
The Electrified Frontier

Exploring Stakeholder Views on the Emerging Intersection of
Electrification, Efficiency, and De-carbonization

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Table of Contents

Table of Contents	1
List of Tables	4
Executive Summary	5
Introduction.....	5
Minnesota Policy Review	6
National Policy Review	6
Stakeholder Interviews.....	7
Technology Review.....	8
Recommendations for Discussion and Engagement.....	9
Introduction and Background	10
Introduction.....	10
Minnesota Context	11
Overview of Contents	11
Background on Topic.....	12
Working Definitions	12
Literature	13
Minnesota Policy Review	17
Decarbonization Policy Goals	17
Efficiency Statutes: §216B.2401 and §216B.241.....	17
Fuel Switching Determinations	19
Peer Practice and Policy Review	21
Fuel Switching.....	21
Illinois	21
Maine	21
California.....	22
Beneficial Electrification.....	23
Vermont	23
Massachusetts	24

New York.....	25
Other State and Regional Activities	25
In-depth Interview Methodology and Findings.....	27
Methodology	27
Interview Participants	27
Invited, not interviewed.....	27
Questionnaire	24
Findings	24
Key Areas of Consensus	25
Key Areas of Disagreement.....	28
Additional Questions.....	33
Technology Research	35
Introduction.....	35
Methodology	35
Annual Energy Cost	35
Source Energy	36
Annual Utility Emissions.....	36
Installed or Initial Cost	37
Impact on Peak Demand.....	38
Heat Pump Water Heaters	38
Description	38
Metrics	39
Other Notes.....	40
Gap Analysis	40
Home Heating with Heat Pumps	41
Description	41
Metrics	42
Other Notes.....	43
Gap Analysis	44
Electric Lift Trucks.....	44
Description	44

Metrics	45
Other Notes.....	45
Gap Analysis	46
Electric Trailer Refrigeration Units	46
Description	46
Metrics	47
Other Notes.....	47
Gap Analysis	48
Industrial Electrification	48
Description	48
Process Heating.....	48
Electric Vehicles.....	51
Description	51
Metrics	51
Other Notes.....	52
Gap Analysis	53
Recommendations for Discussion and Engagement.....	54
References.....	55
Appendix A: Questionnaire	63
Appendix B: Minnesota Source Energy Factor	65

List of Tables

Table 1: Metrics for water heating technologies	39
Table 2: Metrics for home heating technologies	42
Table 3: Metrics for lift truck technologies	45
Table 4: Metrics for trailer refrigeration unit technologies	47
Table 5: Metrics for passenger vehicle technologies	51

List of Figures

Figure 1: Stakeholder identified challenges for electrification	30
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Executive Summary

This paper aims to be an introductory resource for Minnesotans on to the topic of fuel switching and electrification. The topic of electrification has garnered a lot of attention recently. Stakeholders in Minnesota and nationally have identified end-uses where electrification could reduce carbon dioxide emissions, decrease customer costs, and provide energy savings over the lifetime of the equipment. Market growth is driving some electrification, specifically electric vehicle sales, but at least one utility within the state, Otter Tail Power Company, is suggesting that their energy efficiency incentive programs could be a tool to encourage the adoption of electric technologies that provide societal benefits (Otter Tail Power, 2017).

Otter Tail Power's proposal reopened conversations about whether fuel switching should be allowed within the state's energy efficiency program, the Conservation Improvement Program (CIP). Targeted promotion of measures that result in an increase of a utility's energy sales are not currently allowed within CIP (Division of Energy Resources, 2003) (Garvey, 2005). This guidance on fuel switching stems from a regulatory decision rather than a specific prohibition within Minnesota statutes.

This iteration of discussion on fuel switching has additional momentum because electric utilities have the support of many environmental organizations. These organizations see the use of renewable energy to electrify vehicles and residential space and water heating as essential in order to reduce carbon dioxide emissions and combat climate change (for one example see the National Resource Defense Council's report on carbon reduction pathways) (Vignesh Gowrishankar, 2017).

This argument that electrification can provide societal benefits and therefore should be promoted and encouraged in Minnesota raises technical, logistical, and political questions. It is the goal of this paper to help the reader better understand those questions as well as the opinions and perspectives of electrification experts and a cross-section of CIP stakeholders. To do this, we interviewed leaders from 24 organizations about their thoughts on the topic and collected their responses in this paper. In addition, we reviewed and compiled information from dozens of studies, technologies, and state policies on electrification and fuel switching.

This executive summary, it should be noted, is not intended to be a full summary of the work. The opinions and research in the report are too diverse to sum up in a few pages. Instead, this executive summary walks through the sections of the full report, highlighting a few key points, as well as describing the other content in that section of the full report.

Introduction

The [Introduction and Background](#) section sets the stage for this discussion in Minnesota, provides further context and framing for this paper, and offers working definitions. Of particular interest is a literature review section that examines a number of studies completed within the past year (fall of 2017-summer 2018) modeling the impacts of electrification or discussing the technological and political

facets associated with the concept. You'll see a common trend in research that electricity consumption is expected to rise in the next two decades regardless of policy conditions, while overall end-use energy in homes and businesses will fall due to energy efficiency. Policy levers like a price on carbon result in significantly more electrification than baseline scenarios. It is interesting to note that in many of the studies natural gas consumption economy-wide also grows because of its use in electricity generation, as a back-up fuel for home heating, and its persistent role in industrial production (EPRI, 2018).

Minnesota Policy Review

In order to understand Minnesota's context, the reader needs to be familiar with a few key state statutes and regulatory orders, which are outlined in the [Minnesota Policy Review](#) section. The Next Generation Energy Act passed in 2007 created a greenhouse gas reduction goal, and augmented the state's long-standing energy conservation program, called CIP. The statute that governs CIP provides important definitions of what constitutes energy efficiency and conservation. In interpreting the statute, the Minnesota Department of Commerce issued a 2005 order prohibiting fuel switching within the CIP program. The Department amended that decision in 2012 by issuing a guidance document (Division of Energy Resources, 2012) allowing fuel switching in the context of low-income programs for homes using delivered fuels (meaning propane and fuel oil) and non-CIP regulated natural gas.

Regarding the question of whether to allow fuel switching or electrification within CIP, Minnesota's Statutes are fairly silent. Definitions are either fuel neutral or defined in relationship to production output (§216B.241, subdivision 1(d) and 1(f)). There is no specific prohibition of fuel switching, nor is there any language that specifically enables or promotes fuel switching or electrification.

National Policy Review

Minnesota is becoming a leader on this topic, but we are not alone in our work. The [Peer Practice and Policy Review](#) section explores fuel switching policies in Illinois, California, and Maine. Beneficial electrification policies have been adopted by many Northeastern states. This section looks at what's been done in Massachusetts, Vermont, and New York. Minnesota can learn from the efforts of other states. For instance, we can consider the benefits of Illinois' path of regulatory interpretation versus Massachusetts' path of adding new definition within statutes.

When it comes to figuring out fuel switching, very few states have nailed down a methodology. It presents a challenge in many areas to properly distribute the benefits of a reduction in fuel use without permitting efficiency programs to be used to chip away at another utility's customer base. Illinois is one of the few states that offers specific instructions in its Technical Reference Manual for how to split those benefits among all the utilities that choose to participate in the incentive (Illinois Energy Efficiency Stakeholder Advisory Group, 2017).

Increasingly more states are implementing policies around electrification. Almost all the states in the Northeast have electrification policies. A few motivators include: political climates favorable to action on

climate change, high reliance on delivered fuels like heating oil for home heating, and additional funding available through the region's cap and trade market. Utilities in other states like California are providing rebates for electrification in homes. The Sacramento Municipal Utility District is one specific example that provides significant incentives. The Canadian province of British Columbia also has a specific mandate to electrify home heating.

Stakeholder Interviews

The [In-depth Interview Methodology and Findings](#) section compiles 24 interviews with national electrification experts and CIP stakeholders discussing the benefits and challenges that face Minnesota with regards to electrification and fuel switching. We found there is more consensus on this topic than division. Stakeholders expressed very nuanced positions, which should be a positive sign that further dialogue will be productive. There were areas of disagreement even among stakeholders who shared many of the same perspectives on the topic, with a lot of interest in whether and how electrification should be included within CIP. These interviews represent a wide variety of stakeholder perspectives including environmental organizations, gas and electric utilities, efficiency advocates, industry organizations, and state government.

Stakeholders agreed that electrification could be a path to reducing carbon emissions, especially from the transportation sector. Many stakeholders were also interested in potential growth of residential heat pumps for space and water heating. Stakeholders agree that the current status quo prohibition limits a utility's role in supporting consumer adoption of these new technologies. Stakeholders also agree that regulators should be considering this topic, especially as a part of broader grid modernization effort.

On the topic of fuel switching, many respondents named that the status quo was put in place for a good reason. The risk of a utility using a conservation program to promote sale of its product still exists. So, changes to the fuel switching status quo need to be made carefully, in order to ensure that society benefits from the outcome. Most stakeholder did not see justification for treating delivered fuels (propane and heating oil) differently than utility service fuels (natural gas and electricity) at least from a technical analysis perspective. Some stakeholders felt there were political and pragmatic reasons one might start by focusing on fuel switching away from delivered fuels.

Stakeholders agree that there are challenges facing electrification, although they saw different challenges. Market adoption and consumer interest in technologies like heat pumps were seen as a challenge, as well as contractor familiarity. Others saw challenges with grid infrastructure and electricity supply, especially in meeting the winter heating peak. Many saw challenges in pursuing electrification cost-effectively, without impacting Minnesotan's energy costs. One challenge that remains to be addressed is the technical methodology for determining when and how electrification or fuel switching would be beneficial.

Finally, there was not agreement about whether electrification should be included within CIP. Some respondents felt it should be, because CIP is an existing high functioning program and would serve as a

good template. They expressed that, although the goals of CIP and electrification are not identical, they hold enough in common to justify offering electrification programs within CIP. Others felt it did not belong in CIP. They said it would compete with investments in energy efficiency and that a standalone carbon reduction program, parallel to and perhaps modeled on CIP, would best achieve carbon reduction goals at the lowest cost. And there were others who felt both ways on the topic – they saw room for a small set of measures to fit within CIP and saw justification for a broader effort to address carbon reduction through electrification.

Technology Review

The [Technology Research](#) section, we provide an overview and high-level analysis of a variety of technologies frequently proposed as examples in which electrification might deliver societal and customer benefits. The technologies we reviewed include: heat pumps for water heating and space heating, electric lift trucks, electric truck refrigeration units, electric vehicles, and industrial applications for electrification. For each technology, we offer some thoughts on how the costs, emissions, efficiency, and impact on peak demand compare with other fuel options. In the introduction to this section, we provide details on our methodology. We also identify that further work is required to accurately capture the impacts of technologies that can be controlled to consume electricity only when costs or carbon emissions are low.

Residential heat pumps for water heating and space heating have advanced technologically to the point of being both highly efficient, broadly functional, and increasingly affordable. This means that in some situations a case can be made for them as a low-cost, low-carbon alternative to on-site combustion of fossil fuels. At the moment, low cost natural gas still outperforms air source heat pumps on both carbon and cost metrics. New construction applications and replacement of propane and fuel oil equipment are quite a bit more competitive.

Electric vehicles have market headwinds behind them. Customers and car manufactures both are excited by the prospects of electric vehicles, and electric utilities are uniformly interested in the new load. At this point, electric vehicles clearly reduce carbon emissions and operating costs, but upfront costs are still higher than equivalent internal combustion vehicles. Vast improvements are expected in battery life, cost, and variety of models produced.

Industrial technologies, like fork lifts, thermal processing, and refrigerated trucking all pose opportunities for electrification as well. These applications depend on very specific use cases, so their applicability to the mass market is somewhat limited. In some instances, additional benefits beyond cost savings, like productivity and reduced waste, need to be considered in order to demonstrate a value to converting to electricity.

Quantifying emissions impacts will be more complicated than the average emissions factor used in this report. A marginal emissions factor, which takes into account the last kWh loaded onto the grid when a new electrified load is added, better accounts for the incremental addition. Using a marginal emissions factor could provide better justification for controlling the new electrified load into low-carbon and low-

cost periods of electricity production. This methodology can be complicated, so future work will be needed to come to consensus on an approach that provides the right mix of accessibility and accuracy for the State of Minnesota.

Recommendations for Discussion and Engagement

The Department of Commerce has committed to convening meetings on the topic of fuel switching with CIP stakeholders and other interest parties as an outcome of the Otter Tail Power's recent regulatory proceeding (Grant, 2018) (Docket No. G008/CIP-00-864.07). In addition, over the next two years the Department plans to engage stakeholders in a Department of Energy funded planning process around grid modernization and electrification. Both of these processes will provide significant opportunity for stakeholder engagement on this topic as Minnesota shapes their path forward.

Specifically, discussion and engagement would be fruitful around the following topics:

- Should fuel switching and electrification exist within CIP or take place beyond CIP? What are the advantages of a parallel program for carbon reductions versus incorporating more measures into CIP? If the measures fall within CIP, how are utilities compensated and how does it affect savings goals?
- What are the goals of CIP and will electrification help advance those goals? This discussion dovetails with the topic of electrification and fuel switching, but it is much larger than this topic. What is the value of baseline energy efficiency savings versus more responsive demand shifting and storage? Beneficially electrified technologies could play a larger role in demand response scenarios.
- How do we calculate the costs and benefits? Specifically, work needs to be done around building nuance into accounting for carbon emissions. Are they calculated using the MISO mix or the utility's generation mix? What is an accessible approach to calculating marginal emissions impact? What are the real costs of electrification, and will it achieve carbon reductions at the lowest cost for society? It would be useful to develop side-by-side example comparisons for technologies with different fuel mixes, baselines, and controllability using high-resolution emission data.
- What needs to be done to make this process equitable? How can beneficial electrification give opportunities for participation to low-income ratepayers? Does beneficial electrification offer sufficient benefits to non-participant ratepayers? What consideration should be given to the remaining ratepayers of the abandoned fuel who can't afford to or choose not to convert?

Given the attention this topic has received in 2018, Minnesota has an opportunity to be a regional and national leader shaping new consensus and direction for approaches to electrification, carbon reduction, and energy efficiency.

Introduction and Background

Introduction

Electrification has garnered a lot of attention recently across the country. Likewise in Minnesota, electrification and the associated concept of fuel switching within conservation programs, have been the subject of conversations, research, policy dockets, program amendments, and conferences. The surge of interest in electrification stems from a new understanding of electrification providing societal benefits. “Beneficial electrification,” as this subset of electrification has been named, describes instances when electrifying specific fossil-fuel burning technologies reduces total lifecycle carbon dioxide emissions, reduces cost, and brings along other consumer and societal benefits.

Not long ago the conversation around beneficial fuel switching implied a switch away from electricity consumption, toward direct natural gas, due to natural gas’ low cost and low lifecycle emissions compared with coal-generated electricity (Steven Nadel, 1994). However, the math has begun to gradually shift. Today some electric technologies in some parts of the country can be shown to pollute less, cost less, and be more efficient than their fossil fuel burning counterpart. And while not every instance of electrification today can make this claim, the trend shows that the future will be competitive, given the growth of renewable electricity generation, advances in electric technology efficiency, and new abilities to control and schedule consumption into low-cost, low-carbon valleys of electric supply.

Given these potential benefits, a growing community has shown interest in this topic. Particularly, the most supportive parties include environmentalists who appreciate low-carbon electrification as a means to combat climate change and electric utilities who appreciate the opportunity to increase sales while providing a societal benefit. Of course, a topic like this also generates interest from stakeholders who have concerns about assumptions and implications of electrification’s trajectory. Low-income and business advocates are paying close attention to the potential impacts on energy costs. Natural gas utilities and fossil fuel distribution companies are considering the impacts on their fuel and concerned about decision making without careful consideration. Regulators find themselves faced with responding to dockets and setting policy to govern this emerging topic.

