Prepared by Rocky Mountain Institute

for the Minnesota Department of Commerce,
Division of Energy Resources
COMM-20130715-68278

SCOPING AN ENERGY FUTURE STUDY FOR MINNESOTA

PUBLISHED DECEMBER 2013

AUTHORS (listed alphabetically):
GARRETT FITZGERALD, LENA HANSEN, DUNCAN LAWRENCE, ERIC MAURER

SCOPING AN ENERGY FUTURE STUDY FOR MINNESOTA

Prepared by:

Rocky Mountain Institute
www.rmi.org

Garrett Fitzgerald

Lena Hansen
lhansen@rmi.org

Duncan Lawrence

Eric Maurer
emaurer@rmi.org

Prepared for:

Minnesota Department of Commerce,
Division of Energy Resources

Mike Rothman, Commissioner

Bill Grant, Deputy Commissioner

Matt Schuerger, Technical Advisor

Lise Trudeau, Project Manager
651-539-1861
lise.trudeau@state.mn.us

Acknowlegements

MN Laws 2013, Chapter 85 HF 729, Article 12, Section 7 required the Department of Commerce to produce the enclosed study scoping report. This project was supported in part, or in whole, by a grant from the Minnesota Department of Commerce, Division of Energy Resources through utility assessments, which are funded by Minnesota ratepayers.

Disclaimer

This report does not necessarily represent the views of the Minnesota Department of Commerce (Commerce), its employees, or the State of Minnesota (State). Commerce, the State, and its employees, contractors, and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the State. Stakeholders and subject-matter experts consulted during this study did not review the final report before its publication. Their acknowledgment does not indicate endorsement or agreement with the report's content or conclusions.

TABLE OF CONTENTS

Index of Figures and Tables

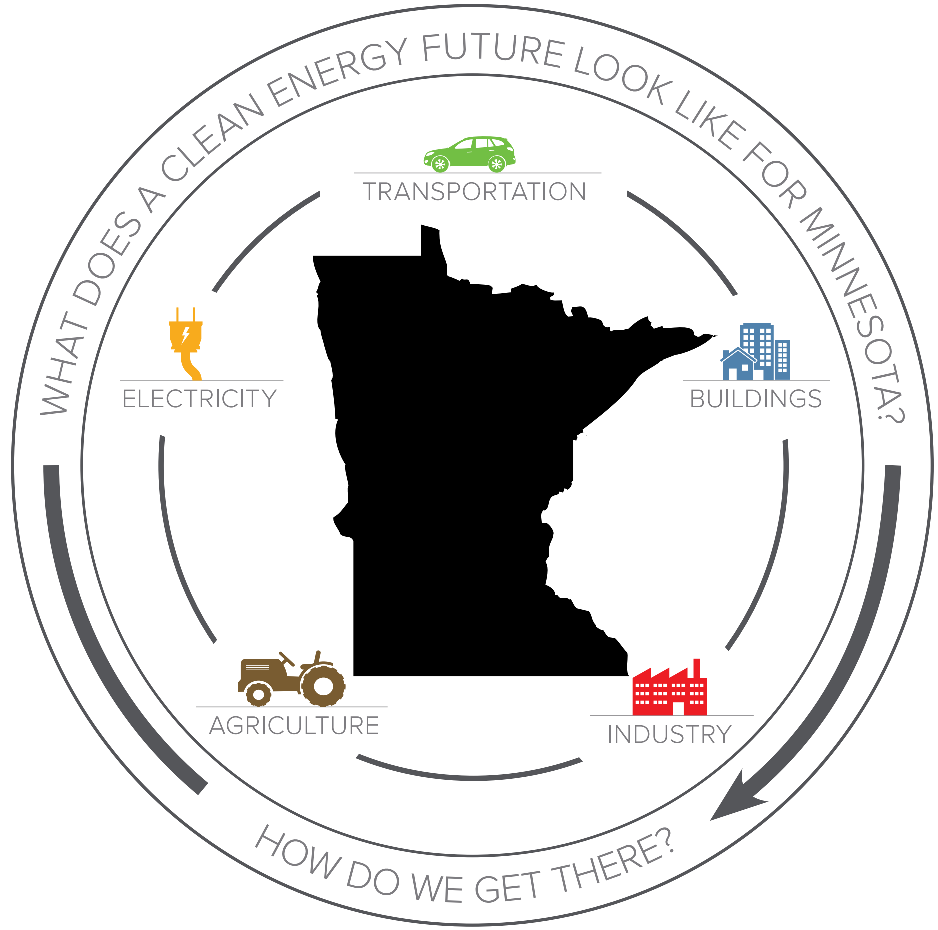
EXECUTIVE SUMMARY

ES

EXECUTIVE SUMMARY

Minnesota's energy future is a matter of choice, not fate. Conducting an energy future study (EFS) offers a rare and valuable opportunity to step back from annual debates over energy policy and take a more measured and longer-term view of the state's energy trajectory. It is a chance to engage a wide range of stakeholders in weighing together the risks and opportunities of different possible energy futures, and ideally coming to some agreement on what sort of energy system Minnesotans ultimately want—whether that's maintaining the status quo or an alternate path that meets most, or even all, of Minnesota's future energy needs with energy efficiency and other forms of clean energy, including renewables.

Making the state's energy choices—and their implications—transparent and meaningful requires building a shared understanding of options, analyzing the cost and reliability implications of various pathways, and identifying the key levers to achieve desired outcomes. Undertaking a comprehensive EFS as outlined in this report can bring clarity and coherence to Minnesota's energy strategy. A clear and coherent long-term energy strategy can, in turn, create a more predictable business environment, reveal new economic development opportunities, and better meet environmental and quality-of-life goals. At its simplest, the reason to conduct an EFS is the same reason businesses conduct scenario planning—to prepare for the future in ways that maximize benefits and minimize risks, in this case for the state's citizens.



Importantly, the EFS would not blindly target clean energy adoption at any cost. Rather, rooted in sound analytics and taking a holistic, multi-stakeholder perspective, the EFS's scope must include an assessment of:

Resource pathways: How much of Minnesota's future energy needs can be met with clean energy, including energy efficiency and renewable energy, and by when?

Cost: Could those pathways be achieved affordably, without unfairly penalizing certain customer classes?

Reliability: Particularly in the electricity sector, could grid reliability and resilience be maintained or even improved?

Environmental implications: How would different energy futures impact the state's air and water quality and health of its citizens? How would those futures help or hinder the state in meeting its greenhouse gas emissions reduction goals?

Economic development implications: What could be gained or lost in terms of in-state economic development?

Risk: What kinds of economic and environmental risks are associated with different energy futures? What near-term "no regrets" actions would position the state to flourish under virtually any possible future? For example, what actions would set the state on the right trajectory for achieving its long-term energy vision, understanding that costs and technologies will change over time?

WHY NOW AND WHAT'S AT STAKE?

When it comes to Minnesota's energy future, there is no such thing as doing nothing. Even maintaining the status quo will require significant investment to address aging infrastructure, changing consumer demands, and the growing risks and opportunities inherent in today's energy system. Cheap natural gas, new federal regulations on greenhouse gas emissions that will likely severely limit the viability of new coal-fired power generation (and some existing coal plants), continued price uncertainty and volatility for fossil fuels (coal, oil, and natural gas), and the fact that Minnesota's nuclear plants will reach the end of their useful lives in the 2030s, all suggest that now is the time for Minnesota to take a clear-eyed look at its clean, reliable, affordable, inexhaustible energy options.

In tandem, Minnesota's clean energy options and choices are changing rapidly as technology costs continue to plummet and new financing mechanisms emerge. For example, as of early 2011 large-scale wind from the upper Midwest was available for just over $30/MWh compared to new natural gas plants at $61–87/MWh.[1] Similarly, the cost of solar panels has fallen nearly 75% since 2008 and solar leasing models, which allow customers to put solar on their roofs for zero dollars down, now account for 70–90% of new installs in states with high levels of solar adoption such as Arizona, Colorado, and California.[2] The choices that Minnesota makes about its own energy future will in part help guide the future of the entire U.S. since the upper Midwest's renewable energy resources, such as windpower, are so significant.

Minnesota, like many other states, is actively seeking new economic development opportunities. It has already identified clean energy technologies as an industrial sector that holds great promise for talent and business attraction, job creation, and keeping energy dollars in the state rather than exporting an estimated $13 billion annually to pay for out-of-state and out-of-country oil, coal, and natural gas. As a case in point, Minnesota was among three states and one U.S. territory selected by the National Governors Association to participate in a program to encourage growth of their clean energy industries. And Minnesota Governor Mark Dayton has set forth the challenge "to use [our] past achievements as springboards for Minnesota's next big leap toward a sustainable energy future."[3]

In the absence of federal action, states are seizing the opportunity to be a dominant force in shaping energy strategy, and states' approaches are diverging wildly. In the face of these forces, Minnesota has already taken action, including a 25% by 2025 renewable energy requirement, a 1.5% per year energy efficiency requirement, climate action planning to meet an 80% greenhouse gas reduction target by 2050, and numerous mass and alternative transit programs. The EFS can build on this body of work and serve to tie these threads together into a holistic, cohesive strategy.

Minnesota's EFS would place it among a select group of states actively exploring their longer-term energy options, and therefore position the state to capture the benefits of leadership, including the ability to catalyze and capture the economic development benefits of energy innovation.

MINNESOTA GOVERNOR MARK DAYTON HAS SET FORTH THE CHALLENGE "TO USE [OUR] PAST ACHIEVEMENTS AS SPRINGBOARDS FOR MINNESOTA'S NEXT BIG LEAP TOWARD A SUSTAINABLE ENERGY FUTURE."

MARK DAYTON
Minnesota Governor

WHAT SHOULD BE THE ENERGY FUTURE STUDY'S SCOPE?

Like most states, Minnesota has tended to craft energy policies separately—and somewhat piecemeal—for the electricity system, for transportation, and to a lesser degree for the way it heats its buildings. Yet these elements of the energy system are, in reality, intertwined and increasingly so. A successful EFS requires rigorous analysis that successfully captures the needs and potential synergies across all of Minnesota's energy-consuming sectors, including transportation, buildings, industry, agriculture, and electricity. While focusing solely on the electricity sector is in some ways more straightforward, it risks missing important cross-sector opportunities and risks, such as electricity being increasingly used as a transportation "fuel" for electric vehicles, or using hot water heaters as a means of thermal energy storage at times when more renewable electricity is being produced than is needed.

To align broadly with climate science, other state and national targets, and legislative intent, the EFS would explore pathways to achieve 80% and 100% clean energy. To gauge the implications and attractiveness of potential pathways, the EFS would utilize a set of evaluation criteria including affordability, reliability, environmental & health impacts, and economic development.

Having a sufficiently broad analytical scope is important, but the EFS cannot simply be an analytical exercise. Given the study's long time horizon, the goal is not absolute precision—since costs and technologies will inevitably change—but rather to engage a diverse range of Minnesota stakeholders in developing a strategic, shared vision—informed by rigorous analysis—of how far and how fast the state could transition to a clean energy system while maintaining affordability and reliability for its citizens and businesses. Thus, the stakeholder dialogue would be supported and informed by in-depth scenario development and analysis that give Minnesotans confidence that the clean energy path chosen is technically achievable, reliable, affordable, and wise.

The EFS will need to engage experts and stakeholders throughout the process. That stakeholder engagement could follow a more conventional approach that solicits input on one or two occasions, but Minnesota also has the opportunity to use the EFS as a vehicle for a more robust and ongoing stakeholder process that allows for disparate interests to co-create Minnesota's energy future. Key steps in the overall EFS approach are:

- Identify and assemble a broadly representative stakeholder group and the right technical team
- Get stakeholder agreement on the study's purpose and objectives, system definition, and analytical approach
- Analyze the feasibility of various energy pathways and develop a strategic vision and "no regrets" recommendations, including milestones to track progress
- Create an ongoing process to spur effective implementation over time

The EFS would not be successful if it ended in a report that sat on a shelf. Rather, the EFS must also include action planning by identifying signposts along the way and near-term "no regrets" actions, a clear plan for integrating those insights into ongoing processes that will ensure action, periodic revisiting and redirection as appropriate, and stakeholder commitments. As such, the EFS is a foundational and integral step towards orienting government and stakeholder action towards the future they want.

WHAT RESOURCES ARE REQUIRED FOR THE EFS TO BE SUCCESSFUL?

An EFS that successfully accomplishes the purpose laid out here would be a significant and complex endeavor, but is not without precedent. This type of study has been conducted in leading states and countries, and the EFS's design and potential approach presented here has been informed by input from Minnesota stakeholders. For the EFS to be successful, the following are required:

- Clarity of scope and purpose, for which this report serves as a starting point
- Commitment and an agreed-upon pathway for action
- In-depth, diverse, and ongoing stakeholder engagement during and after the study
- Financial support, ranging from $1.5 to $2.0 million, depending on key scoping choices
- A realistic timetable, likely requiring 12 to 18 months
- Institutional leadership, including a sponsor, convener, and champion(s)
- Independent and well-coordinated facilitation and analytical support

At a Glance: **Selected Scope Recommendations**

TOPIC	RECOMMENDATION
Stakeholder Engagement Process	Use three levels, each with different people, purpose, and process: 1. Core stakeholder leadership group 2. Multiple subject-specific working groups 3. Broad outreach to wider set of stakeholders via informational meetings
Aspiration	The EFS should answer the question, "How far and how fast can Minnesota transition to a clean energy system while maintaining affordability and energy reliability for its citizens and businesses?" Clean energy = renewable energy and energy efficiency Test cases: • Business-as-usual baseline • 80 and 100% clean energy target • 2050 and 2030 timeline
Evaluation Criteria	The EFS should consider and evaluate: • Cost and affordability • Reliability • Economic development • Environmental quality • Public health and quality of life • Risk
Sectors	The EFS should include all energy-using sectors: • Buildings • Industry • Agriculture • Transportation • Electricity
Technology	Focus on commercially available technologies and strategies, with a sensitivity to consider the effects of emerging technologies
Budget	$1.5–2.0 million
Study Process Duration	12–18 months

ABOUT THIS REPORT

AB

ABOUT THIS REPORT

In 2013, Minnesota's legislature approved H.F. 729, which included funding to scope a study that would evaluate how Minnesota can achieve a sustainable and cost-effective energy system that does not rely on burning fossil fuels. This report addresses that requirement and summarizes the potential scope and value proposition of such an energy future study (EFS).

The Minnesota Department of Commerce (Commerce) contracted Rocky Mountain Institute (RMI) to conduct the study scoping work. The RMI team, with guidance and input from Commerce, first conducted a snapshot assessment of Minnesota's current energy landscape. Subsequently, the team reviewed 10 energy future studies from other states, regions, and countries to identify best practices and possible approaches. Based on this review and RMI's own experience, the study team developed a set of scope options that were provided for stakeholder input. On October 22, 2013, Commerce convened a stakeholder meeting to present results from the initial two tasks and the scope options. Stakeholders contributed valuable feedback during the meeting and submitted extensive written comments that provided important insight that was incorporated into this report as appropriate.

The purposes of this study scoping report are to:

- Identify the value proposition for Minnesota in conducting an EFS
- Provide clear guidance around critical study scope considerations to ensure that Minnesota can efficiently and effectively conduct an EFS
- Provide a foundation from which Minnesota stakeholders and the Legislative Energy Commission can start an action-oriented dialogue around the future of energy in the state

On behalf of Commerce, RMI will be available to present an overview of this report to the Legislative Energy Commission in the first quarter of 2014. The Legislative Energy Commission can then, as part of its development of an energy framework, use the report to inform discussion and construct the parameters to conduct the actual energy future study.

INTRODUCTION

IN

INTRODUCTION

AN ENERGY FUTURE STUDY CAN INFORM A COMMON ENERGY VISION FOR MINNESOTA AND GUIDE THE MULTI-BILLION-DOLLAR ENERGY INVESTMENTS THE STATE WILL MAKE OVER THE NEXT QUARTER CENTURY.

Some of the most difficult and divisive questions Minnesotans face today revolve around energy demand and supply. Should natural gas and nuclear power be the major energy sources for the next century? Is the state on the brink of investing "too much" in wind or ethanol? Should Minnesota take on the risks of transitioning to a cleaner energy system or accept other risks of not transitioning to that system in favor of incumbent fossil fuels?

While stakeholders have very different perspectives on these questions, almost everyone agrees about one thing: no decision about demand or supply is purely about energy. These decisions won't just determine the costs Minnesotans will pay for access to reliable energy for the next decades, they will also drive far-reaching impacts on the state's economic trajectory, in-state job development, and human and environmental health. This is true whether these questions are resolved by default or by design, through separate initiatives or through a deliberate, comprehensive energy strategy.

