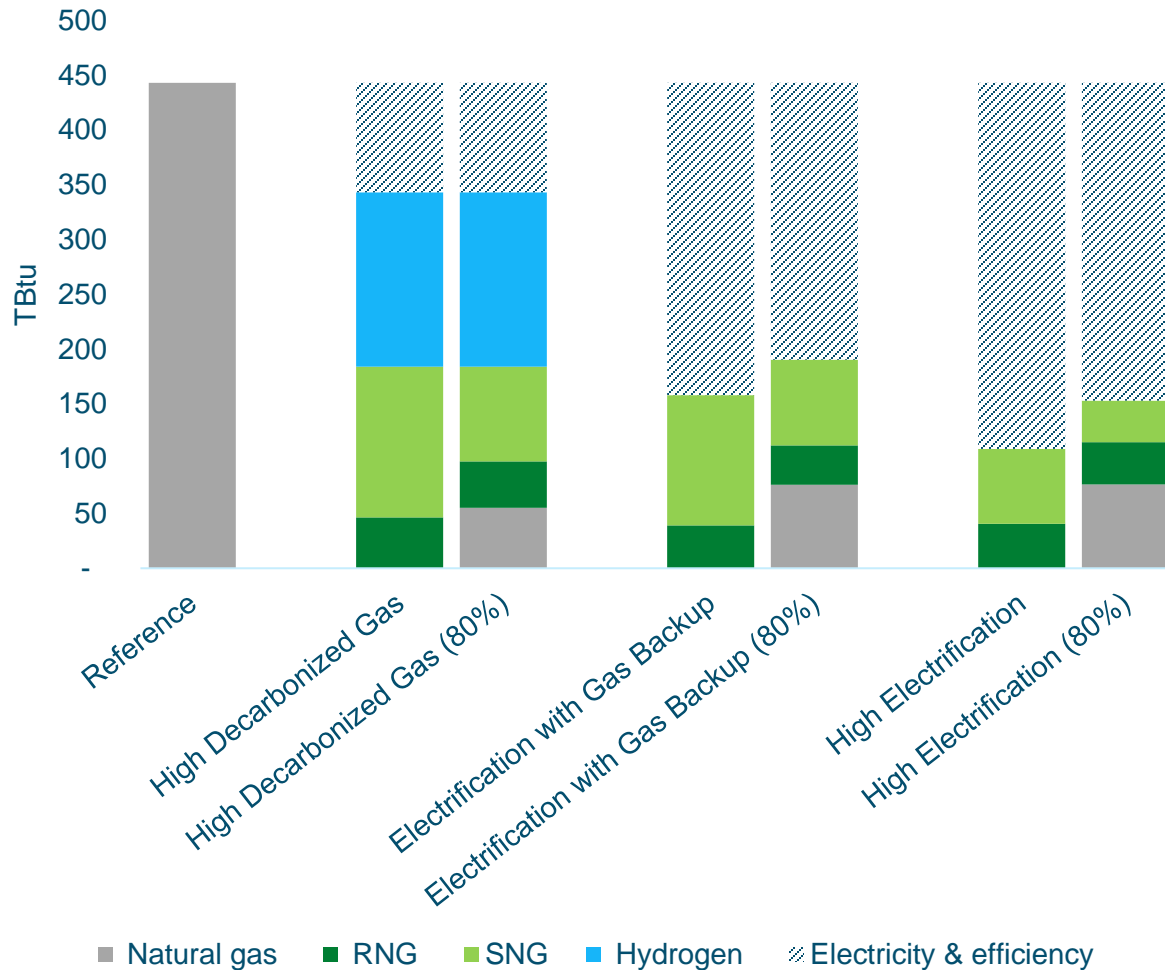


Sources & assumptions: Electricity & efficiency includes efficiency from fuel switching (electrification) and efficiency from additional building shell upgrades compared to the reference. RNG blend is determined based on an average of the optimistic and conservative scenario from E3's biofuels module.



What if: natural gas end-uses reach 80% GHG reduction?

Gas commodity blend in 2050 (sensitivity)



- + Reaching 80% GHG reduction over 100% for natural gas end-uses results in a fuel blend towards 2050 where natural gas still plays an important role.
- + This fuel blend mainly reduces the need for SNG as SNG represents the most expensive resource on the RNG supply Curve
 - Up to 50 TBtu less SNG supply (depending on scenario) compared to 100% reduction cases

Sources & assumptions: RNG includes Renewable Natural Gas from biomass and Synthetic Natural Gas (SNG) from hydrogen + CO₂. Electricity & efficiency includes efficiency from fuel switching (electrification) and efficiency from additional building shell upgrades.



Electricity consumption increases in Electrification scenarios

High Decarbonized Gas

- + Electricity load increases by around 4%
- + Limited growth in industrial sector as a result of electrification in sectors with low temperature heat

Electrification with Gas Back Up

- + Electricity load grows by 52%
- + Most of load growth corresponds to significant industrial electrification
- + Load in buildings increases only slightly as a result of efficiency

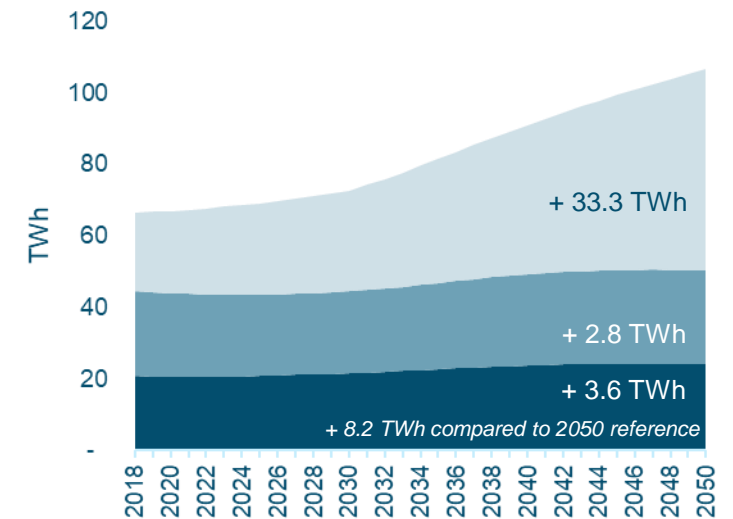
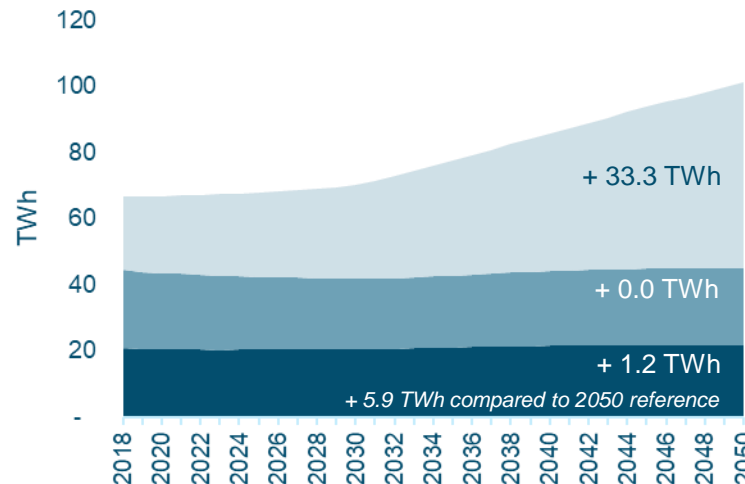
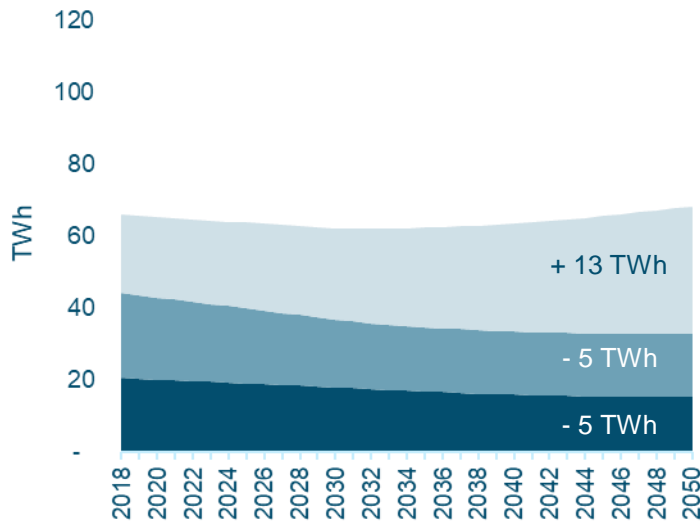
High Electrification

- + Electricity load grows by 59%
- + Most of load growth corresponds to significant industrial electrification
- + Load in buildings increases only slightly as a result of efficiency

Residential

Commercial

Industrial



Sources & assumptions: electricity consumption is largely influenced by energy efficiency measures in the reference scenario. Increases electricity sales in High Electrification and Electrification with Gas Back Up scenario are the result of fuel switching. Average COPs per measure are included in the Appendix.

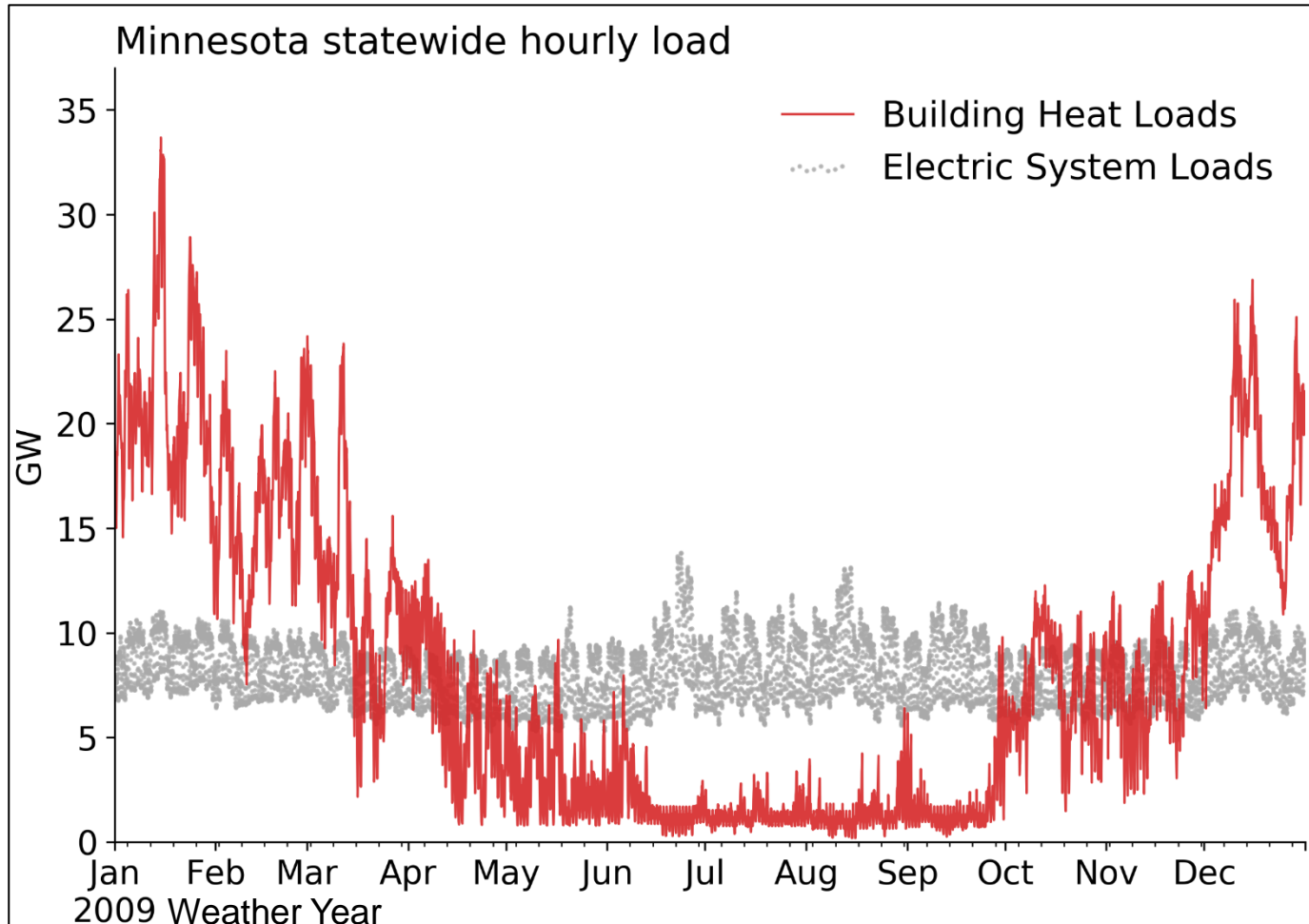


Energy+Environmental Economics

Electricity sector impacts



Minnesota's current electric system peaks in summer



+ Currently, Minnesota's electricity system experiences peak load in Summer months

- Load peaks at around 15 GW, mainly as a result of residential and commercial air conditioning

+ Minnesota's *building heat load* however, currently mainly supplied by gas, shows a large peak in Winter as a result of the state's cold winter climate

- Building heat loads represent *service demand* of both space and water heating, i.e. total heating load if all supplied by electric resistance
- Moving the thermal load from gas to electric will result in a significant increase in electric peak in winter

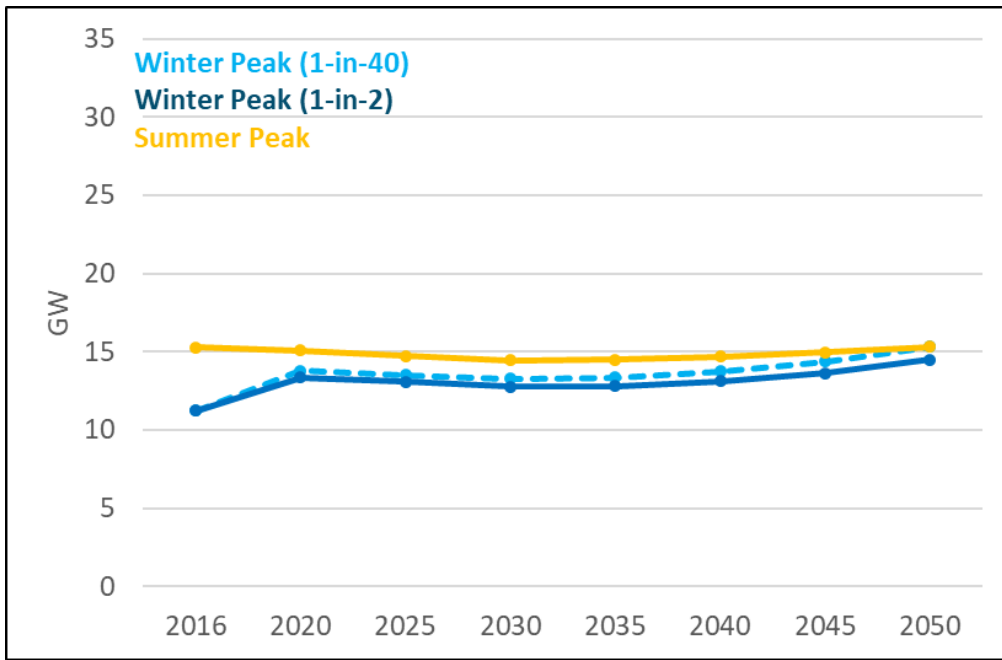
Sources & assumptions: Building thermal load is based on PATHWAYS total space and water heating service demand benchmarked to the MN Energy Efficiency Potential Study. Shape of the thermal load is calculated using E3's RESHAPE model. 2009 features a cold snap that resulted in a 1-in-10 peak heat demand, meaning that the coldest hour of 2009 only occurs once every 10 years based on 40 years (1979-2019) of historical weather. The 2009 historical load shape is based on the MISO Load Zone 1.



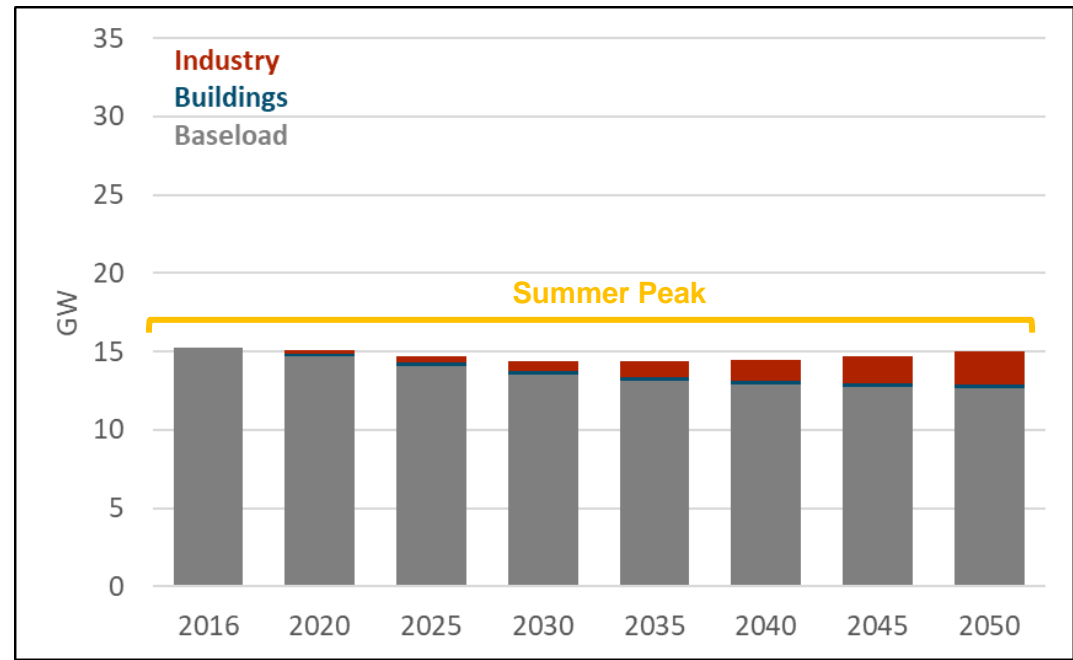
The summer peak continues in the long-term in the High Decarbonized Gas scenario

- + Relying on decarbonized gas in the existing gas infrastructure to decarbonize building heat demand would likely keep Minnesota's electric system peak at the current level.