The Minnesota Department of Commerce commissioned this white paper through their Conservation Applied Research and Development (CARD) fund to gather stakeholder perspectives on electrification and fuel switching. The goal of this paper is to:

- 1) Provide Minnesota-centric analysis on the topic of electrification and fuel switching.
- 2) Provide a primer to inform all CIP stakeholders and enable better participation in future stakeholder engagement opportunities.
- 3) Frame-up key questions and decision points for discussion by stakeholders and consideration by regulators.

This paper does not seek to prescribe answers. This paper aims to equally and accurately represent the variety of opinions and the areas of consensus on this topic. Interviews with stakeholders about electrification and fuel switching are the basis of this research. In addition, to address the rapidly growing body of electrification research, policy approaches, and evolving technology, this paper serves as a quasi-literature and technology review to introduce readers to the topic.

Minnesota Context

The following brief overview provides introductory context to Minnesota’s policies and decisions on fuel switching (and therein electrification). Further discussion on the topic occurs later in the paper.

The conversation around fuel switching in the context of Minnesota’s energy efficiency program is not new. In 2005, the MN Department of Commerce (the Department) issued an order that fuel switching would not be allowed within any utility’s Conservation Improvement Program (CIP) (Garvey, 2005). This ruling stands in effect today.

In 2007, the State of Minnesota passed comprehensive legislation addressing climate change, called the Next Generation Energy Act. This law revised and expanded energy efficiency programs and created a greenhouse gas (GHG) reduction goal for the State of Minnesota.

In 2012, an exception to the 2005 fuel switching order was issued by the Department, which allowed fuel switching in the case of low-income programs, provided they addressed the whole building envelope and that the customer was either using propane or heating oil for space heating or was the customer of a CIP-exempt natural gas utility (Division of Energy Resources, 2012).

In 2016, ACEEE completed a policy review as part of a study on cold climate heat pumps in MN which outlined a potential CIP program rebating air source heat pumps for customers currently heating with propane, fuel oil, or electricity (Kushler, 2016). In 2017, Otter Tail Power submitted a program modification request to the Department for a similar program (Otter Tail Power, 2017). The Department denied the proposal in 2018 on grounds that the proposed program was prohibited by the 2005 order (Grant, 2018). This filing served to re-spark the fuel switching conversation, create a record of stakeholder commentary, and generate momentum to convene stakeholders around how electrification and fuel switching may play a role in CIP.

Overview of Contents

This paper is divided into three sections – a policy and literature review section, a section summarizing content from the stakeholder interviews, and a section introducing and discussing technology considered for beneficial electrification.

The first section examines literature on the topic, reviews Minnesota’s policy, and gathers up policy efforts from around the country to explore how other states are approaching electrification and fuel switching.

The summary of stakeholder interviews highlights areas of consensus and disagreement among stakeholders. Individual opinions that differ from a common consensus are specifically highlighted. Information from stakeholders also informed the other sections of this paper.

Technology analysis comprises the final portion of this report. This section provides a high-level analysis of some key technologies that are frequently promoted for electrification. Each technology is viewed through the lens of the impacts electrification may have on cost, efficiency, carbon dioxide emissions, and electric peak demand. The introduction to this section describes the specific assumptions and limitations of this overview analysis. Additional work will be needed to calculate and compare the benefits and costs of these technologies.

Background on Topic

Working Definitions

Stakeholders often expressed the need for clarity of definitions in their interviews. The Minnesota Department of Commerce understands the needs for clarity in terminology. In a recent request to stakeholders, the Department asked for definitions of “what constitutes fuel switching” (Fryer, 2018). There will be further work to define these concepts in Minnesota. While not seeking to preclude valuable stakeholder discernment, this paper uses terms as defined in this section.

In a 2003 report to the Commissioner, Department of Commerce staff defined fuel switching conservation, and while it appears that the definitions may need clarity and revision, we will use the existing definition in this paper.

Fuel Switching or Fuel Switching Conservation: “A utility’s promotion of a measure that will result in a greater increase in that utility’s energy sales than if the measure had not been implemented.” Or an alternative definition, “converting customers from one fuel to another when the costs of conversion are less than the costs to society of not converting.” (Division of Energy Resources, 2003)

Electrification: An instance of fuel switching that shifts the fuel use toward electricity regardless of the baseline fuel and regardless of societal benefit.

Beneficial Electrification: A subset of electrification, which limits electrification to only those instances when electrification provides societal benefit. The Regulatory Assistance Project (RAP) has done the most work promoting Beneficial Electrification as a term of art. They define Beneficial Electrification as the subset of electrification that “must meet one or more of the following conditions, without adversely affecting the other two: 1. Saves consumers money over the long run; 2. Enables better grid management; and 3. Reduces negative environmental impacts” (David Farnsworth, 2018).

In the interview questions asked of stakeholders, the phrase “electrification or fuel switching” was used exclusively. Many respondents opted for the more specific term of “beneficial electrification.” No one used terms like “strategic electrification” or “efficient electrification”, although those terms have been used in literature on the topic. The definitions of those variations are all similar.

Literature

The baseline for electrification through the late nineteenth and the first part of the twentieth century was not natural gas or propane end uses, but rather, no electric service. Electrification in this context brought benefits like indoor lighting and refrigeration into homes. Electrification enabled a higher quality of life, including safety, education, and clean drinking water. The mission of extending electric service was core to the foundation of rural electric cooperatives, which began in an effort to electrify rural communities lacking electricity (Munson, 2005). For the 1.2 billion people in the world currently without access to electricity, electrification can still provide what are now considered basic elements for a higher quality of life. This un-electrified population mostly live in Africa and Asia, but some Americans lack access to electricity, notably Native Americans living on reservations in New Mexico, or Puerto Ricans living in the aftermath of a hurricane. (Angelou, et al., 2013) This kind of electrification is notably different than the kinds of electrification being considered in Minnesota today.

Instead, the focus on electrification today is the replacement of technologies fueled by fossil fuels – propane, fuel oil, natural gas, diesel fuel, and gasoline – with electric technologies. While electric utilities have never stopped seeking ways that electrification could provide cost-effective solutions for customers, this new wave of electrification is distinct because its motivation couples increasing sales with achieving a net reduction in carbon dioxide emissions. The concerns around mitigating impacts of climate change unite many policymakers, environmentalists, consumers, and electric utilities behind electrifying a broader cross-section of the economy.

The opportunity to reduce carbon emissions through electrification has been on the minds of certain advocates for years. In 2015, Keith Dennis of the National Rural Electric Cooperative Association wrote a paper in which he referred to a set of electrification technologies providing benefit to the public (Dennis, 2015). Dennis later co-wrote another paper with staff from the Regulatory Assistance Project (RAP), which led to more conversation on the topic (Keith Dennis, 2016). RAP has contributed significantly to the conversation around defining what Beneficial Electrification includes, most recently in a paper released in the summer of 2018 that outlines three key conditions for electrification to be beneficial (David Farnsworth, 2018).

Publications and interest in electrification swelled through late 2017 and early 2018. Major energy research and policy organizations have all released studies during that period, including studies from the national labs, research institutes, regional energy efficiency organizations, and advocacy/trade associations.¹ In addition to research, politicians and regulators are turning toward beneficial

¹ Reports in 2018 include studies from NREL, EPRI, AGA, NRDC, RMI, MEEA, and SWEEP. Citations for all the reports can be found in the bibliography.

electrification for its potential to reduce greenhouse gas emissions. The policy section in the paper discusses many of those policy efforts. Utilities have also moved quickly toward beneficial electrification. Most notably, the Tennessee Valley Authority announced in 2018 that it would no longer provide energy efficiency rebates and programs to customers, but instead would provide electrification programs. (Crocker, 2018)

Among the research reviewed, a number of studies focus on modeling the impacts of wide-spread electrification across the economy. These efforts have been done with different goals in mind, which has resulted in a variety of conclusions. However, it is notable that some similarities emerge between the different modeling efforts.

The National Resource Defense Council (NRDC) modeled what it would take to achieve an 80% carbon dioxide emissions reduction using existing “off-the-shelf” technology. To reach that goal, they relied heavily on energy efficiency (2% annual savings), electric vehicles, and air source heat pumps for residential heating and water heating. They found that achieving their desired carbon reduction by 2050 would cost consumers 1% more per year, compounding. Electricity consumption would rise to about half of all final (end-use) energy, but the total amount of final energy consumed would decrease even while the economy grows, thanks largely to energy efficiency. (Vignesh Gowrishankar, 2017)

The Electric Power Research Institute (EPRI) released their economy-wide modeling of efficient electrification in the summer of 2018. Unlike the goal-driven model from NRDC, EPRI built their model based on consumer economic behavior. Technology adoption in their model is driven by consumer cost-effectiveness and operational characteristics. Fuel choice is derived from the outcome of the consumer decision-making model. Consumer choice is influenced in some of their modeling scenarios by the introduction of a carbon price in 2020. One scenario sets the price at \$15/ton and the other at \$50/ton of carbon dioxide. (EPRI, 2018)

The result of EPRI’s modeling also shows electric consumption increases in both scenarios with a carbon price while total final energy consumption of all fuels drops. In the EPRI study, natural gas use increases in all of their scenarios. Natural gas use primarily fuels electricity production, industry, and home heating, including use as a backup fuel for some air source heat pumps. Although the goal of their study was not to hit a specific carbon reduction target, emissions drop by nearly 70% from 2015 levels by 2050 in their scenario with the highest carbon price. (EPRI, 2018)

In 2018, the National Renewable Energy Laboratory (NREL) released the second report in a multi-year series exploring the impacts of electrification. This report focused on the adoption of electrification technologies. They modeled three scenarios (reference, medium and high) of increasing technological advancement, policy support and consumer enthusiasm for electrification. In their assessment, transportation electrification experienced the greatest transformation toward electrification, with EV penetration ranging between 11% and 84%. Buildings and industry saw less transformational change, but certain end-uses in certain regions saw high adoption of electric technologies. (Trieu Mai, 2018)

In NREL’s study, US consumption of electricity increases in every scenario between 1.2-1.9% annually, almost doubling by 2050 in the most aggressive scenario. And for some utilities in heating dominant

states, home heating electrification drives a flip from a summer electricity demand peak to a winter peak. (Trieu Mai, 2018)

The American Gas Association (AGA) released a paper in 2018 as well. Their analysis (conducted by ICF) modeled the impacts of “policy-driven” electrification. In their analysis, they looked at the impact of a hypothetical policy that halted all sales of residential fossil-fueled water heaters and furnaces in 2023. Their analysis found 1 to 1.5% of US GHG emissions could be reduced through electrification. Emissions from residential direct fuel consumption comprise 6% of total US GHG emissions. The upper edge of their emissions reduction forecast came from their scenario where renewable energy was the only new resource used to meet increased demand. In their scenario that used natural gas electricity generation to meet load growth, some regions, including the Midwest, were not electrified because emissions would have increased. (ICF, 2018)

The AGA found that a forced approach to electrification resulted in extremely high costs to consumers and a high relative cost per ton of carbon. The average increase in energy-related costs for affected households was between \$750 and \$910. The cost of emission reductions was between \$572 and \$806 per metric ton of CO₂. The AGA report states this cost of carbon reduction is many times more expensive than the carbon reduction from other methods like energy efficiency or carbon sequestration. (ICF, 2018) In comparison, the cost is dramatically higher than the carbon price used in EPRI’s scenarios as a driver of economic change (\$15 and \$50). The policy approach chosen for the model drives this price disparity. The AGA models a hypothetical national policy that requires all consumers to convert to air source heat pumps with electric backup at the end of their existing equipment life regardless of cost. The EPRI model includes a policy-driven price of carbon, but models consumers making the most economical choice. The AGA scenario converts about 60% of fossil-fueled housing stock to electricity by 2035. EPRI’s model shows less decline, even with a carbon price, in natural gas heating and a significant role for natural gas as a backup fuel for air source heat pump systems in cold climates. (EPRI, 2018)

The Rocky Mountain Institute released a report titled, “The Economics of Electrifying Buildings” in 2018. Their analysis looked at the costs and emissions reductions associated with transitioning residential and commercial space and water heating away from fossil fuels. Their analysis used specific rate designs from five different US cities. They found that for some sectors heat pumps already cost less over their lifetime. This was not true for homes with existing natural gas appliances, but it was true for new construction. The other immediately cost-effective segment was customers using propane and fuel oil to heat their homes. In those cases, switching to electric heat pumps for space and water heating saved money. (Sherri Billimoria Leia Guccine, 2018) The conclusion about cost reductions for existing propane customers but not for natural gas customers has been supported by other research (Jenny Edwards, 2018).

In the Midwest, in summer 2018 the Great Plains Institute released the first of a series of three stakeholder developed reports developing a “Road Map to Decarbonization of the Midcontinent.” The first report focused on decarbonization of electricity and it will be followed by a report about decarbonization of transportation and then buildings. In this report, they model for the Midcontinent Independent System Operator (MISO) grid a variety of generation mixes and policy conditions. They found that under business as usual conditions none of the modeled future scenarios resulted in

substantial decarbonization. (Collaborative, 2018) This led to the conclusion from the stakeholder collective that policy and market drivers would be needed to achieve deep decarbonization of the MISO grid.

Decarbonization Policy Goals

The Next Generation Energy Act, passed in 2007 by the Minnesota Legislature and signed by Governor Tim Pawlenty, sets clear goals for greenhouse gas emissions reductions, decreased consumption of fossil fuels, and increased energy conservation.

The legislation in Minnesota Statutes §216H.02 subdivision 1 reads, “It is the goal of the state to reduce statewide greenhouse gas emissions across all sectors producing those emissions to a level at least 15 percent below 2005 levels by 2015, to a level at least 30 percent below 2005 levels by 2025, and to a level at least 80 percent below 2005 levels by 2050.” Another section of the legislation, §216C.05 Subdivision 2, specifically names the energy policy goal of the state to be a reduction in per capita fossil fuel use by 15 percent by 2015 and 25% by 2025. This will be achieved “through increased reliance on energy efficiency and renewable energy alternatives.”

These goals for Minnesota encompass all energy-using sectors and the Minnesota Pollution Control Agency reports every other year on the annual emissions data for each economic sector in Minnesota. In their latest report published in January 2017, with emissions data through the end of 2014, the electric generation sector’s emissions decreased by 17% from a 2005 baseline. The electric generation sector was the only sector on track to meet the emissions reduction target of 15% by 2015. Transportation declined 7%, agriculture declined 2%, and all other sectors increased their emissions from a 2005 baseline. Industrial and commercial emissions both climbed by 20%, residential emissions increased 19% and emissions from waste increased 8%. (Clafin, January 2017)

In the interview with Will Seuffert, Executive Director of the state’s Environmental Quality Board, he summed up Minnesota’s progress as such, “if you just isolate the energy sector, we’re on track to hit that 2025 target from an emissions standpoint. How you get to 2050 is a little bit different, but, I would say with some confidence, I do think that in the state our utility sector will get there. I have more anxieties about the other sectors because ... we struggle to even visualize the kind of change that needs to happen in the other sectors.”

Efficiency Statutes: §216B.2401 and §216B.241

Minnesota’s energy efficiency programs are governed from two parts of the statutes, the first is §216B.2401. In this brief statute, the legislature articulates a goal that pursuing “cost-effective energy savings are preferred over all other energy resources.” The statute continues, “energy savings should be procured systematically and aggressively in order to reduce utility costs for businesses and residents, improve the competitiveness and profitability of businesses, create more energy-related jobs, reduce the economic burden of fuel imports, and reduce pollution and emissions that cause climate change.” The language of §216B.2401 casts a broad scope as to how a 1.5% reduction in energy consumption

might be achieved – including non-program related market changes, behavioral programs, and “other efforts.”

The second statute, §216B.241, governs many details regarding the creation and implementation of the Conservation Improvement Program. In this more detailed statute, the legislature defines terms, grants authority, sets goals, and creates programs to structure the implementation of energy efficiency in the state of Minnesota.