While conflicting perceptions of the risks and implications of clean energy lock different stakeholders in debate, Minnesota is losing time to craft a competitive energy strategy that adapts the state to the fast-paced changes evolving in the energy sectors today and leverages the substantial economic opportunities around clean energy. The state needs to engage its diverse constituents productively to compare the risks and trade-offs between different potential energy futures.

RMI proposes a year-and-a-half-long energy future study (EFS) for Minnesota to accelerate a shared understanding around the following key questions:

- How much of Minnesota's future energy needs could be met with clean energy, including efficiency and renewables? In what time frame?
- Could this be achieved affordably, without unfairly penalizing certain customer classes? How would it affect existing energy service providers?
- What are potential risks or benefits to energy reliability and resilience?
- What could be gained in terms of environmental and human health impacts?
- How might various pathways across multiple sectors such as buildings, transportation, agriculture, industry, and electricity create competitive advantage and drive in-state economic development for Minnesota?

Section 1 of this document outlines Minnesota's current energy landscape; identifies the global, regional, and local trends that are redefining the energy system; and articulates the potential benefits of conducting an EFS. Section 2 describes the potential scope and key scoping choices for the EFS. Section 3 provides clear guidance on the timeline, budget, and criteria for success for the EFS.

Rather than commit Minnesotans to long-term energy, economic, and environmental consequences by default, an EFS can lay a sound analytic foundation for a deliberate energy strategy that engages individuals, businesses, and the state toward a common energy goal.

THE CONTEXT AND CASE FOR AN ENERGY FUTURE STUDY

01

THE CONTEXT AND CASE FOR AN ENERGY FUTURE STUDY

A CHANGING ENERGY LANDSCAPE

National and global forces affecting the energy system are changing more rapidly than ever before, in some ways creating a perfect storm that means no matter what, the future of Minnesota's energy system will be significantly different than its past.

Economic development and the cost of fossil fuels
Despite its significant use of oil, coal, and natural gas, Minnesota has no in-state fossil fuel resources. Coal to fire its power plants, natural gas to heat its buildings and run its industries, and oil to fuel its vehicles comes from out of state. That means that Minnesotans send approximately $13 billion annually to other countries and states, which is almost equivalent to Minnesota's entire annual tax burden.[4] To put that cost in perspective, $13 billion could pay for all of Minnesota's teachers (~53,000), all of its police officers (~9,000), 30,000 small-business entrepreneurship loans, and 10,000 new affordable homes, with more than a billion dollars left over.[5]

Clean energy could present an opportunity to keep some of that money in the state, driving local economic development. Nationally, clean energy has been a catalyst during the economic recovery. From 2010 to 2011, the U.S. economy added over 150,000 jobs in establishments that benefit the environment or conserve natural resources, outpacing job growth in other areas. A major component of this growth comes from construction and installation of renewable energy and energy efficiency, as jobs in this area grew by 26%.[6] And Minnesota is positioning itself to attract clean energy jobs. For example, Minnesota is one of only three states and one U.S. territory selected to participate in the National Governors Association Policy Academy on Targeting Clean Energy for Economic Development.[7] As part of the Academy, Minnesota will develop and implement an action plan to foster growth in clean energy technologies and build out the supply chain necessary to enable this growth.

Just as growth in clean energy is creating local jobs throughout the country, developments in the domestic production of natural gas are creating jobs in places such as North Dakota and Texas. In these areas, hydraulic fracturing has opened up vast new natural gas reserves that have pushed the price of natural gas down and fueled a national shift toward gas as a cheaper, cleaner fuel (compared to dirtier fossil fuels such as coal).

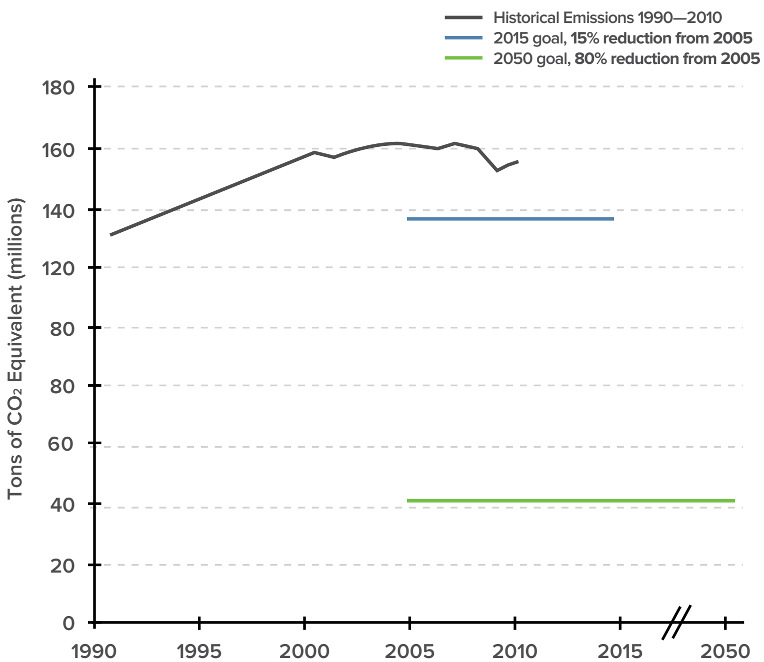
Shifting action on climate and environment
There is increasingly widespread recognition of and urgency around climate change and other environmental and health impacts associated with burning fossil fuels. Minnesota has experienced substantial increases in GHG emissions between 1990 and 2005, with modest reductions since 2005 driven by an economic downturn that has caused reduced energy consumption, a shift away from coal in favor of renewables, and the ongoing implementation of efficiency measures. The state has established GHG reduction targets of 15% by 2015 and 80% by 2050, yet as of 2010 has only achieved a 3% reduction.[8] At the same time, the U.S. Environmental Protection Agency is moving forward with carbon dioxide emissions reduction regulations that would make new, and potentially even existing, coal-fired power plants increasingly uneconomic.[9]

Beyond climate concerns, Minnesota has good overall air quality, yet some pollutants—ozone and fine particulates—are approaching federal limits. The human health costs associated with these criteria air pollutants are built into energy planning choices, but those values have not been updated since 1996 and the Minnesota Public Utility Commission has received a request to update them based on recent research that estimates total health-related costs of $877 million annually.[10]

A desire for increased resiliency

Americans and Minnesotans have become increasingly and acutely aware of the fragility of the existing energy infrastructure.

Figure 1: **Carbon Emissions in Minnesota, 1990–2050**



Source: Minnesota Pollution Control Agency (2013); Ciborowski and Claflin (2012)

Storm-related power outages from Hurricane Sandy, primarily in New York and New Jersey, cost an estimated $14–26 billion, for example.[11] And Minnesotans witnessed the largest power outage in state history in 2013 when over 500,000 customers lost power due to intense summer storms.

Appropriately directing needed investment

All other issues aside, there is a looming need for significant energy infrastructure investment both in Minnesota and across the United States. Estimates suggest that national electricity infrastructure will require an investment of $1.5–2 trillion from 2010 to 2030.[12] In Minnesota, the state's two nuclear power plants are likely to retire in 2030 and 2033/2034 when their respective operating licenses expire,[13] and over half of Minnesota's coal plants will be 40 or more years old by 2017.[14] These significant replacement needs coupled with ongoing expansion needs create unique opportunities to direct investment towards the future Minnesota wants. The time to make those choices is now, since energy infrastructure investments (e.g., power plants, pipelines) are uniquely long lived.

Ample renewable resources

Minnesota and its neighboring states are endowed with some of the best wind resources in the country, and the state's solar resource, while not as great as in the desert Southwest, receives 23% more sun on average than solar PV leader Germany.[15] Driven by this resource availability and the state's renewable portfolio standard (RPS), Minnesota ranked fourth in the nation in 2011 in net electricity generation from wind energy, and the 7.6 million megawatt-hours produced in 2011 marked a 60% increase from 2010.[16] Overall, renewables now account for 15% of Minnesota's electricity generation annually, up from 4% in 2000.

The state now meets 10% of its gasoline demand with ethanol, and is such a large producer that it exports 79% of its ethanol production.[17]

Technology and price evolution

Changes in technology cost and performance are opening up new possibilities as the state considers infrastructure upgrades. Renewables are seeing unprecedented price drops—since 2009, the average levelized price of wind power purchase agreements has fallen over 40% to $30/MWh and Xcel Energy, which serves the majority of Minnesota's electricity customers, has said that wind is now less expensive than a 20-year natural gas contract.[18] Solar module prices have plummeted almost 75% since 2008, and the total installed cost of distributed solar has fallen 38% in that same time period.[19] Recent studies document that as much as 64% of residential solar installation costs are "soft costs" such as permitting, suggesting room for significant additional cost reductions.[20] As prices of variable renewable power sources decline, the technological capability to enable integration is also advancing through the use of demand response, smart grids, and diverse storage mechanisms. These clean-energy technologies coupled with competitive prices present opportunity to generate new, stable jobs and help direct investments to local communities.

Customer empowerment and changing customer demands

Importantly, rapidly declining prices and the emergence of new technology are opening doors for customers—residential, commercial, and industrial. A recent report shows that 60% of Fortune 100 and Global 100 companies have climate-related targets, renewable energy targets, or both. In Minnesota in particular, four of its five Fortune 100 companies have greenhouse gas reduction goals, including one of the world's largest retailers, Target.[21] Technology and business model innovations are making it easier for these dynamic companies to achieve their goals. Customers of all kinds, presented with alternative energy options that are increasingly cost effective, are beginning to shift their buying and investment patterns. At the same time, energy-intensive manufacturing industries, low-income customers, and some others particularly affected by energy costs are increasingly concerned about rising costs.

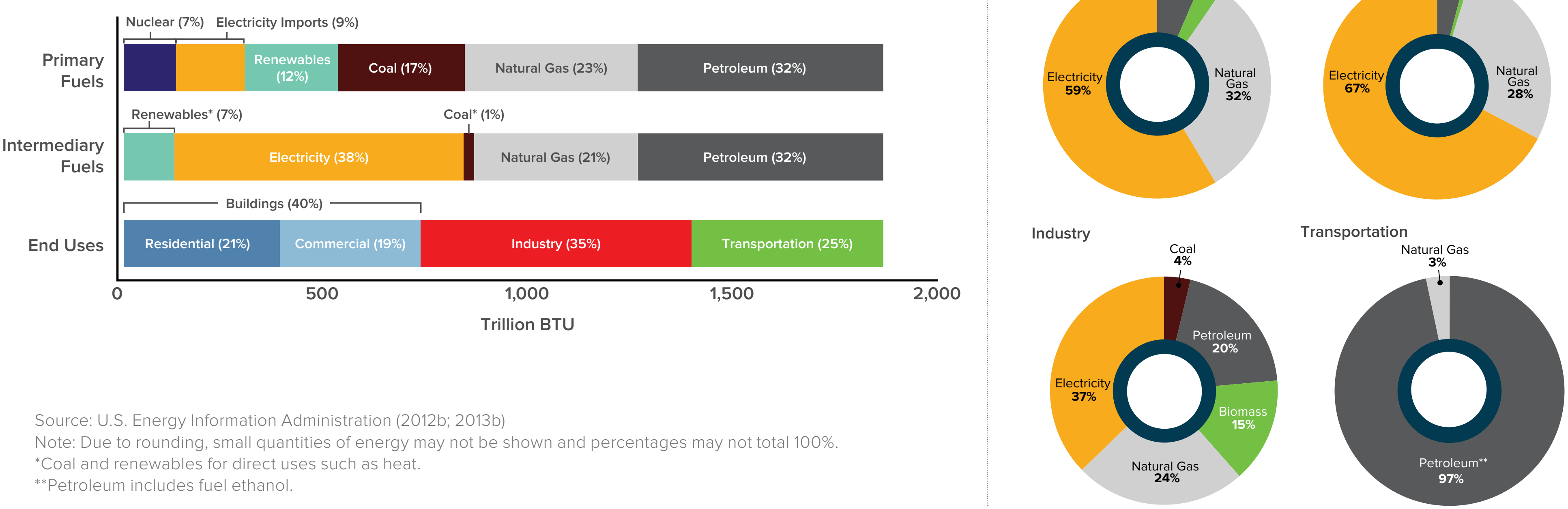
Dramatically falling distributed solar prices coupled with innovative financing mechanisms have made solar an increasingly attractive option for customers in many parts of the United States. In large part driven by these innovations, the number of net-metered solar projects installed in the U.S. in 2012 was 46% higher than in 2011, and solar broadly accounted for nearly half of new generation capacity in the first quarter of 2013.[22] Beyond solar, smart thermostats are making it easier for customers to manage their energy use and cut overall demand. Worldwide electric vehicle sales jumped by almost 900% between 2010 and 2012, and the majority of major vehicle manufacturers offer at least one hybrid model.[23]

Growing energy demand and continued reliance on fossil fuels

Despite reducing the amount of energy it takes to generate a dollar of gross domestic product,[24] Minnesota's total energy use from residential and commercial buildings, transportation, industry (including agriculture), and electricity production still increased by 50% over the last three decades, driving associated increases in fossil fuel use and GHG emissions.[25] The state's growing population—partly responsible for growing energy demands—is projected to increase 23% by 2040 and up to 70% in some counties, placing increased pressure on transportation and building services.[26] With growth patterns highly concentrated in suburban areas surrounding Minneapolis and St. Paul, drivers already impacted by roadway congestion are likely to experience more of the same.

Minnesota's energy use from fossil fuels has declined from 80% to 72% since 2000, thanks to efficiency improvements and renewables adoption.[27] Its main energy-using sectors—industry, transportation, and buildings—use roughly the same amount of energy, but in very different ways and with different energy challenges and opportunities into the future (see Figure 2). Across all sectors, important opportunities remain for drastically enhanced energy efficiency. Minnesota's residential and commercial electricity rates have remained below the national average, although its prices are now higher than in some surrounding states creating some concern for large industrial customers.

Figure 2: **Fuel Use in Minnesota, 2011**



Source: U.S. Energy Information Administration (2012b; 2013b)
Note: Due to rounding, small quantities of energy may not be shown and percentages may not total 100%.
*Coal and renewables for direct uses such as heat.
**Petroleum includes fuel ethanol.

MINNESOTA'S RESPONSE

In the face of these driving forces, Minnesota has taken important steps to manage risks, mitigate negative impacts, and open new opportunities for its citizens and businesses. The state's GHG reduction goal of 80% by 2050 has been complemented with mandates of 25% renewable electricity by 2025 and energy efficiency of 1.5%/year. Utilities can no longer build new in-state fossil-fuel-fired plants exceeding certain emission limits nor import electricity from similarly situated out-of-state fossil-fuel-fired plants built after 2007.[28] New approaches to better integrate efficiency and renewables are being explored, including decoupling and a value-of-solar rate structure.

Multiple energy planning efforts within the state have charted pathways to achieve these goals. For example, in 2008, the Minnesota Climate Change Advisory Group produced a detailed assessment of different ways to achieve the state's carbon target and offered 46 policy recommendations, and efforts are now under way to revisit and advance that work. And across Minnesota, organizations are working toward enhancing energy efficiency and renewable adoption, while maintaining energy affordability and quality of life. There are extensive research efforts, such as the Great Plains Institute's report on ENERGY STAR buildings, which provide necessary information to better understand and leverage important emerging markets.[29] There is also on-the-ground action and transformation—Clean Energy Resource Teams (CERTS) are working hand-in-hand with Minnesota communities to increase the adoption of energy efficiency and renewable technology.[30]

WHY AN EFS IS NEEDED

Minnesota has developed and executed an impressive array of clean energy goals, plans, and actions that have put it in a good position to meet its RPS and energy-efficiency goals. These early efforts have demonstrated the promise of clean energy in supporting local economic development, reducing environmental impacts, and maintaining reliability and affordability. For many of Minnesota's customers, such as those served by Xcel, a shift toward more renewables has resulted in lower energy costs.[31] What is not clear is how much larger a role clean energy can play in Minnesota's long-term energy future, at what cost, and in what timeframe.

Without a clear understanding of—and stakeholder alignment on—how clean energy fits into the state's energy future, Minnesota risks an uncertain business environment and high transaction costs (both political and economic) as stakeholders battle each year about whether a modern economy can operate on high percentages of clean energy affordably and reliably. The prosperous, clean, and healthy state Minnesotans desire will also be difficult to achieve in the absence of a concrete path that can help channel efforts of citizens, businesses, and the state toward a common goal. Without a clear understanding of its energy options and their pros and cons, Minnesota is in danger of misallocating its resources, missing economic opportunities, and being forced to react to the fast-moving global and local trends that are reshaping the way energy is produced, distributed, and used. The only way to address these challenges is to look beyond near-term goals and actions to consider and chart the long-term role of clean energy in the state.