Peak Load Projection 2016-2050



Contribution to 1-in-2 System Peak by Sector



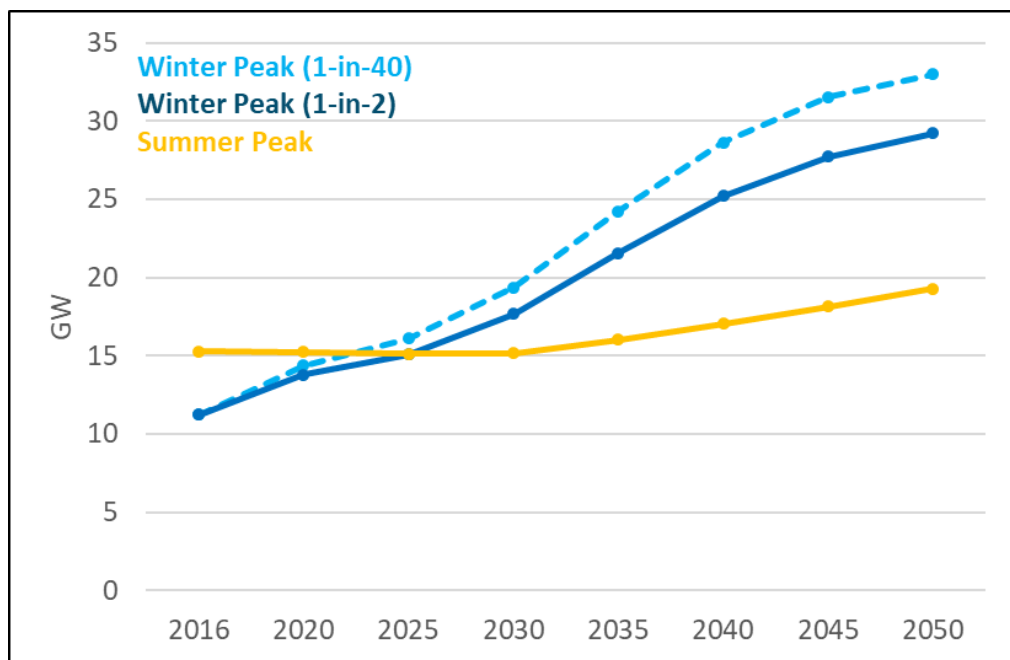
Sources & assumptions: Coincident peak load is based on a modeled hourly load for MN. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2016 weather added to the 2016 historical load.



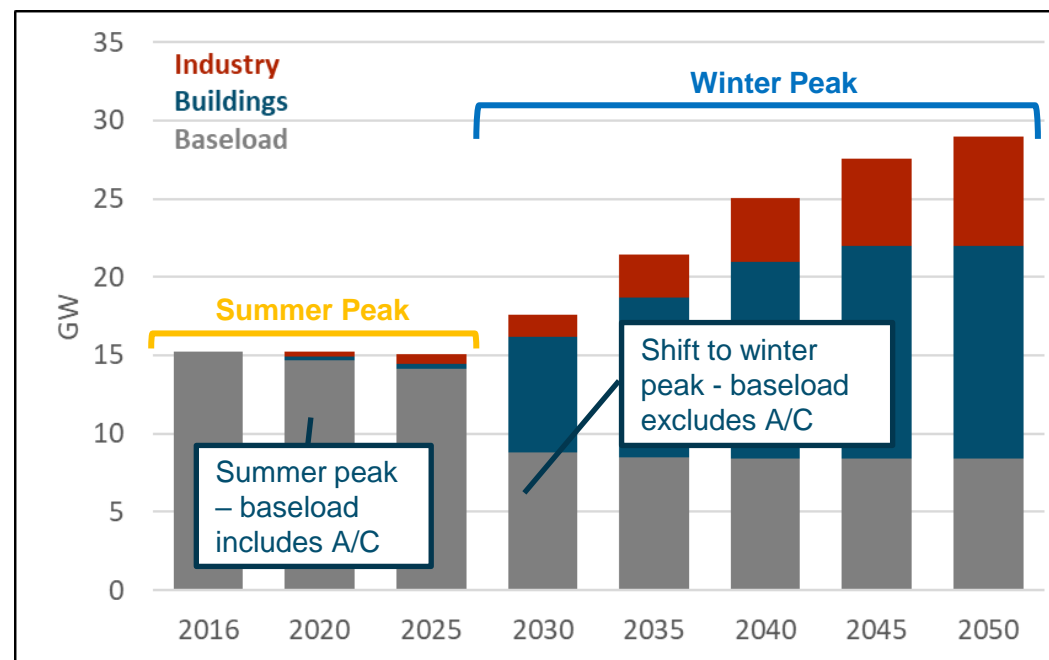
The High Electrification scenario leads to a large shift in peak load to a winter peaking system

- + High levels of building electrification shifts Minnesota's electric system to winter peaking between now and 2025, even with high-efficiency cold-climate ASHPs.

Peak Load Projection 2016-2050



Contribution to 1-in-2 System Peak by Sector



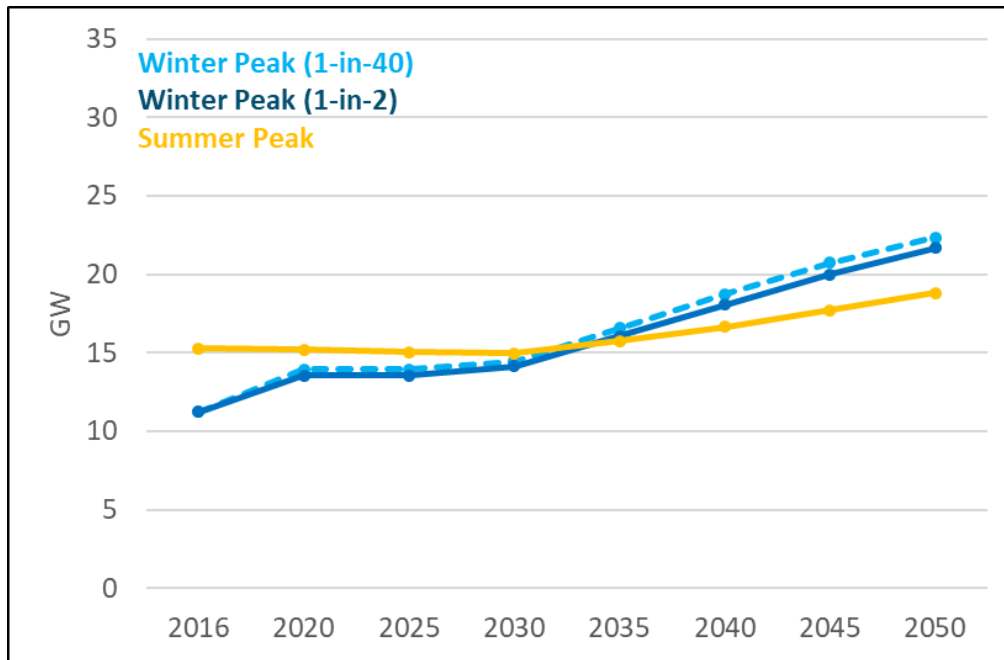
Sources & assumptions: Coincident peak load is based on a modeled hourly load for MN. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2016 weather added to the 2016 historical load.



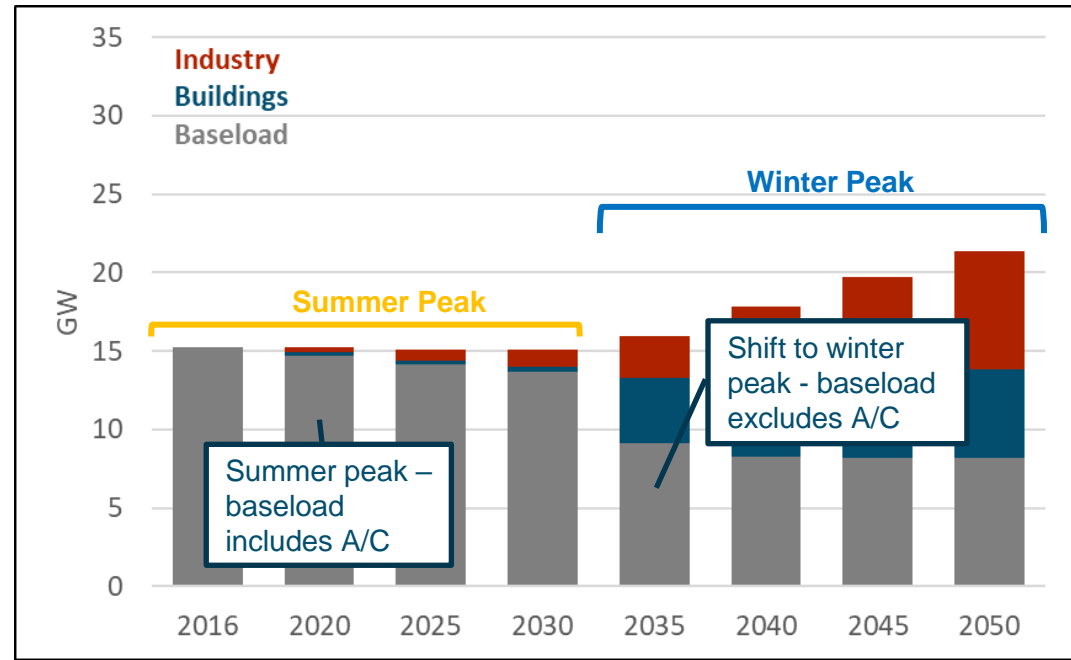
High Electrification with Gas Back Up results in an 8-9 GW peak load reduction in 2050 compared to all-electric

- + Using the gas system as back-up to provide peak heat demand during cold days significantly reduces the peak impact on the electric system, delaying the system shifting to winter peaking by almost a decade.

Peak Load Projection 2016-2050



Contribution to 1-in-2 System Peak by Sector

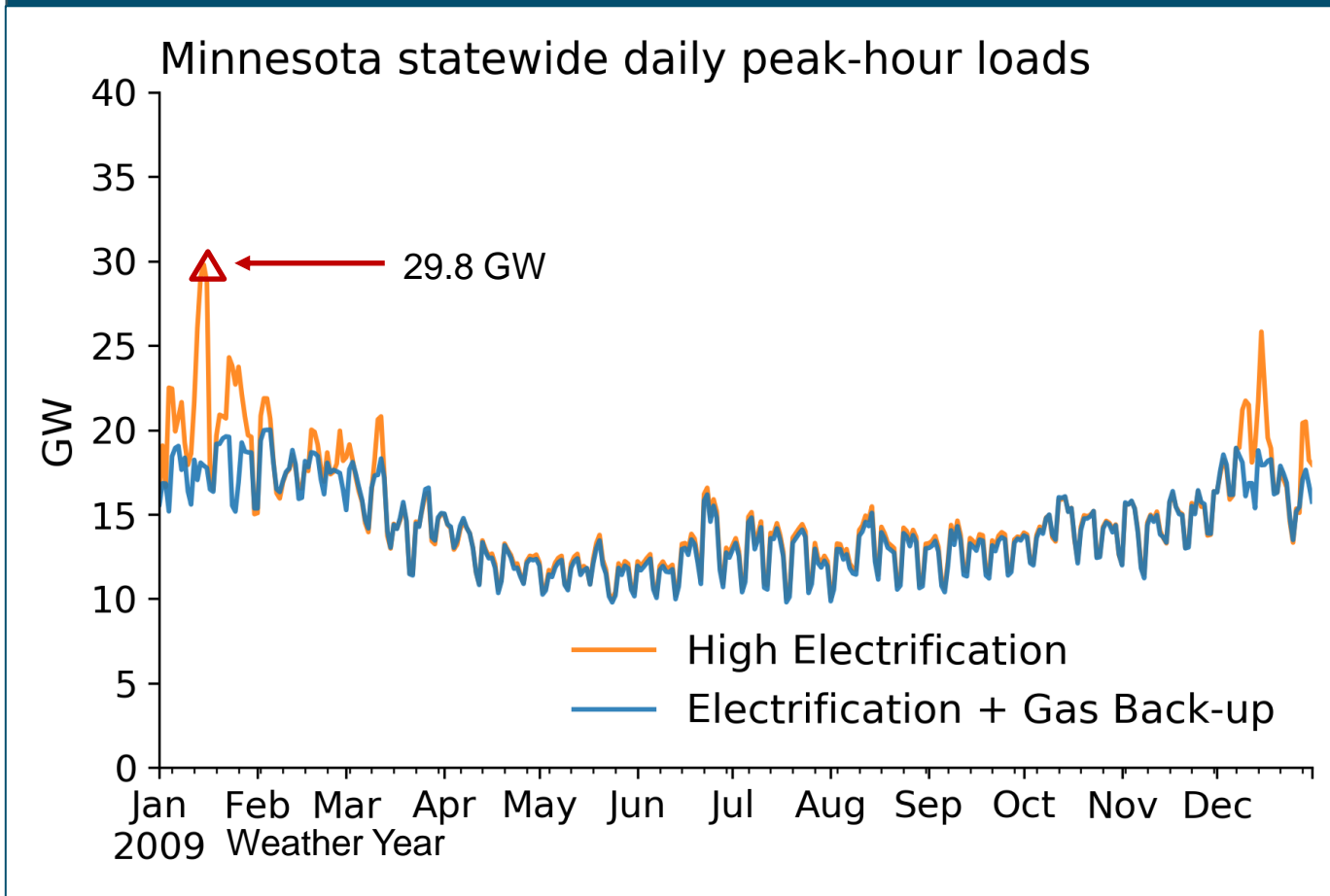


Sources & assumptions: Coincident peak load is based on a modeled hourly load for MN. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2016 weather added to the 2016 historical load.



The main benefit of the back-up scenario occurs during the coldest hours of the year

Load impact in 2050: all-electric vs. gas back-ups



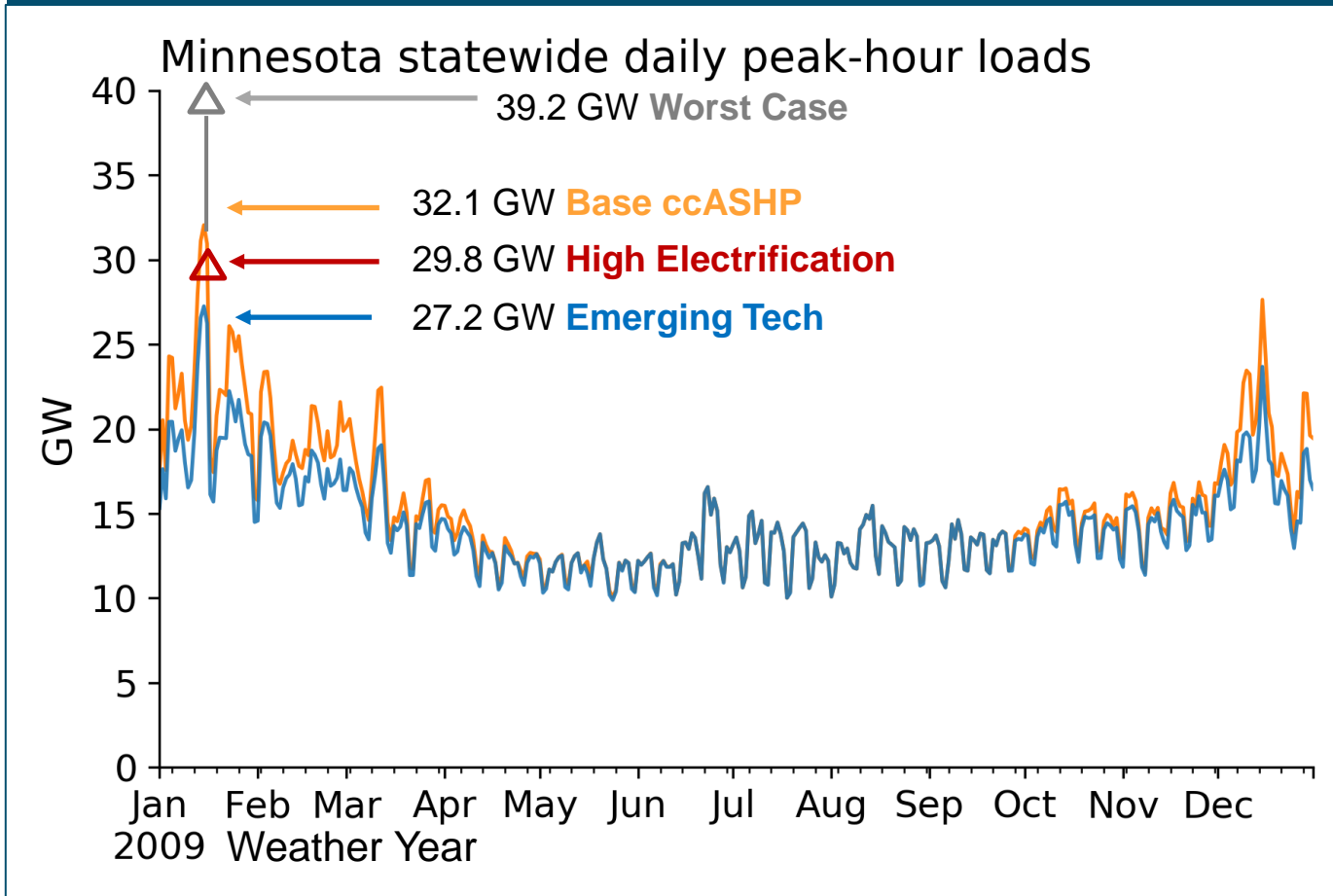
- + **Peak heat loads occur during a few hours of a year, when gas back-up systems can significantly reduce heat load compared to ASHPs with electric resistance back-up**
 - The Electrification + Gas Back-up scenario shows a reduction in winter peak load by ~30% compared to the High Electrification scenario
- + **From customers' perspectives, gas back-up systems can avoid oversizing of ASHPs**
 - Large sizing without gas back ups is necessary only for a few hours of peak heat demand during the year

Sources & assumptions: Hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2009 weather. The High Electrification scenario assumes a mix of base (20%), medium-efficiency (60%) and best (20%) ccASHPs on the market today. The Electrification + Gas Back-up scenario assumes medium-efficiency ccASHPs paired with gas furnaces/boilers.