In §216B.241, commonly called the CIP statute, definitions tighten around what qualifies as an Energy Conservation Improvement. The statute allows for either energy conservation or energy efficiency to be counted as an Energy Conservation Improvement. In the statute, “Energy conservation means demand-side management of energy supplies resulting in a net reduction in energy use. Load management that reduces overall energy use is energy conservation” (§216B.241, subdivision 1(d)). Energy efficiency means measures or programs that are “designed to produce either an absolute decrease in consumption of electric energy or natural gas or a decrease in consumption of electric energy or natural gas on a per unit of production basis without a reduction in the quality or level of service provided to the energy consumer” (§216B.241, subdivision 1(f)).

The terms are distinct in that energy conservation must result in a net reduction of energy use. This is non-fuel specific. Efficiency, on the other hand, is defined in relation to output. Efficiency could result in a net increase in consumption of electricity or natural gas if output also rose such that productivity increased. Under this definition, efficiency could look like more widgets produced at a decreased kBtu/widget, or perhaps, more vehicle miles traveled (VMT) at a lower kBtu/VMT, or more air heated and cooled at a lower kBtu/CFM.

Neither definition discusses whether energy savings should be measured at the site or at the source. Measuring at the source would include fuel burned at the power plant to generate electricity and is more comprehensive when comparing electricity consumption with direct fossil fuel consumption. Measuring at the site is simpler and sufficient when only analyzing a single type of fuel.

Neither §216B.2401 or §216B.241 specify that the reduction of energy use needs to be achieved by maintaining the use of the original fuel through to the new efficient technology. In fact, §216B.241 subdivision 1(e) explicitly allows for waste heat recovery to be used for electricity or thermal energy. This distinction around waste heat might be interpreted as openness to conservation or efficiency occurring within a measure that switches fuel, assuming either the equipment becomes more productive, or the total fuel use decreases.

During the stakeholder interviews, Will Nissen of Fresh Energy commented on this. He said, “our statutes are fairly silent on electrification and fuel switching. The CIP statute in particular really only talks about energy savings and isn't really fuel-specific at all. So, it neither encourages nor discourages, is our read of the statute, so that then falls to the Department to determine policy.”

The legislature granted the Commissioner of the Department of Commerce authority to interpret and enforce §216B.241 which allows the Department leniency to determine how aspects of CIP are implemented (subdivisions 1c(a), 2(a), and 2(b)). While the topic of fuel switching is not clearly

delineated, the statute is clear that activities, including electrification or fuel switching, only belong in CIP if they can achieve a net reduction of energy consumption, or an increase in efficiency. Recent Department staff analysis affirm this delineation: cost savings or emissions reductions alone don't meet the threshold for energy efficiency or energy conservation (Grant W. , 2018). The issue of whether source efficiency meets the statutory definition of energy efficiency or energy conservation remains to be interpreted by the Department or clarified in the statute.

Fuel Switching Determinations

The Department has made a determination on the question of whether to allow fuel switching within the CIP program in the past. In a 2005 Order (Docket No. G008/CIP-00-864.07), the Department ruled that “targeted fuel-switching projects are not allowed in the Conservation Improvement Program.” The process to arrive at this ruling lasted three years and included written commentary, meetings with interested parties, and research by Department staff (Garvey, 2005).

The origin of the order was a proposed filing amendment from Reliant Energy Minnegasco to allow them to provide a large rebate through CIP for power-vented natural gas water heaters to make them more competitive compared to electric water heaters. Natural gas water heaters were losing market share in new home construction due to an inadvertent change to the ventilation requirements in Minnesota's Energy Code. Minnegasco based their justification of the proposal on a “total net energy comparison” in order to account for the Btu content of the fuel “consumed from the point of extraction to the point of use” (Reliant Energy Minnegasco, 2002).

This proposal elicited a response from electric utilities who claimed it amounted to fuel switching, which had previously been discouraged in CIP. Otter Tail Power was among the utilities that filed a response. In their response, they stated this project was equivalent to “Otter Tail proposing to replace all gas furnaces with renewable electric geothermal heat pumps, along with a customer rebate of approximately 50% of the additional cost of installation” (Otter Tail Power Company, 2002).

The 2005 Order excludes targeted fuel-switching projects, states that “a Btu comparison is not necessary,” and describes how utilities can measure the impact of measures that have an ancillary impact on a fuel not served by the utility (Garvey, 2005). The Order does not provide much justification for its decisions and does not address specifically whether energy savings in source Btus would count as energy conservation. Offering a little more context, the Department staff analysis provided to the Deputy Commissioner recommends that “Utility rebates should be based on the energy savings of the fuel the utility sells” (Division of Energy Resources, 2003).

Department staff also specified that an exception to a prohibition on fuel switching ought to be made to allow utilities to provide more robust programs to low-income customers (Division of Energy Resources, 2003). Nine years later, in 2012, the Department made the allowance for fuel switching within low-income programs provided the fuel being replace was either a delivered fuel like propane or heating oil or was natural gas served by a CIP-exempt small natural gas utility (Division of Energy Resources, 2012). It did so on the grounds of equity concerns for ratepayers who paid into CIP programs with their electric

bill but had little opportunity to benefit and on the grounds of benefits to ratepayers and society (Kushler, 2016).

Those two determinations, the 2005 decision prohibiting fuel switching and the 2012 guidance allowing fuel switching for low-income programs, provide the existing regulatory interpretation and precedence for this topic in Minnesota.

Peer Practice and Policy Review

In this section, we look beyond Minnesota for insight on how other states have legislated and regulated their utilities with regard to fuel switching and beneficial electrification. Other states can specifically help Minnesota answer questions about whether and how fuel switching could be allowed into efficiency programs, and whether and how states are incorporating beneficial electrification into their policies governing utilities.

Fuel Switching

Illinois

Since 2013, the Illinois statutory definition of energy efficiency has stated that energy efficiency reduces the total Btus of electricity and natural gas while performing the same output. In 2016, the passage of the Future Energy Jobs Act, which significantly expanded the state's energy efficiency efforts, further tweaked the definition of energy efficiency to cover any fuel. The state's definition now reads: "Energy efficiency' means measures that reduce the amount of electricity or natural gas consumed in order to achieve a given end use. ... 'Energy efficiency' also includes measures that **reduce the total Btus of electricity, and natural gas, and other fuels** needed to meet the end use or uses" (20 ILCS 3855/1-10, emphasis added) (Public Act 099-0906, SB 2814 Enrolled, 2016).

In 2014, the Illinois Commerce Commission ruled that combined heat and power (CHP) measures would be appropriate within utility energy efficiency portfolios (2014, pp. 90-92). It is from this ruling on CHP measures that other fuel switching measures have been developed in Illinois (Shah, 2018).

In practice, only three technology applications for fuel switching have been included in the Illinois Technical Reference Manual (TRM). They are geothermal heat pumps, ductless heat pumps, and CHP. The TRM measures include a method to calculate energy savings from these technologies by apportioning the credit for saving energy between both the gas and electric utilities that participate in funding the project. As an example, for residential geothermal heat pumps, the natural gas utility claims the therms replaced (by removing a gas furnace) minus the therm equivalent of new baseline geothermal heat pump measured at the source (energy consumed at the power plant). The electric utility claims the incremental efficiency gained by shifting a customer from a lower efficiency heat pump to a high-efficiency heat pump. (Illinois Energy Efficiency Stakeholder Advisory Group, 2017, pp. 105-121) Or put more simply, the gas utility gets the credit for fuel switching away from their fuel to a baseline unit, and the electric utility gets credit for incremental efficiency above a baseline unit.

Maine

Maine provides flexibility for residents and businesses to change fuel within the context of the programs offered by Efficiency Maine, their independent state energy efficiency implementer. There is quite a bit

of fuel oil use in Maine, and it's been considered a priority to replace that fuel with more efficient and cleaner fuel (Energy Office, 2015). A single statewide efficiency program must serve all the residents of Maine regardless of which utility provides the fuel. This simplifies the equation by avoiding the complication of a utility trying to sell more of their product through the energy efficiency program. And because Maine is part of the Northeast's Regional Greenhouse Gas Initiative (RGGI), there is additional funding available to help cover the costs of decarbonization (Efficiency Maine Trust, 2016).

For example, if a customer currently burning fuel oil to heat their home wants to change to a high-efficiency air source heat pump, Efficiency Maine will provide them a rebate. Part of that rebate comes from energy efficiency funds from the state. The amount of the energy efficiency rebate is calculated by comparing the new high-efficiency air source heat pump with a standard efficiency baseline option. RGGI funds are used to support the transition by providing funding to incentivize the switch from burning fuel oil to buying the baseline air source heat pump. RGGI funds are particularly flexible because unlike efficiency funding, RGGI can still provide incentives when projects are not cost-effective (Uchtmann, 2018).

California

Fuel switching is allowed in California and is governed by the three-prong test. The three-prong test permits fuel-substitution in programs where 1) source Btu consumption does not increase, 2) cost-effectiveness tests² pass and 3) there aren't adverse effects to the environment (CPUC, 2013). However, as of April 2018, stakeholders in California have successfully petitioned the CPUC to review the test and provide additional clarity and simplicity in meeting the test's conditions (Seel, 2018).

The petitioners, which include the Sierra Club, the National Resources Defense Council, and the California Energy Efficiency Council, claim that despite its appearance of providing clear guidance the three-prong test effectively functions as a "roadblock to incentives using utility customer funds for fuel substitution in buildings – even when there are significant climate benefits and energy savings available – and [it] is opaque in terms of the 'burden of proof' required to pass the Test" (Merrian Borgeson, 2017). In addition to a review of the test in light of current California climate and energy policy, the petitioners specifically ask for clarity around the substitution of regulated fuels versus substitution between regulated and unregulated fuels (like propane and wood), and they ask for examples of how programs or projects could be assessed using cost-benefit methodologies (pp. 2-3).

Since almost a year passed between when this motion was introduced and when the commission agreed to take up the review, it's not clear when the CPUC will arrive at a conclusion about how to proceed with the three-prong test for fuel substitution.

² The program/measure/project must have a Total Resource Cost (TRC) test and the Program Administrator Cost (PAC) Test benefit-cost ratio of 1.0 or greater.

Beneficial Electrification

Some states have made strides toward addressing and incorporating beneficial electrification into the fold of their utility regulation. Other states are at a stage, similar to Minnesota, of gathering stakeholder perspectives and developing a shared understanding of the opportunities and challenges.

Vermont

In 2015, Vermont enacted a new renewable energy standard (RES) focused on “Energy Transformation”. The standard established three tiers of requirements that the State’s distribution utilities would need to meet. Tier one reinforces the state’s existing renewable energy standard and tier two carves out a portion of that production that needs to be distributed generation (State of Vermont, 2018). Tier three is the part that’s particularly relevant to this paper.

Tier three established a requirement for utilities to spend 2% of sales on energy transformation projects in 2017, rising to 12% of sales by 2032. These projects would “reduce customer fossil fuel consumption and save money” and examples of projects include “weatherization, biomass heat, [and] cold-climate heat-pumps” (Ellis, 2015). Transportation demand management strategies and electric vehicle charging can also meet this standard’s requirements (Buckley, 2015). To evaluate which projects deserve to be implemented, “Energy Transformation Projects will be screened for life cycle cost-effectiveness under the societal cost test and against an alternative compliance payment of \$0.06/kWh, adjusted for inflation” (Buckley, 2015).

Vermont is particularly well positioned to benefit from electrification. According to the Energy Information Administration, the state has no fossil fuel reserves, no in-state fossil fuel electric generation, and has one of the lowest carbon emission intensities of any state. A majority (about three-fifths) of households heat using petroleum-based fuels (fuel oil, propane). Only three counties in the state have natural gas distribution. (EIA, 2018) The state has a goal to eliminate nearly all petroleum consumption including heating and transportation (Vermont Department of Public Service, 2016). These factors combine to position residential heating as a key target for reduction of carbon emissions, through electrification and other approaches including biomass heating and home weatherization.

The Rocky Mountain Institute (RMI) recently completed a report for Green Mountain Power (GMP), Vermont’s largest utility, assessing how GMP could advance their vision of being an energy transformation company. In that report, RMI discuss the tier three energy transformation goals. They identify the best opportunities for GMP as “fuel switching away from natural gas and petroleum to electricity for space heating, water heating, and vehicles. Satisfying these requirements with fuel switching will require tens of thousands of GMP customers to adopt heat pumps, heat-pump water heaters, and/or electric vehicles over the next 15 years” (Rachel Gold, 2017). Some of the programs that Green Mountain Power currently implements that contribute to meeting these goals include no-money-down financing of cold-climate heat pumps and water heaters, build-out of electric vehicle charging

stations, support for vehicle charging in homes, and grid-interactive control for water heaters and ductless heat pumps.

Green Mountain Power recently filed its 2018 plan for meeting the tier three RES requirements. In that plan, they shared observations from the first 10 months of implementing programs to meet the goal for 2017. They found that customers were deterred from switching to cold climate heat pumps because fossil fuel prices continued to remain low during 2017. They report that while most customers make decisions based on economic factors, there is a population of customers that make the decision based on non-economic factors, like clean energy objectives, personal comfort, and convenience. They report approximately 16.5% of cold climate heat pumps installed in their service territory were purchased through the GMP program. They also report that tier three goals have created “a non-collaborative, competitive dynamic” in the relationship between the distribution utility (Green Mountain Power) and the state’s energy efficiency utility (Efficiency Vermont) because of competing thermal savings targets (Green Mountain Power, 2017).

Despite still being early into implementation, the experience of Vermont utilities and regulators could help inform best practices for Minnesota and other states looking to pursue energy transformation.

Massachusetts

The state of Massachusetts passed a new clean energy law that was signed by the Governor on August 9, 2018. This law includes a change to expand the scope of what’s permissible within the state’s energy efficiency programs. The previous statute read that the electric and natural gas utilities would create a plan that would include “efficiency and load management programs.” Now that description is appended to read: “efficiency and load management programs including energy storage and other active demand management technologies, and strategic electrification, such as measures that are designed to result in cost-effective reductions in greenhouse gas emissions through the use of expanded electricity consumption while minimizing ratepayer costs.” (M.G.L ch.25 §21) (H.4857)

In addition to adding this flexibility for the type of resources that can be included in the energy efficiency plans, the new law also relaxed cost-effectiveness standards. “It does this by broadening the definition of benefits that are counted and applying cost-effectiveness screening at the sector level, instead of the level of individual programs, as has been the practice in the past,” explained the Acadia Center, a non-profit organization working on climate change policy in the Northeast. (Mark LeBel, 2018)

One interesting dynamic is that this legislation passed without an expansion to the state’s natural gas pipeline capacity. According to the Boston Globe, some business groups, with the backing of utilities Eversource and National Grid, sought that legislation but “natural gas is the third rail of Massachusetts politics, and House leaders steered clear. The Senate meanwhile approved legislation that would make it harder, not easier, for utilities to expand gas pipelines” (Chesto, 2018). In the end, the legislation only contained a provision to reduce methane leaks in existing pipeline (Mark LeBel, 2018).

New York

New York has been a leader in innovation in the utility sector in the past few years. New York State's effort, Reforming the Energy Vision (REV), has been the source of new ideas, approaches, and pilots trying to tackle the evolving grid, growth of renewable energy, and changing customer expectations. REV takes an active role in designing new initiatives and partnerships to meet the state's energy goals, which by 2030 are a 40% reduction in GHG emissions, 50% renewable electricity, and a 600 Trillion Btu increase in energy efficiency. (New York State, 2018)

Recently the New York State Energy Research and Development Authority (NYSERDA) issued a report called "New Efficiency: New York" in which they laid out key means to achieving the goal of increased energy efficiency. NYSEDA's efficiency goal will be measured in fuel neutral site energy efficiency. This opens the door for fuel switching or beneficial electrification to help New York meet its goals.