EFS KEY QUESTIONS AND DESIGN PRINCIPLES

The EFS will address these challenges by producing an analytical and strategic investigation to determine the technical and economic feasibility of a clean energy system that does not rely on fossil fuels. It will explore how far and how fast the state can transition toward clean energy while maintaining affordability and reliability. It then will build on that analysis to develop a strategic vision of Minnesota's clean energy future, highlights signposts along the way, and identifies near-term "no-regrets" actions. Stakeholder input has informed a set of six key questions the EFS must answer:

1. ***How much of Minnesota's future energy needs can be met with clean energy, including energy efficiency and renewables? In what time frame?***

2. ***Can it be done affordably?***
The EFS must weigh the economic benefits and costs of meeting all or the majority of the state's energy needs with clean energy resources and compare such a future to the cost of a business-as-usual approach that continues to rely heavily on fossil fuels. It should include all relevant sources of benefit and cost (e.g., externalities, life-cycle costs). The analysis must assess the economic impacts of such a transition on different customer groups (e.g., low-income, industrial) and different parts of Minnesota (e.g., rural, urban)—an "average" cost analysis is insufficient. Finally, it must consider how a changing resource mix might affect existing energy service providers like electric utilities.

3. ***Could it do so while maintaining or improving reliability and resilience?***
The energy system, whether relying on fossil fuels or clean energy, must be highly dependable, consistently supplying energy when and where it is demanded. The study team and stakeholders should determine the criteria and metrics for assessing reliability and resilience in each sector. For example: How can the many modes of transportation work together to deliver convenient mobility solutions? How can renewable process-heating options deliver high-temperature heating for the industry sector with minimal downtime? How can an electric sector with many forms of renewable energy deliver electricity to customers reliably?

   More specifically, two major sources of clean electricity—solar PV and wind power—are variable, which means their output fluctuates with the weather and their output cannot be ramped up or down at will by grid operators. Greater resource variability thus necessitates changes to the way the grid is operated to maintain reliability. Real-world examples from Europe show that it is possible to manage a system with 40–50% variable renewable energy (in the context of an integrated European grid system), and studies have analyzed the feasibility of 80% or more.[32] However, this is one of the most critical issues facing a clean energy future, and the EFS must look beyond demonstrated results to test if and how the regional electricity system can meet or exceed reliability expectations with high levels of clean energy. A particular feature worth exploring is the extent to which customer-sited (i.e., distributed) resources can increase system resilience.

4. ***What could be gained in terms of environmental and human health impacts?***
   Pollution from burning fossil fuels has local, regional, and global effects. The study should quantify how different amounts of clean energy would reduce emissions and associated environmental (e.g., climate) and health impacts (e.g., fewer asthma cases).

5. ***How might various energy future scenarios create competitive advantage and drive in-state economic development for Minnesota?***
   The EFS should quantitatively evaluate the effect of increasing levels of clean energy on in-state economic development by considering how net jobs change over time with growing clean energy adoption. "Net jobs" account for job gains from clean energy, job losses in fossil fuel industries, and any indirect job gains or losses associated with added energy cost or savings.

6. ***What near-term and "no regrets" actions would set the state up for success?***
   Regardless of the clean energy pathway chosen, there are likely "no regrets" actions that make sense no matter what happens in the future. This set of actions represents one of the best opportunities to generate broad support, and also one of the best opportunities for identifying immediately actionable items that can generate momentum. The study should identify and prioritize these actions.

The process the EFS follows to answer these questions is critical to success, and a set of key design principles should guide Minnesota stakeholders as they move forward with developing and executing the EFS:

- ***Transparent***—Clear objectives and process; publicly accessible assumptions, inputs, and results.
- ***Collaborative***—To the extent possible, co-creation and engagement with decision makers and stakeholders to foster ownership and political durability of results.
- ***Aspirational and open-minded***—Willingness to engage with diverging perspectives and explore what may be possible rather than being limited by perceived constraints.
- ***Analytically grounded***—Results and recommendations based in fact and analysis.
- ***Pragmatic and action-oriented***—Focuses on opportunities and challenges for real-world actors, always with a filter for how study processes, recommendations, and deliverables drive action.

Achieving all of this is no easy task. It involves making many important choices that will scope the EFS and determine the outputs it produces. The remainder of this report provides a guide for the state and its stakeholders that lays out the options for scoping the EFS and provides input and recommendations to help scope the study.

HOW OTHERS ARE APPROACHING THE CHALLENGE

A growing number of communities and countries have conducted energy future studies as a way to confront the issues around a changing climate, growing population, and aging energy system. As part of the scoping process, the RMI team reviewed 10 recent studies that ranged in geographic scope from the entire globe to individual states such as Vermont and New York.[33] The studies vary significantly in terms of detail, rigor of technical analysis, and objective. RMI identified the following insights to help inform the EFS scoping process:

- The majority of studies look exclusively at the electricity sector. Transportation, agriculture, and non-electric energy use in buildings and industry are addressed superficially, if at all.
- By and large, studies target an 80–100% reduction in fossil fuels or carbon emissions by 2030 or 2050.
- Studies find that such transformational reductions are feasible, according to specified criteria.
- Results are driven by a combination of input assumptions (e.g., technology cost forecasts), degree of analytical rigor, and key levers included (e.g., efficiency, vehicle miles traveled reductions, etc.).
- Scenarios reflecting a range of renewable penetration levels or carbon reductions are common; scenarios reflecting changing system conditions or input assumptions are less common.
- Studies engaged stakeholders in a variety of ways, from limited input on technical assumptions to in-depth workshops to co-creating the analysis.
- Half of the studies used a pre-established goal, while the other half let the studies' analysis guide the ultimate aspiration.

MINNESOTA-SPECIFIC STUDIES TO BUILD ON

Efforts by individuals, nonprofits, and the government provide useful input into a comprehensive attempt to understand the future role of clean energy and chart a path forward in Minnesota. These efforts include:

***Renewable Minnesota* by Makhijani, Mills, and Ramana**[34]
This report tests the feasibility of a fully renewable electricity system that covers Xcel Energy's territory in Minnesota.

Minnesota Climate Change Advisory Group[35]
This report outlines the set of strategies necessary to achieve the state's long-term greenhouse gas reduction target. It provides a guide to the types of technologies that could form the state's clean energy future.

HOW SHOULD THE ENERGY FUTURE STUDY BE DONE?

02

HOW SHOULD THE ENERGY FUTURE STUDY BE DONE?

An EFS is a major undertaking that seeks to understand the state's energy system and plot a path toward a clean, reliable, and affordable energy future. Although the effort to develop such a path for a state like Minnesota is complex, the approach to carry out a project of such magnitude can be broken down into discrete steps, outlined in Figure 3.

Each step entails many choices that can make a study of this scope feel daunting and unattainable. The choices range from very high-level considerations like determining the aspiration or goal that the study is testing to very specific options like choosing whether and when to use a societal discount rate or a private discount rate in the study's financial analysis. Fortunately, governments, companies, and nonprofits have tackled exercises that are similar in scope, and Minnesota can learn from and build on these. Collective experience from this and other studies discussed earlier in this report show that the hundreds of choices that are made over the course of a study of this magnitude do not have to be paralyzing and that a successful study can be launched by focusing on several key decisions:

1. ***Stakeholder engagement process***—Who will be involved and how they will be involved throughout the EFS process.
2. ***Objective***—What the state and its stakeholders aspire to create for Minnesota's energy future, and what criteria it will use to make choices and tradeoffs.
3. ***System definition***—Which energy-using sectors are included, which levers should be assessed, and which connections between those sectors and levers to reflect.
4. ***Analytical approach***—How the study team should analyze the options and distill insights from the analysis.
5. ***Methodological details***—What specific methodological approaches should be employed.
6. ***Project plan***—What deliverables should be produced, in what timeline, and for what budget.
7. ***Criteria for success***—What is required for the EFS to be a success.

Figure 3: **Key Steps of the EFS**

ASSEMBLE

Assemble the right team.

The team that will drive the study is assembled, comprising a consultant support team, core stakeholder leadership group, and technical working groups.

ALIGN

Align on objective, system definition, and analytical approach.

The study team lays out the aspiration the study is testing, develops the decision criteria that will allow the team to evaluate different strategies, and defines the shape, form, and process of the study.

ASSESS

Assess feasibility, develop strategic vision, and build recommendations.

The bulk of the study analysis. The study team evaluates the clean energy levers and builds resource pathways within a set of scenarios. The study team uses decision criteria to compare pathways and build a strategy that highlights the largest opportunities for Minnesota.

ACT

Create an ongoing process to keep the work alive.

To ensure the EFS continues to be current and relevant, the study team recommends a process through which the EFS will inform other efforts and will be regularly revisited. Additionally, the study team lays out a set of actions to set Minnesota on a successful path.

The remainder of this report seeks to illuminate each of these decisions. As an initial scoping document, the purpose of the following sections is to provide context and guidance around what the EFS could or should look like, not to define or dictate the myriad methodological and data choices that ultimately need to be made. RMI provides recommendations and guidance, summarized in Table 1, around those scoping elements that shape the direction of the EFS. RMI also identifies but leaves open a variety of other elements (not highlighted in Table 1). In this way, decision makers can understand the overall purpose and direction, but the team ultimately chosen to conduct the EFS will still have the ability to work with stakeholders to develop the details.

Table 1: **Summary of Key Recommendations**

SCOPE AREA	DESCRIPTION	RECOMMENDATION
Stakeholder Engagement Process	The approach the EFS takes to engaging stakeholders from outset through completion.	Execute stakeholder engagement through three levels: 1. Core stakeholder leadership group 2. Multiple subject-specific working groups 3. Broad outreach to wider set of stakeholders via informational meetings
Aspiration	The qualitative and quantitative energy goals the EFS seeks to study and evaluate.	The study should test the following question: How far and how fast can Minnesota transition to a clean energy system while maintaining affordability and energy reliability for its citizens and businesses? To operationalize this question, the EFS should define clean energy and several adoption and timeline targets for testing. The recommended definitions for these terms are below. • **Clean Energy**—Includes renewable energy and energy efficiency. • **Adoption Level**—Test 80% and 100% clean energy. • **Timeline**—Evaluate 2050 and 2030 as timeline for goal.
Decision Criteria	The criteria and metrics used to evaluate different pathways that accomplish the same aspiration.	Use decision criteria that highlight each pathway's effect on cost and affordability, reliability, economic development, environmental quality, and public health and quality of life. Engage stakeholders to define the specific metrics to measure each criterion.
Sectors	The sectors define the energy uses that are included in the study and the groupings that will drive the analysis.	Include all energy-using sectors and initially break the analysis down into buildings, industry, agriculture, transportation, and electricity sectors.
Levers	The technologies, behaviors, or other tactics that provide clean energy.	Start the analysis by considering commercially available levers. Perform a sensitivity to consider the effects when emerging technologies are also included.

continued →

Table 1: **Summary of Key Recommendations** (cont'd)

SCOPE AREA	DESCRIPTION	RECOMMENDATION
System Linkages	The system linkages are the points of interconnection between sectors. For example, a critical linkage is the electricity demand from electric vehicles in the transportation sector.	Perform analysis that sizes the quantitative value of supply and demand interconnections across sectors. Carry out qualitative analysis to understand synergies or unintended consequences that strategies in one sector drive in the other sectors.
Feasibility and Pathways	The stage in the EFS that assesses whether and how Minnesota could reach its clean energy objective.	• Break the phase into four steps: 1. Sense and understand; 2. Design scenarios; 3. Assemble data, inputs, and outputs; 4. Model scenarios. • Engage stakeholders more heavily than is typical. • Combine portfolio and transformative scenario planning approaches. • Use technical working groups to carry out modeling. Perform modeling with a host of tools that are sector-specific, but also integrate sector results.
Strategic Vision and Recommendations	The phase of the EFS that takes scenario results and uses them to craft the strategy and near-term recommendations.	Break this phase of the EFS into three stages: 1. Strategic vision and signposts 2. Barriers and solutions 3. Near-term action and ongoing process
Budget	The total cost to conduct the EFS based on estimating the size of the study team and the project duration.	$1.5–2.0 million
Study Process Duration	The length of time it would take to complete the EFS, with the time range driven by the level of stakeholder engagement.	12–18 months
Project Team Capabilities	The minimum set of skills and experience that must be present on the study team to carry out a successful EFS.	Strategy and Analysis: • Ability to understand energy end uses and analyze economic and environmental dimensions of clean energy technologies • Experience across all energy-using sectors • Ability to use a whole-system perspective Stakeholder Process: • Credibility to convene wide range of Minnesota stakeholders • Ability to facilitate through process of co-creation • Experience pushing stakeholder engagement beyond staked out positions to identify shared interests

The remainder of the document provides a more detailed explanation of the recommendations in Table 1 and input on other elements, including the analytical approach, methodological details, project plan, and criteria for success.

1. STAKEHOLDER ENGAGEMENT PROCESS

The stakeholder process shapes how the EFS will engage Minnesotans, and we discuss it first because it is one of the most important factors defining the ultimate success of the EFS. In RMI's experience, when stakeholders are only superficially engaged, the likelihood of the end result getting traction and driving action is low. In comparison, engaging stakeholders more directly in co-creation and collaborative analysis can produce better outcomes.

HOW SHOULD STAKEHOLDERS BE ENGAGED?

Through a set of meetings to inform and solicit input.

The most common approach to stakeholder engagement in EFS-like efforts involves large meetings scheduled several times throughout the study process to present information and ask for comment or questions. This type of engagement can result in the discovery of important concerns or issues the study team must understand. It is a time-efficient way to get perspective and input from a large variety of stakeholders, and input gathered from these meetings can be incorporated in the analysis and final product. Deeply engaging stakeholders is time intensive and it is impossible to deeply engage the thousands of stakeholders that have an important stake and interest in Minnesota's energy future.

Through a more in-depth, co-creative approach.

A more in-depth stakeholder process that involves co-creation of strategy, collaborative analysis and multi-forum public input is more likely to drive ownership and action. Most strategy work that does not take this approach does not lead to sustained action in the stakeholder community, and lack of interest and action often leads to even the most thoughtful piece of analysis, study, or strategy being shelved.

Our perspective

The goal of the EFS is to drive action, and to do so, it must engage stakeholders deeply. To do so while balancing time efficiency and management capacity, it should engage different stakeholders in different ways, including a core leadership group, multiple subject-specific working groups, and a means of more broadly engaging the public.

To effectively strike the right balance, the EFS stakeholder process should involve three levels of engagement (see Figure 4).

Figure 4: **Three Levels of Stakeholder Engagement**

- ***Core leadership team:*** Comprising 20–30 business, government, and civil society stakeholders that represent all energy-using sectors, the core leadership team brings the leverage, knowledge, and resources needed to guide the EFS process and enable action. This group will define decision criteria for the EFS and work with the consulting study team to process technical outputs, build a strategic vision, and craft recommendations. Further, they will act as a key conduit for sharing information and soliciting input from broader groups of stakeholders for whom they serve as representatives. Meeting regularly throughout the study process, the core leadership team provides the continuity needed to carry out a rigorous and complex study.
- ***Working groups:*** A handful of smaller working groups would collaborate with the consultant support team and the core leadership team in the development and execution of the technical analysis. Populated with in-state experts that work on energy issues in transportation, buildings, industry, agriculture, and electricity, working groups would focus on a particular part of the analysis (e.g., clean technology costs and characteristics, transportation levers) to develop and articulate inputs, assumptions, and desired outputs and metrics. In this way, stakeholders participate actively in the analysis and create greater legitimacy.
- ***Public:*** The broader public would be engaged via regular stakeholder update meetings used to inform stakeholders about progress and solicit input and comment. This could be accomplished through a series of town-hall-style meetings in key geographic locations throughout the state. Involvement of members from the core leadership group as well as working groups at these meetings would create an important degree of continuity across the stakeholder process.
- ***Consultant support team:*** The consultant support team is the organization or group of organizations that together drive the EFS process and analysis. The consultant support team will spearhead the stakeholder engagement process, providing organizational and facilitation support to ensure a successful, informative, and collaborative process. Additionally, the consultant support team will provide primary design and analytical support for scenario development and technical analysis.

One related decision will be what stakeholders to include, especially if there are different levels of engagement. At a minimum, the process should include representatives from these important areas, each contributing valuable expertise:

- ***Business***—Economic expertise, leadership, implementation, and adaptation
- ***Energy Sector*** (e.g., energy efficiency providers, electric and natural gas utilities, biofuels refineries)—Hands-on technical expertise and integral to business model transformation
- ***Government***—Regulatory, technical, and policy expertise
- ***Civil Society***—Diverse interests, leadership, hands-on pragmatic knowledge and technical expertise
- ***Academia***—Technical and policy expertise

This type of stakeholder process, though challenging, will form the basis for a successful EFS and help ensure that it creates action. In Hawaii, for instance, a core group of motivated stakeholders, combined with sector-specific working teams, was an integral component in the successful Hawaii Clean Energy Initiative, one of the most aggressive renewables initiatives in the country. Not only were stakeholders involved in the analysis and strategy planning, but working groups have also been important in generating continued action related to the initiative.