A worst-case electrification scenario can result in a 12 GW higher peak load compared to a best-case scenario

Load impact in 2050: Base vs. Emerging Tech ccASHPs



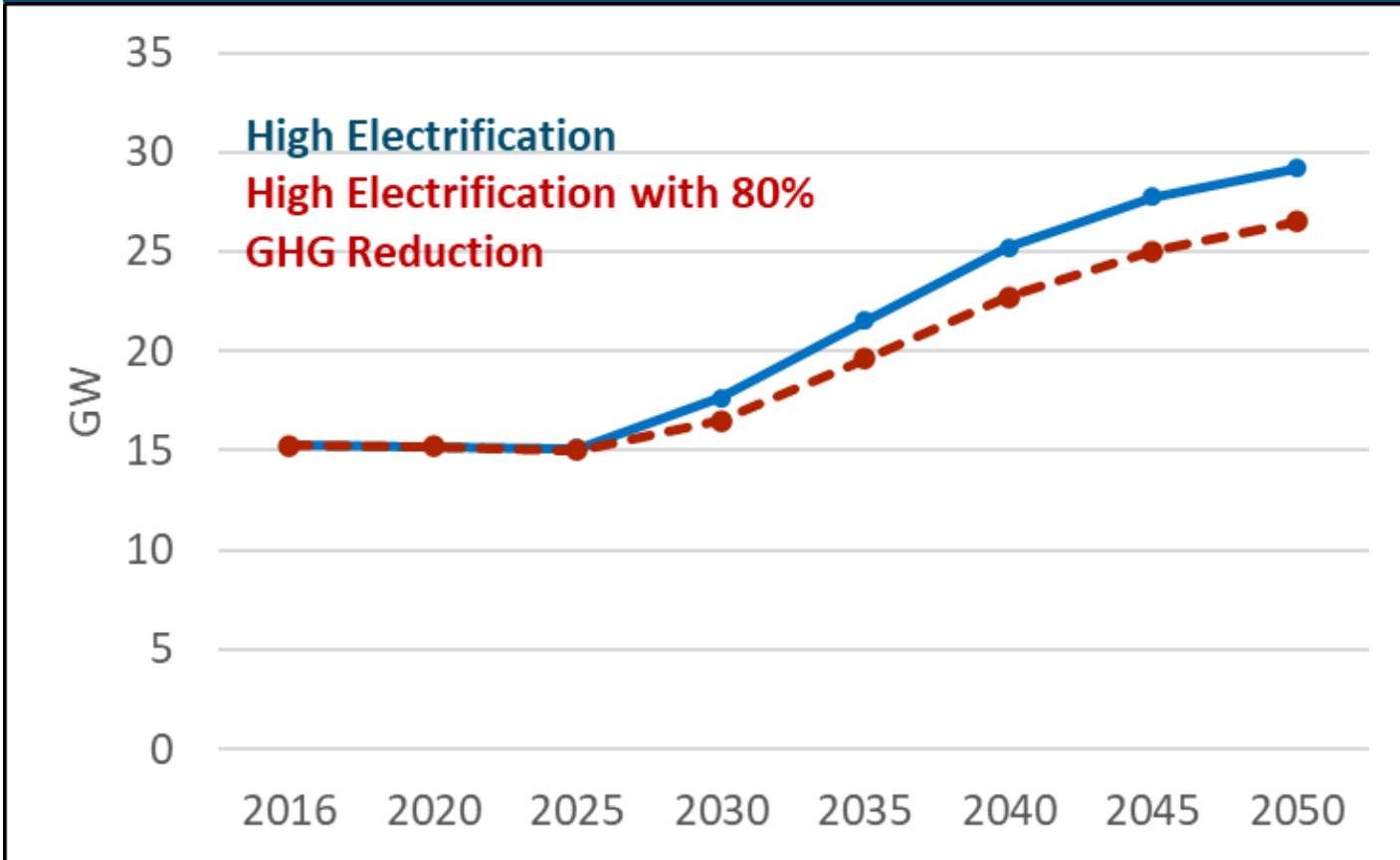
- + The counterfactual scenario represents the “worst-case” electrification scenario with no shell improvement and only base ccASHPs
- + Base ccASHPs are the products that just meet the NEEP cold climate heat pump standards
 - COP 1.75 @5F
 - COP 1.3 @-17F
- + High Electrification scenarios assume a combination of base, medium-efficiency and best ccASHPs on the market today
- + Emerging Tech are based on the DOE Building Technology Office’s Emerging Technology development goal for variable speed ccASHPs
 - COP 3.5 @17F
 - COP 3 @-17F

Sources & assumptions: Hourly load is calculated by adding incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2009 weather. The High Electrification scenario assumes a mix of base (20%), medium-efficiency (60%) and best (20%) ccASHPs on the market today.



With 80% GHG reductions in 2050, peak load reduces by 10%

Load impact comparison: 80% GHG reduction

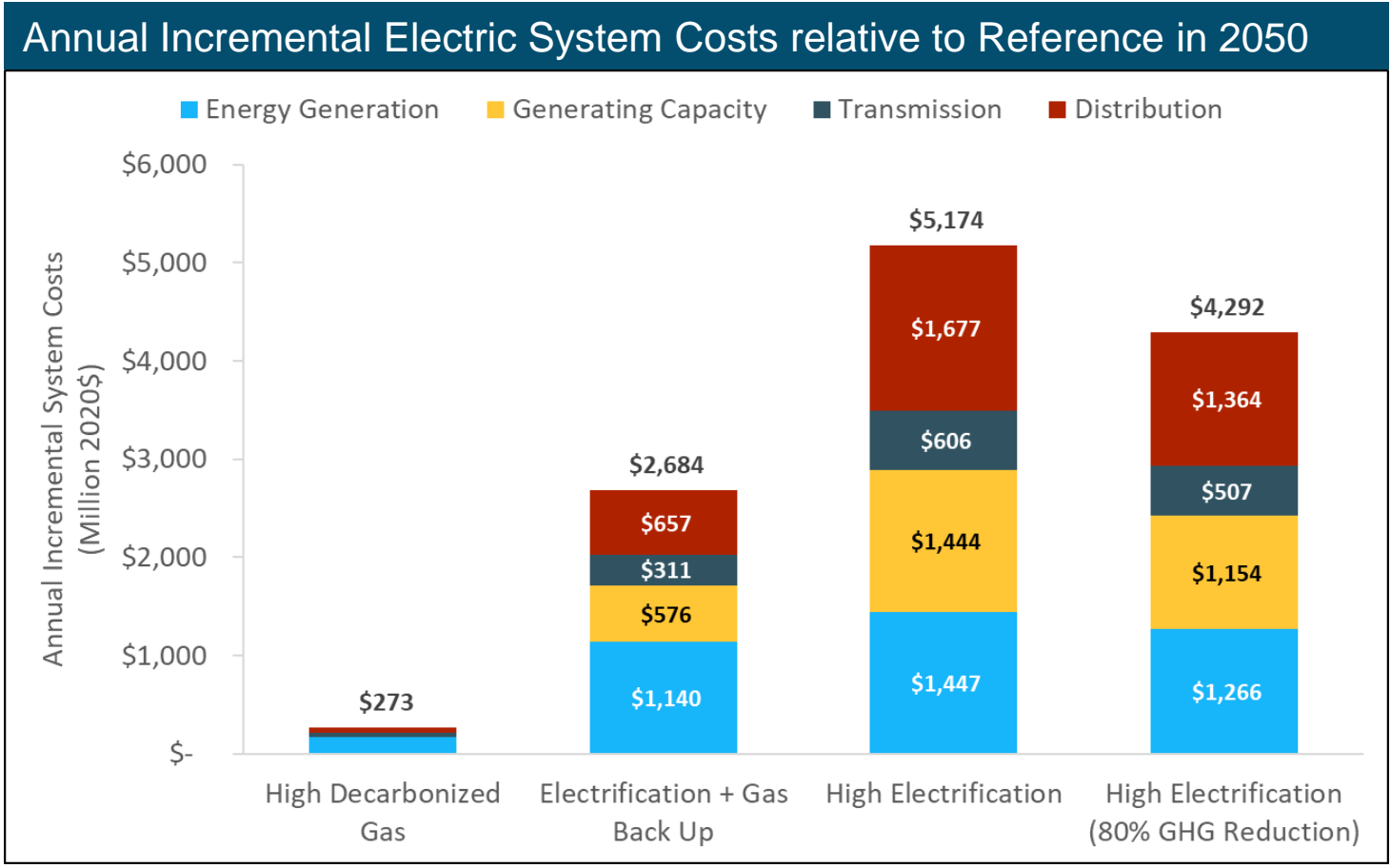


- + A High Electrification scenario that reaches 80% GHG reduction by 2050 has a 20% lower heat pump adoption than the High Electrification Scenario that reaches 100% GHG reduction
- + As a result, peak load in this scenario is 10% smaller compared to a 100% GHG scenario as building heat loads contribute to half of the system peak load

Sources & assumptions: Coincident peak load is based on a modeled hourly load for MN. The projected hourly load is calculated using incremental load in 2050 modeled from PATHWAYS and end-use shapes from RESHAPE based on 2016 weather added to the 2016 historical load.



Meeting electric loads in the High Electrification scenario requires around \$5 billion of incremental system costs



- + High levels of electrification significantly increase electricity system costs, mainly for meeting peak capacity needs
- + Pairing ASHPs with gas furnaces systems can save about half of the incremental costs, mainly by avoiding T&D infrastructure and generating capacities
 - System costs in the Electrification with Gas Back Up scenario are \$2.7 million in 2050 compared to \$5.2 million for the High Electrification scenario

Sources & assumptions: Details of the electric sector cost assumptions are documented in the Appendix



Energy+Environmental Economics

Economic impacts



Gas rates may see a significant increase in low GHG scenarios

Gas rates increase both as a result of commodity costs and delivery costs

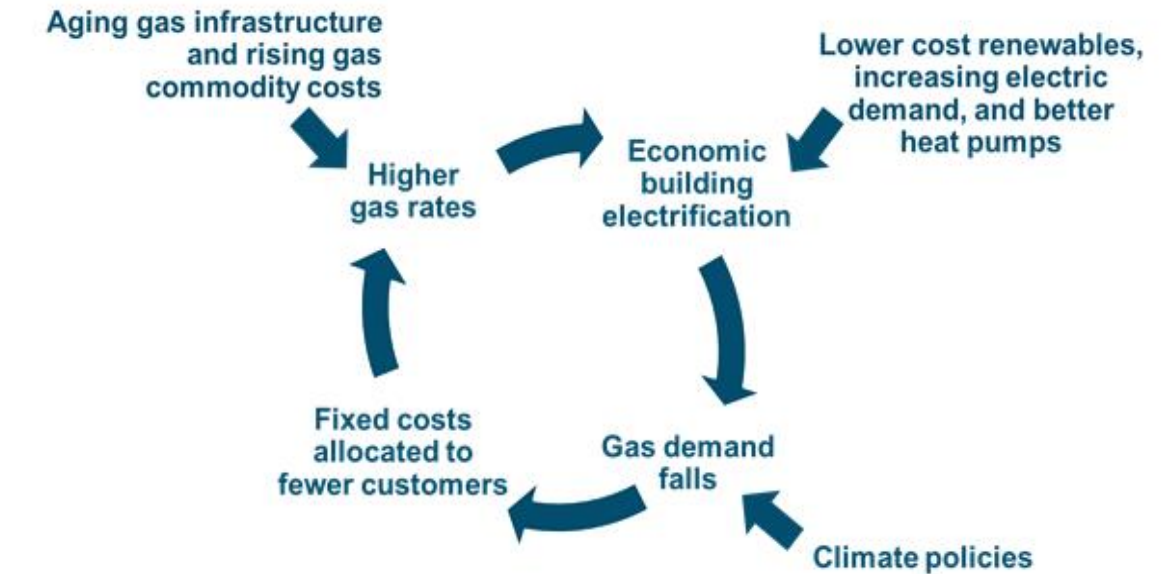
+ Commodity Rate (cost of gas):

- Blending zero-carbon fuels into the pipeline reduces emissions
- \$/MMBtu commodity rate will increase due to high cost of biogas and hydrogen

+ Delivery Rate (cost of infrastructure):

- Throughput falls due to electrification, but gas system costs continue to grow as heat pump adoption occurs at end-of-life
- \$/MMBtu delivery rate must increase to meet system revenue requirement

A “vicious cycle” (feedback loop) may develop, driving gas costs higher



E3, California Energy Commission: “The Challenge of Retail Gas in California’s Low-Carbon Future” (2020)

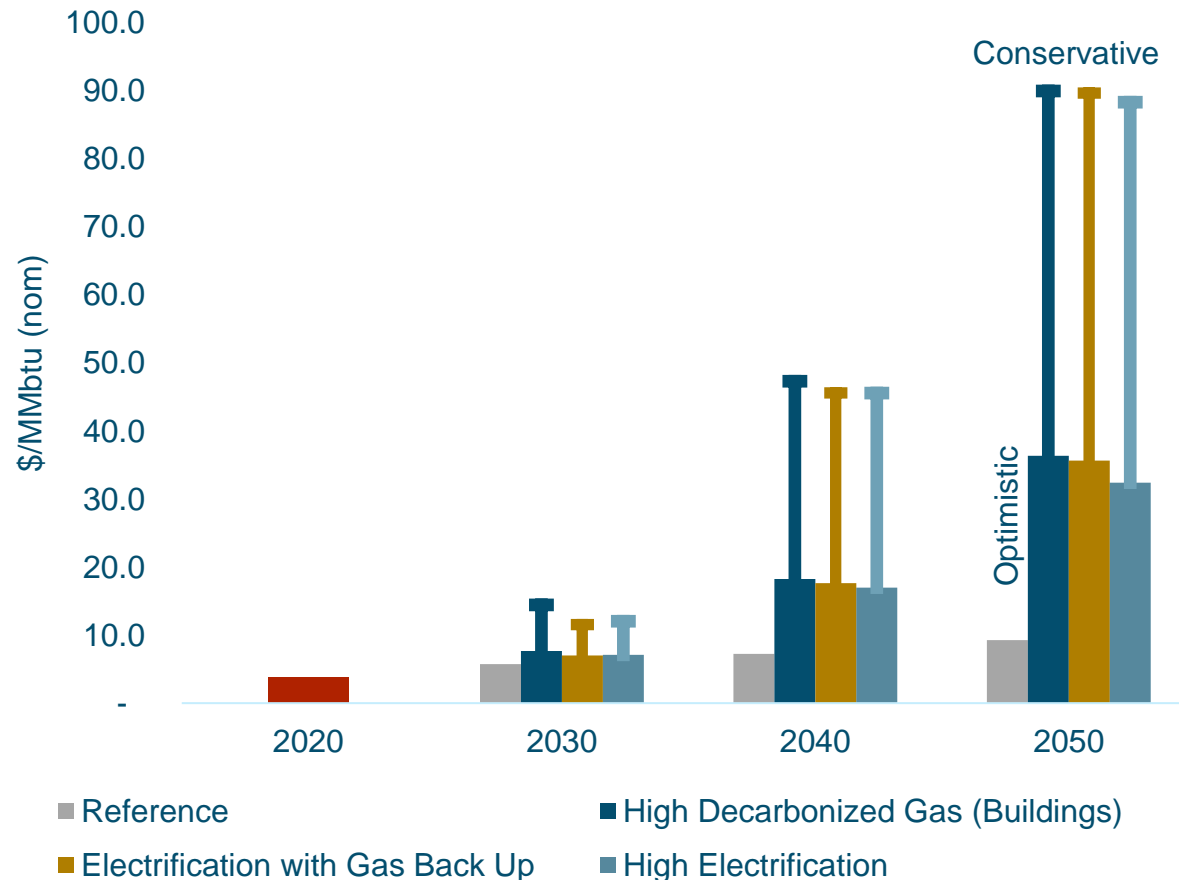
+ Customer impacts may be inequitable

- Burden on those unable to switch away from gas (renters and low-income customers)



Commodity costs of gas grow as a result of an increased zero-carbon fuels blend

Average annual commodity costs of gas per scenario (\$/dth)



+ Commodity costs of gas increase steeply as a result of blending of zero-carbon fuels

- Uncertainty range shows difference between 'optimistic' and 'conservative' RNG Supply assumptions, resulting in a significant differentiation

+ Commodity costs for the High Decarbonized Gas scenario apply to buildings only

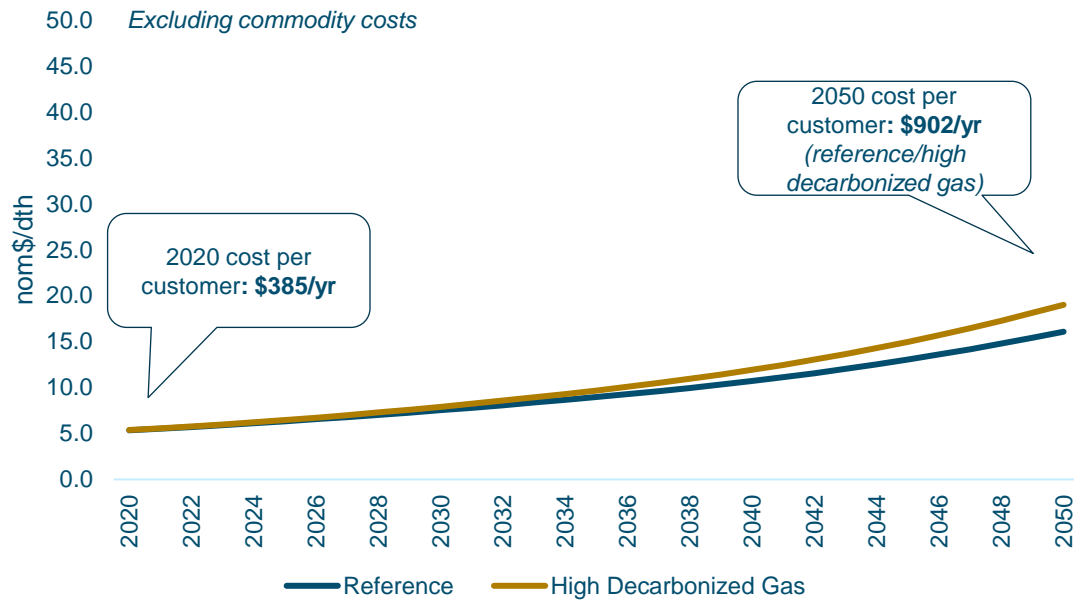
- Industry is able to benefit from lower prices in the High Decarbonized Gas scenario as a result of dedicated hydrogen consumption

Sources & assumptions: cost assumptions for RNG and hydrogen based on E3's biofuels module and Hydrogen Production module (see Appendix). Costs in the reference case are based on natural gas prices from EIA AEO 2020.