A section of the report addresses this dynamic, "Given the magnitude of New York's GHG emission reductions goals (40% by 2030 and 80% by 2050), the Biennial Report to the 2015 State Energy Plan named electrification of thermal end uses in buildings as a core opportunity for New York State. As a key component of New York's continued climate leadership, the Biennial Report called for the State to 'seek to develop electrification policies and opportunities as steps for early action.'" (NYSEDA, 2018)

Renewable Heating and Cooling has been a focus of REV. Thermal energy consumption in the residential and commercial sectors accounts for 37% of the state's net energy consumption. Geothermal heat pumps, cold climate heat pumps, and solar hot water systems are the primary focus for renewable heating and cooling efforts. The state is considering sources for incentives to support these technologies, including thermal-renewable energy credits, ratepayer funds, and REV Clean Energy Fund. (NYSEDA, 2017)

One interesting development from New York comes in the form of a recent rate case for Central Hudson Gas & Electric Corporation. The Public Service Commission approved the utility's joint proposal with stakeholders to create an Earning Adjustment Mechanism to reward the utility for Environmentally Beneficial Electrification (Wyman, 2018). The utility may develop programs for measures like geothermal and air source heat pumps, as well as electric vehicles. Programs will be evaluated based on carbon dioxide savings and reported on in a Carbon Reduction Implementation Plan. (Joint Proposal, 2018)

Other State and Regional Activities

Clearly, the Northeastern states are active on electrification. In addition to New York, Massachusetts, Vermont, and Maine, Connecticut and Rhode Island have also been active. In Connecticut, electrification of transportation and heating end-uses were included as part of a recently developed Comprehensive Energy Strategy (State of Connecticut, 2018). The public utility commission in Rhode Island has embarked on an ambitious visioning and reformation process called the Power Sector Transformation. One of the deliverables is a white paper on Beneficial Electrification Principles and Recommendations opening the possibility of utility proposals to advance beneficial electrification (RIPUC, 2017).

The Government of British Columbia passed enabling legislation in late 2017 allowing the state-owned subsidiary, BC Hydro, to pursue electrification projects with its customers (Government of British Columbia, 2017). BC Hydro started small pilot efforts for both residential and commercial customers in order to develop the business case and gauge customer interest (Travers, 2018).

Beyond the state-led activity, the Northeast Energy Efficiency Partnership (NEEP) has led some research and stakeholder conversations on electrification in the region. NEEP is the Regional Energy Organization (REO) for the Northeast. Recently, NEEP published a regional assessment of strategic electrification, which broadly outlined a strategy for using electrification as a component in meeting Northeastern states' carbon reduction goals (NEEP, 2017).

Other REOs across the country are also engaging in this topic, especially as it pertains to residential end-uses. The Midwest Energy Efficiency Alliance (MEEA) will release a study on heat pump performance in the Midwest in 2018 (Ian Blanding, 2018), and the Southwest Energy Efficiency Partnership (SWEPP) recently released a paper on the benefits of heat pumps for homes in the Southwest (Neil Kolwey, 2018).

Municipal utilities have had flexibility to move quickly toward implementation of electrification programs. Generally municipal utilities that strategic direction from a board of directors or city leadership rather than regulators. This allows them to implement new programs without the same regulatory process as investor owned utilities. As one example, Sacramento Municipal Utility District (SMUD) has started offering incentives to customers to promote residential electrification, specifically heat pump adoption. These incentives can provide as much as \$10,250 to help a customer convert to electric heat pumps. Different building stock and equipment baselines receive different levels of incentives. Scott Blunk, a Strategic Business Planner at SMUD, says that while these incentives are large, they are not generous. SMUD has been able to justify all of the incentives by showing a positive net-present value from the investments for the organization. (Blunk, 2018)

In-depth Interview Methodology and Findings

Methodology

In-depth interviews with stakeholders comprise the majority of primary research conducted for the white paper. The project team, including MN Department of Commerce staff, invited stakeholders who represented a variety of sectors, organizations, and positions engaged in and affected by fuel switching and electrification, both as it pertains to CIP and in the broader economy.

We invited 32 organizations to participate in the stakeholder interviews. Of those, 24 agreed to participate in the interview. In some cases, more than one staff person from an organization participated in the interview. When participating staff each had distinct views on the majority of the questions asked, we documented their response as an individual participant, leading to 28 distinct respondents. Participants received a written copy of the questions prior to the scheduled interview. Interviews were recorded, transcribed, and responses coded to identify common themes.

Interview Participants

ACEEE (American Council for an Energy-Efficient Economy)
Center for Energy and Environment
CenterPoint Energy
Connexus Energy
EPRI (Electric Power Research Institute)
Fresh Energy
Fuels Institute
Geothermal Exchange
Great Plains Institute
Great River Energy
GTI (Gas Technology Institute)
McKnight Foundation
Minnesota Chamber of Commerce
Minnesota Citizen's Utility Board
Minnesota Environmental Quality Board
Minnesota Municipal Utilities Association
Minnesota Public Utilities Commission
Missouri River Energy Services
National Rural Electric Cooperative Association
Otter Tail Power Company
Regulatory Assistance Project
Rochester Public Utilities
Southern Minnesota Municipal Power Agency
Xcel Energy

Invited, not interviewed

Andeavor
MEEA (Midwest Energy Efficiency Alliance)
Minnesota Energy Resources
Minnesota Power
Minnesota Pollution Control Agency
Minnesota Rural Electric Association
MISO (Midcontinent Independent System Operator)
University of Minnesota—
Energy Transition Lab

Questionnaire

This report includes a copy of the full questionnaire in [Appendix A](#). The questionnaire includes 18 questions. Topic covered can loosely be divided into the following elements:

- 1) Information gathering:
 - a. The opportunities and challenges provided by electrification and fuel switching
 - b. Policies and process in other states/jurisdictions
 - c. Technologies that interest the participant's organization
 - d. Who else should be included as a stakeholder
 - e. Who is supportive and who is in opposition (relative to their own position)
- 2) Input on process and policy:
 - a. Desired outcomes for MN regulation and/or legislation
 - b. Opinions on the status quo prohibition of fuel switching within CIP
 - c. Metrics for evaluating electrification and fuel switching
 - d. Goals and objectives of regulation and/or legislation
 - e. Equitability of the process and potential policies

Findings

The following section highlights some of the key areas of consensus and disagreement. Some questions are yet unanswered, which presents interesting discussion opportunities for future stakeholder gatherings. Any direct quotes were approved by their owner for publication.

In general, the areas of consensus on this topic are greater than the areas of disagreement. The cleavages between stakeholders were generally cross-cutting and not reinforcing, meaning that, for instance, not all electric utilities held the same opinions. Generally, stakeholders expressed a lot of nuance in their answers, which indicates open-mindedness to other positions on the topic.

One piece that is important to stress: the sample of stakeholders is not equal across all organizational types and as such, any numerical results need to be taken with appropriate caveats and in context. We conducted interviews with eight utilities/wholesale power distributors. Three of them served natural gas customers, one with only gas service in Minnesota, and two with combination gas and electric service. The five electric-only utilities offered variety in geographic territory (2 urban, 3 rural) and business model (1 IOU, 2 Coops, 2 Muni).

The analysis below occasionally highlights minority views, or views expressed infrequently, by stating them in a separate subsection. Since these interviews provide non-statistical information gathering, minority views need special attention, because they may represent a much wider cross-section of society.

Key Areas of Consensus

Benefits of electrification

Respondents were asked about what they felt the opportunities of electrification were for their organization or the state of Minnesota. Nearly all respondents identified carbon reduction as a possible benefit to electrification. Electric vehicles, in particular, were universally viewed as a means of reducing carbon from the transportation sector, a sector which lags behind the electricity sector in meeting carbon reduction goals. Other benefits mentioned by respondents include increased efficiency, reduced customer costs, and the addition of a flexible, grid-beneficial load. For commercial and industrial customers, there could be benefits of increased productivity and improved indoor air quality. Increased consumption and production of local renewable resources and its ensuing economic development were mentioned. Stakeholders mentioned positive health benefits from reduced pollution. And utility stakeholders shared that increased load growth would help combat the recent trend of declining sales and could reduce customer costs by spreading out fixed costs over more sales.

Regulators need to consider this topic

Out of 28 individual responses, 24 people expressed in their own words that electrification and fuel switching was important or very important for regulators to consider. The importance for respondents stemmed from the fact that electrification is trendy and utilities and interveners are pushing it forward. Regulators need to be prepared to respond to these requests and engage in the dialogue. Some respondents noted that electrification was a component of a broader electricity-sector reformation that is happening and for this reason was important to consider. The more ambivalent respondents shared that if this topic is driven by regulators wanting to lead on carbon reduction, then it was important, but at this point, consumers aren't pushing for electrification in a way that necessitates regulatory intervention.

Transparent, collaborative processes will yield positive outcomes

The respondents were asked to reflect on how the issue of electrification and fuel switching should be addressed in order to yield an outcome that stakeholders would agree was equitable. The word equitable caught many people's attention. It elicited comments about winners and losers as a result of policy changes and decarbonization efforts. It raised questions about whether equity was a realistic or desirable outcome, given the changes needed to reduce carbon dioxide emissions. And people raised concerns about equity of access to electrification technologies for participants of all socio-economic statuses and equity in terms of benefits for both participating and non-participating ratepayers.

Stakeholders emphasized that the route to an equitable process would be through transparency and a clearly defined goal. Transparency around money was particularly important – some respondents wished to know how much beneficial electrification would cost and who would pay for it. Development of cost-effectiveness tests for electrification would help ensure benefits are realized, and more

generally, the process of determining metrics would be an important opportunity for stakeholder review and engagement.

Status quo needs careful change

When asked what concerns stakeholders had about changing the status quo prohibition on fuel switching within CIP, the majority of respondents (19 out of 28) stated that they had “no concerns” or that the policy needed to change. A few of those 19 put some caveats around their support, but many of the stakeholders felt strongly that the prohibition was a barrier to efficiency and needed to change because of increased end-use efficiency and decreased carbon emissions of the electric grid. Supporters of change expressed that this prohibition did customers a disservice by restricting customer access to some efficient technologies (because their utility couldn’t promote or incentivize it).

Utilities and organizations with a stake in natural gas sales were more cautious about their answer to this question. But that is not to say they were universally opposed to careful change on fuel switching, or that they were alone in raising concerns about removing the prohibition.

Concerns expressed by stakeholders include that allowing fuel switching without very specific criteria opens the doors to utilities taking advantage of CIP to build load. Stakeholders also expressed concern that the utility’s financial incentives within CIP are necessary because efficiency is, by its nature, against a utility’s self-interest. The same is not true for increasing sales through electrification. Stakeholders were concerned that fuel switching projects, allowed within CIP, might displace other cost-effective energy efficiency projects. And some stakeholders shared that they were concerned this might affect peak and cause rates to increase.

Shawn White with Xcel Energy states some of these concerns. He says, “The reason those [fuel switching] provisions were put in place still exists. Electrification can certainly be done for the benefit of the utility only, increasing sales. That gets back to cost-effectiveness, customer protections, emissions reductions, putting the right caveats in to make sure that fuel switching would be done for societal benefit.”

Treat all fuels in a unified manner

When responding to whether delivered fuels should be treated differently than natural gas, the vast majority of respondents suggested that they didn’t see why there should be a difference. In fact, unanimously, respondents said that from a technical perspective, each fuel needs to be analyzed with the same rigor, using the fuel’s respective cost, carbon emissions and the efficiency of the use of that fuel. Determining the exact metrics and methodology remains to be worked out, but any adequate calculation will be able to easily process different fuel inputs. As David Farnsworth of the Regulatory Assistance Project stated, “If the public interest is least cost and least emissions, how does this distinction serve either of those?”

A few respondents (7 total) suggested that despite wanting a level playing field of technical analysis, there may be reasons to focus first on electrification of delivered fuels, and in particular propane. Those respondents cited a few lines of reasoning.

First, focusing on delivered fuels may be more politically expedient. These are fuels that do not participate in CIP. Legislators and residents still have memories of propane shortages and price spikes during the winter of 2014, which makes propane a less desirable choice for consumers.

Second, the fact that natural gas utilities are regulated monopolies presents a particular conundrum that makes it both simpler and quicker to start with electrification of unregulated fuels. Specifically, if regulators allow natural gas customers to opt out of natural gas use toward electric use, what impact does that have on the remaining natural gas customers? What obligation do regulators have to protect those customers?

Finally, people argued that equity and efficiency are at stake. Propane heating customers, who do not specifically choose to live in a part of the state not served by an energy efficiency program, lack access to rebates, information, and technical support to help them improve their home's heating efficiency. Efficiency would be better achieved in those homes if utilities could offer solutions for the whole home envelope. Bob Jagusch of MMUA said this argument of better serving customers was a driving factor in creating the 2012 fuel switching allowance in CIP for low-income programs. When customers run out of propane in the middle of winter and can't afford to get their tank refilled, they switch to expensive electric space heaters. Eliminating the fuel switching prohibition for this customer segment allowed utilities to better serve low-income customers. The same line of justification may be a reason to start with CIP-exempt fuel, like propane.

Fuel switching rules need to be fuel neutral

A couple of stakeholders specifically mentioned that rules for fuel switching within CIP need to be fuel neutral. They argued that if a project can prove itself beneficial, based on clearly defined metrics and criteria, then it should be completed – regardless of which fuel is replacing which fuel. Audrey Partridge at the Center for Energy and Environment was one of the people to make this statement. She said, “I think that we should be evaluating fuel switching on a list of criteria, not simply by fuel. For example, if there are instances where switching from some fuel to natural gas is beneficial, based on fuel-neutral criteria, then that should be something we do.” A few stakeholders mentioned similarities between efforts to promote and regulate Combined Heat and Power (CHP) and efforts around fuel switching and beneficial electrification.

Vehicle electrification doesn't easily fit into current formulation of CIP

Stakeholders nearly uniformly agreed about the importance and market momentum of vehicle electrification. Stakeholders commented that the rapid growth in the market, consumer interest, and manufacturer plans to aggressively pursue electric vehicles were evidence that the growth of electric vehicles presents a persistent trend.

Additionally, there was general agreement that vehicle electrification does not appropriately fit within CIP. Stakeholders expressed this as “fitting a square peg into a round hole” and “I don't see how electric vehicles belong in CIP. CIP is about buildings and the electric system.” The consensus on this topic was not perfect, in part because the question was poorly worded, framing the questions as to whether gasoline should be considered a delivered fuel – and not specifically asking whether vehicle electrification had a place within the CIP. But enough stakeholders decisively spoke on this topic to indicate that rolling vehicle electrification into the umbrella of CIP would require, at a minimum, a major reworking of CIP mission and goals.

In particular, stakeholders raised concerns about how transportation was distinctly different than buildings, equipment, and industry – which is the current scope of CIP. They commented that saving gasoline would not be sufficiently linked to ratepayer benefits to justify vehicle electrification as an energy efficiency measure. Others expressed concerns about using CIP to effectively regulate the free market economy of gasoline sales, especially when gasoline is subject to different regulations and taxes.

Vehicle electrification is clearly regarded as a huge opportunity for the state of Minnesota and electric utilities as they rise to the challenge of meeting that new load with low-carbon electricity in a way that maximizes grid benefits. What's more, customers who drive electric vehicles stand to save money as up-front vehicle costs decrease and to save energy in terms of total Btus of transportation energy. As a result, some stakeholders were interested in the opportunity to use vehicle electrification as a new, and significant, “energy efficiency” measure to meet their energy efficiency goals. Others commented that in the future, efficiency measures may be available for electric vehicles. One current example of that is the efficiency gains that can be realized by helping a customer install a level 2 charger instead of a level 1 charger.

While there was some diversity of opinion, most respondents struggled to imagine how vehicle electrification would fit within the current formulation of CIP. A number of respondents proposed a parallel framework, modeled on CIP, to address transportation efficiencies and carbon reductions in what has become the largest sectoral source of emissions in Minnesota's economy.

Key Areas of Disagreement

Challenges of electrification

The challenges stakeholders identified, in response to an open-ended question on the topic, reflect a wide variety of considerations. People identified programmatic, political, regulatory, cultural, economic, and technical challenges. Many respondents identified multiple challenges.

One common theme among respondents was the idea that the end-user technology is now market ready, and adoption barriers are mostly related to policy and consumer comfort with the technology. Advances in electric vehicles and heat pumps, in particular, are expected in the coming years, but at this point, either technology could be purchased by a consumer and it would meet their transportation, home heating, or water heating needs. Policy barriers, like the prohibition of fuel switching programs

within CIP, could hinder widespread adoption. And consumer education barriers, like not understanding the benefits and costs, a default preference for natural gas, and the need for contractor comfort with the technology provide the biggest barriers.