No matter what stakeholder process is developed for the EFS, organization and involvement needs to happen early and often. Delaying involvement or failing to develop a clear stakeholder plan will significantly impede a successful EFS.

2. OBJECTIVE

Clarity of purpose and process is critical to the ultimate success of an EFS. Doing so requires alignment on the aspiration and decision criteria to evaluate different pathways to achieve the aspiration.

Aspiration and Decision Criteria

H.F. 729 established a starting point for defining the EFS's aspiration: to create a sustainable and cost-effective energy system that does not rely on burning fossil fuels.[36] Input received from stakeholders during the scoping process aligned with this aspiration broadly, but also reflected a variety of additional considerations ranging from the importance of maintaining electricity reliability to ensuring cost equity across customer classes. Based on that input, we recommend the following question lead the EFS:

HOW FAR AND HOW FAST CAN MINNESOTA TRANSITION TO A CLEAN ENERGY SYSTEM WHILE MAINTAINING ENERGY AFFORDABILITY AND RELIABILITY FOR ITS CITIZENS AND BUSINESSES?

To answer this question, the EFS must define the goal metric and one or more quantified targets and timelines to evaluate. We recommend the study use clean energy as a metric (rather than GHG reduction or fossil fuel reduction) that encompasses both renewable energy and energy efficiency.

As defined here, clean energy does not include natural gas, coal with carbon capture and sequestration, or nuclear. However, Minnesota stakeholders will ultimately establish a definition at the outset of the EFS and could choose at that point to include some or all of the resources discussed here, or others such as large hydroelectric power. Two factors guide this working definition. Natural gas, coal, and nuclear are not renewable forms of energy, and each has its own set of significant negative environmental implications. Additionally, carbon capture and sequestration is often used as part of a fossil fuel extraction and processing loop (enhanced oil recovery). Although not defined as clean energy sources, each may be an important short- and long-term enabler for incorporating high levels of clean energy.

Using a clean energy metric that includes both renewable energy and energy efficiency has two advantages over fossil fuel or GHG reduction metrics. First, it frames the effort in positive terms, which enhances motivation and reduces the likelihood of isolating important stakeholder groups. Second, it better aligns with existing and successful state initiatives to increase renewables and energy efficiency, therefore leveraging important existing momentum.

The study should focus on exploring pathways to meet 80% and 100% of the state's energy needs with clean energy. These target levels can be tested against different timelines to assess how quickly the state can achieve a certain level of clean energy. Our recommendation is to test 80% and 100% clean energy by 2050, and then roll the date back to test the achievement of these goals by 2030. This discrete set of targets and timelines will enable Minnesota to consider how far and how fast it can go without the analysis becoming overly complex, time consuming, and difficult to interpret and message to stakeholders.

WHAT IS THE APPROPRIATE CLEAN ENERGY TARGET?

100%

Setting bold and aggressive goals can help break through long-held mental models and reveal new possibilities. Forty years ago few would have imagined a world so infused with technology or hundreds of thousands of people driving electric cars. Even ten years ago integrating 10% renewables into the electricity system seemed implausible, yet Xcel Energy in Colorado exceeded 60% renewables in a single hour in 2013. The benefit of hindsight shows that renewables have consistently surpassed expectations, forecasts, and beliefs, so why place an arbitrary threshold on them now? Target the maximum—100%—and scale back from there if analysis shows it's prudent to do so.

80%

Just like a marathon where the final few steps can be the most painful, it seems likely that getting the final few percentage points of clean energy could be much more difficult and expensive. Targeting 80% is more plausible and creates a framework for action by avoiding the inertia that can form around a goal that many believe is impossible or imprudent. Further, 100% is not necessary to meet global climate targets, so why make it harder than necessary.

Less than 80%

Starting below 80% improves the chances that the EFS could develop a clean energy solution that is technically and economically feasible. Studying a lower target may make it more likely that a wider group of stakeholders will engage. And looking at lower targets could help Minnesota set the next stretch target that comes after the 2020/2025 Renewable Portfolio Standard and 2015 biofuel blend mandate.

Our perspective

Test 100% and 80% clean energy. In this way, the spirit of Minnesota's aspiration is met and the range of options and opportunities can be brought to light, including a better understanding of what it would take to transition Minnesota entirely off fossil fuels. Designing the EFS to also test a pathway to 80% clean energy will enable the state to evaluate what it takes to meet existing state goals.

Possible pathways to meet Minnesota's clean energy aspiration must be evaluated using a set of decision criteria that highlights each pathway's effect on affordability, electricity reliability, economic development, and environmental quality and public health. Each of the decision criteria must be translated into specific metrics that are quantifiable, transparent, comprehensive, and representative of the state's goals. Further, the list of metrics should be concise enough that they paint an accessible picture and clarify rather than confuse.

Potential metrics that may meet these design guidelines are described in Table 2. We have chosen not to recommend specific metrics because it is important that the consulting study team work with stakeholders to vet these decision criteria and metrics and consider adding, removing, or modifying metrics based on that dialogue. The list of criteria and metrics must reflect the priorities of the state and its stakeholders since these metrics play a large role in defining and choosing between the clean energy pathways. These metrics must also be economy-wide whenever possible, yet still reflect localized outcomes.

Table 2: **Decision Criteria and Potential Metrics**

DECISION CRITERIA	POTENTIAL METRICS	OUR PERSPECTIVE
Affordability	• Net present value • Life-cycle cost, including externalities • Required investment • Utility rates	The economic analysis should consider externalities and the exclusion of federal fossil fuel and clean energy subsidies as sensitivities. It must compare business-as-usual costs with the cost of a clean-energy-based system. The list of possible metrics excludes energy price, since energy prices (e.g., natural gas price) are part of national and global markets that are typically not swayed by one state's actions.
Reliability	• Standard utility criteria (e.g., 1 day in 10 years) • Resilience	The analysis should test reliability using an hourly dispatch for the MISO region. Resilience can be qualitatively considered based on how EFS electricity resources change overall design of the system.
Economic development	• Net jobs • Dollars kept in-state	Jobs analyses are notorious for providing dubious estimates. It is critical that the jobs analysis uses a transparent approach and takes a comprehensive view of net jobs. Jobs estimates should only be one part of the analysis—it is as important to understand changes in total energy costs and how and where dollars are flowing in the economy.
Environmental quality & public health	• Air pollution (greenhouse gases, criteria pollutants, air toxics) • Public health impacts (e.g., asthma cases) • Land use • Water use and pollution	Focus on the metrics that matter most to the state (e.g., land use, given Minnesota's agricultural base) or that tie to a specific goal (e.g., carbon emissions).

THE CHALLENGE OF DESIGNING METRICS

Several metrics in Table 2 present analytical challenges that the study team must consider. For example:

Life-Cycle Cost with Externalities: Understanding the life-cycle energy needs and the externality costs of energy requires the team to fully inventory cost and benefits, and to develop approaches to quantify those costs and benefits that are not typically accounted for in traditional economic analyses. The costs of energy include damages to the environment and negative effects on public health from air and water pollution. Developing credible estimates for these types of benefits could and has encompassed entire studies. The scoping team recommends the study balance the need for full cost accounting with the analytic effort required to develop such estimates. One approach to doing this is to run sensitivities with readily quantifiable externalities, many of which have a range of current and future estimates, including those in use by the Minnesota Public Utilities Commission.[38]

Net Jobs: Since the recession began in 2008 it is increasingly important to attach job creation numbers to public and private investment programs. The broad scope of a state-level strategy that looks across all energy-using sectors over a long timeframe means that investment in clean energy technologies is large and the potential jobs impact could also be correspondingly large—magnifying the importance of jobs analysis. The scoping team recommends this analysis focus on net jobs, ensuring that the analysis should include both job creation from new investment and any job loss associated with transitioning to new energy types or from changes in energy costs.

Resilience: The National Association of Regulatory Utility Commissioners defines resilience as “robustness and recovery characteristics of utility infrastructure and operations which avoid or minimize interruptions of service during an extraordinary and hazardous event.” To derive quantitative estimates for electricity system resilience requires detailed and time-intensive distribution system modeling. We recommend the study limit this type of analysis because it is more detailed than is required to provide feedback on the types of electricity systems that are more or less resilient. The National Infrastructure Advisory Council developed a list of factors affecting sector resilience. The most pertinent factors for the EFS to consider include effects on system interconnectedness, ability to store energy, cyber dependence, and dependence on inputs from other sectors (e.g., fuel). Reducing interconnectedness of energy assets, increasing storage capacities, reducing cyber dependence, and lowering reliance on inputs from all sectors serve to increase energy resilience.[39] The study should consider whether and the extent to which each pathway incorporates these elements and form a qualitative assessment of how resilience changes across pathways.

3. SYSTEM DEFINITION

What's included and not included in the system to be analyzed plays a large role in shaping the analysis and in what ultimately may be possible. Key aspects of the system definition include:

- Which energy-using ***sectors*** to include,
- What set of clean energy ***levers*** (i.e., technologies, behavioral strategies, or other tactics) to analyze, including how to incorporate ***emerging technologies***, and
- How to assess ***interconnections*** between sectors

Sectors

H.F. 729 notes that the EFS should cover energy use from the electrical, transportation, thermal, and industrial sectors. With additional stakeholder input, we recommend that these sector definitions be revised to better align with how energy data is reported, how energy analysis is conducted, and how other similar studies have defined sectors. Sectors to be included are transportation, buildings, industry, agriculture, and electricity. We recommend breaking out agriculture, normally included in industry, as a separate sector because of the outsized role it plays in the state's economy as well as unique levers that can be employed in agriculture as compared to other forms of industry.

Table 3: **Sector Definitions**

TRANSPORTATION	Energy to move people or freight by passenger vehicle, medium- and heavy-duty truck, rail, ship, plane, and bus as well as alternative forms of transport such as bicycles.
BUILDINGS	Energy to heat, cool, light as well as operate electric products in residential and commercial buildings.
INDUSTRY	Energy to operate equipment and generate process heat in a wide variety of industries such as, but not limited to, petroleum and coal products, food manufacturing, data centers, and paper and pulp.
AGRICULTURE	Energy to operate machinery and equipment as well as light, heat, and cool farm buildings; includes on-farm uses of energy.
ELECTRICITY	Energy to generate electricity from sources such as solar PV, wind, nuclear, coal, natural gas, and hydroelectric in order to service the electricity needs across end-use sectors.

Levers

To evaluate pathways that achieve the clean energy aspiration in each sector and across the entire energy system, all commercially available clean energy levers should be included. ***A clean energy lever is any technology, behavioral strategy, or other tactic (e.g., mass transit, industrial ecology) that either reduces energy use or provides clean energy*** (as defined in the “Aspiration and Decision Criteria” section earlier). Emerging technologies should be considered as sensitivities, after the team has evaluated how far conventional means can take the state toward its goal. While not comprehensive, Table 4 identifies some of the levers that should be included in the EFS. Others may be identified as part of the EFS stakeholder process.

Table 4: **Sample Levers in Each Sector**

TRANSPORTATION	Levers below focus on passenger vehicles. Other segments include aviation, heavy trucking, and rail. • Reduce vehicle miles traveled—Major opportunities in system efficiency, smart growth, mobility options, and pricing • Improve vehicle efficiency—Encourage adoption of vehicles with higher fuel economy • Substitute for fossil fuels in vehicles—Encourage adoption of vehicles that use electricity or biofuels
BUILDINGS	• Reduce building load—Insulation, daylighting • Improve equipment efficiency—High-efficiency lighting, furnaces, etc. • Substitute for fossil fuel in building and water heating—Electric heating from renewable sources, biofuels • Deep energy efficiency retrofits that rely on energy analysis to identify ways to harness currently wasted sources of energy, such as has been done at the Science Museum of Minnesota, Faribault Foods, and elsewhere
INDUSTRY	• Improve efficiency—Target efficiency of electric drive, process heat, and chemical processes • Substitute for fossil fuels in process heating—Biogas, solar thermal • Transform industrial approach—Industrial ecology, dematerialization
AGRICULTURE	• Reduce water pumping needs—Precision application and drought-resistant crops • Improve efficiency of equipment—Equipment like tractors and water pumps • Substitute for fossil fuels in equipment—Electricity, biofuels
ELECTRICITY	• Provide clean energy—solar PV (utility-scale and distributed), wind power, biomass • Resources that help balance the system—demand response and storage.

HOW SHOULD THE EFS TAKE EMERGING TECHNOLOGIES INTO ACCOUNT?

Don't include emerging technologies at all.

The future is almost impossible to predict, and trying to guess what technologies will become commercially viable and widely adopted is fraught with error. By including only existing, commercially available technologies, the EFS provides a conservative estimate of what can be accomplished and is more credible. Assuming no technological breakthroughs creates a clear path forward around a set of near- and long-term actions.

Assume emerging technologies are available.

History has proven how rapidly technology evolves and the transformative impact it can have on how energy is used and supplied, its economics, and the opportunities that it creates. Assuming emerging technologies will become available is rooted in experience and allows for a more thorough exploration of what is possible rather than constructing a limited view based on conservative assumptions. Without considering the role of emerging technologies, Minnesota might not anticipate important developments. In this way, the state can better prepare for the future.

Our perspective

Start with only commercially available technologies, and test the potential impact of emerging technology as a sensitivity. This provides an important conservatism, but also allows a consideration of the implications of emerging technologies. Excluding emerging technologies except as sensitivities means that any future technological transformations will increase the opportunities around how fast and how far the state can move. By conducting sensitivity analysis around certain technologies, the analysis can provide a clearer picture of the impact of technological breakthrough without tightly pinning the state's energy strategy to the unknown.

System Linkages

In order to simplify the study analysis it is necessary to break the work into the suggested sectors. However, a critical part of the study analysis is to integrate results across sectors to understand system linkages. The integration process serves to uncover hidden synergies where investments in one sector may provide benefits in many sectors. In addition, integration allows sector teams to consider how strategies in each sector may have unintended consequences that are only visible by expanding the problem and looking at the whole energy system.

In one classic example of unintended consequences, a town in the arid Southwest implemented a strategy to improve water efficiency thinking that this would help alleviate a major local issue that was leading to high water prices and constraining how and when residents could use water. Instead, the water efficiency program worked so well that it actually enabled developers to expand new construction, which increased populations and intensified stress on limited water supplies. Connecting these types of feedback loops across the energy system is an essential part of the EFS.

The EFS should characterize the quantitative linkages across sectors. Those linkages include such things as increases in electricity demand from electric vehicles or the electrification of home and building heating demand. There are also less obvious but equally important linkages, like how the demand for liquid transportation fuels in Minnesota and in the region affects refining output and energy use in the industry sector. Table 5 highlights these and other common system linkages. Beyond quantifying these linkages, the study team should employ a qualitative process that articulates synergies and unintended consequences, so that these considerations can feed back in and inform the strategic vision and recommendations developed as part of the EFS.

Table 5: **Critical System Linkages**

TRANSPORTATION	BUILDINGS	INDUSTRY	AGRICULTURE	ELECTRICITY
• Coal use in electricity sector affects rail transport needs • Density, layout of city affects vehicle miles traveled for freight and passenger modes • Natural gas demand for heat affects fuel transport use	• Transportation congestion affects urban planning/ home types • Electricity prices affect amount and timing of energy use	• Transportation use of gasoline, diesel, and biofuels affect refining • Building heating affects demand for district energy	• Land use for electricity production affects availability for farming • Biofuels demand affects type and amount of crop needs	• The following affect the amount and timing of demand for electricity: energy efficiency of buildings and industry sectors, demand response of buildings and industry sectors and electric vehicles, adoption of distributed generation (e.g., combined heat and power), demand for electrolysis in industry sector, electrification of building heating, electric vehicles and electrification of rail

4. ANALYTICAL APPROACH

Designing a clear and effective analytical approach supported by in-depth stakeholder engagement is critical to making the EFS manageable and meaningful. This section offers a potential approach (summarized in Figure 5) at a high level, recognizing that the eventual consultant support team will need to refine and adapt this approach and build out the underlying methodological details.