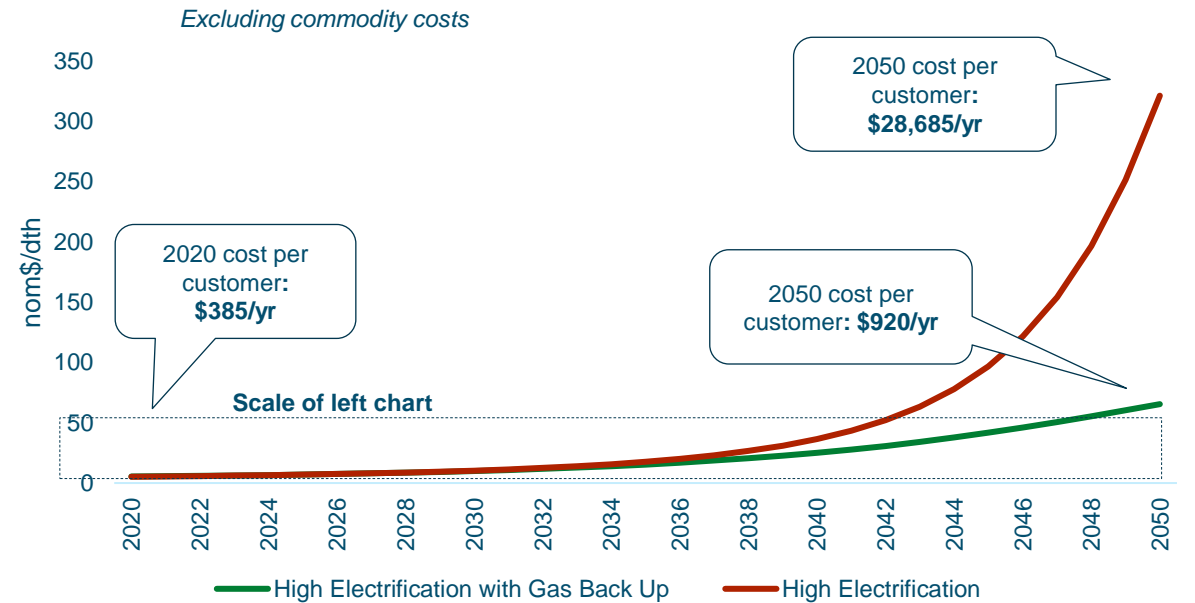


Delivery costs of gas increase dramatically as more and more households electrify

Residential delivery costs of gas in “gas centered” scenarios (\$/dth)



Residential delivery costs of gas in “electric centered” scenarios (\$/dth)



- + Scenarios assume annual utility Capital Expenditures for gas system improvements stay flat
- + Costs increase in reference & high decarbonization scenarios as a result of efficiency improvements (declining gas throughput)

- + Scenarios assume the gas system needs to be maintained in “unstructured” transition (up to \$2bln/yr in 2050 allocated to residential sector)
 - Less the costs of new construction (~10% of CAPEX)
- + Costs per household increase dramatically as more and more households leave the gas system

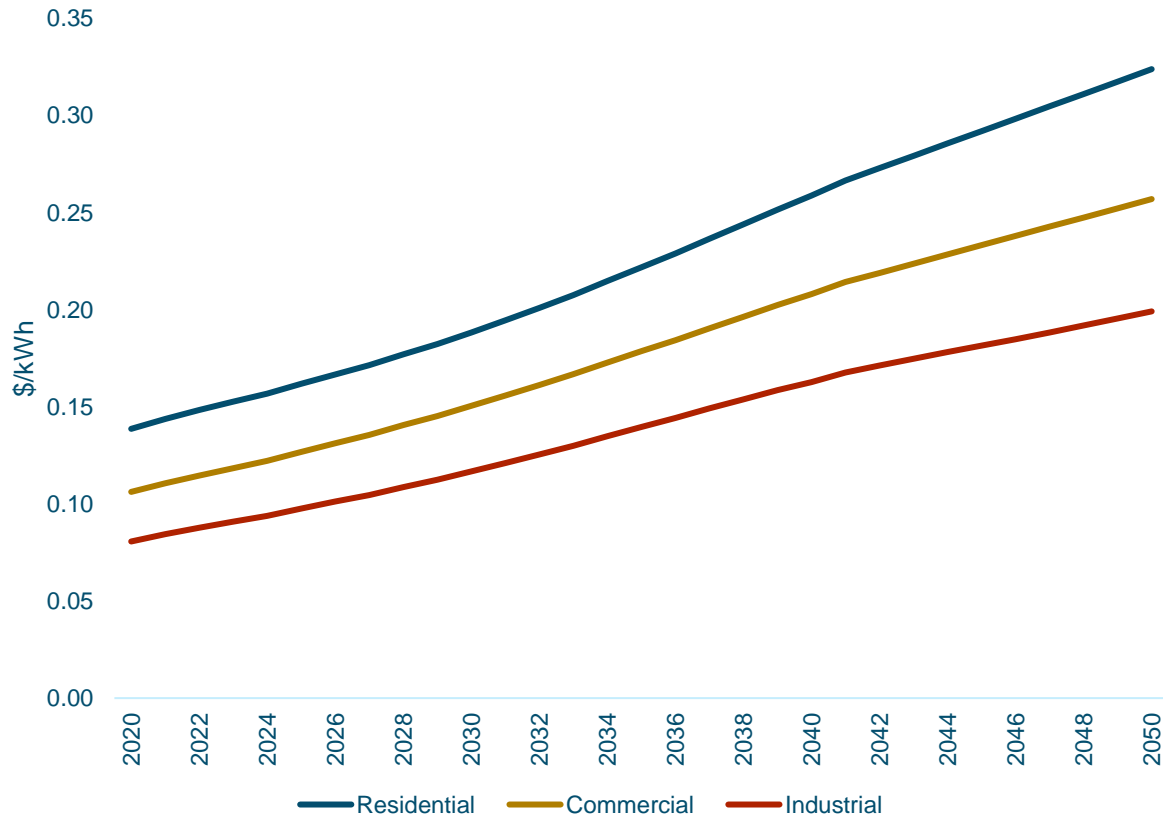
Sources & assumptions: current Revenue Requirement (RR) is estimated using Minnesota specific delivery prices per sector from EIA. Rate base increases are based on historical averages and flat capital expenditures (see Appendix). Scenarios assume a “Business as Usual” allocation of Revenue Requirement to customer groups. Cost allocations might shift as the ratio of consumption changes.



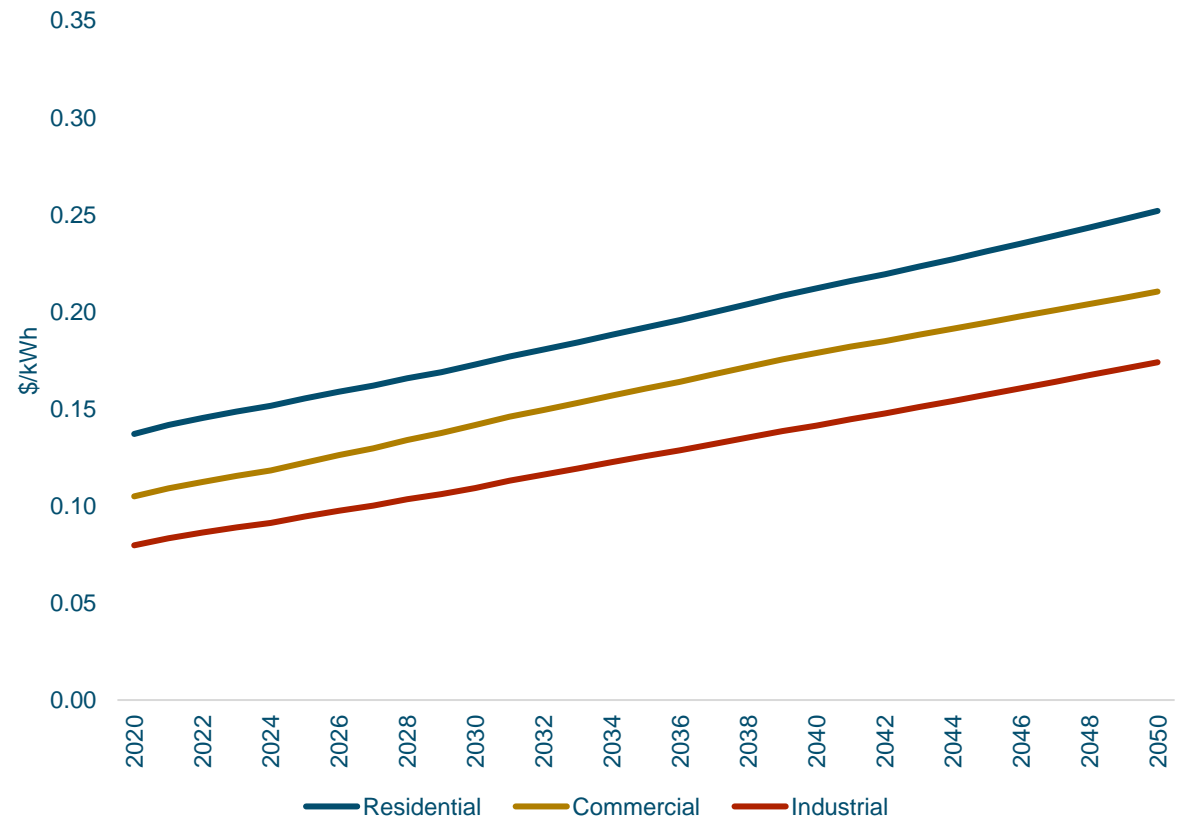
High Electrification scenario shows a more rapid rate increase compared to Electrification with Gas Back Up

+ The Electrification + Gas Back-up scenario is projected to have a lower rate increase because it has a smaller load factor and manages to avoid the expensive peak capacity investment.

Electric rates in the High Electrification Scenario (\$/kWh)



Electric rates in the Electrification + Gas Back-up Scenario (\$/kWh)



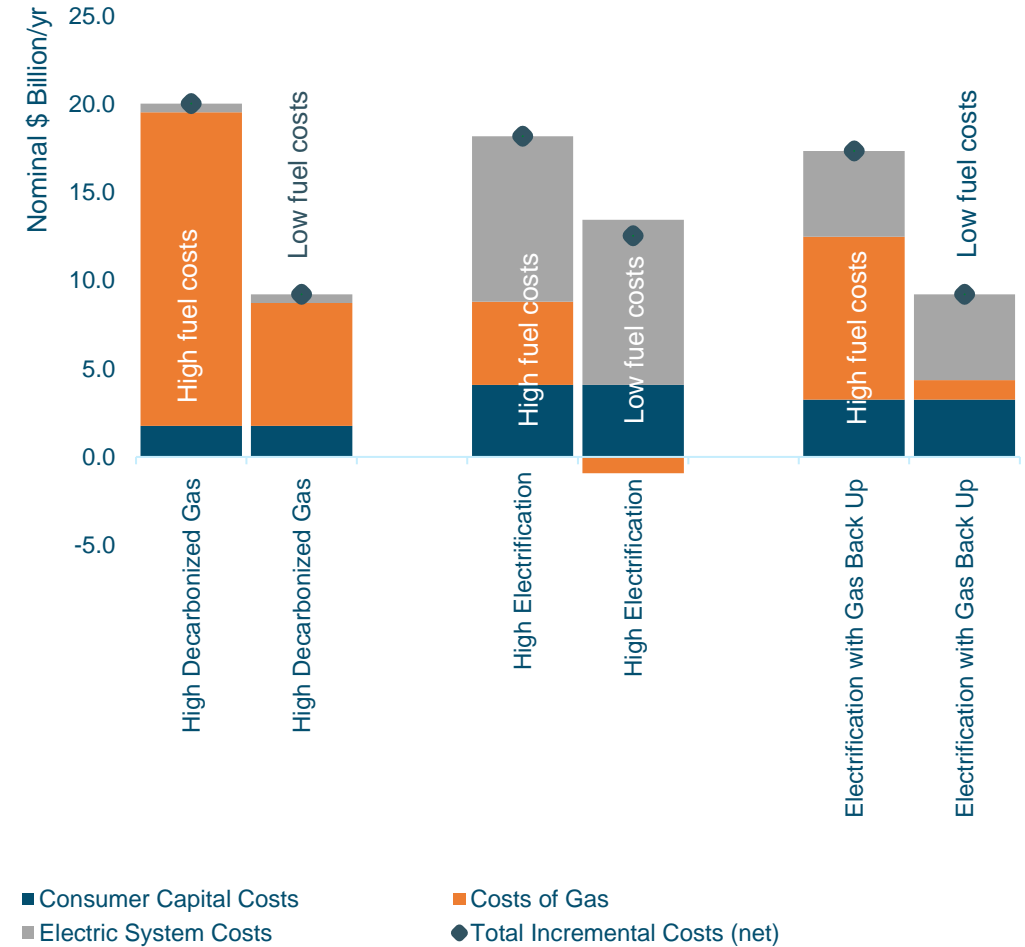


Total incremental resource costs show an advantage for Electrification with Gas Back Up scenario on the long run

Incremental Resource Costs for all sectors (2030)



Incremental Resource Costs for all sectors (2050)

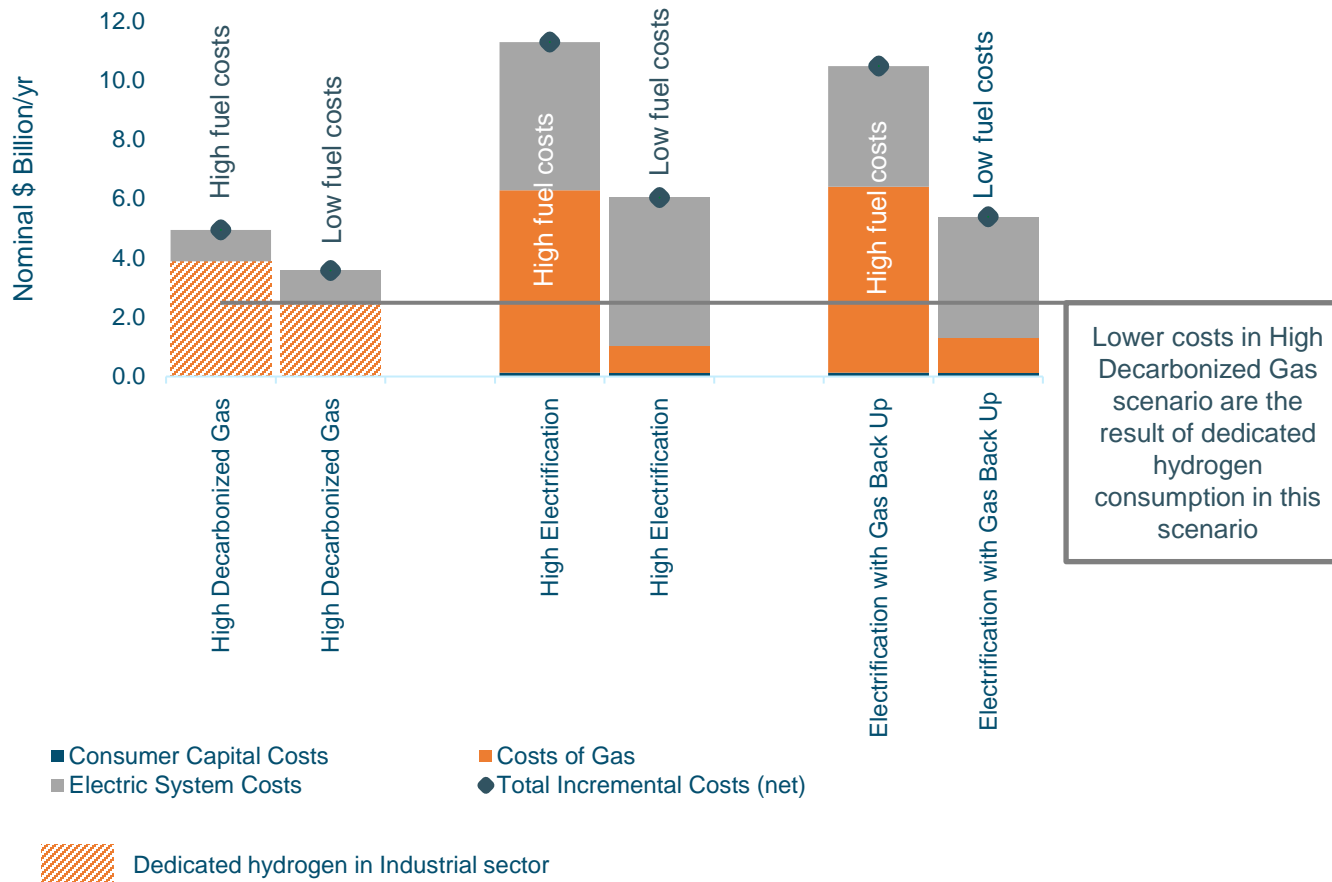


Sources & assumptions: These charts show incremental resource costs of the scenarios compared to the reference scenario. Capital costs applied in the residential and commercial sector are outlined in the Appendix. Capital costs for the industrial sector are based on high level estimations only using capital costs assumptions from the National Energy Modelling System (NEMS), the Electrification Futures Study (NREL), Emerson Climate Technologies and the European Technology and Innovation Platform.



Industry could benefit from dedicated hydrogen consumption; though further feasibility research is required

Incremental Resource Costs for Industry (2050)



- + Resource costs in the industrial sector are lowest in the High Decarbonized Gas scenario with limited electrification and dedicated hydrogen consumption
 - This is mainly the result of low fuel costs for hydrogen compared to RNG + SNG
 - Further research on the (technical) feasibility of infrastructure conversions to hydrogen is required
- + Industrial resource costs are characterized by fuel costs and electricity system costs; incremental capital costs are assumed to be low

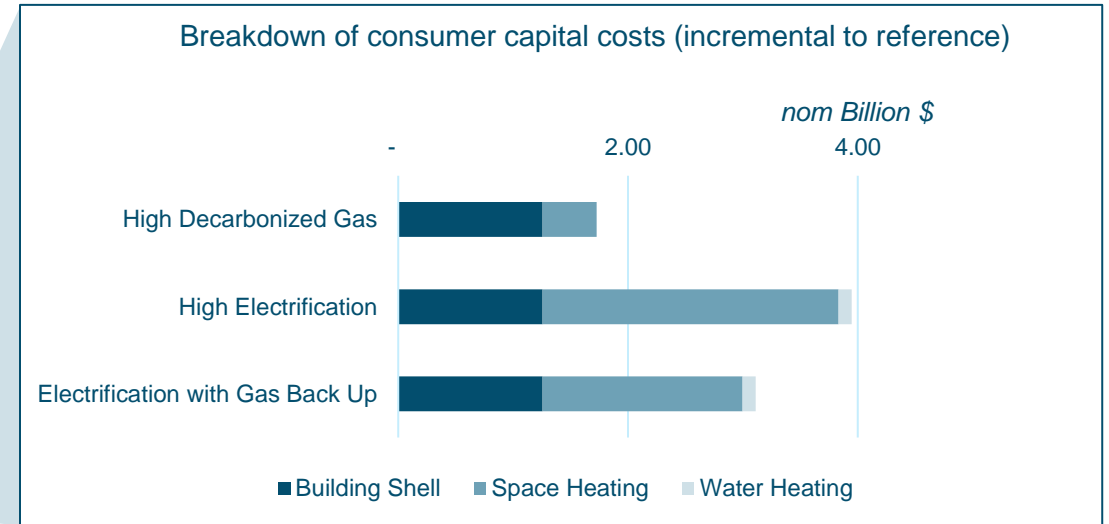
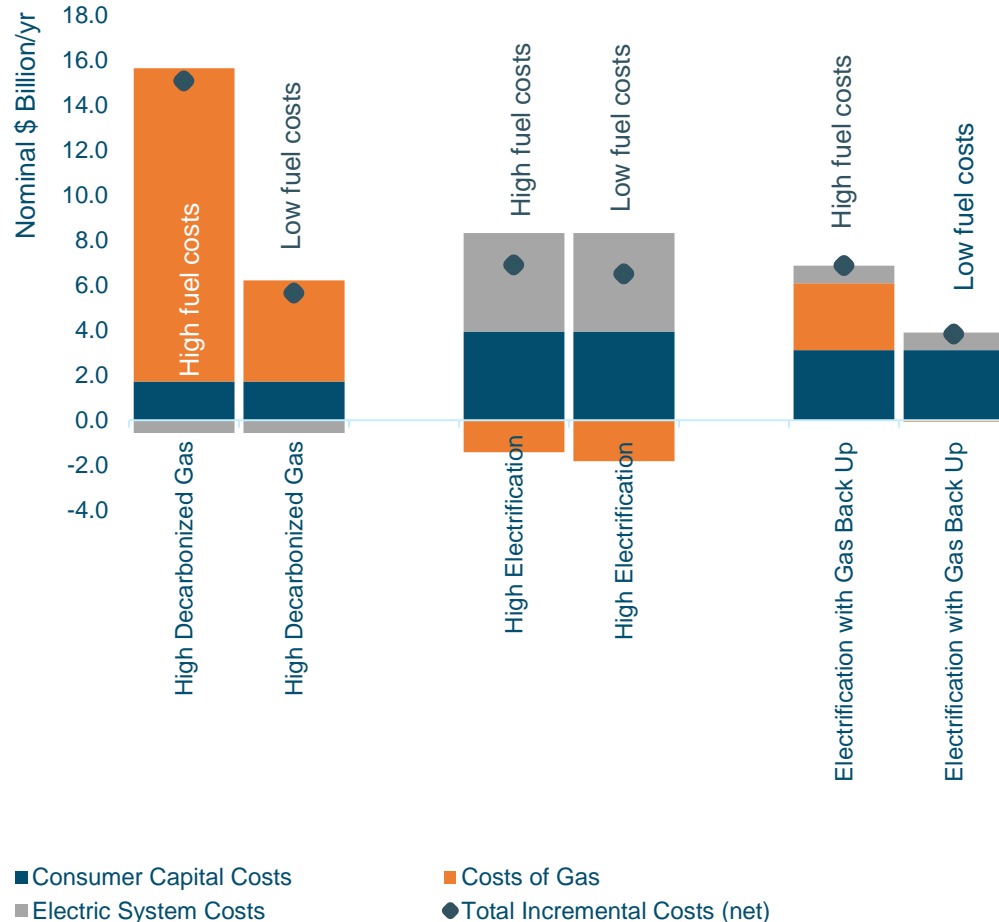
Sources & assumptions: These charts show incremental resource costs of the scenarios compared to the reference scenario. Capital costs for the industrial sector are based on high level estimations only using capital costs assumptions from the National Energy Modelling System (NEMS), the Electrification Futures Study (NREL), Emerson Climate Technologies and the European Technology and Innovation Platform. Costs for process electrification are assumed to be equal to reference installation costs.