Another common theme was concern about getting the policy right. It will be challenging to properly measure benefits and create a system that ensures that Minnesota promotes only beneficial instances of electrification. The opinion was expressed by many individuals. Nick Mark at CenterPoint Energy stated it this way, “I think there are places where [electrification or fuel switching] does create opportunities for real benefit, but you need to think carefully about which end use you're talking about in any given context. ... One of my big worries through a lot of this process is that people are taking a paint roller to what really needs to be a pretty fine brushed sort of picture.”

There is work to be done to establish definitions and criteria for what qualifies as beneficial. There is work to be done aligning the load with the right generation mix to maximize benefit. There are unresolved questions about how to coordinate beneficial electrification within and beyond CIP, and whether that meshes with existing statute. Utilities need guidance as to what their role might be. The impact on non-participating customers of regulated electric and natural gas utilities needs to be considered. These are all pragmatic challenges identified by stakeholders.

Shawn White from Xcel Energy described these concerns. “Electrification can be beneficial under the right conditions. It would have to be a complex implementation, where you knew that you were going to get the right benefit from doing so. To make managed charging or water heaters’ benefits pay out, you can only use those when the wind is blowing or the sun is shining. Right now in CIP if you go and buy a light bulb you get a rebate, and electrification may be more complex than that.”

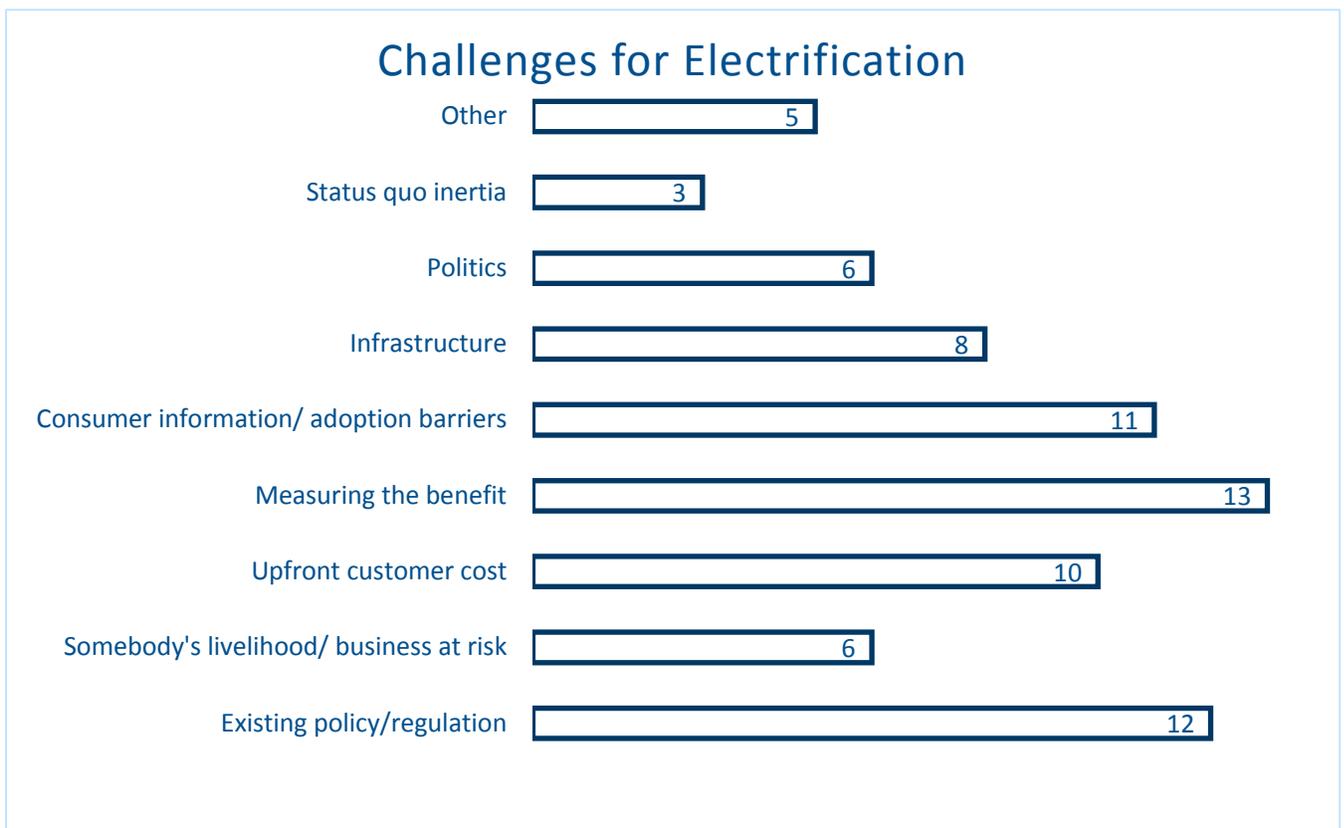
Some respondents commented that a challenge in future scenarios of an electrified economy will be addressing the winter heating peak and meeting the increased load from electric vehicle charging, especially from fast chargers. At the moment in Minnesota, most of that heating peak is fueled with direct combustion of natural gas and propane. Shifting that entire load (or even a large portion of it) onto electric heating will be complicated and may be costly. Without the right planning and control of technologies, this would put upward pressure on rates. On the vehicle charging side, one stakeholder stated that an EV fast charger draws 350 kW of demand, which compares to a grocery store’s peak of 450 kW. If fast charging becomes common, the grid will need to be able to accommodate a pretty large, intermittent load.

Some stakeholders felt society has developed a default preference for gasoline fueled vehicles and for natural gas fueled homes. Gasoline vehicles have been unchallenged as the default choice for over a century. Extending natural gas pipeline to unserved communities has been seen as a strategic priority in Minnesota for many years. Historically, the use of natural gas for space and water heating has been preferred because of low costs and higher efficiency. Engineering rules of thumb default to electric heat being two to three times more expensive than natural gas heat. New electric technologies add more variables that need to be considered, but any new technology must overcome the inertia of the status quo.

Political change may be challenging too. The underlying benefit of electrification is the reduction of carbon dioxide emissions. The drive to reduce carbon dioxide emissions stems from a desire to mitigate climate change. If climate change is a politically taboo subject, then beneficial electrification loses a strong part of its justification. Likewise, some stakeholders expressed uncertainty about how much and how organized opposition to legislation would be from propane dealers, biofuel manufactures, and petroleum refiners.

Figure 1 shows the diversity of challenges that stakeholders identified.

Figure 1: Stakeholder identified challenges for electrification



Desired outcomes from regulation

Responses to desired outcomes fell into two buckets – those who answered programmatically (from a perspective of CIP or a similar utility implemented program) and those who answered societally (from a perspective of consumers). Programmatically, some stakeholders expressed an interest in an outcome that would allow them to choose to pursue electrification and do so with some certainty around cost-recovery. For others, the most desired outcome was a replacement or reworking of CIP to allow for and include beneficial electrification. And another subset of respondents was particularly concerned about ensuring the outcome protected and fully valued energy efficiency. Clarity and definitions were a commonly sought outcome – specifically around the current goal of CIP, how to measure cost-

effectiveness of electrification, and how electrification will maintain the same customer protections (verification, validation, review, and approval) that make CIP so effective.

Those respondents who thought about societal outcomes were most concerned about serving the public interest, reducing carbon dioxide emissions and reducing costs for consumers. These stakeholders expressed interest in ensuring that electrification was truly beneficial, reduced costs, reduced carbon emissions, and made the grid more resilient and flexible. A positive outcome would be one that reduces barriers to the market and would engender public buy-in to support market transformation.

Businesses want low energy costs and open markets

A couple of stakeholders made it clear that their first priority in addressing opportunities for beneficial electrification (and other utility regulation issues) is keeping costs low. Nearly everyone included cost as a litmus test for whether electrification was beneficial, but a few stakeholders put a finer point on it. As an example, Cam Winton of the Minnesota Chamber of Commerce said that while electricity currently costs less in Minnesota than in coastal states, “the problem is the trend lines are going in the wrong direction. The price of electricity in Minnesota is going up faster than the national average, and the price of electricity in Minnesota is going up faster than inflation.” Winton said the Chamber’s member organizations, specifically those in retail, see value in reducing carbon emissions because their customers are expecting it. But, the expectation for electrification should be, as Winton said, “Bringing down cost and, if possible, while still bringing down cost, bringing down carbon. And, so to clearly rank it, what I hear from members is that cost is most important, and carbon is secondarily important.”

Fuels Institute Executive Director, John Eichberger, shared the business perspective on outcomes from regulation. “I think, for the most part, most organizations I interact with are the business-oriented. They are very much supportive of level playing fields, don’t pick winners or losers, let the customer decide. A more gradual, strategic, planned approach, one that brings the market along at a pace that makes sense and is sustainable is the right approach.”

One size fits all approach won’t work

There was interest in nuance and flexibility in any regulation of beneficial electrification. Kurt Hauser from Missouri River Energy Services stated, “We’d hope to see flexibility for utilities to find the best ways to promote and reduce and pursue beneficial electrification while they weigh whether each measure makes sense to utilities, the customer, and the carbon reduction goals. I hope we get to, not to a point where it’s required, but allowed.” Bob Jagaush of MMUA indicated that “investor owned utility solutions don’t work for 99% of municipal utilities. Communities with less than 1,000 customers can’t fit into the same policy as a larger utility.”

Additionally, there was some discussion from stakeholders about how technically rigorous calculations of costs and benefits present a challenge for smaller utilities. Some smaller utilities hoped that benefits of electrification measures could be figured out on average and included in the Minnesota Technical Reference Manual.

Whether electrification should be included in CIP

Respondents were divided when asked whether electrification could or should be implemented through CIP or whether it needed a framework of its own. The oversimplified distillation of their responses show that about a 1/3 of respondents said it required its own framework, 1/3 said it did not, and 1/3 said it was complicated.

While a few people expressed unabashed support for directly slotting electrification into CIP, most of those in favor of adding electrification to CIP recommended narrow criteria for what kind of electrification should be allowed. Recommended restrictions would narrow the scope of allowable electrification to those technologies where fuel switching offers some positive combination of consumer cost savings, total energy savings (in Btus of fuel used), and emissions reductions. Supporters stated that using the existing CIP framework would reduce administrative costs. CIP has proven administrative and consumer protection elements, which could also benefit electrification efforts. Others stated that efficiency is a core component of electrification. It's only because new, highly efficient technologies are on the market, that electrification can be considered beneficial. From a pragmatic perspective, using the existing CIP framework was suggested to be the extent of what is currently politically possible. However, supporters also commented that using the existing CIP framework may require a shift in CIP's goals, away from the reduction of one single type of fuel, toward a grid management, total Btu, or carbon reduction goal.

Respondents who thought that electrification did not belong within CIP argued that the reasons we might want beneficial electrification are different enough from the reasons that we want energy efficiency, and that keeping them separate would deliver better outcomes for both efforts. One concern was that adding a load-building activity into a conservation program would result in backsliding or erosion of the efficiency outcomes of CIP. Utilities have a market incentive to encourage electrification, but the same is not true of energy efficiency without incentives from CIP – so keeping them separate would allow better management of those financial incentives.

Meeting the 1.5% reduction goal would be complicated by including efforts that increase sales. Keeping them separate, with electrification falling into a yet-to-be-created carbon-reduction program would allow regulators to encourage the most cost-effective carbon reduction strategies. Strategies that fit within CIP might be more expensive than other carbon abatement strategies, and a separate framework would allow cross-sector comparisons of costs per ton of carbon reduced.

Many respondents felt both ways about the topic or weren't sure of the best way to proceed. They saw some instances and reasons to allow some beneficial fuel switching within CIP, and still other reasons to encourage it beyond the scope of CIP. Their comments echo elements of the other positions: the need to rework CIP's goal, get financial incentives right, and put in narrow criteria for what qualifies as beneficial. Some expressed that beneficial electrification *could* fit within CIP, but that did not mean it necessarily *should* fit. If regulators and stakeholders determine that housing electrification within CIP is a bad choice, there would still be societally beneficial reasons to pursue it within a different framework or mechanism.

Efficiency and electrification will compete for resources

“If electrification is simply lumped into CIP, I think there's a real risk of a zero-sum game adversely affecting energy efficiency,” said Martin Kushler, at ACEEE. Most stakeholders agreed that energy efficiency provided value to Minnesota and that programs should be maintained. Many stakeholders made the point that beneficial electrification was only possible because of highly efficient new technologies. However, a smaller group of people took the step to state that electrification would compete with efficiency resources if allowed to. Kushler suggests it would be wiser to keep the two separate because, given the opportunity, utilities will prefer to promote the end use which consumes more of their fuel, rather than less of it. He says, “I would recommend a separate framework. Given a limited overall tolerance for costs that are imposed on ratepayers, program costs and so forth, there will be some finite amount that can be expended on CIP. Within that budget ‘pie’, if you give the utilities a choice, they'd much rather spend it towards electrification than efficiency. If you lump it all under the same goal and the same umbrella, they're going to be pushing hard to do more of what they want and less of what they don't. Whatever the final structure, it's very important that distinct savings goals, funding and incentives for energy efficiency are maintained.”

Beneficial electrification will increase CIP goals and RPS goals

Goals for CIP and Minnesota's renewable portfolio standard (RPS) are set as a fixed percentage of a utility's sales. Growth in sales, as a result of beneficial electrification, will also result in growth in those goals. Minnesota's RPS goal is 25% renewable energy by 2025 (§216B.169). CIP contains both a spending requirement and a savings goal based on a percentage of annual sales (§216B.241, subdivision 1(a) and 1(c)). Stakeholders especially struggled to rectify how CIP goals would shift as the utility achieved beneficial electrification objectives. Some utilities felt this goal would become much harder to meet if it grew as a result of widespread electrification, especially of the transportation sector.

Additional Questions

Many questions were raised by stakeholders that need further consideration as a stakeholder community, and by regulators in the state. A compilation of those questions is provided below.

Questions around policy and program development:

- What are the goals of electrification?
- Should any electrification be counted toward CIP goals?
- What is the goal of CIP?
- How can societally-beneficial things be done in a least-cost manner?
- Should beneficial electrification be supported as a public good in the rate base or funded by consumers themselves?
- How can programs be designed and implemented?

Questions around the public's reception and equity:

- How receptive will end-users be to switching away from whatever they are using today?
- How can these benefits be attained for all income levels?
- How do you advance cleaner and cheaper technology in a way that's fair for all Minnesotans?
- How do we ensure consumer protections?

Questions about costs and benefits:

- What are the specific air quality and GHG emissions benefits from each beneficial electrification technology at a given time of day?
- How much does it cost and who will pay for it?
- How can we be as transparent and specific as possible in assigning costs and benefits?

Questions about the utility's role:

- What is the guidance regarding what is allowable for utilities?
- What costs can utilities recover?
- Should all utilities have the same policy for fuel switching?
- What's the utility's role in promoting a specific fuel type's use?
- How can we tailor policy to the utility, so we don't have a one size fits all solution?

Technology Research

Introduction

Calculating the benefits and costs of new technologies is complicated in the cases of electrification and fuel switching. There are many impacts and benefits that are difficult to quantify, including indoor air quality, mobile point-source emissions, demand flexibility, storage capacity, and process improvements. Costs can be challenging to quantify. Firm installation costs can be hard to gather and are dependent on region, the scope of the individual project, and even time of year. And unique factors like using marginal versus average emissions factors and costs to non-participating ratepayers of both the fuel selected and the fuel abandoned, need to be considered.

Work is needed to develop the right metrics for evaluating these technologies, as the standard tools in our energy efficiency and regulatory toolbox may not deliver the sophistication needed.

This paper seeks to provide an introductory look at a few of the technologies that have garnered the most interest, both in market share and mindshare. This section is not meant to be an exhaustive analysis of these technologies, but rather an introduction to the technology, a discussion of what they would replace, the costs and benefits, and a chance to point readers to additional research. In short, this section presents a technical literature review of electrification technologies.