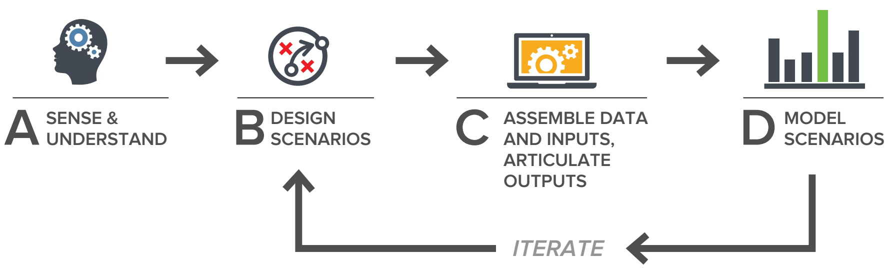
Figure 5: **Overview of EFS Analytical Approach**

	Feasibility & Pathways	Strategic Vision	Recommendations
Key Question	Is it technically and economically feasible to meet 80% and 100% of the state's energy needs with clean energy by 2050? By 2030? If not, what level aspiration is feasible and by when?	What does Minnesota need to be aware of to enable the future it wants?	How can Minnesota overcome key barriers towards its vision, and what can the state do immediately?
Activities	• Assess resource potential • Assess resource cost and characteristic • Develop and model scenarios	• Compare pathways and develop strategic vision • Identify risks, opportunities, and signposts	• Identify barriers and possible solutions • Develop near-term "no regrets" actions • Design next steps and ongoing process
Outputs	• Resource supply curves and quantified scenario inputs • Discrete set of scenarios that test most significant choices and driving forces	• Comprehensive assessment of risks and opportunities • Signposts that can guide future choices	• Set of prioritized barriers and possible solutions • Set of high-priority, no-regrets actions that can be taken in the near term, along with who needs to take them • Developed process, along with institutional lead, to take work forward and revisit regularly

Feasibility and Pathways

The foundation of the EFS is assessing whether and how Minnesota could reach its clean energy objective while maintaining affordability and reliability for its citizens and businesses. That assessment, described here, should analytically describe the technical and economic feasibility of multiple future scenarios. Figure 6 outlines the recommended approach.

Figure 6: **Approach to Assess Feasibility and Develop Pathways**



A. Sense and understand

To design informative scenarios and produce useful results, the consultant support team and stakeholders must first work together to understand the current situation, the myriad resource options that could help achieve its EFS objective, and the priorities and concerns of different stakeholders. This phase of work should be done through a combination of consultant research and collaborative stakeholder dialogue.

Activities	*Outputs*
• Assess resource potential of levers (e.g., wind, mass transit) • Assess current cost and cost trajectories, technical characteristics, and impacts (e.g., environment, job creation) of levers • Map stakeholder priorities and concerns • Align on analytical approach and plan	• Resource supply curves over time • Resource characteristics and impacts • Stakeholder priorities and concerns that will shape scenario analysis

While much of this information could be assembled by the consultant support team alone, it will have much more impact throughout the study if stakeholders are engaged from the start by participating in dialogues and by being invited to bring forth data, studies, and perspectives they think are relevant.

B. Design scenarios

In the sensing and understanding phase of work, the study team and stakeholders will no doubt uncover uncertainties, risks, and options—some of which Minnesota can influence and others it cannot. Building a discrete set of scenarios around those driving forces is a critical tool to bring clarity and inform important strategic questions. Scenario planning is particularly important in contexts where investments are large and long lived with high uncertainty, making them particularly well suited to the energy system. There are three principal and potentially complementary approaches to scenario analysis that could be considered for the EFS:

- ***Portfolio scenarios*** test the technical and economic feasibility of different resource portfolios, and the impacts of each against a set of decision criteria and metrics. They comprise different combinations of energy supply and demand resources, recognizing that the wide variety of available levers offer many ways to meet the same clean energy target. Portfolios are sometimes created as somewhat random aggregations (e.g., +/- nuclear, +/- efficiency), but best-practice portfolio scenarios create concise and internally consistent views of what the energy system could look like in the future. Each portfolio describes the levers that dominate, and can be used to develop analytical constraints and inputs that can be modeled. Portfolio scenarios could require the least stakeholder engagement, but should still engage stakeholders up front to shape the defining attributes of each.

  Example: Rocky Mountain Institute's 2011 book *Reinventing Fire: Bold Business Solutions for the New Energy Era* analyzed four portfolio scenarios to understand the tradeoffs between possible electricity system futures. One was a base case and three used different combinations of technologies to meet a fossil fuel reduction target. The first step in developing these scenarios was understanding the direction that different forces might push the electricity system and determining the combination of technology choices these forces would drive. For example, in one scenario, customer interest in energy increases, rapid cost declines continue in rooftop solar PV, and the combination of these forces produce an electricity system with significant investment in efficiency, rooftop solar, and other distributed resources.

- ***Adaptive scenarios*** explore different ways in which the world may evolve, and by doing so, develop signposts and "no regrets" actions that will allow Minnesota to adapt to changing conditions with no particular end-state goal. They entail story-based descriptions of the future based largely on driving forces Minnesota does not control. Adaptive scenarios are created by building an understanding of what is happening in the energy system, and hypothesizing what driving forces will lead to the biggest changes in the future. Those driving forces that are uncertain account for differences between scenarios, while those that are certain are held constant across scenarios. Through this approach, the team can uncover hidden issues that may be increasingly disruptive or powerful in the future and test how strategies fare across different scenarios, thereby better understanding risks and opportunities. Adaptive scenarios provide a rich basis for considering strategic implications and choices in the face of changing conditions, and being prepared to adapt according to identified signposts.

Example: Over the course of 2011, the Western Electric Coordinating Council (WECC) used adaptive scenarios as part of its regional transmission expansion planning process. The scenarios, developed by a wide range of stakeholders, will be used to help guide long-term capital investment decisions by helping managers effectively evaluate timing, scale, and risk of those investments. Each of four resulting scenarios has a different core focus: economic recovery, clean energy, short-term consumer costs, and long-term societal costs. Importantly, each of these scenarios was then used to generate inputs for a comprehensive quantitative long-term planning tool. For instance, differences in policy across the four scenarios would provide modifications to the baseline quantitative model. Overall, the adaptive scenarios process created alternative qualitative visions to help transform the thinking of WECC and better enable planners to prepare and adapt.

- ***Transformative scenarios*** explore different ways in which the world may evolve in order to understand how Minnesota can not only adapt but also influence and transform its own future. Scenarios are developed through a collaborative process to reflect how Minnesota's energy future *could* unfold, rather than how stakeholders *want* it to or *think* it will. Transformative scenarios are useful in addressing situations that people view as unsustainable, when transforming the situation cannot be accomplished by working solely with the like-minded, and when transforming the situation cannot immediately be accomplished through direct action. Transformative scenarios can complement portfolio scenarios by helping stakeholders envision alternative futures through a process that generates a greater understanding of the situation, shifts mental models, and subsequently drives actions. The analysis undergirding portfolio scenarios grounds stakeholders in a set of technically feasible alternatives, while transformative scenarios provide the framework to drive future action.[40]

WHAT IS THE RIGHT SCENARIO APPROACH FOR THE EFS?

Portfolio Scenarios.

The most important question for the EFS to address is the technical and economic feasibility of transitioning to a clean energy future. Portfolio scenarios are the most straightforward approach to answering that question, and are the most common form of scenarios used in studies like this. This approach is also the most time efficient while still allowing stakeholders to provide input into scenario design and assumptions.

Transformative Scenarios.

The world is changing more rapidly than ever before, and that means that Minnesota has an opportunity to proactively shape its own future rather than waiting to see what will happen and adapting. Transformative scenarios offer an alternative and powerful mechanism for creating a path forward amidst a set of complex social, political, and economic issues.

Adaptive Scenarios.

The world is changing more rapidly than ever before, and it's not clear what the future will hold. The best way for Minnesota to anticipate and manage risks and opportunities is to look at all the possible futures, not just clean energy, and figure out what "no regrets" actions it can take across scenarios and then what to look for to understand if the world might be moving in one direction versus another. The state should take an approach of smart adaptation.

Our perspective: All of the above

It's critical to test different resource portfolios (e.g., portfolio scenarios) to understand big tradeoffs, but doing so can be most effective when coupled with an understanding of how Minnesota's energy future could actually develop and how the state can influence that future (e.g., transformative scenarios).
This is a "best of both worlds" approach.

In the "all of the above" scenarios approach recommended here, the study team and stakeholders would co-create a discrete set of scenarios (e.g., three or four) for what could happen in the future based on a set of driving forces such as whether or not there is carbon regulation, the extent of declining technology costs, and whether Minnesotans choose to more actively engage in their energy choices or not. There would be at least one "base case" scenario, and at least two scenarios targeting 80–100% clean energy.

The team would then build and test a resource portfolio within each, shaped by factors such as the level of decentralization of the electricity system, whether carbon-free resources such as nuclear and coal with carbon capture and storage are added to clean energy options such as renewables, and how much energy efficiency can be captured. Finally, the team would test a discrete set of sensitivities across scenarios. These sensitivities should be things that could legitimately vary within any scenario, such as natural gas price.

Conducting this "all of the above" scenarios process would require convening stakeholders over the course of months to sense and understand, construct stories of what could happen, discover what can and must be done, and then finally act to transform the system. It is an iterative process that requires the extensive involvement, critical thought, and insight of diverse stakeholders, and is a major investment of time and resources. Facilitating such a process requires detailed knowledge of the key actors in a system; an ability to create an open, comfortable, and yet insightful environment; and a clear ability to distill and merge ideas into cohesive and logical stories. Key activities to design scenarios are outlined next; developing inputs, modeling, and building recommendations are described subsequently.

Activities

- Identify range of driving forces (e.g., changing economics, policy/ regulatory decisions)
- Either deductively or inductively, develop a discrete set of scenarios for how Minnesota's energy future could evolve
- Articulate key portfolio design principles to test as portfolio scenarios in those futures

Outputs

- Written report and possibly physical models that summarize thinking (and different viewpoints) about energy system and driving forces
- Narrative of each scenario, descriptive picture, and report or other media to inform stakeholders

C. Assemble data and inputs, and articulate outputs

Once scenarios are qualitatively designed, the study team and stakeholders must develop quantitative inputs that will allow each scenario and portfolio to be modeled. This phase can be time intensive and engender significant debate among stakeholders. An effective approach can be to develop technical working groups (the second type of stakeholder engagement described in Section 1 above) to focus on discrete aspects of this work. Likely the most straightforward approach is to develop sector-focused groups (e.g., transportation, buildings, industry, agriculture, and electricity).

Activities

- Identify technical working group topics and members
- Develop appropriate data and inputs
- Evaluate modeling tools
- Seek input from a broader stakeholder group via traditional stakeholder meetings

Outputs

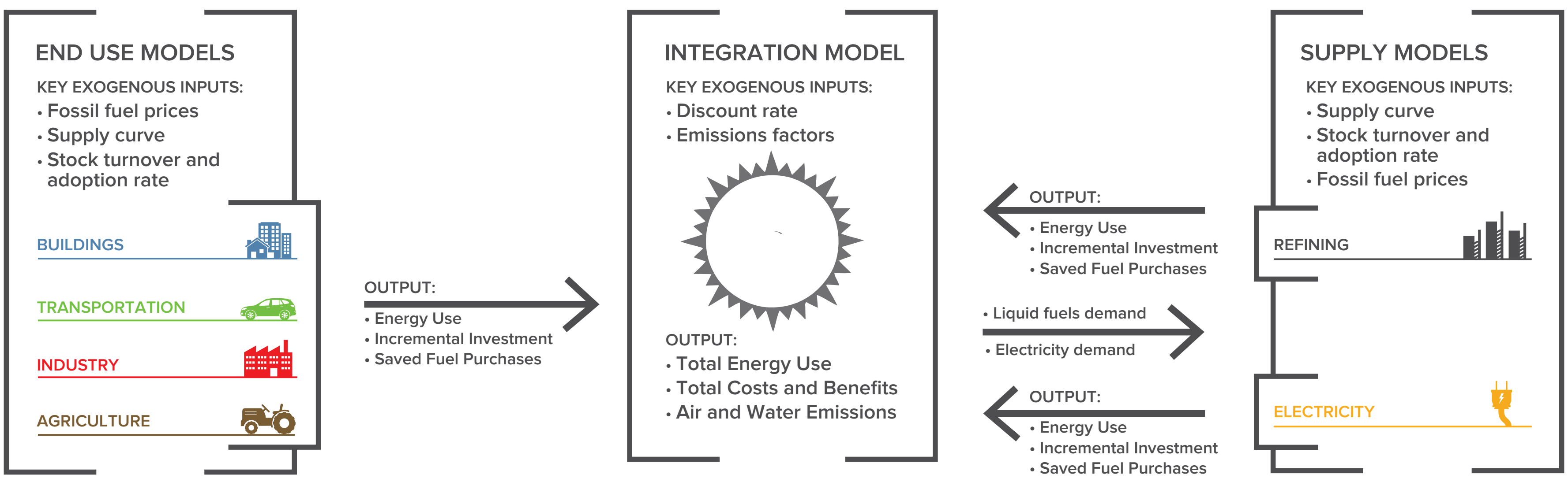
- Technical working group charters defining roles, responsibilities, and team rules
- Workbook with data inputs for each scenario

Stakeholders would work closely with the consultant support team via technical working groups. Therefore, the consultant support team would provide research and analytical capacity, but stakeholders would be equally responsible for crafting and finalizing the data and inputs. Engagement could be via in-person meetings, webinars, or both.

D. Model scenarios

With scenarios designed and data and inputs created, the study team would model resource portfolios, implications, and impacts. Figure 7 shows how the modeling work could be broken into discrete pieces yet tied together effectively.

Figure 7: **Energy Model Types and Relationships**



In the EFS, the modeling of resource portfolios and their impacts will use several different analytical tools. The need to evaluate energy consumption as equipment/technology changes in industry, buildings, transportation, and agriculture; test electricity sector operations; assess economy-wide economic impacts; and integrate strategies across sectors creates special modeling needs.

Industry, Buildings, Transportation, and Agriculture Tools
The sectors that use energy, rather than supply it, determine the state's overall energy requirements. Total energy use in these sectors is a function of many elements, including population, economic growth, and investments in efficient equipment and practices. Stock turnover models in each sector characterize the energy-using equipment, capture how the equipment stock grows, track when it is replaced, and enable the study team to assess whether more efficient use of the equipment or replacement of the equipment affects clean energy adoption. The stock turnover models generate outputs that include investment, energy use, and economic savings in each sector, and these outputs plug into an integration model discussed below and highlighted in Figure 7.

In addition to modeling stock turnover, the transportation sector merits more granular modeling that assesses local effects of different clean energy scenarios on traffic patterns, congestion, and use of different modes of transportation. For this purpose, fine-grained geographic demand and logistic modeling can be used in key transportation corridors to understand the impact of system changes (e.g., adoption of electric vehicles).

Electricity Sector Tools
The increased penetration of clean energy resources can have both positive and negative effects on the cost and reliability of the electricity grid. Several grid-modeling tools provide a means of capturing and analyzing these effects.

Capacity expansion planning models develop portfolios of electricity-generating resources to meet projected demand over a specific timeframe, like 20 years. Dispatch modeling works hand-in-hand with capacity planning to show which electricity resources are used in each hour of the year based on considerations such as marginal cost and transmission constraints. The dispatch modeling can also serve to test the reliability and operating characteristics of a proposed system. Transmission planning models identify points of power flow congestion in the transmission system, and allow users to create transmission expansion plans. Distribution planning models identify the need for upgrades in the distribution system by modeling power flows and the effects of those flows on equipment needs.

For strategy-level analyses like the EFS, capacity expansion planning, dispatch modeling, and some degree of transmission planning are likely to provide the appropriate level of detail and analytical rigor. A more limited treatment of distribution planning is appropriate for the EFS and would focus on identifying potential strategy and value implications.

Economic Impact Tools

One of the critical components in assessing an alternative energy future is the impact, positive or negative, it may have on Minnesota's economy. Just as policy makers need to assess the economic impact of a new law or initiative, Minnesota will need to assess the economic impact of a transition to clean energy. Regional economic impact analysis has become increasingly important to state and local governments for estimating a program's effect on jobs, product and service sales, income, and taxes.

There are four major modeling approaches used to estimate regional economic impacts: Input-Output, Econometric, General Equilibrium, and Economic Geography. The theory underlying these models breaks industries down into basic and non-basic. Basic industries, like manufacturing, agriculture, and tourism, are exporting industries, and non-basic industries, such as services, retail, and government, exist to support basic industries. Economies strengthen by developing basic industries, which create the need for more jobs in non-basic industries. Modeling tools attempt to quantify the relationships between industries by looking at how an investment affects a specific industry and how that cascades throughout other industries in the state.[41]

Integration Tools

As Figure 7 shows (page 46), there is significant sector-specific analysis needed to make the analysis tractable; however, it is important to integrate results from each of the sectors to estimate total economy-wide energy use, costs and savings, and air and water emissions. This type of integration model can be simple in form, but serves important book keeping functions—ensuring all activities in the strategy are appropriately counted and avoiding duplication of energy use or savings across sectors.

Activities

- Input data and run analysis
- Seek input from technical working groups
- Revise analysis
- Document findings

Outputs

- Written report, including findings and appendix describing methodology
- Presentation illustrating potential pathways

Because this task involves detailed analytical modeling, stakeholders would be less engaged in the actual modeling and the consultant support team would carry the bulk of the work. However, modeling results would be understood in conjunction with stakeholders and scenarios, data, and inputs potentially revised in an iterative loop.