The Building Sector benefits from an Electrification with Gas Back Up scenario to hedge for uncertainty in fuel costs

Incremental Resource Costs for Buildings (2050)

Commercial + Residential sector



+ Building sector costs show large variation across scenarios depending on gas fuel costs (optimistic/conservative supply curve)

- An Electrification with Gas Back Up scenario could potentially “hedge” for this uncertainty given its lower overall costs in both bookends

Sources & assumptions: These charts show incremental resource costs of the scenarios compared to the reference scenario. Capital costs applied in the residential and commercial sector are outlined in the Appendix. Capital costs for the commercial sector are based on high level estimations only using capital costs assumptions from the National Energy Modelling System (NEMS).



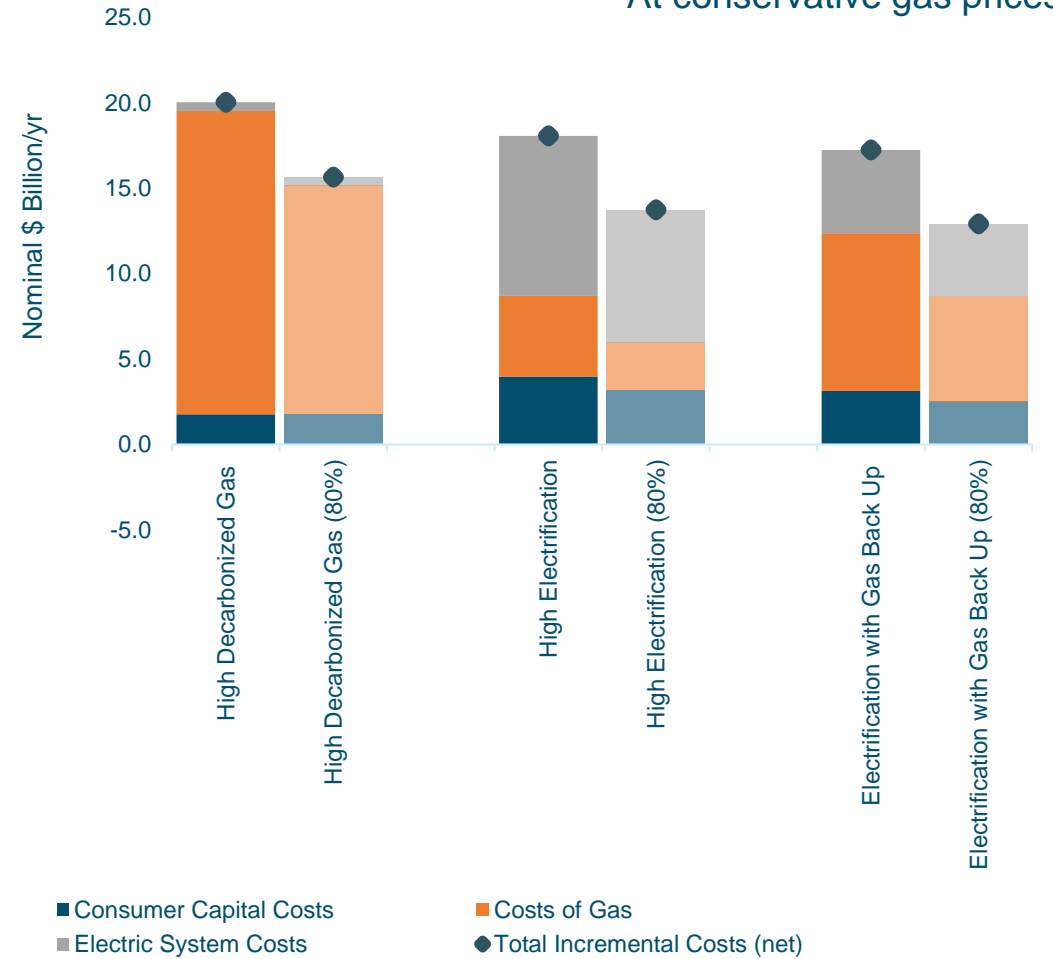
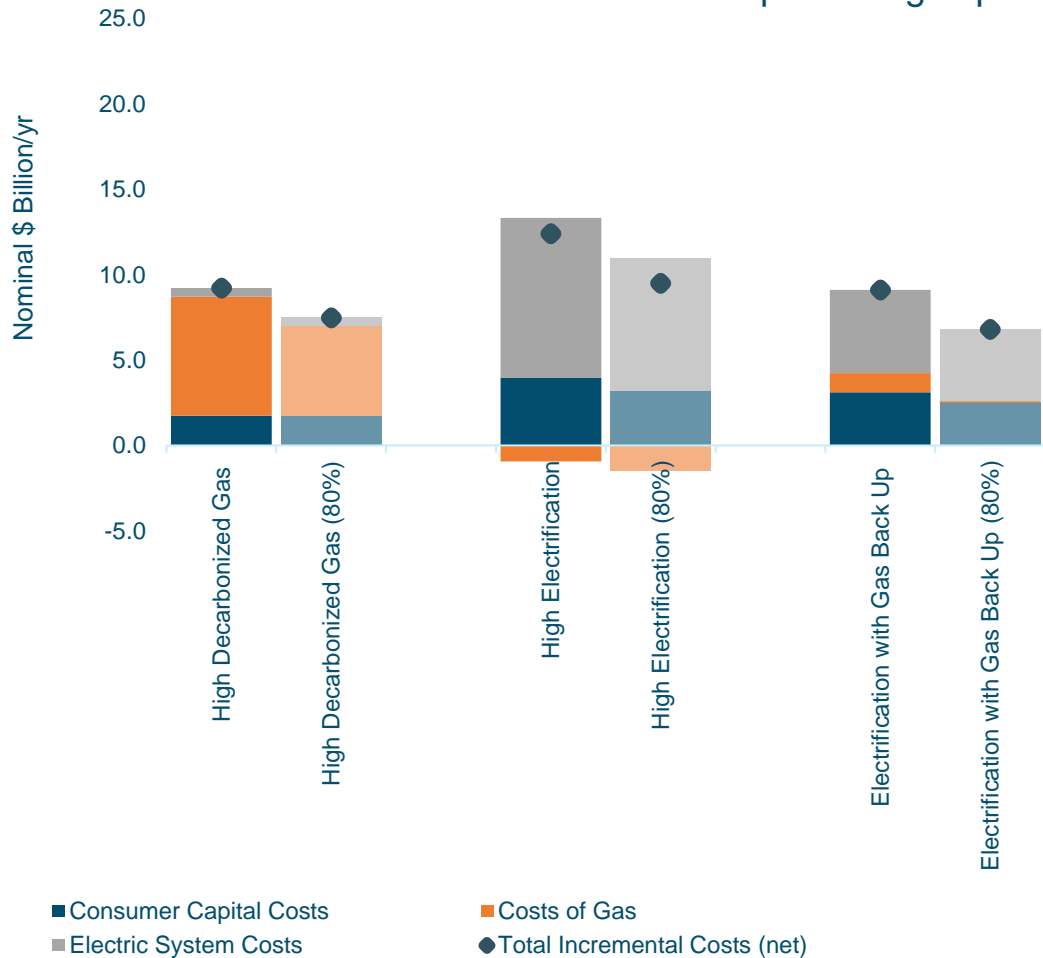
Sensitivity shows lower costs in 80% GHG reduction by 2050

Total Resource Costs at 80% GHG reduction (2050)

Total Resource Costs at 80% GHG reduction (2050)

At optimistic gas prices

At conservative gas prices



Sources & assumptions: These charts show incremental resource costs of the scenarios compared to the reference scenario. Capital costs applied in the residential and commercial sector are outlined in the Appendix. Capital costs for the industrial sector are based on high level estimations only using capital costs assumptions from the National Energy Modelling System (NEMS), the Electrification Futures Study (NREL), Emerson Climate Technologies and the European Technology and Innovation Platform.



Energy+Environmental Economics

What about district systems?



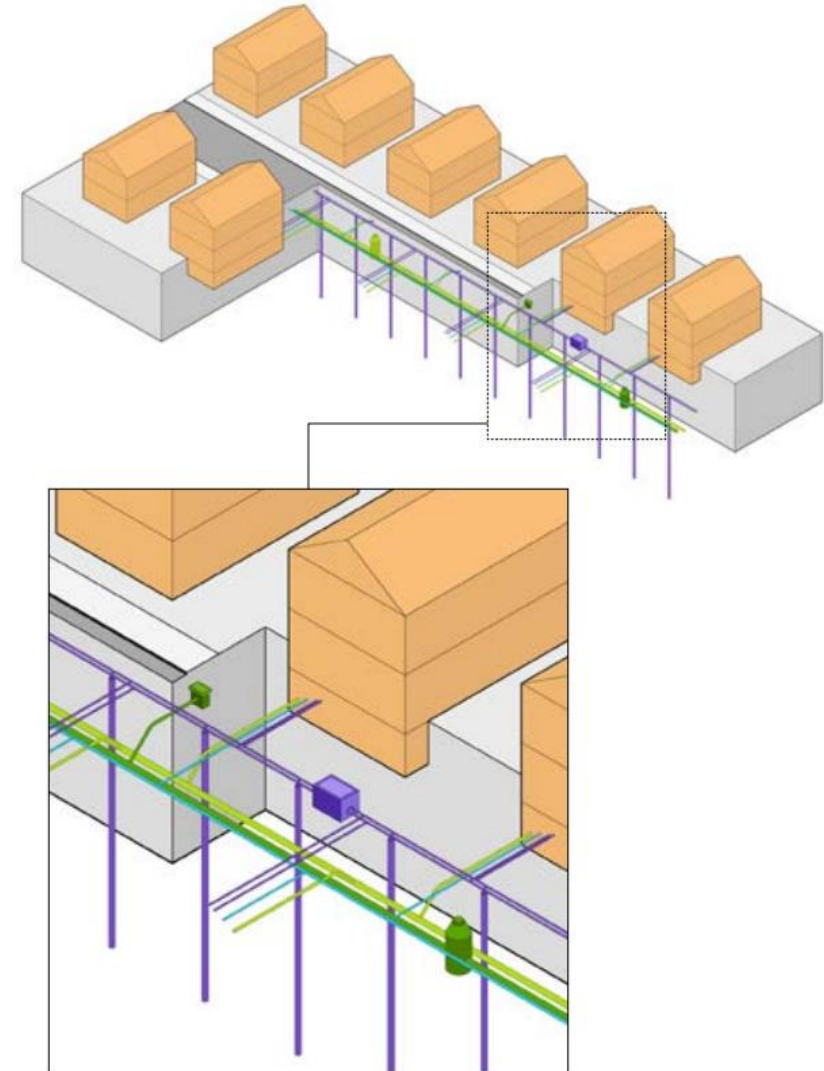
District system sensitivity looks at GeoMicroDistricts in new construction

+ In the District System sensitivity scenario, all new construction converts to 'GeoMicroDistricts'

- The gas system in Minnesota is relatively new and not expected to require full replacements; therefore our scenario design only takes district systems in new construction into account.
- GeoMicroDistricts considered in this approach are closed vertical GSHP systems that connect several homes to a central infrastructure.

+ Advantages:

- Installation of GSHP systems over ccASHP reduces weather dependency.
- More buildings connected to the system can help “smooth” demand patterns and take advantage of coincident heating and cooling loads.
- Variety of thermal sources (using residual heat from local industrial or commercial sources) can continuously help lower demand further.

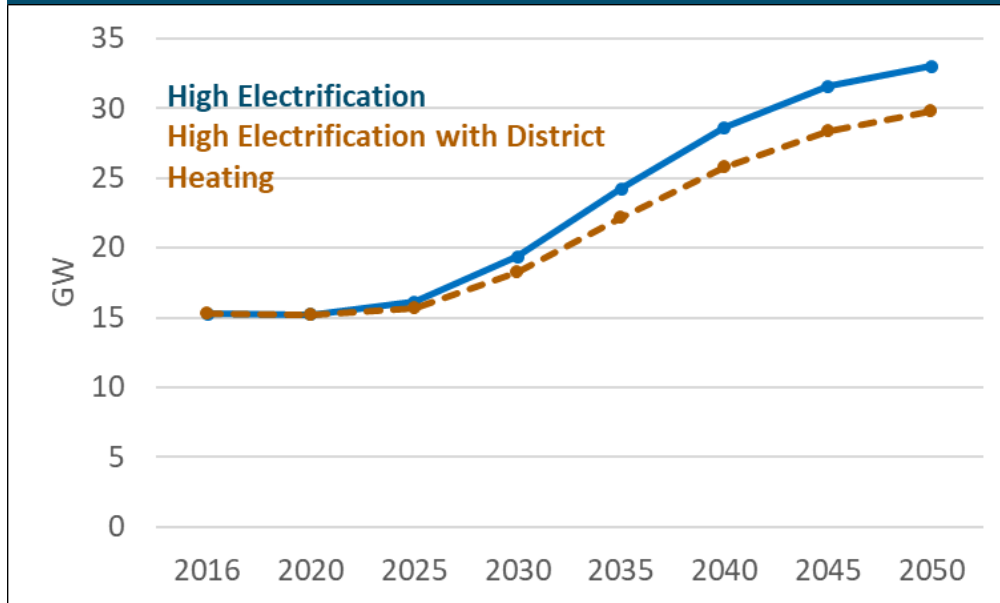




District systems reduce peak load...

- + Installing district heating systems in new construction (roughly 20% load in 2050) can reduce 1-in-40 peak load by 3 GW (~10%) compared to the High Electrifications scenario
- + This results in incremental cost savings on the electric system of up to \$1.2 billion/yr in 2050 (nominal \$)

1-in-40 peak impact comparison: district systems



+ This estimate is conservative:

- It takes the effect of (higher efficiency) GSHP over ccASHP in account, but not the effect of industrial/commercial load sharing
- Connecting systems to commercial or industrial sources can significantly drive down demand, further reducing the electric peak
- As more and more GeoMicroDistricts are interconnected, demand patterns will smooth out and lower coincident peak. This effect requires further investigation on a local level.



...But are costly to install and subject to technical and regulatory uncertainty

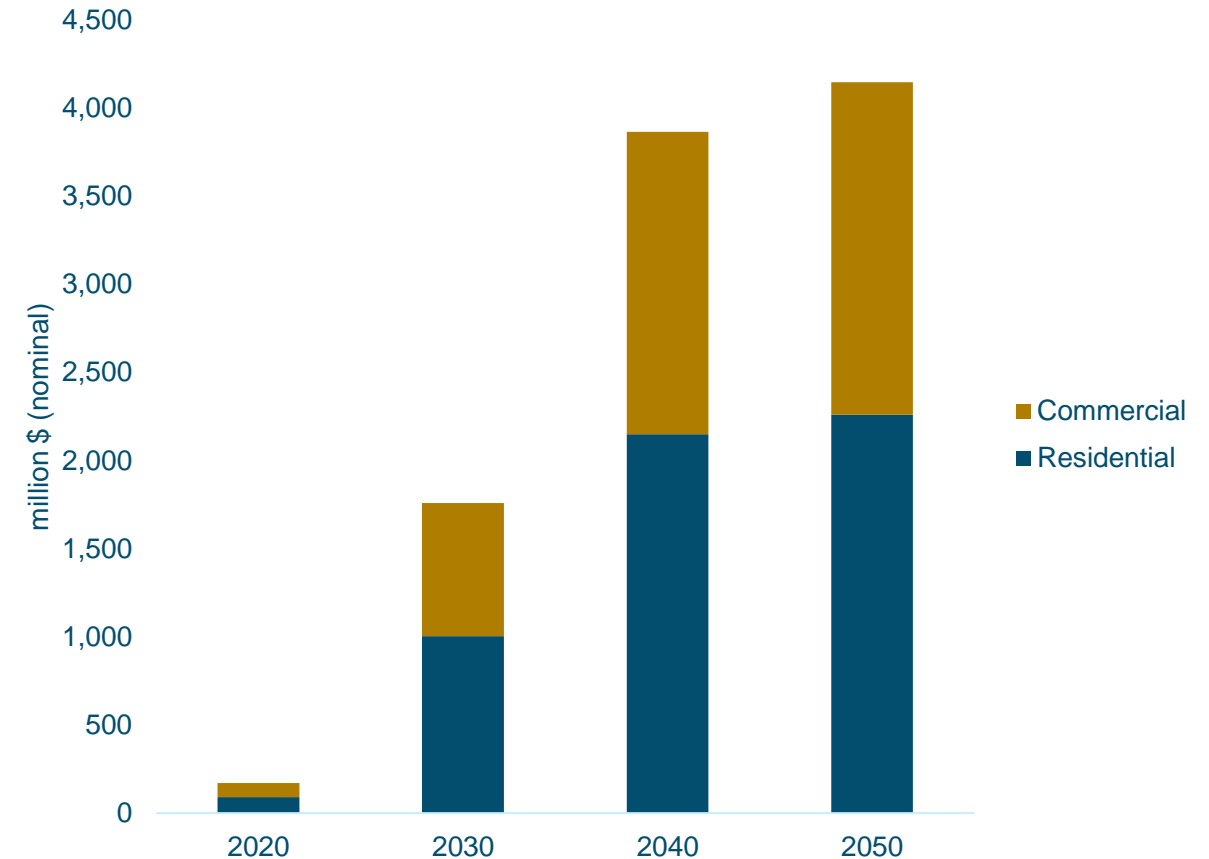
+ There is currently no regulatory context for cost allocation of district systems

- If costs of installation and operation were to be allocated to customers similarly to the gas system, infrastructure costs are roughly estimated to increase up to \$4 billion in 2050
- This corresponds to annual costs of around \$4,000 per household using district systems in 2050 (excluding upfront capital costs)
- These costs do not take the potential benefits of diversified heat resources into account

+ Both cost levels and technical feasibility are highly uncertain and dependent on local conditions

- More insight into the benefits and costs of district systems in Minnesota requires extensive further research.

Estimated annual costs of installing and operating district systems infrastructure



Sources & assumptions: costs are based on an average installed capacity of \$13,000/ton (HEET/Buro Happold GeoMicroDistrict Feasibility Study), O&M costs of 1% of capital investment (IEA ETSAP 2013), system life of 30 years, a 10% discount rate, 50/50% split in equity vs. debt and an interest rate of 4%. Costs include the costs of installation and operation of the system, but not the upfront building conversion costs (energy efficiency retrofits, GSHP conversion, etc.)