Methodology

Annual Energy Cost

Annual energy cost for each technology is calculated using publically-available data. In most cases, the Minnesota Technical Reference Manual calculation methodologies are used. For certain cases, published papers or calculators from research organizations are used instead. Sources for each calculation methodology are included in the respective technology section, along with assumptions specific for each case.

Electrical energy use is converted to cost using an average blended rate of \$0.10/kWh, based on EIA data on the average retail price of electricity in Minnesota for 2016.³ For heating fuels, energy cost calculations use an average natural gas rate of \$0.80/therm⁴ and an average propane rate of

³ [U.S. Energy Information Administration, Minnesota Electric Profile, 2016 \(https://www.eia.gov/electricity/state/Minnesota/\)](https://www.eia.gov/electricity/state/Minnesota/).

⁴ [U.S. Energy Information Administration, Natural Gas Prices, Minnesota \(https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SMN_a.htm\)](https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SMN_a.htm).

\$1.73/gallon⁵. For transportation fuels, energy cost calculations use an average gasoline rate of \$2.83/gallon and an average diesel rate of \$3.00/gallon⁶.

Source Energy

Energy use for most technologies is calculated in terms of source energy (sometimes called primary energy). Efficiency and customer costs are typically calculated based on the energy use at the end-use level (also known as site energy or final energy). Source energy use, on the other hand, captures the energy required to generate and deliver the energy, as well as operate the equipment.

Electricity generation using fossil fuels takes two to three times the amount of energy delivered to the site to generate the energy at the source, based on the efficiencies of the power plant and transmission losses. The source energy of these fuels, sometimes called “heat rate,” is between 7,800 and 11,000 Btus per kWh of electricity generated, depending on the fuel type. Recent guidance from the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) states that the renewable energy sources should be treated as delivering electricity at the conversion rate of Btus to kWh: 3,412. This method is known as the “captured energy” approach. (DOE EERE, 2016) Renewable sources are not 100% efficient at capturing the energy from their respective resource (i.e. wind, sun, water), but this methodology accounts for the fact that renewable resources consume a free fuel and that they do not waste the portion of unused fuel like other generation. The difference in source energy use between renewable and traditional generation is important in the context of electrification because as the fuel mix for the grid becomes more renewable, the overall source energy use for electricity will decrease.

In order to determine the source energy used by a particular technology, the energy consumed by the equipment at the meter (site energy) is multiplied by a source energy factor. The source energy factor is essentially a weighted average of all electricity generation by type and their respective source energy factors. Using the “captured energy” methodology outlined by the DOE EERE, the overall source energy factor for Minnesota is 2.8 based on the statewide fuel mix in 2017 (EIA). The full calculation of the Minnesota source energy factor is given in [Appendix B](#).

Annual Utility Emissions

Along with energy use and cost of energy, carbon dioxide (CO₂) emissions are an important metric when comparing technologies, especially since a justification for the benefit of electrification is climate change mitigation. The increasing amount of intermittent renewables on the grid make calculating emissions for a specific end-use complex. In this paper, we used a high-level annual emissions analysis, because it was

⁵ [U.S. Energy Information Administration, Petroleum & Other Liquids, Weekly Minnesota Propane Residential Price \(https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=W_EPLLPA_PRS_SMN_DPG&f=W\)](https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=W_EPLLPA_PRS_SMN_DPG&f=W)

⁶ [U.S. Energy Information Administration, Weekly Retail Gasoline and Diesel Prices, U.S. \(https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm\)](https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm)

accessible and provides a rough picture of the benefits. However, we recommend that more sophisticated calculations and models be developed.

In this paper, annual CO₂ emissions for electricity are calculated using an average rate of 1.3 pounds of CO₂ per kWh, which is based on the Minnesota fuel mix in 2017⁷. Other emissions factors include 11.7 lbs CO₂ per therm of natural gas, 12.7 lbs CO₂ per gallon of propane, 23.5 lbs CO₂ per gallon of gasoline, and 22.4 lbs CO₂ per gallon of diesel fuel.

Emissions are not only dependent on the overall fuel mix of the grid, but the instantaneous fuel mix at the time of electricity generation. Marginal emissions analysis becomes necessary when discussing the kinds of generation sources activated at various times of the day. For example, plugging in an electric vehicle at 11 PM will likely coincide with peak wind energy production in Minnesota. In this case, the marginal emissions for adding widespread EV loads could be quite low, as wind has no associated emissions factor. However, home cooling at 4 PM corresponds to peak grid demand, typically satisfied by coal generating plants in MISO territory, so additional load results in higher marginal carbon dioxide emissions.

This topic is of keen interest to many stakeholders because how emissions are calculated can impact the change-over point for when a technology becomes beneficial. The Regulatory Assistance Project outlines three methods for identifying marginal emissions. Their methods vary in complexity and accessibility. The first and most robust method for calculating marginal emissions is a true hourly marginal emissions model. The system operator would publish data on the generation resource on margin for each hour of the year which can be compared to the load shape (or profile of energy consumption) for a given electrification measure. The second method is a deemed savings model, where each electrification measure would be analyzed and then generalized to provide standardized values for marginal emissions impact. Finally, system operators or regulators could review historic marginal generation to provide guidance as to which resource is likely on the margin at which time of year. This generic data could be used for estimating emissions impacts. (Regulatory Assistance Project, 2018)

Installed or Initial Cost

Installed or initial costs are provided for all technologies save for industrial processes. In all cases, publically available cost data is listed for each technology. Most residential costs are taken from the NREL National Residential Efficiency Measures Database, supplemented by deemed costs from the Minnesota TRM and Illinois TRM as noted. For commercial measures, costs listed in other research papers and online calculators were used.

⁷ Minnesota generation data from EIA. Fuel specific emissions factors: 2.2 lb CO₂/kWh generated from coal, 1.0 lb CO₂/kWh generated from natural gas. Data also referenced from [Alternative Fuels Data Center \(https://www.afdc.energy.gov/vehicles/electric_emissions_sources.html\)](https://www.afdc.energy.gov/vehicles/electric_emissions_sources.html) and [Xcel Energy and Carbon Emissions Reporting \(https://www.xcelenergy.com/staticfiles/xe-responsive/Environment/Carbon/Carbon-Reduction-2016-Energy-and-Carbon-Summary.pdf\)](https://www.xcelenergy.com/staticfiles/xe-responsive/Environment/Carbon/Carbon-Reduction-2016-Energy-and-Carbon-Summary.pdf)

Installed costs can vary widely based on region. Cost ranges are given to reflect the variety of costs based on installation parameters and complexity.

Impact on Peak Demand

The metrics given for peak demand are intended to be order-of-magnitude, designed to reflect whether a particular technology will increase or decrease peak demand relative to another. When possible, the maximum peak demand was calculated using publically available data. In other cases peak demand estimates were unavailable.

For technologies involving charging and plug-in equipment, the impact on peak demand will be greatly affected by the charging schedule and usage patterns. Additionally, certain technologies like heat pump water heaters allow for advanced controls to shift hot water production to off-peak periods. The coincident peak demand values given in this analysis do not account for any scheduled charging or load shifting. In other words, the coincident peak demand is calculated based on the “worst-case” scenario.

Heat Pump Water Heaters

Description

Heat pump water heaters (HPWHs) use a vapor-compression system to extract heat from surrounding air to heat water. Ambient air passes over an evaporator coil, which boils refrigerant and cools the air. Hot refrigerant gas is compressed and then sent through a condenser in the storage tank, heating the stored water. The cooled refrigerant passes through an expansion valve into an evaporator to be re-heated by ambient air.

HPWHs are designed to replace both electric-resistance and gas-fired water heaters and can be used in both residential and commercial applications. HPWHs are much more efficient than both electric-resistance and gas-fired water heaters on a site energy basis (how much energy the equipment itself consumes), but can impose a heating load depending on the nature of the space where the unit is located.

Metrics

Table 1: Metrics for water heating technologies

Water Heater Type	Energy Factor	Annual Energy Cost	Annual Source Energy	Annual Utility Emissions	Installed Cost	Impact on Coincident Peak Demand
Storage tank water heater, electric-resistance	0.96	\$340	33 MMBtu	4,700 lbs CO ₂	\$540 - \$660	0.4 kW
Storage tank water heater, natural gas	0.68	\$130	17 MMBtu	1,900 lbs CO ₂	\$850 - \$1,000	None
Storage tank water heater, natural gas condensing	0.80	\$110	15 MMBtu	1,600 lbs CO ₂	\$1,200 - \$1,400	None
Storage tank water heater, propane	0.68	\$310	16 MMBtu	2,300 lbs CO ₂	\$850 - \$1,000	None
Storage tank water heater, propane condensing	0.80	\$260	14 MMBtu	1,900 lbs CO ₂	\$1,200 - \$1,400	None
Heat pump water heater, electric-resistance home heating (COP = 1)	2.35	\$200	20 MMBtu	2,800 lbs CO ₂	\$1,400 - \$2,600	0.2 kW (heat pump operation) 0.4 kW (electric backup)
Heat pump water heater, gas furnace home heating (AFUE = 80%)	2.35	\$170	18 MMBtu	2,400 lbs CO ₂	\$1,400 - \$2,600	0.2 kW (heat pump operation) 0.4 kW (electric backup)

Energy calculation methodology per MN TRM: “Residential Hot Water – Heat Pump Water Heater”. Assumes: 50-gallon water heater; installation in a single-family home in central MN; 20.4 gals/person hot water usage; 2.59 residents (on average); and 120°F and 51.3°F hot and cold water temperatures, respectively. Cost data comes from the NRELNREMD and supplemented by data from the IL TRM.

Water heaters are rated using energy factor, which is the efficiency of the unit including heat losses to the surroundings measured over a 24-hour period with a standard usage profile. Traditional gas-fired water heaters have a typical energy factor (EF) of around 0.68, while high efficiency condensing water heaters have an EF of around 0.8. Electric-resistance water heaters have an EF of around 0.9. By contrast, HPWHs have an EF of 2.0 and above, meaning that heat pump units deliver more energy than they consume in fuel. By pulling heat from the space in which they are located, HPWHs achieve an EF of greater than 1.0. This does mean that an incremental space heating load is added to the HVAC system, which can result in net energy use increasing in the building depending on the efficiency of the building’s HVAC system itself and where the water heater is located. It is also important to note that the efficiencies used in this analysis are sample efficiencies, and the energy factors of actual equipment can vary from these examples even among units with the same fuel source.

On a site energy basis (how much energy is used at the building or site level), heat pump water heaters are much more efficient than either gas or electric-resistance water heaters. On a source energy basis, however, a standard-efficiency gas-fired water heater is comparable to both cases of heat pump water heater installations (gas furnace and electric-resistance heating). With a gas-fired water heater as a baseline, a HPWH will contribute to a small increase in electric demand. According to the Building America House Simulation Protocols data, peak domestic hot water use in the residential sector is 9:00 AM, and from 6:30 PM to 9:00 PM, while commercial usage varies depending on the building type (NREL, 2013). MISO defines electric utility on-peak hours as 6:00 AM CST until 10:00 PM CST, so residential hot water use will fall within peak periods. Impacts on peak demand can be alleviated by installing a HPWH with a high insulation rating, and advanced controls to generate hot water during off-peak times.

Other Notes

Any type of water heater with a tank offers the ability to store hot water for later consumption. Super-insulated, large capacity tanks are available for even longer storage of hot water. HPWHs and electric water heaters could provide a benefit to the grid by being charged when renewable energy is abundant and cheap. Consumers benefit by getting lower priced energy. This combination of lower priced energy and control of water heaters into consumer energy with low emissions changes the standard assumptions that feed into this technical analysis.

Gap Analysis

In general, the research and published literature for HPWHs is robust. The technology is well-understood, and HPWH units have become a feasible and energy-efficient alternative to gas-fired and electric water heaters over the last few years. A study conducted by the Center for Energy and Environment (CEE) in 2015 concludes that, particularly for existing electric-resistance water heaters, HPWHs are a good energy-efficient alternative. CEE's study collected field data on water heater usage from homes in the Twin Cities. According to the data, the average peak demand of a HPWH is about 0.5 kW between 7 AM and 9 AM. The same data shows the average peak demand of electric-resistance water heater is almost 2.5 kW during the same time period, which is much higher than the demand calculated using the methodology provided in the TRM. This is most likely due to the TRM calculations providing an average annual kW, which does not necessarily reflect the true peak demand of the equipment. The study also shows a smaller peak demand reduction from electric-resistance to heat pump water heaters during the evening. (Center for Energy and Environment, 2015)

As mentioned previously, a HPWH draws heat from the surrounding area. If the HPWH is located in a conditioned area, this will result in an increase in either gas or electric usage depending on the building's heating fuel. For electrically heated buildings, this can also result in an additional peak demand load during the heating season. The effects of this peak demand increase due to HVAC interaction were not quantified in this analysis. The CEE study does quantify the incremental heating use of an air-source heat pump HVAC system when the additional HPWH load is added, but is not specific about impacts of

incremental heating on the peak demand for such a system. These impacts will likely require a more rigorous hourly analysis, between several types of home heating systems (gas furnace, electric-resistance, air-source heat pump).

As HPWH technology evolves, methods for controlling heat pump units will also improve. Simple on-off, “on-demand” controls are considered baseline for water heaters, but advanced methods such as time-of-day scheduling and even predictive control systems are now being studied for future implementation (Delforge, Larson, & Vukovich, 2018). Controlling when and how often a HPWH runs during the day will have significant impacts on energy cost, source energy, and utility emissions. Again, a full hourly analysis is needed (specific to Minnesota grid fuel mix and prices) to quantify the full benefits of such advanced controls.

One aspect of published HPWH analyses that hasn’t been quantified is the benefit of dehumidification during the summer. Because a HPWH pulls heat from the surrounding air, cold air is exhausted from the unit, dehumidifying the space. If a home with a damp basement is equipped with a standalone dehumidifier, a residential HPWH could offset dehumidifier use (as long as the HPWH was located in the same space as the dehumidification need).

Because the technology has matured, cost data has changed significantly over the past five years. As a result, newer costs should be collected and studied in order to inform utility program cost-benefit tests.

Home Heating with Heat Pumps

Description

Heat pump technology has existed as a method of conditioning buildings since the 1970s. While they still represent the minority of HVAC installations for heating and cooling homes, their penetration into new homes has been increasing steadily since the mid-1990s (Lapsa, Khowailed, Sikes, & Baxter, 2017). Heat pumps use vapor-compression systems to provide both heating and cooling with the same compressor system and transfer heat from a heat sink either into or out of the home. Heat pump heat sinks can be in the ground (geothermal or ground-source heat pumps, GSHPs), a water loop (water-source heat pumps), or ambient air (air-source heat pumps, ASHPs). Air-source heat pumps, in particular, have dropped in cost and improved their low-temperature operation. Specifically, cold-climate air-source heat pumps (CCASHPs) are now becoming viable for home heating in heating-dominated climates due to recent developments in refrigeration technology and the advent of variable-capacity heat pumps. Some cold-climate heat pump units can provide partial heating down to ambient temperatures as low as -15°F. Other configurations may require switching to a backup heat source at a higher cut-off temperature. Ground-source heat pumps do not have the need for a backup heat source because the temperature of the ground well does not drop as low as the air. However, they do require a more expensive installation of a well field.

Heat pumps can replace both gas furnace and electric-resistance heating units. The Minnesota TRM includes both gas furnace and electric-resistance heating as qualifying baseline technologies, as well as an existing but less efficient air-source or ground-source heat pump.