Strategic Vision and Recommendations

With scenario results in hand, the team would have everything it needs to develop a strategic vision and recommendations. Whereas the technical and economic feasibility analysis and scenario development provides the foundation of the EFS by building confidence that a clean energy future is possible and credible, it is alone insufficient given stakeholders' expressed interest for the EFS to be action oriented. The study team and stakeholders must also:

- Compare scenarios and develop a shared strategic vision
- Identify risks, opportunities, and signposts along the way
- Assess barriers and possible solutions
- Develop near-term "no regrets" actions along with next steps and an ongoing process

Strategic Vision and Signposts

A strategic vision can build greater stakeholder alignment and shared ownership in Minnesota's energy future. Doing so requires evaluating the various scenario results to highlight the characteristics of a desired end state. Making choices around that vision should be driven by stakeholder dialogue focused on prioritizing decision criteria and comparing how various scenarios perform against those. This work will draw on existing analysis done in the feasibility work, but it is almost never the case that there will be a clear-cut winning scenario based on just looking at the analysis.

Importantly, developing a strategic vision does not mean the state or its stakeholders must choose and commit to all the particulars of a single pathway (e.g., a certain amount of wind power or distributed solar PV). Rather, the strategic vision paints a picture of what Minnesota's energy future could look and feel like, its overall clean energy goal, and key characteristics of that system. Signposts can be developed that help stakeholders evaluate progress and adjust choices and actions as needed. Together, the strategic vision and signposts represent a policy framework that is focused on outcomes, and purposefully leaves room for flexibility in the means to reach those ends as new technologies and other opportunities emerge.

Barriers, Solutions, and Near-Term Actions

With a strategic vision mapped out, stakeholders and the consultant support team can identify the key barriers slowing progress towards that vision, and the possible strategies or solutions to overcome those barriers. Doing so will result in a set of high-level recommendations, ideally coordinated with other ongoing activities in the state, to guide action. Near-term actions, including "no regrets" actions that are a win-win no matter the scenario or impacts of key driving trends, should focus on the next 2–5 years and should be accompanied by a more detailed description and specific next steps.

For example, if the study highlights building energy efficiency as an important resource, the next step would lay out the key barriers that could prevent widespread adoption. In many states, one such barrier is that utilities are not incentivized to invest in energy efficiency because it reduces energy (kWh) sold and utility revenue. A solution to that problem (under discussion in Minnesota) is to use decoupling and new incentives to encourage the utility to pursue energy efficiency. In the action planning stage, these solutions would then receive detailed work plans with associated budgets and timelines.

Plan for Ongoing Process
A poor outcome from the EFS would be a study that sits on a shelf—as many studies do. Therefore, it is imperative to create a plan for how the EFS work will be carried forward. This should include, for example, a requirement that the study be revisited every 2–3 years, progress assessed, and the next set of recommendations and near-term actions developed.

5. SECTOR-SPECIFIC CONSIDERATIONS

A number of sector-specific considerations unique to Minnesota must be addressed when conducting the EFS, including:

Transportation

- Urban vs. rural divide—Minnesota's population is split between several dense, urban centers and many rural communities. Transportation needs are different in urban and rural areas and the EFS's transportation strategies must consider and embrace these differences.
- Vehicle miles traveled (VMT)—Like the rest of the country, most Minnesotans commute in single occupancy vehicles.[42] Minnesota is investing to upgrade the public transit system in the Twin Cities to provide transportation alternatives to passenger vehicles. In addition, non-traditional commuting alternatives are increasing in popularity. For example, four car-sharing companies now offer services in Minneapolis.[43] It is important that the EFS look beyond just traditional commuting options to consider how public transit and new commuting options can reduce VMT.

Buildings

- Population growth—Parts of Minnesota are expected to experience significant population growth in the next 30 years. Population growth creates new demand for building and housing stock, and means that strategies that focus on improving the efficiency of new construction and supporting principles of smart growth in the placement of new homes and buildings could have a significant effect on future energy use in these high-growth areas.
- Renewable heating and district heating—Fossil fuel combustion to heat water and interior spaces in buildings accounts for approximately half of the delivered energy used in buildings.[44] A clean energy solution must address this large need that is met today primarily through the burning of natural gas. Alternative solutions include the electrification of heating (assuming the electricity system becomes renewable) and the use of biogas or biomass. These systems can provide for heating at the source using an air-source heat pump at a house, for example, or can develop district-heating solutions that generate heat at a larger facility and distribute that heat through pipes that connect a network of buildings and homes. St. Paul and Minnesota already have mature district-heating systems. The EFS should consider both the source of renewable heating and the right scale of the solution.

Industry and Agriculture

- Biofuels—The state has considerable biofuel resources in the form of corn-based ethanol. Minnesota's annual production capacity has increased from 20 million gallons to 1.1 billion gallons over the past 20 years.[45] Statewide production is nearly five times consumption, making it a significant export commodity for the state. As the Environmental Protection Agency has signaled it may lower gasoline/ethanol mix requirements in coming years and there is ongoing debate about the environmental impacts and competition for food supplies associated with using corn for ethanol, there are likely challenges on the horizon for corn-based ethanol and major implications for farmers and refiners.[46] However, there are also emerging industries in Minnesota with tremendous growth potential around advanced biofuels (e.g., cellulosic) and biochemical industries that could not only grow the energy sector but forestry and agriculture as well. This raises an open question of what the biofuel industry will look like in the future.
- Renewable Process Heating—The industrial sector relies on burning fossil fuels to produce high-temperature heat that is used in goods manufacturing. Currently, there are limited renewable process-heating options, and the options are generally more costly than using fossil fuels. The EFS should consider whether Minnesota's biomass and biofuels resources could provide potential in-state resources for renewable process heat.

Electricity

- Nuclear—Minnesota's two nuclear power plants are up for relicensing in 2030 and 2033/2034, when they will be 59 and 60 years old.[47] These two assets serve a quarter of the state's electricity demand.[48] Their potential retirement creates a major need for new investments in both efficiency and generating capacity.
- Transmission—The Midwest region has a large low-cost wind resource. Accessing this resource will likely require additional expansion in transmission that may run across state lines. Historically, it has been difficult to site and recover costs for new interstate transmission projects. It is important that the EFS consider the feasibility and cost of transmission expansion.
- Hydroelectric power—Manitoba Hydro's development plan includes nearly 2.2 gigawatts of new hydroelectric capacity.[49] It also plans on developing a large U.S. interconnection to support additional exports. The availability of additional electricity from Canadian hydropower may affect state expansion planning for the electric system.
- Distributed resources and customer action—Electricity customers have increasing access to a variety of on-site electricity technologies such as rooftop solar PV, electric vehicles, and smart thermostats. As these technologies become more popular and overall adoption grows, Minnesota must consider technology growth trajectories and the implications and opportunities that these technologies can create.

6. METHODOLOGICAL DETAILS

Developing the EFS will require the study team make a host of more detailed decisions around how it conducts the study analysis. These decisions are critical because the team's analysis approach, modeling tools, and assumptions will have a large effect on the results. The most important methodological details include:

- Baseline
- Technology Cost and Performance
- Geographic Boundary and Granularity
- Temporal Granularity
- Life-Cycle Energy Use
- Inputs and Assumptions

Baseline

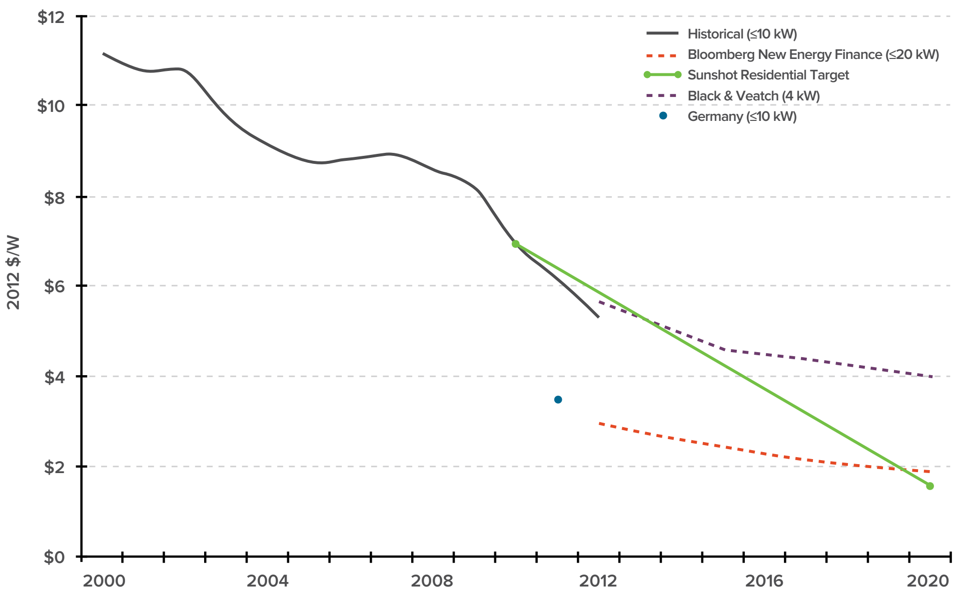
The baseline is the quantitative representation of the scenario that most closely resembles a business-as-usual approach, and draws heavily from existing energy policies and current trends in energy use and supply. It helps decision makers understand how the energy system might evolve under current conditions, and it facilitates comparisons with alternative energy scenarios. The EFS baseline should leverage inputs and assumptions from existing baseline analyses, including the U.S. Energy Information Administration's *Annual Energy Outlook* (AEO) and any Mid-Continent Independent System Operator (MISO) forecasts, but will most likely need to be designed specifically for Minnesota.

Technology Cost and Performance

The cost and characteristics of each lever are central considerations that the study team uses to develop unique combinations or portfolios of levers, estimate the total cost of each portfolio, and determine each portfolio's performance against chosen decision criteria. Some of the technologies that the EFS will consider have shown rapid changes in their performance and cost in the last several years. Solar PV provides a frequently cited example—the cost of installed PV systems under 10 kW has declined by nearly 7% per year over the last decade and the Department of Energy is working to drive PV costs from an average installed cost of $5.30/watt in 2012 to $1.50/watt by 2020 for residential rooftop PV.[50]

The EFS should employ an analytical approach that estimates cost declines and performance improvements over time. In particular, large cost declines could occur in battery technology (affecting both electric vehicles and the electricity sector), fuel cells, utility-scale and commercial/residential rooftop PV, advanced biofuels (e.g., cellulosic ethanol), alternative process heating (e.g., biomass process heat, concentrated solar thermal), and ground-source and air-source heat pumps. Best practice uses learning curves to forecast cost declines—the EFS may create these as part of its scenario development, or potentially use existing, credible sources that have already developed cost forecasts for many of these technologies. Figure 8 provides an example of cost forecasts and goals for small PV systems.

Figure 8: **Total Installed Cost for Small PV Systems**



Source: Ardani et al. (2013); Barbose et al. (2012); Black and Veatch (2012); Chase (2013); Seel et al. (2013)

Geographic Boundary and Granularity

Electricity

As part of a regional electricity system, Minnesota imports electricity from power plants that are outside its borders, and exports electricity to energy consumers in other states, enabling it to reduce costs by balancing electricity supply and demand across a larger balancing area managed by MISO. As Minnesota increases the share of renewable electricity, its regional partnerships will become even more important. There are major low-cost sources of renewable electricity in adjacent states, such as North Dakota wind. And with greater share of variable renewable energy—generating electricity only when the wind is blowing or the sun is shining—a broader regional portfolio of these assets diversifies and smooths renewable output since the wind may be blowing in North Dakota but not Minnesota. Given the current and growing importance of Minnesota's link to a regional electricity system, the geographic scope of the Minnesota electricity sector analysis should account for these regional interactions. This has three implications for the EFS:

- ***Renewable sourcing*** may include both in-state and out-of-state, regional sources.
- The ***operational and reliability assessment*** should consider the entire MISO footprint. The study should assess any incremental use of fossil fuels needed to provide flexibility and load following in a clean energy system.
- The ***geographic granularity*** of the analysis should quantify any incremental transmission investment needed to accommodate a regional mix with more renewable energy, and should consider incremental distribution investment

needed, although it is likely not necessary or feasible to model the entire distribution system for this strategy-level analysis.

Transportation
As with electricity, regional boundary issues matter in the transportation sector. The interstate transport of freight in heavy trucks and freight and people in airplanes means that these transportation modes originate, terminate, and pass through Minnesota. The study team must determine how much of this energy use to allocate to the state of Minnesota. Determining the right measurement approach requires balancing the need for analytic tractability with the desire to capture the incremental energy use from these activities that Minnesota consumers and businesses generate.

Data availability will likely limit the study's ability to most accurately capture transportation energy use. Using fuel use data to estimate in-state transportation will likely provide reasonable energy use estimates for vehicles and freight, and can also be used for aviation. Other approaches like using passenger miles traveled for passenger vehicles or commodity flow data are possible, but the study team may face data limitations in operationalizing these approaches.

Temporal Granularity

Raising the share of renewable electricity in the system requires new operating strategies to maintain system reliability, and accurately assessing those impacts requires modeling the electricity system on an hourly basis at minimum. States in Germany are already successfully integrating 40–50% variable renewables, and national and regional analyses for the U.S. and Europe have analyzed 80% or more.[51] And there are now a host of real-world examples closer to Minnesota. For example, Public Service Company of Colorado, an Xcel Energy subsidiary, met 17% of its 2012 load with renewable energy primarily from wind power, and in mid-2013, supplied over 60% of its load with renewables in a single hour.[52]

Any electricity system portfolio must be able to provide reliable power affordably. To test these issues requires an analysis with a sufficient level of temporal granularity (e.g., sub-hourly, hourly, daily, seasonally, annually). We recommend hourly analysis because it captures much of the impact without requiring unreasonably detailed analytics. It is possible to look at sub-hourly dynamics, particularly useful when considering significant levels of distributed energy resources like rooftop solar PV. In this instance, a sub-hourly analysis will help determine the challenges to operating such a system and the incremental investments required in the distribution system to enable safe and reliable operation. However, sub-hourly analysis is likely not necessary or feasible for the type of strategy-level analysis that is part of the EFS. It may, however, form an important next step should the strategy highlight the importance of distributed resources.

Life-Cycle Energy Use

Across all sectors, energy is expended in two ways. There is the direct energy consumed within Minnesota's boundaries to fuel a vehicle, power a generator, manufacture a product, or heat a building. Direct energy use only represents a share of the life-cycle energy consumption of the products and fuels used in the state. For example, the wind turbine that produces energy in Chandler, Minnesota, took energy to construct, including energy spent in the extraction and refining of minerals and metals contained in the turbine, and will take energy to recycle or dispose of at the end of its useful life. If its manufacture and eventual disposal occur outside of Minnesota's boundaries, then upstream and downstream energy use is not accounted for in Minnesota's baseline. As Table 6 illustrates, life-cycle energy use, even for a single product in a given sector, involves a complex set of energy uses.

Table 6: **Example of types of energy use in each phase of a vehicle's life cycle**

TRANSPORTATION

PHASE OF LIFE CYCLE	TYPE OF ENERGY USE
Extraction	Raw material extraction (e.g., iron ore, bauxite)
Production	Steel and aluminum production, plastic manufacturing, car assembly, etc.
Use	Fuel consumption, maintenance
Disposal	End-of-life demolition/recycling

For the EFS, a detailed accounting of the full life-cycle value of energy use that it takes to sustain Minnesota is ideal. However, measuring full energy use is time and data intensive and impractical for a study that covers all sectors and an entire state. The study team should consider if there are alternative approaches for considering life-cycle energy use, such as identifying the areas where life-cycle energy is likely to be the largest and charting strategies to drive down full energy use.

Inputs and Assumptions

Many data inputs and assumptions go into the quantitative analysis in each sector and overall. It is critical that the working team define these inputs and assumptions together. The credibility of many studies has fallen apart because stakeholders do not agree with the inputs and assumptions, so generating agreement and alignment among key stakeholders from the start will guard against this risk. Four of the most important inputs and assumptions are highlighted and described in Table 7 (page 56).

Other common inputs the study team will likely pursue include energy-related federal policies and subsidies, inflation forecasts, and power plant, equipment, and vehicle turnover rates. Should the study team decide to build its own baseline estimates, various data would go into these calculations, including macroeconomic and demographic variables like gross domestic product (GDP), income, new housing sales, new vehicle sales, population growth, and employment.