Conclusions and next steps



Conclusions

- + All scenarios demonstrate technologically feasible pathways to achieve 100% decarbonization of natural gas end-uses by 2050.**
- + Achieving the gas-end use decarbonization pathways would require extensive technology deployment and commercialization efforts.**
- + The commodity costs of gas increase significantly towards 2050 as Renewable Natural Gas and Synthetic Natural Gas are blended into the pipeline.**
 - The magnitude of this cost increase is uncertain and highly dependent on competition for, and availability of, biomass resources as well as learning curves for SNG and hydrogen.
 - A focus on dedicated hydrogen in the industrial sector seems beneficial, but requires further research regarding system costs and feasibility.
- + The High Electrification scenario results in a significant shift from a summer peak to a winter peak, mainly as a result of space heating loads in winter.**
- + The Electrification with Gas Back Up scenario shows lowest overall costs while also reducing reliance on technologies that have not yet been widely commercialized or that are uncertain in their scalability.**
- + The average costs of the gas service are likely to increase in an electrification scenario as customers leave the system and infrastructure costs are spread over a smaller customer base.**
 - Emphasis on mitigating the energy burden with customers 'staying behind' is important.



Next steps

This study investigates high-level pathways towards 100% gas decarbonization in Minnesota. Based on the results of the analysis, we recommend the following next steps:

- Further investigate the value of an optimized Electrification with Gas Back Up strategy where customers rely on both the electric system and gas system for space heating purposes.
 - Examine least-cost pathways to implementation looking at type of buildings, geographic characteristics and infrastructure conditions.
 - Analyze long run Revenue Requirement, rates and cost allocations for the gas system in an Electrification with Gas Back Up scenario (how should customers pay for the gas system with significantly lower overall usage?)
 - Analyze customer economics for different types of customers, including the potential increase energy burden for those customers that continue to rely more heavily on gas.
- Further investigate feasibility and costs for building shell upgrades on granular (building stock) level, including costs and opportunities for deep retrofits.
- Further investigate peak load implications of electrification across a variety of planning conditions, combined with effects of transportation electrification.
- Investigate different scenarios for availability and costs of RNG, hydrogen and SNG to increase understanding of fuel cost drivers and risk mitigation.
- Investigate feasibility of electrification in the industrial sector and analyze the costs and feasibility of serving hydrogen to industrial sectors with dedicated hydrogen pipelines based on end-uses, system characteristics, geographic spread and current assumptions on pipeline retrofiting.
- Analyze least-cost opportunities for the production and storage of hydrogen in Minnesota.
- Further investigate potential value of district systems in Minnesota based on granular local conditions.



Energy+Environmental Economics

Appendix



Scenario summaries

		Efficiency	Electrification	RNG	Hydrogen
High Electrification	All homes switch to Heat Pumps • All-electric for new construction • High efficiency through building retrofits • Industrial electrification where technically viable	High 	High 	Low 	Low
Electrification with Gas Back Up	All homes switch to Heat Pumps with a Gas Furnace Back Up for coldest hours • All-electric for new construction • Industrial electrification where technically viable	High 	Medium-high 	Low-medium 	Low
High Decarbonized Gas	Gradual Replacement of Natural Gas with RNG (consisting of biomethane and Synthetic Natural Gas) • High efficiency through building retrofits • Dedicated hydrogen in industrial sector	High 	Low 	Medium-high 	Low-medium



Detailed scenario parameters

Sector	Parameter	Reference	High Electrification	Electrification with Gas Back Up	High Decarbonized Gas + H2 for industry
Buildings (residential + commercial)	Overall efficiency	1% for gas and 1.5% for electricity (annually)	Reference + extra building shell upgrades + fuel switching efficiency	Reference + extra building shell upgrades + fuel switching efficiency	Reference + extra building shell upgrades + efficiency from gas-fired HPs
	Building shell efficiency	50% of homes have high efficiency shells in 2050 (high efficiency shell = 29% savings in space heating service demand)	100% of homes (residential) have high efficiency shells in 2050	100% of homes (residential) have high efficiency shells in 2050	100% of homes (residential) have high efficiency shells in 2050
	Building electrification (heat pump sales share)	Linear adoption trend from historical sales of heat pumps (24% of space heater sales are heat pumps by 2050)	100% sales of heat pumps by 2035 <ul style="list-style-type: none"> • 80% ccASHP • 20% GSHP • Electric resistance back-up 	<ul style="list-style-type: none"> • 100% sales by 2035 of ccASHP with gas furnace backup for non-new construction natural replacements • All-electric new construction with 80% ccASHP and 20% GSHP 	<ul style="list-style-type: none"> • Reference for electric HPs • Gas-fired HPs (20% of sales) • Gas in new construction
Industry	Economic growth	1.9%	Reference	Reference	Reference
	Efficiency	1% for gas and electricity (annually)	1.5% annual efficiency in both gas and electricity + efficiency from fuel switching	1.5% annual efficiency in both gas and electricity + efficiency from fuel switching	1.5% annual efficiency in both gas and electricity + efficiency from fuel switching
	Electrification / fuel switching	None	Low + medium temperature heat: 50% of gas consumption electrified (after efficiency)	Low + medium temperature heat: 50% of gas consumption electrified (after efficiency)	Low temperature heat: 20% of gas consumption electrified (after efficiency)
Decarbonized gas	Gas fuel blend in 2050	100% natural gas	100% RNG (used mainly for industry): <ul style="list-style-type: none"> • 93% from biomass and Synthetic Natural Gas • 7% hydrogen blended 	100% RNG (used for both industry and gas backup): <ul style="list-style-type: none"> • 93% from biomass and Synthetic Natural Gas • 7% hydrogen blended 	100% RNG in buildings: <ul style="list-style-type: none"> • 93% from biomass and Synthetic Natural Gas • 7% hydrogen blended 100% (dedicated) <u>hydrogen in industry</u>
Electricity	Electricity sector emission intensity	Zero carbon generation by 2050 <ul style="list-style-type: none"> • With sensitivity in gradual change towards 2050 	Reference	Reference	Reference



Efficiency levels

- + Overall efficiency levels in the reference scenario are based on historical achievements in Minnesota and statutory (CIP) goals.
- + Efficiency levels are applied to total sales – not taking into account exemptions from participation in energy efficiency programs through CIP under Minnesota’s large customer opt-out provision (Laws of Minnesota 1999, chapter 140)
 - 13% of electric load and gas sales in 2018*

Energy Efficiency assumptions

Buildings

- **Reference case:**
 - 1%/yr for gas (to 2050)
 - 2%/yr for electricity to 2034 and 1%/yr thereafter
- **High Electrification:** Reference + extra building shell upgrades + fuel switching efficiency
- **Electrification with Gas Back Up:** Reference + extra building shell upgrades + fuel switching efficiency
- **High Decarbonized Gas:** Reference + extra building shell upgrades + efficiency from gas-fired HPs

Industry

- **Reference case:** 1%/yr for gas and electricity (similar to MN EE Potential Study)
- **Scenarios:** 1.5% annual efficiency in both gas and electricity + efficiency from fuel switching

*Data from MN EE Potential Study, published in 2018. https://www.mncee.org/MNCEE/media/PDFs/MN-Potential-Study_Final-Report_Publication-Date_2018-12-04.pdf



Building shell upgrades

- **Efficient building shells are assumed to lead to a 29% reduction in service demand (absolute heating demand), based on a weighted average across types of homes, building age and average square footage per home (source: US Census Bureau)**
- **A building shell upgrade consists of wall insulation and attic insulation:**
 - Wall insulation: to R-12 for older homes (built <1990) and R-21 to newer homes (built >1990) and new construction (conform MN Building Code for both wood-frame walls and mass walls).
 - Attic insulation: to R-49 for older homes (built <1990) and R-60 to newer homes (built >1990) and new construction (conform EnergyStar recommendations).
- **Costs range from 1.77- 2.11 \$/sq footage for wall insulation and 2.05 – 2.49 \$/sq footage for attic insulation****

Minnesota's current building stock

	Total housing units	Avg sq ft (SF)
Built 2014 or later	78,074	2,467
Built 2010 to 2013	59,096	2,323
Built 2000 to 2009	329,476	2,248
Built 1990 to 1999	329,075	2,044
Built 1980 to 1989	318,371	1,810
Built 1970 to 1979	364,482	1,659
Built 1960 to 1969	233,230	1,427
Built 1950 to 1959	238,757	1,227
Built 1940 to 1949	110,375	1,026
Built 1939 or earlier	394,701	916

Share of Single Family Homes: 74%

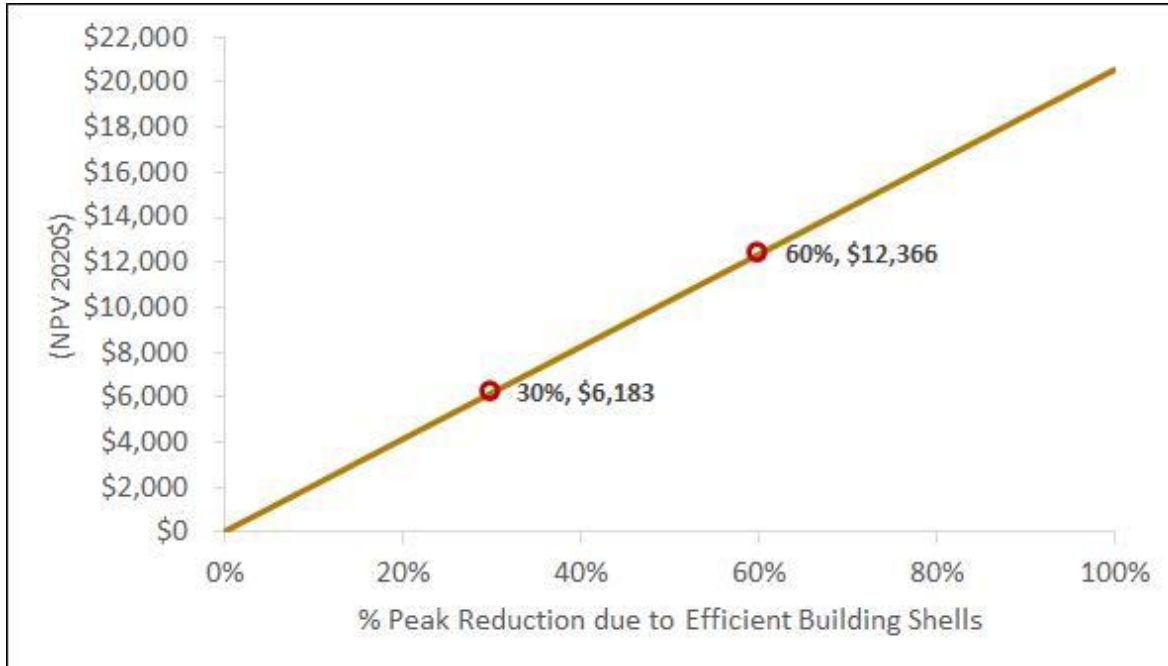
Building material	Total housing units (%)
Wood or vinyl/aluminum siding	74%
Brick, concrete or stone	26%

Sources & assumptions: R-values are based on the MN EE Potential Study for older homes and on the MN [Residential Building Code](#) and [Energy Star Recommendations](#) for newer homes and new construction. Building stock data is based on the [US Census Bureau](#) and the [EIA Residential Energy Consumption Survey](#)



Estimated breakeven cost of building shell improvements

Breakeven cost of building shell improvement with avoided energy and capacity costs (2050)







- + This chart shows the estimated value of reduced electric peaks as a result of efficient building shells
 - E3 used this estimation to roughly find the breakeven costs of building shell improvement in a High Electrification case
- + The results show that a 30% reduction in peak due to efficient building shells has an NPV benefit of around ~\$6,000
 - This is roughly similar to the cost levels of building shell improvements applied in this study (around \$5,600 weighted average for 29% reduction in service demand).
- + The study does not take deep retrofits or net zero buildings into account; cost levels of these measures are uncertain.

NPV calculation assumes a 40 year lifetime and 7% real discount rate



Different types of decarbonized gas considered

+ E3 considers a variety of decarbonized gas sources and has compiled a supply curve based on estimates of the availability and costs of each source.

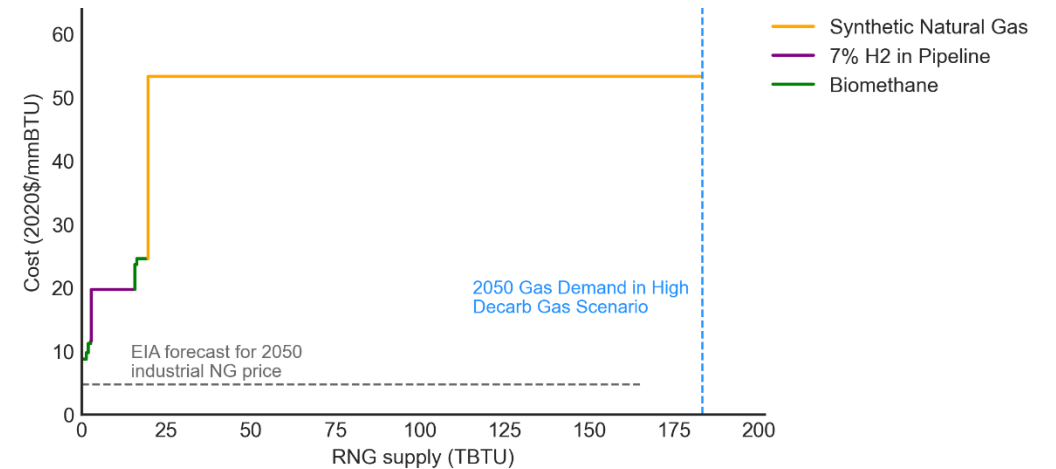
Waste biogas	Gasification of biomass	Hydrogen	Synthetic Natural Gas (SNG)
			
Sources: Municipal waste, manure, landfill gas	Sources: Agriculture and forest residues, and purpose grown crops, e.g. switchgrass;	Sources: Electrolysis + zero-carbon electricity or Steam Methane Reforming of natural gas with Carbon Capture and Sequestration (not considered in this study)	Sources: Renewable hydrogen + CO2 from biowaste (bi-product of biofuel production) and/or direct air capture (DAC)
Constraints: Very limited supply	Constraints: Limited supply and competing uses for biofuels	Constraints: Limited pipeline blends (7% by energy) without infrastructure upgrades, cost	Constraints: Limited commercialization, low round-trip efficiency, high cost



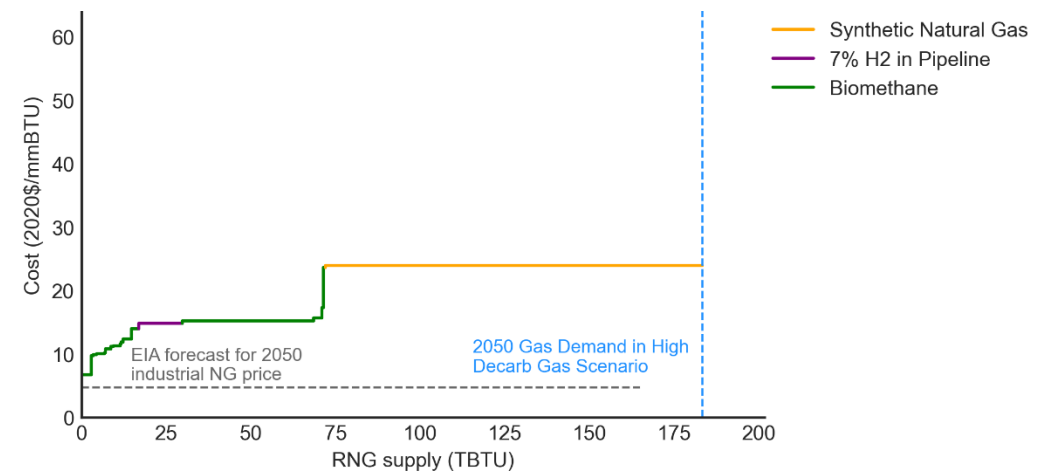
RNG Supply Curve

- + RNG supply assumptions are developed from E3's biofuels optimization module, which determines the most cost-effective way to convert biomass into biofuel across all sectors.
- + Minnesota is assumed to use its population-weighted share of the national supply of waste biomass, determined from the DOE Billion Study (this means MN only gets about 25% of MN biomass, since MN has a disproportionately high biomass supply compared to its population).
 - MN is assumed to use MN biomass only to minimize transportation costs. Supply is mainly from corn stover, and assumes that MN corn production will continue at similar levels to today
- + Biofuels module accounts for competing demands for renewable diesel in MN (corresponding to about 80% of 2016 transportation diesel demand).
 - Renewable diesel demand matches MN Pathways to Decarbonizing Transportation Study (moderate mitigation scenario)
- + The remaining biomass (green line) corresponds to in-state biomass that is “left over” after these other competing demands. Under a MN-wide or national biofuels market, it may turn out to be more cost-effective to use this biomass for displacing more expensive fuels (diesel, jet fuel, etc).
- + Estimates do not account for competing biomethane demand from MN electric generators.

Conservative



Optimistic





Biomass Gasification: Process Cost Assumptions

- + Costs developed by University of California, Irvine (UCI) based on literature review of actual gasification plant costs, with an assumed learning rate over time
- + Interconnection costs are implicitly included in the assumed capital costs

	2020	2025	2030	2035	2040	2045	2050
Gasification plant capital costs (2016\$/kWth)*	1400	1134	927.6	834.8	761	719	695
Fixed O&M (2016\$/kW-yr)	59	47.8	39.1	35.2	32.1	30.3	29.3
Variable O&M (2016\$/MWh)	13	10.5	8.6	7.8	7	6.7	6.5
Resulting process costs for gasification of corn stover (2016\$/dry ton)**	153.1	125.3	103.1	93.1	85.1	80.6	78.1

*Interconnection costs are included in gasification plant capital costs and average at \$2.3 million in 2020 (capital costs only) with a 12% learning rate, based on a 50 MW plant (cost developed by UCI and outlined in Appendix C of the [CEC Study on The Challenge of Retail Gas in California's Low Carbon Future](#)).

**Process costs are different for each feedstock, as they are dependent on the HHV for the specific conversion pathway. Corn stover is used as an example, as it makes up the majority of available MN biomass in the DOE Billion Ton Study. The costs for all pathways are shown on the next slide.