Metrics

Table 2: Metrics for home heating technologies

Heating System Type	Heating Efficiency	Annual Heating Energy Cost	Annual Source Energy	Annual Utility Emissions	Installed Cost	Impact on Winter Coincident Peak Demand
Electric-resistance heating	1.0 (COP) 3.1 (HSPF)	\$2,000	196 MMBtu	27,800 lbs CO ₂	\$3,600 - \$4,400	11 kW
Furnace (natural gas)	80% (AFUE)	\$700	91 MMBtu	10,200 lbs CO ₂	\$4,400 - \$5,400	None
Condensing furnace (natural gas)	95% (AFUE)	\$600	77 MMBtu	8,600 lbs CO ₂	\$4,900 - \$6,000	None
Furnace (propane)	80% (AFUE)	\$1,600	88 MMBtu	12,100 lbs CO ₂	\$4,400 - \$5,400	None
Condensing furnace (propane)	95% (AFUE)	\$1,400	74 MMBtu	10,200 lbs CO ₂	\$4,900 - \$6,000	None
Air-source heat pump (electric-resistance backup heat)	2.3 (COP) 7.7 (HSPF)	\$1,100	109 MMBtu	15,400 lbs CO ₂	\$3,700 - \$4,600	5 - 11 kW
Air-source heat pump (natural gas backup heat, 80% AFUE)	2.3 (COP) 7.7 (HSPF)	\$900	88 MMBtu	11,900 lbs CO ₂	\$3,700 - \$4,600	5 kW
Ground-source heat pump	3.7 (COP)	\$400	43 MMBtu	6,100 lbs CO ₂	\$9,800 - \$12,000	2 kW

Energy calculation methodologies per MN TRM: “Residential HVAC - Mini Split Ductless Systems A/C only and Heat Pump”, “Residential HVAC - Ground Source Heat Pump Systems”. Assumes: 3-ton system, 1,200 sq ft home; 1,932 heating EFLH per MN TRM for Twin Cities area. Annual heating energy for ccASHP includes approximately 20% of heating operating using backup fuel (electric or natural gas) with a 10°F changeover temperature, either electric or gas (Center for Energy and Environment, 2017). Cost data comes from the NREL NREMD. Costs are supplemented by data from the report “Cold Climate Air Source Heat Pump” by CEE (Center for Energy and Environment, 2017) and from “Implications of Policy-Driven Residential Electrification” by ICF (ICF, 2018). Costs include replacing central heating and cooling units but not for installing new ductwork or installing utility infrastructure (e.g. gas lines or propane storage).

System costs for heat pump systems vary widely depending on whether:

- The building is new or existing.
- The existing system is ducted (central) or ductless (e.g. baseboard radiation), and whether ductwork will be added.
- The backup fuel currently exists or needs to be added (retrofit applications).
- The home has A/C currently (retrofit applications).

In the table above, cost ranges are based on residential retrofit installations for central heating and cooling systems (ducted systems), using the efficiencies given.

Residential heat pump heating efficiency is typically given as a heating system performance factor (HSPF). HSPF is defined as the heating capacity of the equipment (in MBH) divided by the power used (in kW). Another method to define efficiency is the coefficient of performance (COP), which is defined as heating or cooling capacity divided by the power used, both in consistent units. COP is commonly used for GSHPs specifically.

The 2015 Minnesota Energy Code lists a standard air-source heat pump HSPF of 7.7 (COP = 2.3), and a standard ground-source heat pump COP of 3.7. The Federal efficiency standard for an ASHP is an HSPF of 8.2 (COP = 2.4), and a COP of 3.6 for GSHPs. The table above uses the Minnesota Code efficiency for air-source and ground-source heat pumps. Meanwhile, an electric-resistance heater has a COP of 1.0, and a traditional gas furnace has an AFUE of 80% (AFUE is another measure of efficiency, functionally equivalent to COP). High-efficiency furnaces have an AFUE of 95% and higher in some cases.

New air-source and ground-source heat pumps, in general, have a comparable efficiency in cooling mode as similarly-sized conventional central air-conditioning units. If the heat pump is replacing an older unit there may be a peak summer demand reduction due to improved cooling efficiency. However, some Minnesota homes do not have air conditioning. Therefore, installing a heat pump system that provides cooling, as well as heating, will add a net cooling load to the grid, increasing summer peak.

Other Notes

Air-source heat pumps do require a backup source of heating to function in low ambient temperature conditions; these are typically electric-resistance heating elements. If a particular unit is not rated for temperatures down to -15°F (perhaps only down to 5°F or 0°F), a newly-installed heat pump system will add to the building's peak winter demand during extreme weather more frequently compared to a natural gas or propane-fueled furnace. If comparing to an electric-resistance heating system, there will be no change to winter peak demand at low ambient temperatures. As mentioned previously, this is not a concern with ground-source heat pump systems.

Besides the fact that ground-source heat pumps do not require a backup source of heating, unlike cold climate air-source heat pumps, ground-source systems can also provide domestic hot water. Waste heat from the desuperheater can be collected in a separate water tank and used for domestic hot water in the home, representing 50-60% of the hot water needs for a home depending on the operation of the

GSHP system. The additional benefit of this waste heat for domestic hot water use is not included in this analysis. The main barrier to GSHP adoption, though, continues to be a high first cost for the system.

Air-source heat pumps can be installed as a whole-home central unit (re-using existing or installing new ductwork), or as smaller units in individual rooms or portions of the home. Installation methods can significantly impact the cost of a retrofit heat pump system, depending on factors such as backup fuel source or ductwork needed.

Gap Analysis

The applications and benefits of heat pump systems, specifically air-source heat pumps, are relatively well-documented. However, the next challenge for heat pumps is the integration of such systems into utility programs. Particularly difficult is capturing savings for heat pump systems in instances of fuel switching.

In addition to primary heating and backup heating modes, air-source heat pump systems also operate in defrost mode occasionally depending on the ambient conditions. As the heat pump system operates, the cold outside coil causes ambient moisture to condense and eventually freeze onto the evaporator coil. Periodically, the heat pump will switch to defrost mode, either by activating a dedicated coil heater or by reversing the heat pump system to circulate hot refrigerant through the outside coil. In a reversing defrost mode, the heat pump will actually be cooling the home, requiring the backup heat source to mitigate this effect in addition to providing heating to the home. The amount of time the system spends in defrost mode can have a significant effect on overall system efficiency. While the impacts of such a defrost cycle are well-documented, such impacts must be explicitly included in future hourly models to determine specific peak demand impacts at various times of the day.

Electric Lift Trucks

Description

Lift truck vehicles (also known as forklifts) complete a variety of tasks in commercial and industrial settings. Lift truck vehicles can be powered by a variety of sources: internal combustion (IC) engines, fueled by propane or diesel (or occasionally natural gas), and AC motors and batteries within the unit.

Electric lift trucks have several advantages. Electric lift trucks tend to be smaller than their IC counterparts, mainly due to the smaller size of the motors compared to IC engines but also fewer or smaller auxiliary components like cooling equipment. Electric motors are quieter than IC engines. Electric lift trucks are also much cheaper to operate than diesel or propane units, both from a fuel cost and maintenance cost basis. Decreases in battery cost and size have expanded electric lift truck applications. Finally, since electric motors do not emit any point-source pollution, electric lift trucks can improve air quality and reduce ventilation requirements if the equipment operates indoors. However,

the upfront cost is about 20% to 40% higher than an IC vehicle due to the batteries and charging equipment required to run multiple shifts (EPRI, 2009).

Metrics

Table 3: Metrics for lift truck technologies

Engine Type	Fuel Consumption	Annual Energy Cost	Annual Utility Emissions	Capital Cost	Impact on Coincident Peak Demand
Diesel	1.0 gal/hr	\$18,600	139,000 lbs CO ₂	\$23,000 - \$27,000	None
Propane	1.5 gal/hr	\$20,100	121,000 lbs CO ₂	\$22,000 - \$27,000	None
Electric	7.8 kWh/hr	\$4,900	80,000 lbs CO ₂	\$31,000 - \$38,000	7.6 - 30.0 kW, but minimal if charged during off-peak periods

Average fuel consumption per shift from EPRI online calculator, via a 1994 study by the International Truck Association (EPRI). Assumes: 5000-lb capacity lift truck. Fuel costs: \$2.11/gal propane, \$3.00/gal diesel. Assume 3 shifts, 5 days per week of usage. Cost data from EPRI online calculator; electric lift truck costs include charging equipment.

Other Notes

In addition to reducing emissions on the utility level, electric lift trucks produce no point-source pollution. If lift trucks are used indoors, this can allow facility staff to significantly decrease the ventilation and exhaust levels in their building, provided they were ventilating properly in the first place. The 26th Edition of “Industrial Ventilation: A Manual of Recommended Practice for Design) by the American Conference of Governmental Industrial Hygienists (ACGIH) recommends the following dilution rates for vehicles:

- 10,000 cfm/propane-fueled lift truck
- 100 cfm/hp of diesel-fueled vehicles (ACGIH, 2007)

Assuming the building HVAC equipment meets these requirements with propane- or diesel-fueled lift trucks, switching to electric vehicles would allow staff to significantly reduce ventilation and exhaust levels for the building. This would result in fan energy savings, as well as heating and cooling savings for eliminating the need to condition make-up air.

Recent case studies on electric lift trucks mention that one of the main barriers to adoption is the perception that electric lift trucks are not suitable for outdoor applications. In fact, when equipped with pneumatic tires (as opposed to solid cushion tires, typical for indoor applications), electric lift trucks are just as capable as propane- or diesel-fueled units in outdoor settings.

Peak demand impacts will depend heavily on when the electric truck batteries are charged. Many batteries are capable of sustaining electric lift truck operation for two eight-hour shifts during a typical production day, assuming a typical 50% operating time during each shift (EPRI, 2015). Charging banks can also be programmed to charge only during off-peak periods, so a set of fresh batteries can be charged overnight and swapped before the beginning of a new shift. However, if a customer only purchases one battery or charges batteries manually, there may be additional peak demand if charging is needed during the day.

Gap Analysis

Publicly available calculators and studies on electric lift trucks reference costs that are likely outdated, though the general consensus is that electric lift trucks are 20-30% more expensive on a first-cost basis than conventional vehicles (EPRI, 2009). Interviews with industry experts and studies of current models on the market would help refresh these assumptions. Additionally, those same sources cite that electric lift trucks have 30-40% lower maintenance costs than propane- or diesel-fueled vehicles. Surveys of lift truck costs direct from manufacturers could be useful in refreshing capital cost data, and further studies into maintenance costs with end users would also be beneficial.

As electric lift trucks continue to advance, so too does battery technology. Older battery chargers use ferroresonant (FR) or silicon-controlled rectifier (SCR) technology to charge batteries, but newer units use high-frequency (HF) charging to improve efficiency by up to 10% (PG&E, 2009). HF chargers also enable “opportunity charging,” where batteries can be plugged in during breaks for short durations. However, more recent field studies show that the benefits of HF chargers are highly dependent on lift truck usage and that smaller operations may not benefit from the increased efficiency or capability for opportunity charging (Franklin Energy, 2017). Additional data is needed to clarify these benefits.

Electric Trailer Refrigeration Units

Description

Refrigerated trailers commonly use diesel-powered cooling units to keep goods cold during transport. Trailer refrigeration units (TRUs) first began to be electrified in Europe and have slowly been introduced in the US over the past 10 years. There are two main types of electrified TRUs: hybrid electric TRUs, which use a mechanical diesel-driven compressor with an option for electric plug-in power; and electric TRUs (sometimes referred to as an eTRU), which use completely electric components and include diesel-powered electric generators for on-road use. While an eTRU is “electric-first”, it’s not a fully electrified option due to the dependence on diesel fuel when on-road.

Metrics

Table 4: Metrics for trailer refrigeration unit technologies

TRU Type	Average Fuel Consumption	Annual Energy Cost	Annual Emissions	Capital Cost	Impact on Coincident Peak Demand
Diesel	0.7 gal/hr	\$6,600	49,000 lbs CO2 (point-source)	\$20,000 - \$30,000	None
Electric	2.9 kWh/hr	\$900	12,000 lbs CO2 (utility-level)	\$23,000 - \$33,000	Dependent on plug-in period

Average fuel consumption from Shurepower report on TRUs on behalf of NYSERDA (Shurepower, 2005). Assumptions: 10 hours of standby operation (industry-standard rest time for drivers, the opportunity for plug-in “shore power”), 6 days per week, 50 weeks per year. Fuel consumption, energy cost, and emissions data for standby operation only. Capital cost for electric TRU does not include infrastructure upgrades.

Other Notes

The major hurdle with the adoption of electric trailer refrigeration units is the availability of plug-in connections (also known as “shore power”). Utility customers with a large refrigerated trailer fleet may elect to install eTRU equipment and upgrade or install shore power at their facilities. However, making the required infrastructure upgrades at rest stops and truck parking areas requires a significant municipal or private investment.

One major benefit of an electric trailer refrigeration unit is ambient noise reduction. A diesel generator powering a trailer refrigeration unit produces noise levels up to 70 dB standing next to the unit, which is reduced to approximately 50 dB at 300 feet away (for reference, 70 dB is the sound of a lawnmower at close range, and 50 dB on the lower end of urban ambient sound levels) (Thill, 2013). In an urban area, this sound may not rise about the ambient noise level, but it becomes much more noticeable in quiet residential areas where the ambient noise level is around 20-30 dB. Multiple trailers parked in close proximity will also compound noise levels. Some cities even have noise restrictions specifically for refrigeration units (Shurepower, 2005). Assuming these rest stops install plug-in capability (“shore power”), noise levels during standby operation can be significantly reduced while trailers are parked. However, deciding who pays for the energy used at shore power stops remains an open question.

Another advantage of an eTRU is the reduction in maintenance costs over conventional diesel-powered refrigeration equipment. While an eTRU typically still requires a diesel engine for road power (usually a dedicated generator), relying on the electric components for standby refrigeration results in a net maintenance benefit over the life of the unit. Studies of the technology and estimates from industry professionals have shown maintenance costs to be 30% to 40% lower for an eTRU than conventional refrigeration unit (Shurepower, 2005).

A trailer refrigeration unit will have additional losses when converting from a belt-driven compressor to a standalone diesel generator while on-road, as the generator will have its own efficiency in addition to

the efficiency of the refrigeration circuit. In general, however, these losses do not cancel out the efficiency gains of an eTRU.

Gap Analysis

Electric refrigeration units exist that mount to the truck cab directly instead of the trailer. While this research focused only on the trailer refrigeration unit, energy and maintenance savings are also possible for a truck refrigeration unit. Truck refrigeration units are generally smaller, meaning they cost less upfront but also result in lower savings than the trailer unit. Therefore, the payback on a truck refrigeration unit is similar to a trailer unit.

The potential of this technology is limited by shore power installations at loading docks, rest stops, and parking areas. According to a list maintained by the Alternative Fuels Data Center (AFDC), there are 105 electrified truck stops in the U.S. (DOE EERE). The number of electrified stalls and equipment compatibility varies from stop to stop. According to this list, most electrified truck stops are located on the east and west coasts. Very few locations are included for the upper Midwest, particularly North and South Dakota, Minnesota, Wisconsin, Iowa, and Illinois. It is likely this is not an exhaustive list, but what is unknown is the density of electrified truck stops that is sufficient to truly support this technology.

Industrial Electrification

Description

Electrification of industrial processes offers unique benefits outside the conventional residential and commercial markets, such as reduced equipment size, improved process speeds, and reduced point-source emissions. However, industrial applications typically require custom equipment designed specifically for the customer and their product(s). In some cases, there is not a clear advantage between the electrified process and the conventional technology. Therefore, creating a one-size-fits-all metric for comparison is difficult. The information included below is a high-level exploration of processes ideal for electrification, the benefits of electrification, and tradeoffs for the customer to consider.

Process Heating

Process heating is a general term for any kind of heating of materials in the production of goods. This can include preheating before additional manufacturing steps, surface heat treatment, curing, and drying. The conventional fuel for process heating furnaces is natural gas. Relying on combustion to heat the air inside the furnace (indirect heating) leads to significant losses associated with the exhaust air. As much as 80% of the combustion energy can be lost depending on the process temperature (DOE EERE, 2004), though some of this heat can be recaptured by heat recovery systems. Byproducts of combustion from natural gas furnaces must also be managed to prevent issues with indoor air quality.

Electric-resistance heating

Electric-resistance heating, both indirect and direct, offer several benefits compared to traditional combustion furnaces. Indirect electric-resistance furnaces operate much like a regular oven, using convection to move heat from an electrically-resistive element to the workpiece. Electric-resistance furnaces are more energy efficient than combustion furnaces: up to 90% efficient (DOE EERE, 2004). Indirect electric furnaces are smaller than comparable gas-fired combustion furnaces and are far easier to operate while maintaining an atmosphere-controlled environment or a vacuum, necessary for processing delicate or high-performance alloys and other materials. Finally, an electric-resistance furnace requires no exhaust system to vent combustion gases, and maintenance of the equipment is usually less expensive.

In addition to indirect heating by electric-resistance, an electric current can also be applied directly to an electrically-conductive workpiece. This type of process is known as direct electric-resistance heating and allows for targeted and uniform heating of the workpiece. In addition to being more energy efficient, direct electric-resistance heating also allow for rapid start-up and temperature changes during production. These benefits can lead to improved process time and less scrap than combustion furnaces. Like indirect electric-resistance furnaces, direct electric-resistance heating does not require an exhaust system.

Despite the efficiency improvements, electricity is still more expensive than gas on a per-Btu basis leading to higher operating costs. Electric-resistance furnaces are also typically more expensive than conventional combustion furnaces (EPRI, 2016). The key tradeoffs for customers to consider are whether the process improvements of an electric unit offer benefits to their production that outweigh the upfront capital and ongoing fuel costs.

Induction heating and melting

Another subset of electric process heating is induction heating. Instead of producing heat by passing an electric current through an electrically-resistive element, induction heating induces eddy currents within a conductive workpiece and produces heat. In this way, induction heating is similar to direct electric-resistance heating, except that it does not require physical contact with the workpiece.

Induction heating has similar benefits to direct electric-resistance heating, in that heat can be applied precisely and evenly to specific areas within a given workpiece (as opposed to the entire workpiece, as is the case in a batch furnace). Efficiencies of induction heating equipment range between 55% and 80% depending on the induction technology. There are no combustion gases and therefore no need for an exhaust system. Induction heating produces a much faster temperature rise in metal than furnace-based heating. This reduces the scale build-up on the workpiece. Induction heating also provides a much more uniform heating of the metal, reducing the likelihood of scrap due to non-uniform heating of the part and subsequent cracking or other deformations.

Induction heating also allows for metal melting. In addition to the efficiency and process benefits previously noted, induction metal melting results in an improved metal quality over furnace-based

melting and less metal waste. Eddy currents generated in the molten metal also cause mixing in the liquid, promoting an even heat throughout.

Induction heating and melting equipment typically have smaller capacities than traditional furnaces, which may mean more units to match existing production. Induction heating equipment is also more expensive than traditional furnaces. Finally, induction heat treatment is not always suitable for complex workpieces with intricate geometry and is better applied to parts with more uniform shape (such as shafts and strips).

Curing and drying

Industrial electrification is also applicable to the finishing processes for coatings, specifically curing and drying processes. After coatings are applied to products, they must be “set,” either by curing (a mainly chemical process) or drying (a water mass transfer process). The conventional heating method for both drying and heat-curing processes is by gas-fired combustion furnaces. As mentioned previously, combustion furnaces produce gases that must be exhausted from the production line. Such gases are also a source of inefficiencies in the system. Furthermore, starting up and shutting down a gas-fired combustion curing or drying line can take several hours depending on the size.

One alternative to a combustion process is to use electric infrared (IR) heating for either curing or drying. IR transmits heat in the form of radiation, which is a more direct method of heating than convection (i.e. heating and passing air over a part to heat it). An electric IR unit can be started and stopped much more quickly than a conventional combustion heater and is usually smaller too. Fewer components also result in lower maintenance costs. However, electric IR units are more expensive than conventional combustion units. Also, because IR radiation is transmitted directly from the source to the coating, such processes are not suitable for products with obscured or hidden coated surfaces. Furthermore, coatings must be approved to work with IR radiation curing or drying, which can limit retrofit applications if a customer is locked into a particular coating.

Another option for replacing a conventional curing oven is ultraviolet (UV) curing. Like IR curing, UV uses radiation to initiate a chemical reaction in the coating to cause it to cure rapidly. Unlike IR curing, however, UV does not cure using heat, but rather light. This means that coatings that were cured previously by heat cannot be simply switched over to UV curing. Specific coatings that contain photo-initiators are compatible with UV curing. This is the largest barrier to adoption; an existing curing process must switch to an entirely new coating formulation to utilize UV curing. Such coatings are also more expensive than traditional heat-cured coatings. Similar restrictions involving a line of sight also exist for UV curing. However, once the conversion to UV curing is made, savings can be achieved in the form of energy reductions, process time reductions, and improved products from more uniform curing.

Electric Vehicles

Description

Despite being introduced in the 1800s, electric vehicles (EVs) are just now beginning to take shape as a viable alternative to traditional internal combustion (IC) and hybrid vehicles. Electric vehicles replace the standard IC drivetrain with an all-electric system, swapping the IC engine with an electric motor and the fuel tank with a battery pack. Fuel costs for charging an electric car tend to be much cheaper than gasoline. An electric drivetrain also has fewer moving components than its IC counterpart, leading to a simpler system to maintain and usually lower maintenance costs overall.

The growth of passenger and light-duty electric vehicles has been significant and steady over the past several years. Since 2015, EV sales have increased more than 30% every year (Frontier Group, 2018). Component costs are also slowly decreasing, and consumer interest in EVs is increasing. In particular, battery costs continue to drop, from a 2010 production cost of nearly \$1,000/kWh to \$200/kWh in 2017 (Union of Concerned Scientists, 2017). The DOE has also set a battery production cost goal of \$125/kWh by 2020 (DOE EERE, 2016). Utilities are beginning to seek ways to manage this increased load by encouraging and incentivizing customers to charge during off-peak periods, particularly during the late morning and early afternoon.

Metrics

Table 5: Metrics for passenger vehicle technologies

Engine Type	Fuel Consumption	Range	Annual Energy Cost	Annual Vehicle Emissions	Purchase Cost	Impact on Coincident Peak Demand
Internal combustion	2.9 gal/100 mi (35 MPG combined)	378 miles	\$950	11,500 lbs CO ₂	\$12,000 - \$16,000	None
Hybrid electric	1.9 gal/100 mi (52 MPG combined)	588 miles	\$650	6,300 lbs CO ₂	\$23,000 - \$31,000	None
All-electric	30 kWh/100 mi (111 MPGe combined)	149 miles	\$350	5,100 lbs CO ₂	\$30,000 - \$36,000	AC Level 1: 1 - 2 kW AC Level 2: 7 - 19 kW

Data from DOE online vehicle fuel economy and comparison tool (DOE EERE). Data compared between 2018 Nissan Versa (IC vehicle), 2018 Toyota Prius (HEV), and 2018 Nissan Leaf (EV). Assumes: combined MPG based on 50/50 highway/city driving split, 11,824 miles/year based on Transportation Energy Data Book data from 2013 cited by Alternative Fuels Data Center (DOE EERE, 2018). Emissions data for MN from Alternative Fuels Data Center emissions calculator (DOE EERE, 2018). Peak data from charging rates given in DOE study, "Enabling Fast Charging: A Technology Gap Assessment" (DOE EERE, 2017) and Alternative Fuels Data Center website on EV charging (DOE EERE, 2018).

In addition to lower annual vehicle emissions than both internal combustion and hybrid vehicles, EVs also have lower lifecycle emissions. Lifecycle emissions include not only combustion emissions or power

plant emissions to produce electricity, but the emissions produced from constructing the vehicles, fuel production, and fuel refining. A study from the Great Plains Institute using the MISO fuel mix from 2016 shows that electric vehicles have a lifecycle emission rate of 218 grams CO₂ per mile, whereas conventional gasoline vehicles are rated at 465 grams CO₂ per mile. These rates are based on a lifetime mileage of 160,000 miles (McFarlane, 2017).

Electric vehicles also benefit from reduced maintenance costs, in addition to lower annual costs and reduced emissions. Electric vehicles are powered by an electric motor and battery system, which have fewer moving parts than IC engines and therefore have less regular maintenance requirements. Most EVs are equipped with regenerative braking (as are many hybrid EVs), which reduces wear on brake pads while also recharging the battery.

Other Notes

Despite the gains in efficiency and mindshare alike, there are still significant barriers to the widespread adoption of EVs. First, “range anxiety” still plays a role in the decision to convert to an EV as a daily driver. Though several high-end EVs are available with driving ranges exceeding 250 miles, most EVs (especially at the entry-level) have battery ranges of around 100 miles. While this is more than sufficient for city driving, longer cross-state or cross-country trips would require another charge (or several) mid-journey.

Related to range anxiety is the charging time for EVs. Advancements in battery and charging technology have resulted in DC “fast-charging” stations that can fully charge an EV battery in less than 30 minutes. However, this is still longer than a comparable gas fill-up. Some EV manufacturers have alluded to a network of “battery swap” stations where EV owners would rent replacement batteries temporarily or participate in battery lease program whereby EV batteries are simply transferred from vehicle to vehicle. However, these plans have yet to see mainstream release.

The relative lack of public charging compared to gas station availability fuels range anxiety and charging time concerns. This too has been alleviated somewhat in recent years. However, according to a study by the Frontier Group, citing data from The Economist and Forbes, EV sales since 2011 has outpaced the number of charging stations built (Frontier Group, 2018).

One last potential hurdle in the adoption of EVs, particularly in colder climates, is fuel efficiency. In general, batteries hold less charge in colder weather, resulting in a drop in EV range of over 25% (DOE EERE). However, cold weather also affects IC vehicles at a similar albeit slightly lower amount, reducing fuel efficiency of gasoline-powered cars between 10% and 20% (DOE EERE). However, IC vehicles also produce waste heat that’s used to heat the vehicle cabin, while an EV must spend additional energy from the battery to perform the same function. Additionally, charging an EV in cold weather can take almost three times longer than in mild or warm temperatures (Idaho National Laboratory, 2018).

Gap Analysis

A tremendous amount of work is being done in Minnesota to advance electric vehicles, including advocacy, research, infrastructure development, and the emergence of owner/enthusiast groups. A few gaps identified in this analysis stem from questions raised by stakeholders. One gap is an understanding of how policy might affect EV adoption in Minnesota. Currently, about 50% of all EVs sold in the US are sold in California – sales which are driven by the state’s zero-emissions vehicle standard. A similar policy push in Minnesota would likely increase sales of EVs in the state. Do voters and consumers want that kind of policy intervention in the EV market in Minnesota?

Utilities also identify a gap in regulatory guidance, centered around how or even if they should play a role in the electrification of the transportation sector. Should utilities be allowed to build and own charging infrastructure? How are those costs socialized to ratepayers? Can EVs lower prices for all ratepayers by increasing the load factor of existing infrastructure?

Finally, there is a gap in Minnesota, which is being addressed by some utilities, to provide lower EV rates and time of use charging for EVs. Rates are complicated to develop, and understanding the full opportunity and benefit of new rates will take work.

Recommendations for Discussion and Engagement

There is work that Minnesota stakeholders can do to come to a better understanding and consensus around the opportunities and challenges of beneficial electrification and fuel switching.

Specifically, discussion and engagement would be fruitful around the following topics:

- Should fuel switching and electrification exist within CIP or take place beyond CIP? What are the advantages of a parallel program for carbon reductions versus incorporating more measures into CIP? If the measures fall within CIP, how are utilities compensated and how does it affect savings goals?
- What are the goals of CIP and will electrification help advance those goals? This discussion dovetails with the topic of electrification and fuel switching, but it is much larger than this topic. What is the value of baseline energy efficiency savings versus more responsive demand shifting and storage? Beneficially electrified technologies could play a larger role in demand response scenarios.
- How do we calculate the costs and benefits? Specifically, work needs to be done around building nuance into accounting for carbon emissions. Are they calculated using the MISO mix or the utility's generation mix? What is an accessible approach to calculating marginal emissions impact? What are the real costs of electrification, and will it achieve carbon reductions at the lowest cost for society? It would be useful to develop side-by-side example comparisons for technologies with different fuel mixes, baselines, and controllability using high-resolution emission data.
- What needs to be done to make this process equitable? How can beneficial electrification give opportunities for participation to low-income ratepayers? Does beneficial electrification offer sufficient benefits to non-participant ratepayers? What consideration should be given to the remaining ratepayers of the abandoned fuel who can't afford to or choose not to convert?

These questions could be framed up in the context of determining “when and how” electrification will happen, but it is important to bear in mind that some stakeholders and consumers are wondering “if” and “why.” Information sharing and further stakeholder engagement would provide a good place to start in Minnesota. Working collaboratively to determine how fuel switching and electrification can support the achievement of common goals in Minnesota's energy sector will be challenging and influential work. Given the attention this topic has received in 2018, Minnesota has an opportunity to be a regional and national leader shaping new consensus and direction for approaches to electrification, carbon reduction, and energy efficiency.

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Appendix A: Questionnaire

1. Please, briefly describe your role at your organization and your familiarity with the topic.
2. Tell me your thoughts on the opportunities of electrification or fuel switching for your organization or for the state of Minnesota.
3. Tell me your thoughts on the challenges of electrification or fuel switching for your organization or for the state of Minnesota.
4. At this moment, how important is the topic of electrification or fuel switching for Minnesota's regulators to consider?
5. What kind of outcomes would be important to your organization if this topic were to be addressed for Minnesota?
6. What are the priority questions your organization has that you would like to see addressed by Minnesota's regulators?
7. Currently, Minnesota prohibits utilities counting, toward their energy efficiency goals, any energy savings derived from helping a customer switch end-use fuels. There is an exception for low-income customers. What concerns do you have about changing the status quo?
8. What other organizations, do you think, share your perspective?
9. Are there others who have a different opinion on the topic than you? If so, how would you describe their argument, and why do you believe they feel differently?
10. What are the key aspects of this issue that need to be addressed so that parties with different perspectives on the topic can agree that the outcome is equitable?
11. Do you feel that electrification could or should be implemented through the state's existing energy efficiency program paradigm (called CIP, which stands for the Conservation Improvement Program) or would it need a different framework altogether?
12. How would you recommend the state measure or compare the impact of changing fuels? Is there a preferred approach your organization uses or would like to use?
13. Is it appropriate to draw a distinction between delivered fuels (specifically propane and heating oil), and utility service fuels (electricity and natural gas) for this conversation?
 - a. Should the policy solutions address delivered fuels and utility fuels separately or in a unified manner?
14. Should gasoline be considered a delivered fuel?

- a. If gasoline were considered a delivered fuel, what potential implications would you foresee that need to be considered?
15. Is your organization tracking any specific technologies where switching fuels would provide cost, efficiency, carbon, or system benefits? Which specific technologies are most interesting?
16. What other policy efforts are you aware of around the country at the state or regional level to address electrification or fuel switching?
17. Who else would you recommend we interview or include in future discussions?
18. Are there comments or concerns that have not yet been addressed in this interview that you would like to make?

Appendix B: Minnesota Source Energy Factor

Source energy factor for Minnesota, based on the statewide fuel mix in 2017 according to EIA. Methodology from the EERE report, “Accounting Methodology for Source Energy of Non-Combustible Renewable Electricity Generation”. Statewide energy mix for 2017 from EIA.

Generation Type		Generation (GWh)	Conversion (source Btu/kWh)	Source Energy (Quads)
Fossil Fuels	Coal	23,333	10,428	0.24
	Petroleum	43	10,814	0.00
	Natural Gas	7,139	7,907	0.06
Other Non-Fossil	Nuclear	13,904	10,459	0.15
	Other	396	14,400	0.01
Combustible Renewable	Wood	1,352	10,000	0.01
	Waste	664	13,800	0.01
Non-Combustible Renewable	Hydro	1,257	3,412	0.00
	Wind	10,885	3,412	0.04
	Solar	728	3,412	0.00
Total Source Energy				0.52
Net Generation of Electricity		59,701	3,412	0.20
Estimated T&D Losses		5,910	3,413	0.02
MN Generation for End Use				0.18
Source Energy Factor (Btu source/Btu site)				2.82