Table 7: **Key Inputs and Assumptions**

INPUT/ ASSUMPTION	DESCRIPTION	OUR PERSPECTIVE
Discount Rate	The discount rate represents the cost of borrowing/expected risk/return for a given investment and also expresses the time value of money. It is used to bring cash flows that occur in the future back to the present value to facilitate comparisons between investments with future positive or negative cash flows. The EFS could use a private discount rate or a social discount rate: • Private discount rate is higher and reflects the typical return a private company might expect on an investment • Social discount rate is lower (the U.S. government guides its agencies to use 3%) and can be used to assess the value of a large social investment[53]	Use a private discount rate to evaluate individual investment choices (e.g., which efficiency investments are cost effective). Then, use the social discount rate to assess the overall economics of a clean energy pathway, reflecting the societal choice to move toward one pathway or another.
Adoption Rate	The adoption rate of clean energy technologies determines the uptake of technologies over time and plays a large role in how fast and how far clean energy can go to meeting the state's aspirations. Adoption rates vary, but two potential approaches include using current average adoption/growth rates, as used in World Wildlife Fund's global energy future study, and best-practice adoption/growth rates similar to those developed by Deitz et al (2009).[54]	Use existing best-practice adoption/growth rates to show what is currently possible and then identify what rate would be needed to achieve goals.
Fossil Fuel Prices	Fossil fuel prices in part determine cost savings between scenarios. Price forecasts can vary significantly for oil, natural gas, and coal.[55] For instance, the Energy Information Administration's (EIA) 2013 forecast for oil prices in 2040 range from \$75/barrel to \$237/barrel.[56]	Use baseline forecasts from EIA's *Annual Energy Outlook* (AEO), but test sensitivities based on scenarios from AEO and other sources. Alternative sources could include futures market price quotes and non-government analyst forecasts.
Power Plant Retirement	In the electricity sector, power plants typically have lives that exceed 20 years. In the case of coal and nuclear power plants, lifetimes can push beyond 40 and even 60 years. More than half of Minnesota's coal plants will be above 40 years by 2017.[57] Minnesota's two nuclear power plants have licenses that expire in 2030 and 2033/2034, making the power plants 59 and 60 years old, respectively, at time of relicensing. The eventual retirement of these plants, as it becomes more expensive to run them than replace them, will require new efficiency and/or investment in new distributed or utility-scale generating capacity.	Include additional capital and operating costs for aging power plants as EIA does for plants over age 30 to assess, in the context of new power plant options, when it is cheaper to replace an aging plant. Apply age rule based on economic analysis as a constraint in electricity sector modeling or perform economic assessment within modeling.

PROJECT PLAN AND CRITERIA FOR SUCCESS

03

PROJECT PLAN AND CRITERIA FOR SUCCESS

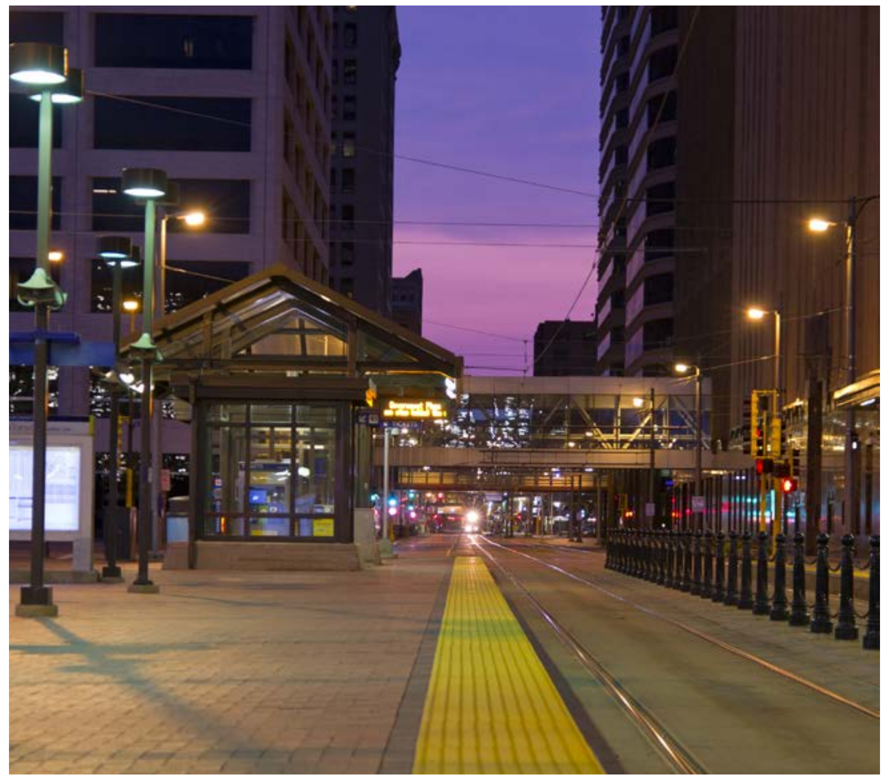
Deliverables

The EFS should produce deliverables that clearly and transparently convey findings in formats that are accessible to key audiences. Deliverables should at least include:

- Stand-alone ***executive summary***
- Detailed ***report*** covering all stages of the strategy process, results from quantitative and qualitative analyses, and next steps
- ***Appendices*** with details on methodology, models, assumptions, and sensitivity analysis
- ***Core presentation*** with key visuals and results, appropriate for a wide range of non-technical audiences
- ***Publicly accessible data and/or models*** when feasible

In addition, certain segments of Minnesota stakeholders will benefit from different formats, tones, and information. The study team should identify the audiences for the EFS, define the purpose for engaging a particular audience, and create and execute customized deliverables tailored to the audience and purpose. Examples of customized deliverables include interactive web tools that gamify the content, single-page fact sheets directed toward specific audiences (e.g., agriculture, transportation, etc.), or multi-day curriculum developed for Minnesota teachers to engage students in energy lessons and discussion.

During the process of customizing deliverables, the study team should also consider who presents EFS content to and engages with each stakeholder group. It is often very powerful when representatives from different stakeholder groups that participated in the EFS also deliver messages to their own constituents, showing a true sense of ownership in the outcome and making it clear that their voices were represented in developing the EFS.



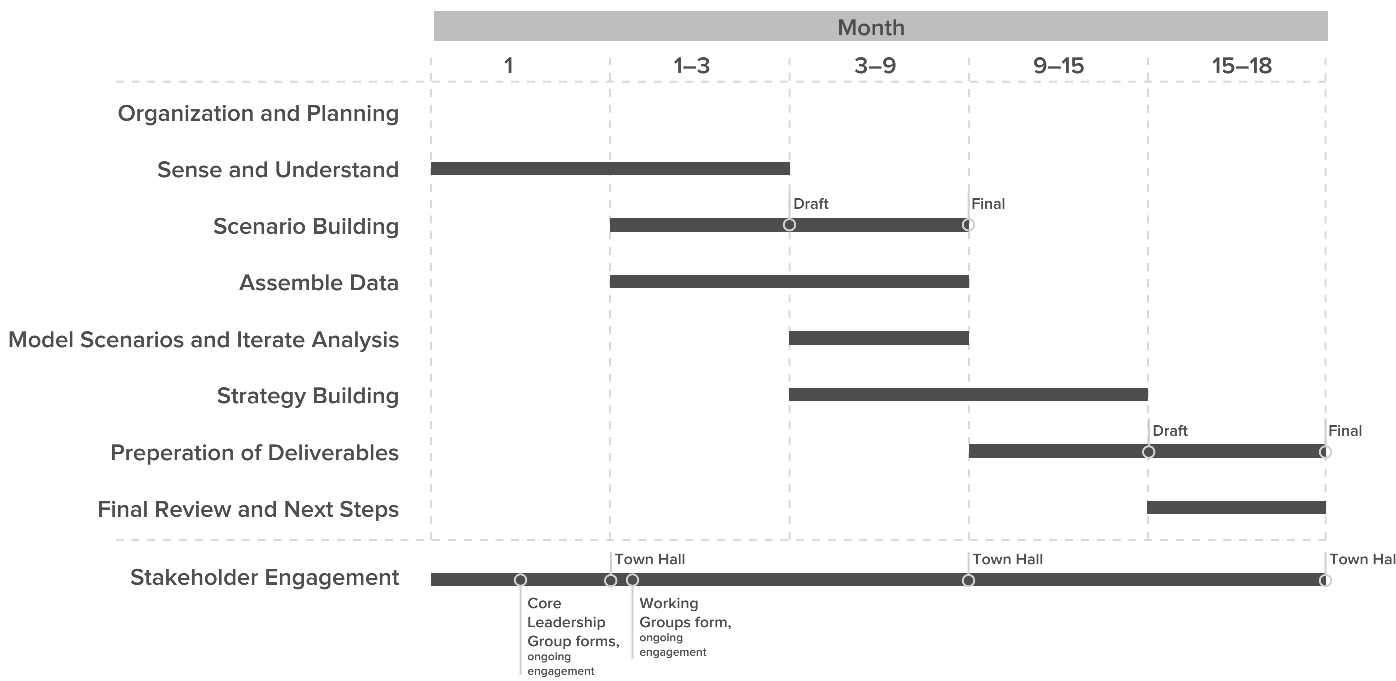
Joe Ferrer / Shutterstock.com

Timeline

The time required for the EFS is primarily driven by the chosen approach to stakeholder engagement. Using a more conventional approach to stakeholder engagement (e.g., several day-long check-in meetings), the study could be conducted in as little as ten months, at which point the state could share the findings, take feedback, and refine. The feedback process adds approximately two months to the timeline, placing the end-to-end timeline for a study that takes a traditional approach to stakeholder engagement at 12 months.

Using the more in-depth stakeholder process recommended in this report, the timeline must be extended to reflect added complexity and more moving pieces. The timeline to co-create the strategy with stakeholders should approach 18 months. A hybrid approach that incorporated elements of more in-depth stakeholder engagement, such as collaborative scenario development, but engaged stakeholders less directly in terms of actually conducting the quantitative analysis, could likely be accomplished over a 15-month period.

Figure 9: **Study Timeline**



Budget

The budget for the EFS should range from $1.5 to $2 million, driven primarily by the level and format of engagement with stakeholders. Also relevant is the size and composition of the consultant support team and how frequently they interact with stakeholders and others.[58]

Table 8: **Budget Range**

	STAKEHOLDER INVOLVEMENT	TEAM SIZE	TIMELINE	LABOR COSTS*
Budget Option 1	3 major meetings	6	12 months	$1,500,000
Budget Option 2	3 major meetings, 15 additional meetings (small working groups)	6	15 months	$1,750,000
Budget Option 3	3 major meeting, 30+ additional meetings (small working groups)	6	18 months	$2,000,000

* Note, labor costs do not include travel expenses that would accrue if some/all of consultant team was from out of state.

Criteria for Success

Key criteria for success include:

- ***Commitment and sufficient resources***—The EFS is a significant undertaking, and conducting it in a way that will drive useful discussion and action well into the future requires sufficient resourcing, both money and time. There may be creative ways of amassing sufficient funding, such as combining funding from government and Minnesota's philanthropic institutions and individuals. Beyond funding, Minnesota's leaders—starting perhaps with government leaders but quickly including business and civil society leaders—must commit to participating actively and with sufficient time availability.
- ***In-depth stakeholder engagement***—The most successful energy future studies—ones that have resulted in concrete action and mobilization—engaged stakeholders as team members, rather than just as a sounding board. A greater level of co-creation and engaging stakeholders on multiple levels (small working groups to large public forums) creates ownership.
- ***The right project team***—Conducting the EFS will require a diverse skill set, likely made up of several partnering organizations, including at least one in-state group that can help drive actions following the study. Key among those required skills are whole-system analysis and strategy development, stakeholder process design and facilitation, and local knowledge. Particular qualifications include:

Strategy and Analysis

- Ability to identify and understand the energy end uses, consider and evaluate levers that address those end uses, and translate adoption of levers into environmental and economic outcomes
- Experience working in all energy-using sectors, including transportation, buildings, industry, agriculture, and electricity
- Ability to understand how actions taken in each of these sectors affect the entire energy system and experience using this thinking to uncover synergies and unintended consequences not easily evident when looking at each sector individually

Stakeholder Process

- Ability to convene all the key stakeholders in Minnesota with the help of the state; requires credibility across stakeholder groups
- Experience facilitating small and large groups of disparate interests through a process of co-creation
- Ability to get beyond traditional staked-out positions of participants to identify shared interests
- Ability to foster agreement among participants on a common set of facts, travel a learning curve together, and develop a shared vision
- Understanding of energy issues
- Ability to access the best national and global thinkers on energy issues

Key factors that make a team of partnering organizations successful include:

1. ***One Integrator***—One organization needs to take responsibility for the integration of analyses in each sector. This organization is the primary state contact on the strategy work, is responsible for driving consistency across sector-level analyses, and is empowered to make sub-consultant level changes as needed and appropriate. If the integrator is not the master contractor, it will be difficult to drive consistency across the strategy analysis.
2. ***Clear Division of Labor***—It may be advantageous to separate the convening and facilitating from the analysis and strategy work. With an impartial facilitator in place during stakeholder meetings, it frees up the analysis and strategy teams to weigh in on content without the burden of facilitating or the need to stay impartial to ideas presented in the room. In terms of the strategy and analysis, no more than one consultant team should be responsible for each sector. Ideally, one consultant team would cover all sectors. This improves chances that the analysis approach will be consistent in quality and approach.

CONCLUSION

CONCLUSION

This report, which provides scoping recommendations for a Minnesota energy future study, illustrates the broad array of options to consider when crafting the study. The report recommends an 18-month energy future study (EFS) for Minnesota to accelerate a shared understanding around the following key questions:

- How much of Minnesota's future energy needs could be met with clean energy, including efficiency and renewables? In what time frame?
- Could this be achieved affordably, without unfairly penalizing certain customer classes? How would it affect existing energy service providers?
- What are potential risks or benefits to energy reliability and resilience?
- What could be gained in terms of environmental and human health impacts?
- How might various pathways across multiple sectors like buildings, transportation, agriculture, industry, and electricity create competitive advantage and drive in-state economic development for Minnesota?

The report goes further and makes recommendations for the EFS stakeholder engagement process, objective, system definition, and analytical approach, and it provides input to inform the study methodology, project plan, and the criteria for success.

And while it is easy to lose one's self in the study recommendations and input, the first part of this report also articulates the value proposition for conducting such a study. In a world where the energy landscape is constantly changing and energy investments span multiple decades, the value of an EFS is high. Without an EFS, the state will be choosing a default energy strategy based on year-to-year choices that do not necessarily build upon one another or add up to a coherent vision, and exposes the state and its citizens to missed opportunities and large risks. With an EFS, the state establishes the analytic foundation for creating a deliberate energy strategy that aligns stakeholders in pursuit of a common goal.

By undertaking this study scoping, the state signals to stakeholders that it is serious about creating a deliberate energy strategy. This report represents the first step in the journey toward creating an EFS, and it should inform conversations about why an EFS is needed and how an EFS is conducted. The first formal conversation to follow this report will occur in the first quarter of 2014, as this report's findings will be presented to the Legislative Energy Commission. However, there is no reason that conversation must follow this timeframe or be limited to this venue, and we encourage interested stakeholders to engage with their legislators and other Minnesota stakeholders about the EFS and the state's energy future.