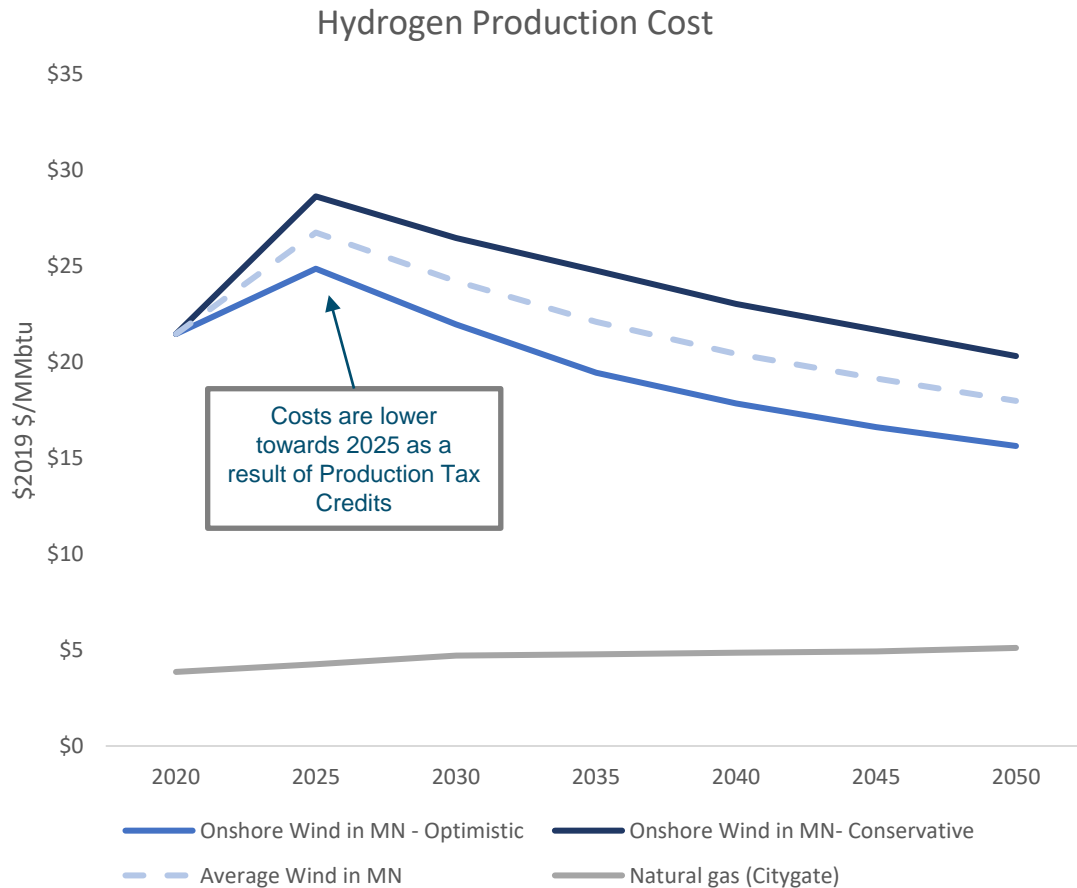
Full gasification process cost assumptions

Gasification process costs by feedstock (2016\$/dry ton)

	2020	2025	2030	2035	2040	2045	2050
Barley straw	\$ 158.09	\$ 129.36	\$ 106.46	\$ 96.10	\$ 87.88	\$ 83.26	\$ 80.65
CD waste	\$ 157.98	\$ 129.27	\$ 106.39	\$ 96.04	\$ 87.82	\$ 83.21	\$ 80.59
Corn stover	\$ 153.10	\$ 125.28	\$ 103.10	\$ 93.07	\$ 85.10	\$ 80.63	\$ 78.10
Hardwood, lowland, residue	\$ 165.90	\$ 135.75	\$ 111.72	\$ 100.85	\$ 92.22	\$ 87.38	\$ 84.63
Hardwood, upland, residue	\$ 165.90	\$ 135.75	\$ 111.72	\$ 100.85	\$ 92.22	\$ 87.38	\$ 84.63
MSW wood	\$ 162.24	\$ 132.76	\$ 109.26	\$ 98.63	\$ 90.19	\$ 85.45	\$ 82.76
Mixedwood, residue	\$ 165.90	\$ 135.75	\$ 111.72	\$ 100.85	\$ 92.22	\$ 87.38	\$ 84.63
Noncitrus residues	\$ 152.76	\$ 125.01	\$ 102.89	\$ 92.88	\$ 84.93	\$ 80.47	\$ 77.95
Other	\$ 144.16	\$ 117.97	\$ 97.09	\$ 87.64	\$ 80.15	\$ 75.94	\$ 73.55
Other forest residue	\$ 152.76	\$ 125.01	\$ 102.89	\$ 92.88	\$ 84.93	\$ 80.47	\$ 77.95
Paper and paperboard	\$ 179.05	\$ 146.51	\$ 120.57	\$ 108.84	\$ 99.53	\$ 94.30	\$ 91.34
Primary mill residue	\$ 172.78	\$ 141.39	\$ 116.36	\$ 105.04	\$ 96.05	\$ 91.01	\$ 88.15
Rubber and leather	\$ 239.64	\$ 196.11	\$ 161.40	\$ 145.70	\$ 133.23	\$ 126.24	\$ 122.27
Secondary mill residue	\$ 172.78	\$ 141.39	\$ 116.36	\$ 105.04	\$ 96.05	\$ 91.01	\$ 88.15
Softwood, natural, residue	\$ 167.42	\$ 137.00	\$ 112.75	\$ 101.78	\$ 93.07	\$ 88.18	\$ 85.41
Softwood, planted, residue	\$ 167.42	\$ 137.00	\$ 112.75	\$ 101.78	\$ 93.07	\$ 88.18	\$ 85.41
Textiles	\$ 157.81	\$ 129.14	\$ 106.29	\$ 95.95	\$ 87.74	\$ 83.13	\$ 80.52
Tree nut residues	\$ 172.00	\$ 140.75	\$ 115.84	\$ 104.57	\$ 95.62	\$ 90.60	\$ 87.75
Wheat straw	\$ 176.00	\$ 144.03	\$ 118.53	\$ 107.01	\$ 97.85	\$ 92.71	\$ 89.80
Yard trimmings	\$ 154.08	\$ 126.09	\$ 103.77	\$ 93.67	\$ 85.66	\$ 81.16	\$ 78.61



Hydrogen & RNG cost assumptions



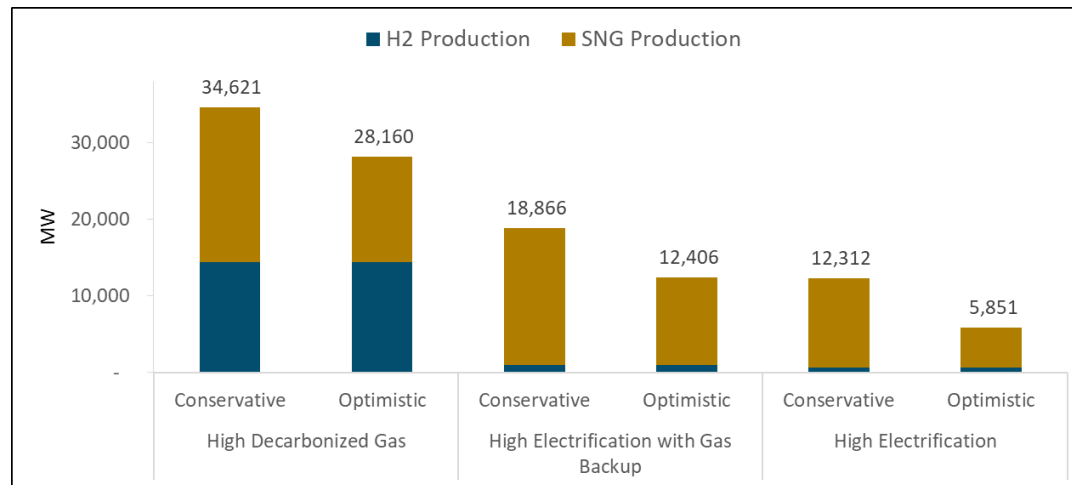
- + Hydrogen is assumed to be produced with onshore wind resources built in-state, assuming a capacity factor of 50%.
- + Production costs are based on E3's hydrogen production model, using the average of a conservative and optimistic curve:
 - Conservative and optimistic rates are defined based on learning rates for electrolysis, starting at \$1,130 \$/kW.*
- + Levelized costs for wind in MN are expected to decline from 117 \$/kW-yr in 2020 to 75 \$/kW-yr in 2050, based on the [NREL ATB 2020](#).
- + Total production costs include costs for delivery and storage (storage is assumed to be out of state)

*Conservative learning curve reflects current proton exchange membrane costs and assumes 14% learning rate; optimistic learning curve reflects alkaline electrolyzer costs and assumes 25% learning rate. Electrolyzer efficiency increases from 70-75% in conservative case and 70-80% in optimistic case. Capital costs and trajectories were developed by the Advanced Power and Energy Program at the University of California at Irvine (UCI) as part of E3's study for the California Energy Commission, "Natural Gas Distribution in California's Low-Carbon Future"



Off-grid Wind Capacity Build for H2 and SNG Production

Wind Capacity for H2 and SNG Production in 2050

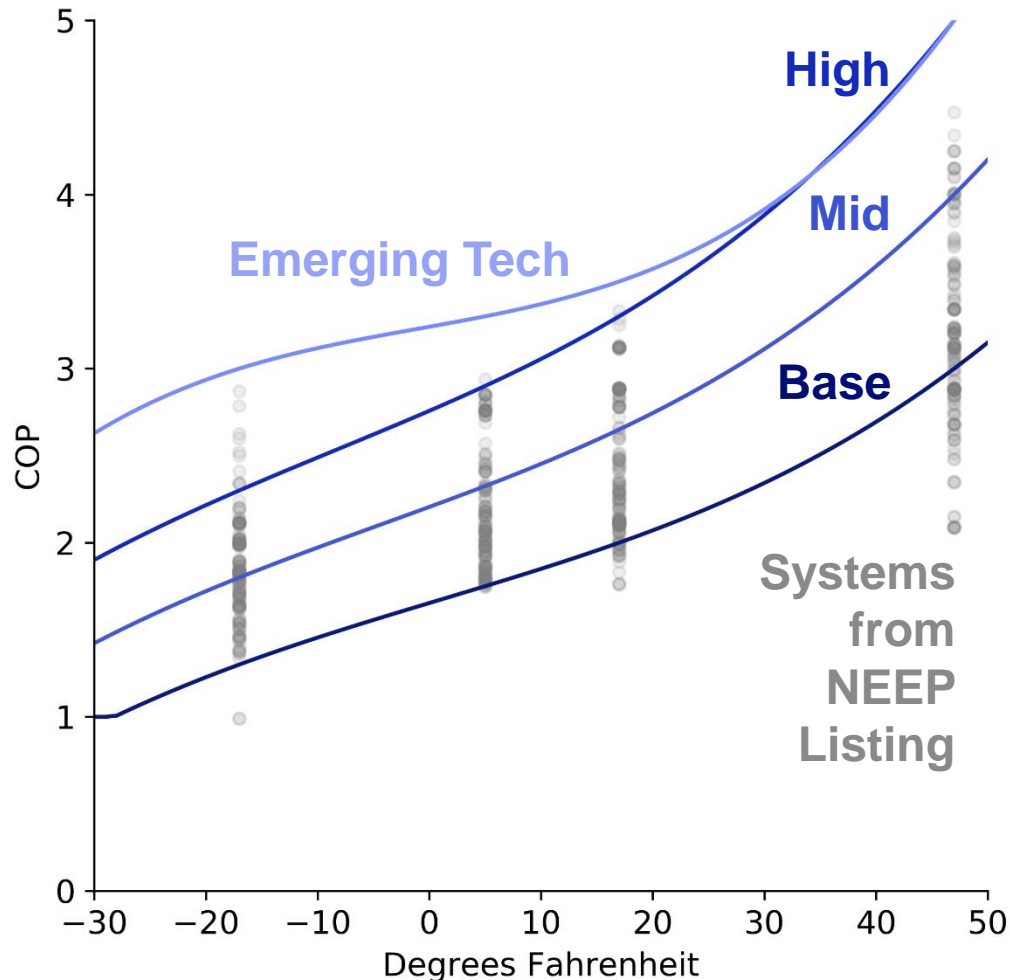


- + This study assumes that off-grid onshore wind will be built to supply electricity for H2 and SNG production.
- + Wind capacity totals 28-35 GW in the High Decarbonized Gas scenario by 2050 to support the large H2 and SNG demand in buildings and industry.
- + Energetically, it is more efficient to directly electrify end-uses than to use H2/SNG produced by renewable electricity.
 - Heat pumps are more efficient than furnaces/boilers in supplying heat
 - H2 production has an efficiency loss of 20-30%, though can serve as an important source of storage



Evaluating the performance of ASHP in RESHAPE

RESHAPE ccASHP Coefficients of Performance



- + E3 used manufacturer reported data on the performance of ccASHPs provided by NEEP in its Cold Climate Product Specification product listing to characterize COPs as a function of outdoor air temperature.
- + Three representative ccASHP systems are considered:
 - **High**: consistent with the best performing systems available today COP of 2.3 @-17F
 - **Mid**: high efficiency systems COP of 1.8 @-17F
 - **Base**: systems that only just meet the NEEP requirement of a COP of 1.75 @5F, 1.3 @-17F
- + **Emerging Tech** ccASHP is modeled in a sensitivity scenario based on the DOE Building Technology Office's Emerging Technology development goal for variable speed ccASHPs
- + **GSHPs** have COP of 4.5, which does not vary with outdoor air temperature.



Sizing criteria for ASHPs

- + ASHP with resistance backup is sized to serve 99% of the heating hours without the need for backup heat (T99 @-7F).
- + ASHPs with Gas Backup are sized to serve a smaller portion of the total heating load.
- + We base the size criteria on system type assumptions and differentiate between different building types:
 - In single family homes and commercial buildings, we assume an integrated central system of ASHP and furnace/boiler. We size the heat pump system to T95, which means the backup system serves the coldest 5% of the heating hours.
 - In multi-family homes, we assume mini-split or packaged terminal heat pumps are installed in one or more rooms, separate from the existing gas furnace/boiler. We size the heat pump system to T80, which means the backup system serves the coldest 20% of the heat hours.

ASHP with Gas Backup	Sizing Criteria	Temperature threshold below which backup system is turned on	% of Heat Load served by Gas Backup
Single-Family Home	T95	3F	16%
Multi-Family Home	T80	20F	41%
Average Residential Home (67% single family and 33% multi-family)	-	-	24%
Commercial Building	T95	3F	26%



Average COPs and efficiency levels of appliances

Efficiency levels of ccASHPs

	Residential	Commercial
Average COP of ASHP with elec. resist. backup	2.71	2.55
Average COP of ASHP with fuel backup	3.07	2.91
Supp Heat % of Total SD for Hybrid ASHP (with fuel backup)	24%	26%

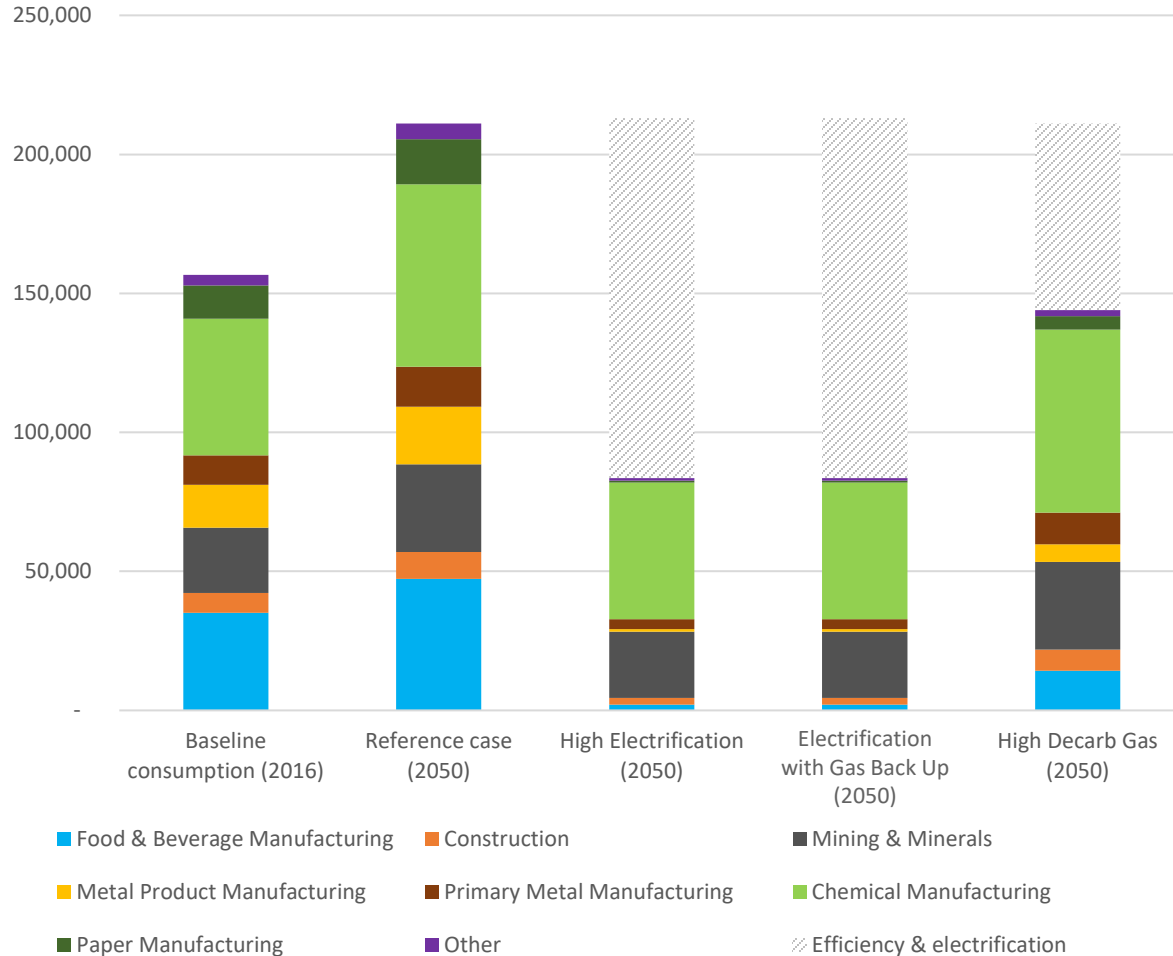
Other efficiency levels

	Value	Note
Average COP applied for industrial electrification	1.75	See next slide for additional information
GSHP COP (regular)	4.5	
GSHP COP (district systems)	5.0	
Gas-fired HPs	1.4	
Efficient gas furnace (reference case)	0.98	

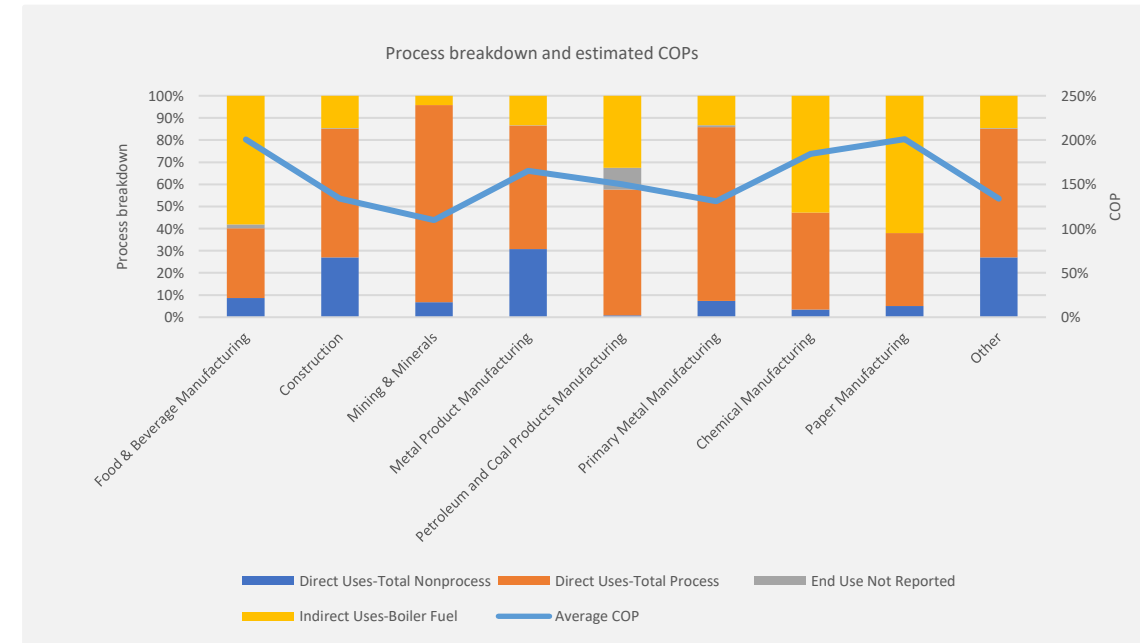


Assumptions on industrial electrification

Gas consumption in industrial sector (in mln cubic ft)



Process	Estimated COP
Direct non-process heat (mostly HVAC)	2.55 (same as commercial)
Direct process heat (furnaces, machine drive, etc)	1
Indirect heat (steam, boiler fuels)	<ul style="list-style-type: none"> •50% electric boilers (COP 1) •50% industrial heat pumps (COP 4)
Non specified	1

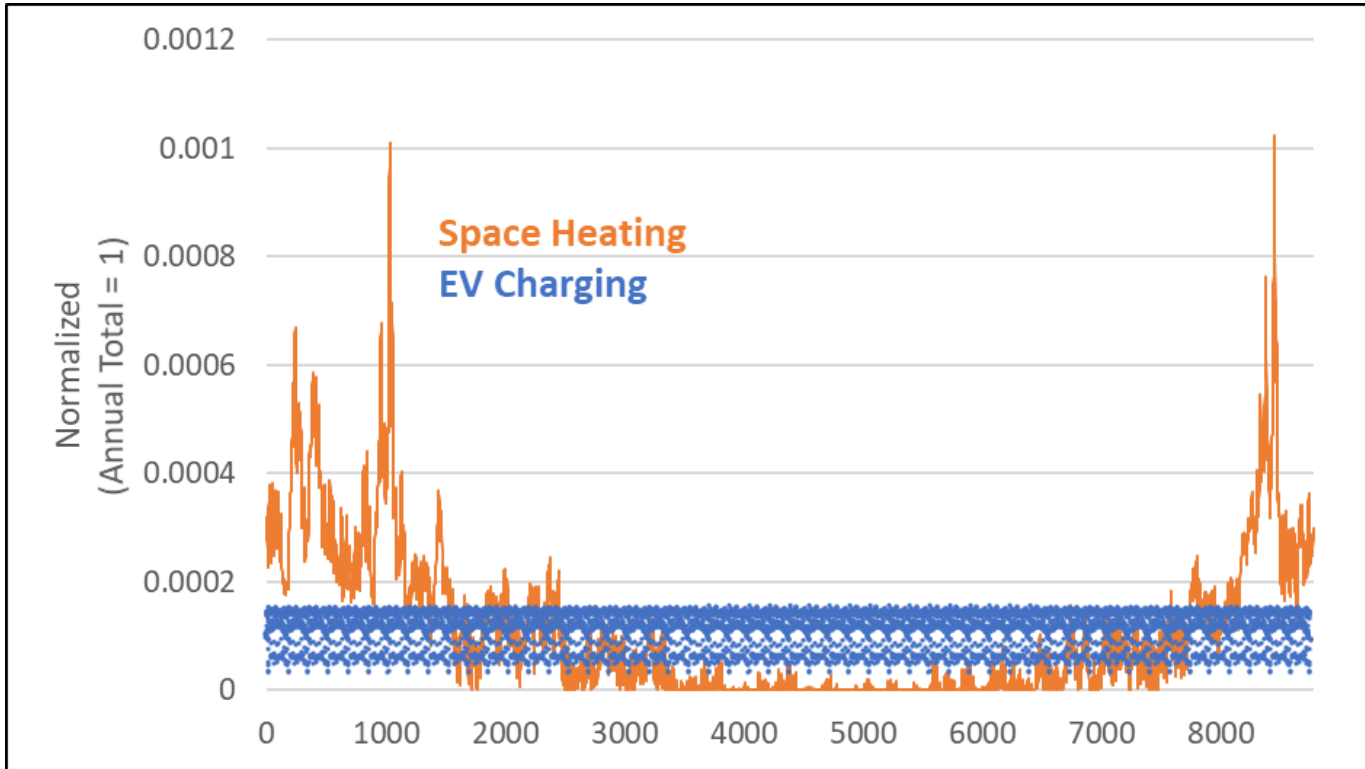


Sources: NREL Industry Energy Tool, EIA Manufacturing Energy Consumption Survey. Note: the assumptions on industrial electrification in this study are estimates; a more granular estimation of possibilities requires a plant-specific approach



Peak Impact of Space Heating vs. EV Charging

Aggregated Statewide Load Shapes: Space Heating vs. EV Charging



- + Generally, the impact of space heating on peak is much larger than the impact of EV charging
- + Space heating peaks are driven by temperature, which has relatively small diversity benefits
 - In case of a cold snap, all heat pumps start working at high capacity at the same time
- + EV charging loads are driven by driving and charging behavior, as well as individual's schedules, which are more diversified and less subject to seasonal variation



Capital cost assumptions (residential)

Appliance	Capital costs	Source	
New ccASHP with electric back-up	\$ 13,500 (Single Family)	Provided by CEE, adjusted for size of heat pumps (SF/MF)	
	\$ 10,860 (Multi Family)		
New ccASHP with new gas furnace back-up	\$ 10,300 (Single Family)		
	\$ 9,300 (Multi Family)		
New gas furnace (efficient)	\$ 4,250		
Groundsource HP	\$ 15,500		MassCEC database
Gas-fired HP (incl WH)	\$ 7,000		Northwest Energy Efficiency Alliance (NEEA)
Space Heating HP learning curve (cost decline rate)	-0.95%		NREL Electrification Futures Study (2017)
Cooking + clothes drying (electric)	1,188		EIA National Energy Modeling System (NEMS)
Cooking + clothes drying (reference)	1,110		EIA National Energy Modeling System (NEMS)
New Water Heating HP	\$ 3,225	EIA National Energy Modeling System (NEMS)	
New gas water heater (reference)	\$ 1,445	EIA National Energy Modeling System (NEMS)	
Water Heater HP learning curve (cost decline rate)	-1.68%	NREL Electrification Futures Study (2017)	
Building shell upgrade	\$ 6,780 (Single Family)	Minnesota Technical Reference Manual for Energy CIPs (2020)	
	\$ 3,710 (Multi Family)		
Air Conditioning	\$ 5,180	NREL National Residential Efficiency Measures Database	



Capital cost assumptions (commercial)

Appliance	Capital costs	Source
Air Source Heat Pump	\$154/kBtu/hr	EIA National Energy Modeling System (NEMS)
Ground Source Heat Pump	\$271/kBtu/hr	EIA National Energy Modeling System (NEMS)
Reference Gas Furnace	\$8.74/kBtu/hr	EIA National Energy Modeling System (NEMS)
Efficient Gas Furnace	\$11.83/kBtu/hr	EIA National Energy Modeling System (NEMS)
Heat Pump Water Heater	\$281.14/kBtu/hr	EIA National Energy Modeling System (NEMS)
Reference Gas Storage Water Heater	\$26.65/kBtu/hr	EIA National Energy Modeling System (NEMS)
Efficient Gas Storage Water Heater	\$29.44/kBtu/hr	EIA National Energy Modeling System (NEMS)



Electricity sector assumptions

Generation

- Total electricity demand by sector based on PATHWAYS
- Incremental renewable generation cost at \$41/MWh assuming a mix of wind and solar build
- Peak capacity need based on RESHAPE
- Incremental generating capacity cost at \$95/kW-yr

Transmission

- Peak system load projected based on RESHAPE, driven by peak heat demand
- Incremental transmission capacity cost at \$22/kW-yr
- Existing transmission cost will growth at 2.3% annually for replacement and maintenance.

Total Electricity System Costs

Distribution

- Non-coincident peak load by sector projected based on RESHAPE
- Incremental distribution capacity cost at \$55/kW-yr
- Existing distribution cost will growth at 2.6% annually

Other

- Increase in number of customers considered based on projected population and GDP growth



Revenue Requirement assumptions in a reference case

- + The total revenue requirement (based on EIA's report of Minnesota statewide rates and electricity sales) and the cost breakdown by generation, transmission and distribution (based on EIA's AEO 2020 Reference case in 2019) is used to estimate embedded T&D costs of the current system.

Cost category	% share of RR
Distribution	21%
Transmission	14%
Generation	64%

- + In the reference case, we assume Revenue Requirement increases annually as a result of continuous system improvements. Escalation factors are based on EIA's AEO 2020 Reference case for MISO West.

Cost Category	Embedded levelized costs (2020\$)	Cost Escalation (historical, nominal)
Transmission	\$65 per kW-yr	2.3%
Distribution	\$50-65 per kW-yr	2.6%



Incremental T&D investments for peak load growth

- + Long-term T&D cost levels are applied for incremental transmission and distribution capacity needs as a result of electrification. Assumptions on cost levels are presented in the table below.
- + Escalation rates of these cost levels are based on historical and projected T&D avoided cost escalation from the 2017 Joint Avoided T&D Cost Study.

Cost Category	Levelized Cost (2020\$)	Annual Cost Escalation (nominal)	Data Source
Transmission	\$22 per kW-yr	4.4%	Transmission investment costs are estimated based on the 2019 Brattle report (Page 48), which estimate load-growth-related transmission investment to average around \$200/kW. (Applied revenue requirement multiplier of 1.61 and cost of capital of 6.16% from recent Xcel filing)
Distribution	\$55 per kW-yr	4.4%	Based on average utility-reported distribution avoided cost from 2016 Xcel filing (page 19).



Incremental generation costs

- + Renewable generation cost are applied to incremental renewable generation compared to the reference case and are estimated based on total electric load and emission intensity trajectories.
- + Generating capacity cost are applied to the incremental peak load due to electrification.

Cost Category	Levelized Cost (2020\$)	Annual Cost Escalation (nominal)	Data Source
Renewable generation	\$41 per MWh	-1.4% before 2030 and 0% after 2030	<ul style="list-style-type: none">Assuming that every incremental MWh of renewable will consist of 2/3 wind and 1/3 solar based on results from the E3-Xcel study (linked below).Wind and solar cost data are from NREL ATB 2020.Transmission connection cost is factored in based on input from Xcel (\$500/kW for wind and \$200/kW for solar)
Generating capacity	\$95 per kW-yr	2.1%	Using the cost of “greenfield” CT from the 2019 E3-Xcel Low Carbon Scenario Analysis



Gas system costs

- + Average current Minnesota gas system costs are based on EIA reports of Minnesota statewide rates and natural gas sales and broken down into Rate Base, Depreciation and O&M costs based on a combined breakdown of Xcel Energy’s and CenterPoint’s (estimated) Revenue Requirement.
- + Annual Capital Expenditures are expected to stay flat in the Reference case and High Decarbonized Gas scenario, based on information provided by CenterPoint.
- + In the High Electrification and Electrification with Gas Back Up scenarios, annual Capital Expenditures are expected to stay flat, with the exception of CAPEX for new construction
 - New construction is estimated at 10% of annual CAPEX based on information provided by CenterPoint

Cost category	Applied annual growth rate (nominal)	Combined (Xcel + CP) CAGR over previous years (2014-2019) – nominal	Note	Source
O&M costs	2.6%	2.6%	Combined (estimated) historical CAGR from Xcel Energy and CenterPoint	Estimated based on NSPM 10-K Filings and CenterPoint General Rate Petitions
Rate Base & Depreciation	4.4% for reference and High Decarbonized Gas and Reference scenarios, 4.1% for High Electrification and Electrification with Gas Back Up scenarios	7.7%	Based on flat annual CAPEX (with exception of electrification scenarios), 2.6% annual depreciation and 7.7% Rate of Return	Information provided by CenterPoint. RoR based on average historical values



Electricity sector emissions

+ Overall methodology:

- Emission intensities are calculated using a weighted average between “Xcel Energy emission intensities” and “Non Xcel Energy emission intensities” based on in-state generation.
- In-state generation is derived from (statewide) EIA data (including EIA-923 and EIA-860 Reports).
- The study only reports statewide emission intensities (without separating between the Xcel vs. Non Xcel estimations)

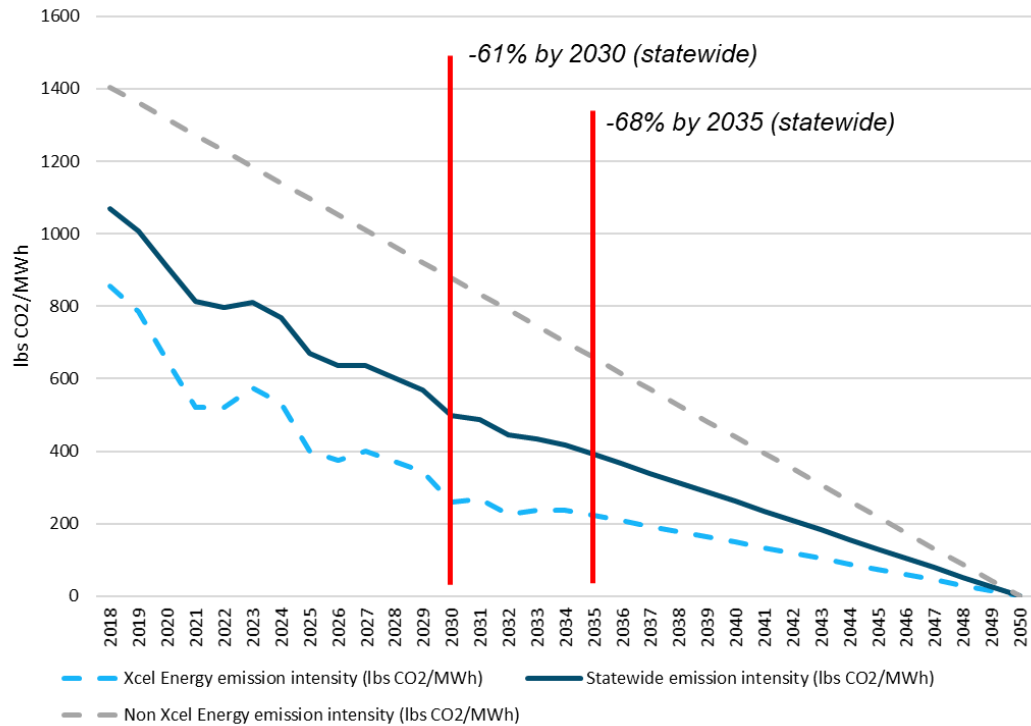
+ Caveats / simplifications:

- The methodology only considers in-state generation (excluding imports), using available public data
- Emission intensities from Xcel Energy represents overall intensity for the five-state NSP system (including purchased power).
- We assume carbon free supply by 2050 in all scenarios, under the caveat that these ambitions have been established without accounting for incremental load from Building Electrification.

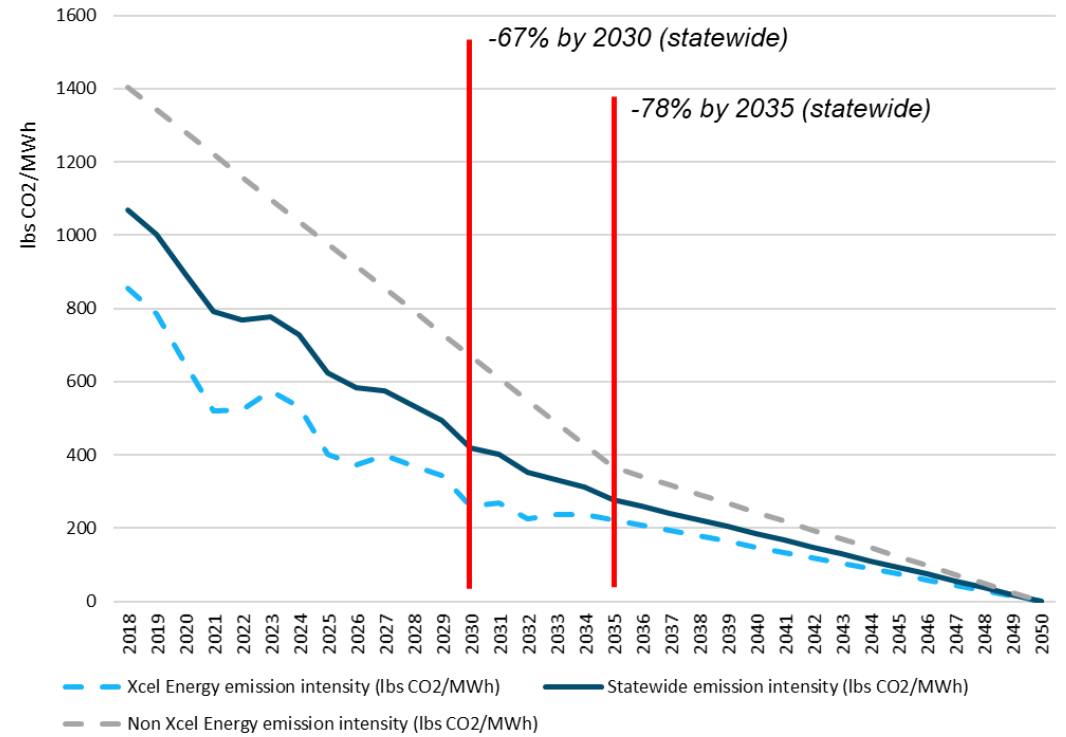


Electricity sector emissions

+ Option 1 (linear decline for non Xcel emission intensities)



+ Option 2 (accelerated decline for non Xcel emission intensities)





Approach to district system modeling

+ District systems are included as high-level modeling sensitivity onto the High Electrification scenario.

- Main modeling question: by how much can the electric peak be reduced if X% of load would be served by a collective district system, and how would it alter the costs?
- Approach: high-level quantification of the potential effect of district systems compared to an electrification scenario, without data analysis on locational feasibility of those systems and their thermal sources

+ Main assumptions/limitations:

- **Load:** district systems are installed in new construction only, leading to a total penetration of 27% of buildings by 2050
- **Thermal source:** study assume all load is supplied by vertical closed GSHP systems. These systems have a higher COP than regular as a result of combined efficiencies from multiple systems (source: GeoMicroDistrict Feasibility study)
 - Limitation: no locational analysis of where and how much geothermal/waste heat would actually be available
- **Gas infrastructure costs:** assuming district systems are only installed in new construction, avoiding the cost for gas systems for new construction.
- **District system connection costs:** taking fixed assumptions on # of buildings per load cluster and retrofitting/infrastructure cost per cluster, using data from GeoMicroDistrict Feasibility study.



Energy+Environmental Economics