NOTES & REFERENCES

N&R

NOTES & REFERENCES

ENDNOTES

[1] Lazard (2013)
[2] Bazilian et al. (2013); GTM Research and Solar Energy Industries Association (2012)
[3] Dayton (2013)
[4] Kushler (2013)
[5] Calculations are based on average Minnesota teacher salary ($53,680), state patrol lieutenant salary ($83,138), loans of $150,000, and an affordable housing unit new construction price of $182,100.
[6] Bureau of Labor Statistics (2013)
[7] National Governors Association (2013)
[8] Minnesota Pollution Control Agency and Minnesota Department of Commerce (2013)
[9] Drajem (2013)
[10] Meador (2013)
[11] President's Council of Economic Advisers (2013)
[12] Chupka et al. (2008)
[13] United States Nuclear Regulatory Commission (2013a; 2013b)
[14] RMI analysis using data from U.S. Energy Information Administration (2013a)
[15] Calculations based on annual sun hours on a flat-plate collector (Trentmann 2013; Marion and Wilcox 1994).
[16] U.S. Energy Information Administration (2012d)
[17] Minnesota Department of Agriculture (2012); U.S. Energy Information Administration (2012a)
[18] Platts (2013); Wiser and Bolinger (2013)
[19] Barbose et al. (2013)
[20] Friedman et al. (2013)
[21] Hodum (2013)
[22] Solar Electric Power Association (2012)
[23] Clean Energy Ministerial (2013)
[24] U.S. Energy Information Administration (2013e)
[25] U.S. Energy Information Administration (2012b)
[26] Minnesota State Demographic Center (2012)
[27] U.S. Energy Information Administration (2012c)
[28] Minnesota House of Representatives (2007)
[29] Nadav and Drake (2013)
[30] Clean Energy Resource Teams (2013)
[31] Cardwell (2011)
[32] European Climate Foundation (2010); Molly (2010); National Renewable Energy Laboratory (2012)
[33] Rocky Mountain Institute (2013)
[34] Makhijani et al. (2012)
[35] Minnesota Climate Change Advisory Group (2008)
[36] The Office of the Revisor of Statutes (2013)
[37] European Commission (2003); Machol and Rizk (2013)
[38] Some of the estimates for these parameters are defined in a market. This value represents the marginal cost to reduce one unit of pollution rather than the inherent value to the environment or human health of reducing a unit of pollution.
[39] National Infrastructure Advisory Council (2010)
[40] The description of transformative scenarios was developed from Adam Kahane's (2012), Working Together to Change the Future: Transformative Scenario Planning.
[41] Steinback (2011)
[42] AASHTO (2011)
[43] Collins (2013)
[44] U.S. Energy Information Administration
[45] Minnesota Department of Agriculture (2012)
[46] Podkul (2013)
[47] Nuclear Regulatory Commission (2013a; 2013b)
[48] U.S. Energy Information Administration (2011)
[49] Manitoba Hydro (2013)

[50] U.S. Department of Energy (2012); RMI analysis using data from Barbose et al. (2013)
[51] European Climate Foundation (2010); Molly (2010); National Renewable Energy Laboratory (2012)
[52] Goggin (2013)
[53] U.S. Office of Management and Budget (2003)
[54] Dietz et al. (2009); Singer and Dunruyter (2011)
[55] The U.S. Energy Information Administration *Annual Energy Outlook* projections to 2040 for coal, oil, and natural gas provide an example of the significant range in low and high price ranges for these fuels. To see the forecast range for coal, view the low and high coal price scenarios (Conti et al. 2013). For oil and natural gas, review Figure 5 and 88 (U.S. Energy Information Administration 2013c; 2013d).
[56] U.S. Energy Information Administration (2013d)
[57] RMI analysis using data from U.S. Energy Information Administration (2013a)
[58] Labor cost estimates are based on estimated rates for a typical project team.

REFERENCES

AASHTO. 2011. “Census Transportation Planning Products Program (CTPP).” http://ctpp.transportation.org/Pages/default.aspx.

Amir Nadav, and Trevor Drake. 2013. “Energy Star Buildings: A Minnesota Market Report”. Great Plains Institute.

Ardani, Kristen, Dan Seif, Robert Margolis, Jesse Morris, Carolyn Davidson, Sarah Truitt, and Roy Torbert. 2013. “Non-Hardware (‘Soft’) Cost-Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013-2020”. NREL/TP-7A40-59155. National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy13osti/59155.pdf.

Barbose, Galen, Naim Darghouth, Samantha Weaver, and Ryan Wiser. 2013. “Tracking the Sun VI: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012”. Lawrence Berkeley National Laboratory. http://emp.lbl.gov/sites/all/files/lbnl-6350e.pdf.

Barbose, Galen, Naim Darghouth, and Ryan Wiser. 2012. “Tracking the Sun V An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2011”. LBNL-5919E. Lawrence Berkeley National Laboratory. http://emp.lbl.gov/publications/tracking-sun-v-historical-summary-installed-price-photovoltaics-united-states-1998-2011.

Bazilian, Morgan, Ijeoma Onyeji, Michael Liebreich, Ian MacGill, Jennifer Chase, Jigar Shah, Dolf Gielen, Doug Arent, Doug Landfear, and Shi Zhengrong. 2013. “Re-Considering the Economics of Photovoltaic Power.” *Renewable Energy* 53 (May): 329–338. doi:10.1016/j.renene.2012.11.029.

Black and Veatch. 2012. “Cost and Performance Data for Power Generation Technologies”. Black and Veatch. http://bv.com/docs/reports-studies/nrel-cost-report.pdf.

Bureau of Labor Statistics. 2013. “Employment in Green Goods and Services 2011”. Washington D.C.: Department of Labor. http://www.bls.gov/news.release/ggqcew.nr0.htm.

Cardwell, Sara. 2011. “Xcel Energy’s Renewable Energy Standard Rate Impact Report Minnesota Public Utilities Comission”. Docket E.999/C1-11-852. https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId=%7BEA562471-DDBE-4916-B9ED-0A3D25B70981%7D&documentTitle=201110-67680-01.

Chase, Jenny. 2013. “PV Market Outlook Q2 2013”. Bloomberg New Energy Finance. Chupka, Marc, Robert Earle, Peter Fox-Penner, and Ryan Hledik. 2008. “Transforming America’s Power Industry: The Investment Challenge 2010-2030”. Washington, DC.: The Edison Foundation.

Ciborowski, Peter, and Anne Claflin. 2012. “Greenhouse Gas Emissions in Minnesota: 1970-2008 Second Biennial Progress Report - Technical Support Document”. St. Paul, MN: Minnesota Pollution Control Agency. http://www.pca.state.mn.us/index.php/view-document.html?gid=17118.

Clean Energy Ministerial, Electric Vehicles Initiative, and International Energy Agency. 2013. “Global EV Outlook Understanding the Electric Vehicle Landscape to 2020.” http://www.iea.org/topics/transport/electricvehiclesinitiative/EVI_GEO_2013_FullReport.PDF.

Clean Energy Resource Teams. 2013. “Certs: Minnesotans Building a Clean Energy Future.” http://www.cleanenergyresourceteams.org/sites/default/files/CERTs_FactSheet_General_2013_3.pdf.

Collins, Jon. 2013. “Car-Sharing Options Grow in Minneapolis.” *The Cities MPR News Notes on the News from the Twin Cities*. http://blogs.mprnews.org/cities/2013/09/car-sharing-options-grow-in-minneapolis/.

Conti, J. J., P. D. Holtberg, J. A. Beamon, S. A. Napolitano, and A. M. Schaal. 2013. “Annual Energy Outlook 2013 with Projections to 2040”. Washington D.C.: US Energy Information Administration. http://www.eia.gov/forecasts/aeo/.

Dayton, Mark. 2013. “2013 State of the State Address” St. Paul, MN. http://mn.gov/governor/newsroom/pressreleasedetail.jsp?id=102-54689

Dietz, Thomas, Gerald T. Gardner, Jonathan Gilligan, Paul C. Stern, and Michael P. Vandenbergh. 2009. “Household Actions Can Provide a Behavioral Wedge to Rapidly Reduce US Carbon Emissions.” *Proceedings of the National Academy of Sciences* 106 (44) (November 3): 18452–18456. doi:10.1073/pnas.0908738106.

Drajem, Mark. 2013. “Coal Industry Cries Foul Over Obama Emission Rules.” Bloomberg. Accessed November 25. http://www.bloomberg.com/news/2013-09-11/obama-said-to-ban-new-coal-plants-without-carbon-controls.html.

European Climate Foundation. 2010. *Roadmap 2050 A Practical Guide to a Prosperous Low-Carbon Europe*. The Hague: European Climate Foundation. http://www.roadmap2050.eu/project/roadmap-2050.

European Commission. 2003. “External Costs Research Results on Socio-Environmental Damages due to Electricity and Transport”. Brussels: European Commission. http://ec.europa.eu/research/energy/pdf/externe_en.pdf.

Friedman, Barry, Kristen Ardani, David Feldman, Ryan Citron, Robert Margolis, and Jarett Zuboy. 2013. “Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey – Second Edition”. NREL/TP-6A20-60412. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy14osti/60412.pdf.

Goggin, Michael. 2013. “Xcel Colorado Sets U.S. Record with over 60% Wind - Blog - Into the Wind.” http://aweablog.org/blog/post/xcel-colorado-sets-us-record-with-over-60-wind.

GTM Research, and Solar Energy Industries Association. 2012. "U.S. Solar Market Insight Report Q2 2012 Executive Summary". A Green Tech Media & Solar Energy Industries Association. http://www.seia.org/research-resources/solar-market-insight-report-2012-q2.

Hodum, Ryan. 2013. "Power Forward Why the World's Largest Companies Are Investing in Renewable Energy". World Wildlife Fund. http://assets.worldwildlife.org/publications/507/files/original/Power_Forward_FINAL_hi_res.pdf?1357935348.

Kahane, A. 2012. *Working Together to Change the Future: Transformative Scenario Planning.* Berrett-Koehler Publishers Inc, San Francisco, USA.

Kushler, Martin. 2013. "Some Ideas for Potential Energy Efficiency Improvements in Minnesota: A High Level View From a National Perspective" presented at the Minnesota Department of Commerce, Division of Energy Resources, Stakeholder Meeting, October 17, St. Paul, MN. http://mn.gov/commerce/energy/images/ACEEE-Marty-Kushler-Pres.pdf.

Lazard. 2013. "Lazard's Levelized Cost of Energy Analysis". 7. Lazard. http://gallery.mailchimp.com/ce17780900c3d223633ecfa59/files/Lazard_Levelized_Cost_of_Energy_v7.0.1.pdf.

Machol, Ben, and Sarah Rizk. 2013. "Economic Value of U.S. Fossil Fuel Electricity Health Impacts." *Environment International* 52 (February): 75–80. doi:10.1016/j.envint.2012.03.003.

Makhijani, Arjun, Christina Mills, and M.V. Ramana. 2012. "Renewable Minnesota: A Technical and Economic Analysis of a 100% Renewable-Energy Based Electricity System for Minnesota". St. Paul, MN: Institute for Energy and Environmental Research. http://ieer.org/resource/electricity-grid/renewable-minnesota-technical/.

Manitoba Hydro. 2013. "Development Plan and NFAT." http://www.hydro.mb.ca/projects/development_plan/index.shtml.

Marion, William, and Stephen Wilcox. 1994. "Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors". NREL/TP-463-5607. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/legosti/old/5607.pdf.

Meador, Ron. 2013. "Energy Groups Ask Regulators to Update Health-Impact Costs Last Set in 1990s." *MinnPost*, October 11. http://www.minnpost.com/earth-journal/2013/10/energy-groups-ask-regulators-update-health-impact-costs-last-set-1990s.

Minnesota Climate Change Advisory Group. 2008. "Minnesota Climate Change Advisory Group Final Report A Report to the Minnesota Legislature". St. Paul, MN: Minnesota Pollution Control Agency. http://www.pca.state.mn.us/index.php/view-document.html?gid=20234.

Minnesota Department of Agriculture. 2012. "Minnesota Ethanol Industry Ethanol Plants in Minnesota 2012". St. Paul, MN: State of Minnesota. http://www.mda.state.mn.us/~/media/Files/food/business/economics/plantsreport.ashx.

Minnesota House of Representatives. 2007. "Next Generation Energy Act." Energy - New Laws 2007. http://www.house.leg.state.mn.us/hinfo/newlawsart2007-0.asp?storyid=608.

Minnesota Pollution Control Agency, and Minnesota Department of Commerce. 2013. "Greenhouse Gas Emissions Reduction Biennial Report to the Minnesota Legislature January 2013". St. Paul, MN: State of Minnesota. http://www.pca.state.mn.us/index.php/view-document.html?gid=18931.

Minnesota State Demographic Center. 2012. "Minnesota Population Projections 2015 to 2040". Minnesota State Demographic Center.

Molly, J.P. 2010. "Status Der Windenergienutzung in Deutschland—Stand 31.12.2010." www.dewi.de/dewi/fileadmin/pdf/publications/Statistics%20Pressemitteilungen/31.12.10/Foliensatz_2010.pdf.

National Governors Association. 2013. "States to Focus on Economic Development through Clean Energy". Washington D.C.: National Governors Association. http://www.nga.org/cms/home/news-room/news-releases/2013-news-releases/col2-content/states-to-focus-on-economic-deve.html.

National Infrastructure Advisory Council. 2010. "A Framework for Establishing Critical Infrastructure Resilience Goals". National Infrastructure Advisory Council. http://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf.

National Renewable Energy Laboratory. 2012. *Renewable Electricity Futures Study.* Edited by M.M Hand, S Baldwin, E. DeMeo, J.M. Reilly, T. Mai, D. Arent, G. Porro, M. Meshek, and D. Sandor. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/analysis/re_futures/.

Office of Revisor of Statutes. 2013. "Minnesota Session Laws." https://www.revisor.leg.state.mn.us/laws/?id=85&doctype=Chapter&year=2013&type=0.

Platts. 2013. "Xcel Energy to Pay $25-35/MWh in Newly Approved Wind Power Contracts: CEO." October 24. http://www.platts.com/latest-news/electric-power/portland-maine/xcel-energy-to-pay-25-35mwh-in-newly-approved-21731960.

Podkul, Cezary. 2013. "EPA Proposes Big Reduction in 2014 Ethanol Blend Volume -Document." Reuters, October 10. http://www.reuters.com/article/2013/10/10/us-epa-ethanol-idUSBRE9990VU20131010.

President's Council of Economic Advisers, Department of Energy, and White House Office of Science and Technology. 2013. "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages". Washington D.C.: Executive Office of the President. http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf.

Rocky Mountain Institute. 2013. "Minnesota Energy Future Scoping Study: Review of Studies". St. Paul, MN: Minnesota Department of Commerce. http://mn.gov/commerce/energy/images/Review_of_Studies_131011vf1.pdf.

Seel, Joachim, Galen Barbose, and Ryan Wiser. 2013. “Why Are Residential PV Prices in Germany So Much Lower Than in the United States? A Scoping Analysis”. Lawrence Berkeley National Laboratory. http://emp.lbl.gov/sites/all/files/german-us-pv-price-ppt.pdf.

Singer, Stephan, and Jean-Philippe Denruyter, ed. 2011. *The Energy Report 100% Renewable Energy By 2050*. Switzerland: World Wildlife Fund. http://wwf.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/renewable_energy/sustainable_energy_report/.

Solar Electric Power Association. 2012. “SEPA Top 10 Utility Solar Rankings”. Solar Electric Power Association. http://www.solarelectricpower.org/media/51303/sepa-top-10-executive-summary_final-v2.pdf.

Steinback, Scott. 2011. “Overview of Regional Economic Impact Models.” July 26. http://www.st.nmfs.noaa.gov/Assets/economics/publications/RecFisheriesDataandModel/Overview%20of%20Current%20Economic%20Impact%20Models_Steinback.pdf.

Trentmann, Jörg. 2013. “The Climate Data Guide: Surface Solar Radiation for Europe, Africa and the Atlantic Based on MVIRI Visible Channels”. EUMETSAT. https://climatedataguide.ucar.edu/climate-data/surface-solar-radiation-europe-africa-and-atlantic-based-mviri-visible-channnels.

United States Nuclear Regulatory Commission. 2013a. “Prairie Island Nuclear Generating Plant, Unit 1.” http://www.nrc.gov/info-finder/reactor/prai1.html.

. 2013b. “Monticello Nuclear Generating Plant, Unit 1.” http://www.nrc.gov/info-finder/reactor/mont.html.

U.S. Department of Energy. 2012. “SunShot Initiative Mission, Vision and Goals.” http://www1.eere.energy.gov/solar/sunshot/mission_vision_goals.html.

U.S. Energy Information Administration. 2011. “Minnesota Nuclear Profile 2010.” http://www.eia.gov/nuclear/state/minnesota/.

. 2012a. “Energy Consumption Estimates for Major Energy Sources in Physical Units, 2011.” http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_sum/html/sum_use_tot.html&sid=US&sid=MN.

. 2012b. “Total End-Use Energy Consumption Estimates, 1960-2011, Minnesota.” http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/tx/use_tx_MN.html&sid=Minnesota.

. 2012c. “Primary Energy Consumption Estimates, Selected Years, 1960-2011, Minnesota.” http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_use/total/use_tot_MNcb.html&sid=MN.

2012d. “Minnesota State Profile and Energy Estimates.” July. http://www.eia.gov/state/?sid=MN.

. 2013a. “Form EIA-860 Detailed Data.” http://www.eia.gov/electricity/data/eia860/index.html.

. 2013b. “State Profile Data- Minnesota.” http://www.eia.gov/state/data.cfm?sid=MI#ConsumptionExpenditures.

. 2013c. “Natural Gas from Executive Summary, Annual Energy Outlook 2013.” http://www.eia.gov/forecasts/aeo/source_natural_gas_all.cfm#natgas_prices.

. 2013d. “AEO 2013 Early Release Overview”. Washington D.C.: US Energy Information Administration. http://www.eia.gov/forecasts/aeo/er/early_prices.cfm.

. 2013e. “Energy- intensity by State (2000 – 2010).” May. http://www.eia.gov/environment/emissions/state/analysis/pdf/table6.pdf.

U.S. Office of Management and Budget. 2003. “Circular A-4”. US Office of Management and Budget. http://www.whitehouse.gov/sites/default/files/omb/assets/omb/circulars/a004/a-4.pdf.

Wiser, Ryan, and Mark Bolinger. 2013. “2012 Wind Technologies Market Report”. US Department of Energy. http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf.