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January 1, 2014

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RE: Value of Solar Thermal Report

Dear Senator Marty, Representative Hortman, Senator Tomassoni, Representative Atkins, Senator Brown, Representative Garofalo, Senator Ingebrigtsen and Representative Hoppe:

I am enclosing a report entitled, "*The Value of Solar Heating and Cooling (SHC) in Minnesota: Solar Thermal and Minnesota Energy and Climate Goals*," prepared by Meister Consultants Group for the Minnesota Department of Commerce, Division of Energy Resources. This report is made pursuant to Minnesota Laws 2013, Chapter 85, HF 729, Article 12, Section 6. The report examines solar thermal and cooling (SHC) technology, economics, and barriers, including recommendations on how to grow solar thermal in Minnesota.

If you have any questions about the report, please contact me or my Deputy, Bill Grant at 651-539-1801 or bill.grant@state.mn.us.

All my best,

Mike Rothman

Mike Rothman
Commerce Commissioner

Enclosure

The Value of Solar Heating and Cooling (SHC) in Minnesota

Solar Thermal and Minnesota Energy and Climate Goals

December 2013

Meister Consultants Group, Inc. (MCG)
www.mc-group.com

Commissioned by the Minnesota Department of Commerce
http://mn.gov/commerce/energy

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Prepared for: **Minnesota Department of Commerce, Division of Energy Resources, Contract Number: 70685**

MINNESOTA DEPARTMENT OF COMMERCE
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Solar Wall Installation at Interdistrict Downtown School [photograph]. In Tebbe, P., Moavani, S. & Schwartzkopf, L. (2011). Performance Analysis of Solar Walls in Minnesota. Submitted to Minnesota Department of Commerce. Retrieved from http://mn.gov/commerce/energy.

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Executive Summary

Minnesota has established robust clean energy and greenhouse gas (GHG) emission reduction goals, aiming to obtain 25 percent of electricity from renewable resources by 2025 and reduce GHG emissions by 80 percent (relative to the 2005 baseline) by 2050. The state is additionally evaluating pathways to create an energy system that does not rely on the use of fossil fuels to power the economy.

Against this backdrop, the Minnesota Department of Commerce commissioned *The Value of Solar Heating and Cooling (SHC) in Minnesota* study (as required by Minnesota Session Laws 2013 Ch. 85, Art. 12, Sec. 6) to assess the potential for solar thermal to contribute to the state's energy and climate goals. Solar is one of few renewable energy technologies that can supply domestic hot water, heated ventilation, space heating and cooling, dehumidification, process heating, and pool heating.

In contrast to solar photovoltaics (PV) (which generates electricity directly from sunlight), solar thermal technologies have not benefited from widespread policy support in Minnesota or across the U.S. This is in spite of the fact that solar thermal and other renewable heating and cooling technologies could make significant contributions to Minnesota's state energy goals. Thermal energy use comprises a significant share of energy consumption in Minnesota. Within the residential sector, for example, approximately 60 percent of building energy use in Minnesota is used for hot water and space heating.[i] By deploying renewable energy technologies such as solar thermal to serve the state's heating and cooling demand, Minnesota can make significant contributions to renewable energy development and GHG emission reductions in the state.

Achieving such objectives will require the development of policies and programs that address market barriers (see Section 4) and encourage investment in solar thermal technologies. A strong solar thermal market requires implementation of policies and programs that improve project economics, build market demand, and increase consumer confidence and awareness. This study identifies a series of recommendations designed to remove market barriers and scale up the solar thermal market. The study focuses on high-value solar thermal market sectors and applications that could be scaled up to capture benefits for the state in the near-term. High-value solar thermal market sectors and applications include:

- **Commercial customers using expensive, conventional heating fuels, such as electricity, propane, or fuel oil:** commercial solar thermal systems can offer cost-competitive heating alternatives to Minnesota consumers using fossil fuel. Commercial solar thermal economics are particularly compelling when compared against delivered fuels (fuel oil or propane) or electric heating, especially if those customers have access to state or utility rebates that can further reduce the installed costs of solar thermal facilities.
- **Agricultural applications where load characteristics coincide with solar resources:** agricultural customers have been identified by solar thermal market stakeholders as a particularly important customer group. Agricultural operations such as dairies have process heating requirements that are well-matched to the solar resource. Many agricultural customers also rely on expensive heating fuels.
- **Low-income housing where fossil fuel price volatility is problematic for owners and residents:** buildings using conventional heating fuels such as propane and natural gas can experience significant heating and cooling price volatility. The U.S. Energy Information Administration (EIA) predicts that natural gas customers will experience a 13 percent price spike in the 2013/14 heating season compared with the previous year. Similarly, propane customers are expected to experience a nine percent increase in prices. Such price volatility makes it challenging for low-income building

managers and residents to plan for heating and cooling expenditures. By using solar thermal technologies, facility managers and residents can "lock in" a portion of their heating costs and reduce the negative impacts of price volatility.

Minnesota also has an opportunity to support larger-scale solar thermal markets in the future by supporting innovations related to industrial and district energy solar thermal systems, solar cooling, and the integration of "solar ready" construction into standard building practices. Bringing solar thermal innovation into the mainstream will be useful for meeting Minnesota's goals to reduce greenhouse gas emissions 30 percent by 2025 and 80 percent by 2050.

In order to capture both short- and long-term solar thermal opportunities, it is recommended that Minnesota consider:

- **Creating or expanding incentive eligibility for high-value SHC customer segments:** Minnesota could target high-value customers for SHC state incentives, including farmers, delivered fuel consumers, low-income housing authorities, and commercial users. This would increase the opportunities for cost-effectively installing SHC technologies in Minnesota.
- **Implement "Solar Ready" building requirements:** In the short- to medium-term, Minnesota could require all new construction and renovated buildings to incorporate "solar ready" design guidelines. This would decrease complexity and reduce installed costs for future SHC retrofits.
- **Require solar thermal in public buildings and/or for the private sector:** Over the longer term, Minnesota could require all new construction and major building renovations to incorporate solar thermal or other renewable heating and cooling technologies. This could be rolled out in phases, focusing on public sector buildings first and eventually expanding to incorporate the private sector. Such an initiative could assist in the reduction of building energy use and enable the state to meet its long-term GHG emission reduction goals (e.g. 80% reduction by 2050).
- **Explore innovative financing options to reduce high SHC upfront costs:** Minnesota could conduct a detailed study to examine the benefits, drawbacks, and resources available to develop a comprehensive solar thermal financing program in the state. By increasing access to solar thermal financing, Minnesota could reduce the high upfront cost burden to customers installing SHC systems.
- **Reduce SHC soft costs by streamlining permitting requirements:** While estimates vary, stakeholders estimate that permitting and zoning soft costs can account for up to 20 percent of installed costs for residential SHC systems. Minnesota could develop permitting and land use outreach and education initiatives for local jurisdictions, supporting the implementation of SHC best practices across the state and reducing soft costs.
- **Reduce SHC soft costs by implementing a community aggregation solar thermal purchase program:** Minnesota could reduce customer acquisition costs and create demand for SHC technologies by implementing a "Solar Thermalize" campaign similar to those in Milwaukee, WI, Massachusetts, and Vermont. Such programs can reduce installed costs by 20 percent or more for residential customers.
- **Create an online, community-based outreach and information campaign:** The state could create a government- and industry-driven outreach campaign to overcome poor public awareness of SHC technologies and benefits. This could include an online platform with SHC building and social media engagement tools to inform and engage prospective customers of SHC installation options.
- **Create a SHC advisory group for metering, certifications, and standards:** Minnesota could create a forum that enables industry leaders and market experts to discuss SHC technical issues and create solutions to overcome them. In the near term, stakeholders indicate that it is important to focus on heat metering policy as well as installation and manufacturing certifications.

- **Engage delivered fuel providers to explore SHC opportunities:** The state could engage both SHC and delivered fuel industries in order to create new market opportunities. Such an initiative could support structured dialogue between industry leaders, provide resources to conduct SHC market opportunity analyses, and award grants to support delivered fuel providers entering the SHC market.
- **Assess potential for integrating solar thermal into district energy systems:** Depending upon characteristics of district energy systems, solar thermal can provide significant system benefits by increasing load diversity and reducing GHG emissions. Minnesota could conduct a study of district energy systems across the state to identify high-value systems to demonstrate benefits for solar thermal integration.

This study represents the first step in evaluating the potential for solar thermal in Minnesota. The set of policy recommendations proposed here were designed to address Minnesota's unique market conditions, mitigate solar thermal market barriers, and leverage priority solar thermal market opportunities. The recommendations in this report provide a starting point for exploring the role of solar thermal – among other renewable heating and cooling technologies – to contribute to Minnesota's energy and climate goals.

Background

The Value of Solar Heating and Cooling (SHC) in Minnesota report was commissioned by the Minnesota Department of Commerce ("Commerce") as required by Minnesota Session Laws 2013 Chapter 85, Article 12, Section 6. Stacy Miller, Solar Programs Administrator, oversaw development of the report on behalf of Commerce.

The Value of Solar Heating and Cooling (SHC) in Minnesota report was developed to assess technical and policy issues that contribute to the understanding how solar heating and cooling (SHC), as one of the few options for renewable heat, can potentially advance Minnesota state energy policy goals of increasing energy efficiency, increasing the use of renewable energy, and reducing greenhouse gases.

Neil Veilleux, Wilson Rickerson, Jayson Uppal, and Jon Crowe of Meister Consultants Group (MCG) provided technical assistance and research services to complete this report. MCG is a sustainability consulting firm that focuses on energy policy and markets. With affiliates in the U.S. and Europe, MCG uses innovative problem solving approaches to advise clients on clean energy policy design, stakeholder dialogue, and program implementation. MCG has an active clean energy policy advisory practice, with expertise in solar hot water and other renewable thermal markets such as biomass thermal, and advanced air- and ground-source heat pumps.

MCG was assisted in its research by several project partners, including Brian Ross and Abby Finis from CR Planning; Nina Axelson from Ever-Green Energy; Lars Lisell; and John Del Mar.

Acknowledgments

To complete this assessment, the Minnesota Department of Commerce and the project team engaged a variety of industry leaders, market experts, and other stakeholders in Minnesota and across the U.S. Stakeholders include:

Ross Abbey, Fresh Energy
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Melissa Pawlisch, Clean Energy Resource Teams (CERTs)
Scott Randall, Apex Solar
Anders Rydaker, Ever-Green Energy
Russel Scherber, Plumbers and Pipe Fitters Union
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Contents

1 Introduction: SHC and Minnesota's Climate and Energy Goals

Since 2007, Minnesota has passed a series of laws that seek to create a sustainable energy system, reduce the use of fossil fuels, drive economic growth, protect the environment, and provide long-term energy security. These laws establish energy and greenhouse gas targets, including:

- Achieve 80% greenhouse gas emission reductions by 2050 compared to the 2005 baseline (and 30% reductions by 2025);[ii]
- Reduce per capita fossil fuel use (as an energy input) by 1.5 percent per year over ten years by increasing use of energy efficiency and renewable energy alternatives;[iii]
- Obtain 25 percent of electricity use from renewable energy resources by 2025.[iv]

Energy efficiency, renewable electricity, and sustainable transportation technologies can be deployed to achieve part of these targets. However, because thermal energy use comprises a significant share of energy use in Minnesota, realization of the state's energy and climate targets will also require investments in renewable thermal technologies. For example, over 60% of residential building energy use in Minnesota (and surrounding states)[1] is used to provide hot water and space heating.[v] Renewable thermal energy technologies – which generate heat from renewable resources like the sun, biomass, or the earth – have not historically been a focus of Minnesota energy policy and represent a "missing link" in state energy and climate security policy.

This report focuses specifically on the potential for solar thermal. Solar thermal includes solar hot water (SHW) and solar air heat systems. These technologies can provide renewable energy for a wide variety of thermal applications, including domestic hot water production, ventilation, space heating and cooling, dehumidification, process heating, and pool heating. Solar thermal technologies can be installed on residential, commercial, or industrial buildings, and can also be integrated into district energy systems.

1.1 Methodology

This study fulfills the Minnesota Department of Commerce's responsibility – as required by Minnesota Session Laws 2013 Ch. 85, Art. 12, Sec. 6 – to assess the value of solar thermal.[vi] This report was developed by Meister Consultants Group (MCG) in partnership with CR Planning, Ever-green Energy, and solar thermal experts associated with the National Renewable Energy Laboratory (NREL) and the Florida Solar Energy Center ("the Project Team"). The Project Team worked with stakeholders across the state to assess the opportunities and barriers for solar thermal in Minnesota, establishing technical potential estimates, comparing the levelized cost of energy (LCOE) of solar thermal technologies with fossil fuel alternatives, and making policy and program recommendations to assist Minnesota in leveraging high priority solar thermal opportunities.

In order to identify the technical and policy issues specific to solar thermal in Minnesota, the Project Team conducted a series of workshops and interviews with solar thermal industry leaders, market experts, policymakers, and other stakeholders. During this engagement process, stakeholders discussed solar thermal market barriers, identified high priority market segments, and proposed development strategies to support priority sectors.

The Project Team also collected solar thermal market data from manufacturers, installers, and state policymakers, among others. The Project Team conducted a survey of the number and type of solar

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[1] The U.S. Energy Information Administration aggregates hot water and space heating use estimates across several states, including Minnesota, Iowa, North Dakota, and South Dakota.

thermal systems installed across Minnesota, and aggregated installed cost data from state rebate databases and installers. While an in-depth study of existing solar thermal systems is beyond the scope of this report, the high-level data collected can serve as a useful baseline to inform solar thermal decision making and strategy development in Minnesota.

The Project Team used state-specific data to develop a residential and commercial solar thermal LCOE analysis, comparing the lifecycle costs of solar thermal technologies against the predominant heating fuels in Minnesota (i.e. natural gas, electricity, propane, and fuel oil). The Project Team also used a methodology developed by NREL to assess the technical potential for solar thermal technologies in Minnesota.

The Project Team also surveyed national and international solar thermal policies. This policy survey was used to benchmark the policy and strategy recommendations collected during the stakeholder engagement process. The set of policy recommendations contained in this report were developed to address Minnesota's unique market conditions, mitigate solar thermal market barriers, and leverage priority solar thermal market opportunities.

1.2 Report Structure

This report is structured as follows:

- **Section 2** describes the various solar thermal technologies and applications and provides high-level technical potential estimates for solar thermal technologies in Minnesota. It additionally includes a number of SHC case studies, describing the types of projects, economics, and lessons learned from installations across Minnesota.
- **Section 3** describes the solar thermal market, including historical market performance and incentive programs for solar thermal technologies in Minnesota. This section also includes an LCOE analysis of various solar hot water, solar air, and transpired air heating applications.
- **Section 4** describes the major barriers to solar thermal market growth in Minnesota.
- **Section 5** proposes recommendations to support solar thermal market growth in order to help achieve Minnesota's energy and climate goals. Additionally, building on results of the economic analysis and stakeholders consultations, this section identifies high-value solar thermal targets and market sectors in Minnesota.

2 SHC Technologies, Applications and Technical Potential

Internationally, over 268 gigawatts (GW_{th}) of solar heating collectors are operational, which produce approximately 225 terawatt-hours (TWhs) of energy per year.[vii] Among non-hydropower renewable energy technologies, solar heating is second only to wind power in terms of capacity installed and energy produced globally (Figure 1).[2] In contrast to the success of solar thermal internationally, the U.S. market is comparatively small (as discussed in Section 3), though U.S. states, like Minnesota, have significant potential to grow the solar thermal market in the future.

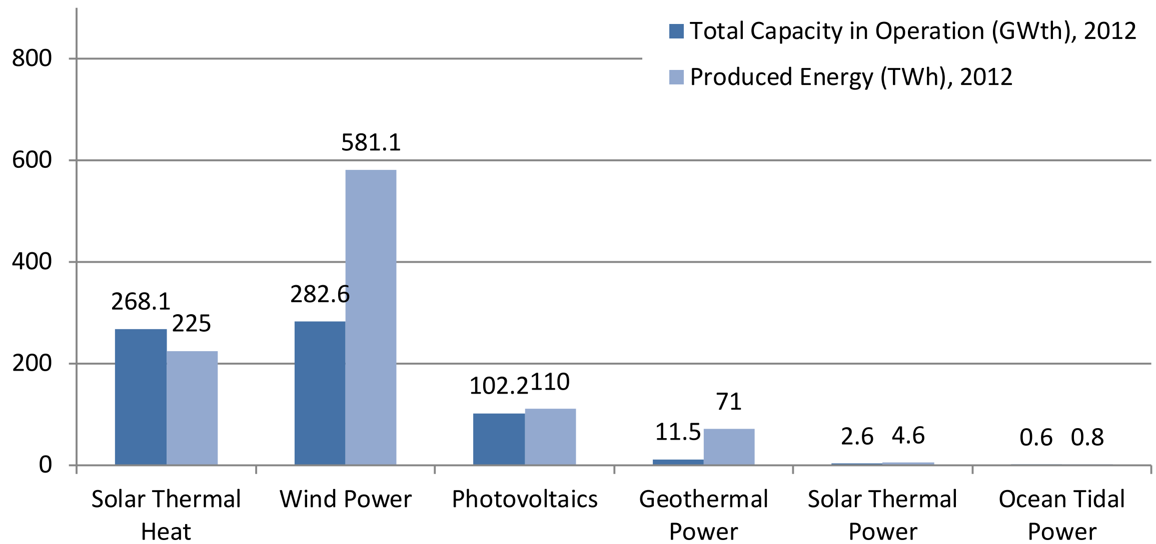

Figure 1. Worldwide solar heating and cooling capacity and production (Source: International Energy Agency, 2013)

This section describes solar hot water (SHW), solar air, and transpired air heating systems and technologies, highlighting typical applications and design requirements. It additionally describes options for solar thermal cooling and integration of solar thermal into district energy systems. This section also provides high level technical potential estimates for various solar thermal technologies and applications.

2.1 Solar Hot Water (SHW)

Solar hot water is the most common solar thermal technology used in the U.S. Its largest application is in pool heating, followed by domestic hot water (DHW). It is also used for space heating in residential and commercial buildings (e.g. for hydronic heat systems) and to provide process heat for industrial processes. Facilities with large, consistent, year-round hot water requirements tend to enjoy the best return on investment from SHW. Facilities that tend to be good hosts include single and multi-family residences, food service and processing facilities (such as restaurants and breweries), dairies, hotels, motels, car washes, nursing homes, hospitals, laundries, correctional facilities and commercial (or school) swimming pools, among others.

A SHW system typically consists of solar collectors, water storage tanks, a controller, a pump, piping, insulation, valves, and gauges. Due to the cold climate in Minnesota, SHW systems typically require freeze protection. This can be accomplished with a variety of designs, but typically includes a propylene glycol working fluid with a heat exchanger to ensure that water will not freeze in the collectors and

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[2] This excludes conventional renewables like hydropower and biomass, which provide more power than wind power or any other renewable energy resource.

damage the equipment.[3] Figure 2 below illustrates a common SHW system design. Solar energy is captured as heat by the solar collector, which concentrates the sun's energy in order to heat a glycol-water heat transfer fluid. A pump circulates the glycol mixture from the solar collector to a heat exchanger located in or near the hot water tank. The heat exchanger transfers heat from the solar heated glycol mixture to the water in the hot water tank. On days when the SHW system cannot produce 100% of the hot water needs, a back-up heating system (e.g. a gas or electric hot water heater or boiler) provides the remainder of the building's hot water needs.[viii] Well-designed systems commonly provide between 70 and 90 percent of domestic hot water energy needs.

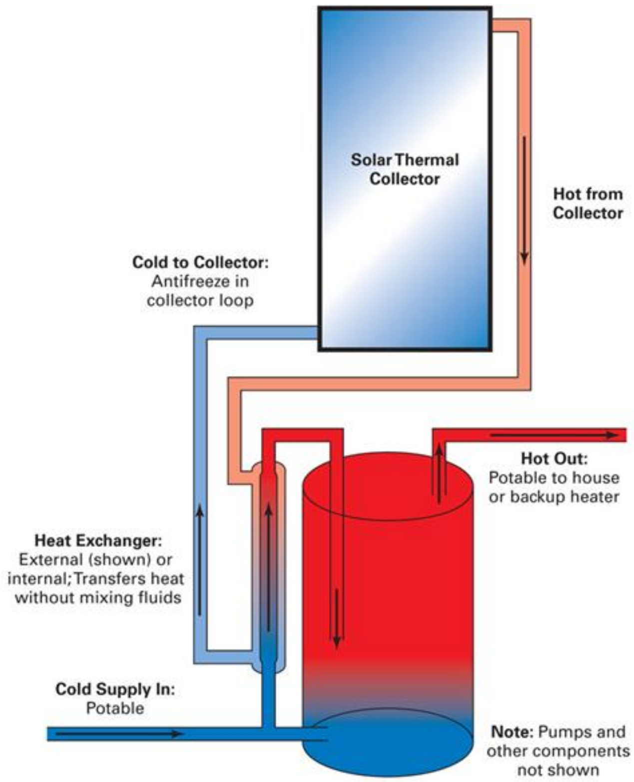

Figure 2. Schematic of a typical SHW system (Source: Home Power, n.d.)

As discussed in Section 2.6.1, the technical potential in Minnesota for SHW is large and untapped. It is estimated that over 27 percent of the residential and 38 percent of commercial domestic hot water demand could be served by SHW systems in Minnesota's. This could provide 12 trillion Btus[4] of renewable heat per year. Case Study 1 describes the experience of Minnesota farmers that installed SHW systems to offset their hot water demand. The most cost-effective systems are typically installed at sites that use expensive heating sources (e.g. electricity, fuel oil, or propane), have consistently large hot water needs, and can easily accommodate solar installations (e.g. they have south-facing exposure on the ground or on rooftops).

[3] Alternately, some installers use a "drain back" system design, which also protects the SHW system from freezing.
[4] British Thermal Units

Case Study 1: Reese Dairy Farm Uses SHW for Farm Sanitization

Reshaping energy use in the dairy sector

Application: Hot water for cleaning

Location: Goodhue, Minnesota

Figure 3. Reese Family Farm in winter

Project Description: When Peter Reese of Reese Family Dairy Farm, conducted an energy assessment of farm operations, he discovered that 41 percent of energy consumed is used to heat water to wash and sanitize equipment. Recognizing the significant potential for energy and cost savings, Peter worked with experts to assess potential for solar hot water (SHW) on the Reese farm. Based on his research, he installed four solar hot water collectors, which substantially reduced the farm's electricity expenditures for hot water when integrated into the existing hot water heating system. The SHW collectors, which were manufactured by Solar Skies – a Minnesota company, provides hot water to the dairy farm year round.

Project Economics: The Reese Dairy Farm spent approximately $14,000 for the solar hot water system. The farm received a $5,000 grant from the Clean Energy Resource Teams (CERTs), a state-wide non-profit that works with communities to encourage energy conservation, energy efficiency, and renewable energy technologies and practices. The Reese Farm also received a rebate from the Minnesota Department of Commerce for approximately $3,000. With these incentives, and estimated electricity savings of 3,600 kWh annually, the Reese Farm SHW system can achieve payback in approximately 17 years. The estimated life of the system is 25 years.

Lessons Learned:

- Peter Reese worked with the system installer to determine the optimal system placement. A detailed site assessment provided critical information for the system's success. The system has now operated well for two years.
- Reese installed the system in winter, and heavy snowfall increased the complexity of the installation process. Installation during better weather conditions could have streamlined the installation process.
- During the financing of the project, Peter appreciated that the CERT grant was timed to match installation expenditures, a structure that he hopes can be applied to future state and federal incentives for solar thermal.

2.2 Air Heat Systems

Solar air heat systems use a solar collector to heat air and typically provide direct supplemental space heating and ventilation in residential and commercial buildings. The two most common types of solar air heating systems are transpired air collectors (discussed in Section 0) and solar air furnaces. Solar air furnaces function in a similar manner to a conventional forced air furnace, providing heat by circulating conditioned building air through solar collectors.[ix] They are fairly simple to operate and can provide energy and cost-savings to residents and businesses.

Like SHW systems, solar air systems use collectors to capture solar heat; however, they use air as the medium for absorbing and transferring solar energy rather than the liquid heat transfer fluid used in SHW systems.[x] Modern solar air heating collectors are typically mounted vertically on south-facing walls (or on rooftops) in order to maximize energy production during winter months when heating loads are highest. This also helps to minimize costs by eliminating costly racking while maintaining building aesthetics. Solar air systems capture solar energy that strikes the glazed solar collector. When enough heat is available, simple controls activate a fan, which moves the heated air through the collector. Temperature sensors, the thermostat, and the unit controller determine when to operate dampers on incoming and outgoing air. These simple controls also prevent reverse thermo-siphoning (heat loss at night or on cold overcast days) and seasonal overheating.[xi]

As discussed in Section 2.6.2, the technical potential for solar air heating is significant. It is estimated that approximately five percent of residential space heating and over six percent of commercial space heating demand could be served by solar air systems. This could provide 8.8 trillion Btus of renewable heat per year. Case Study 2 describes the experience of a farmer who installed a solar air heating system to pre-heat ventilation air.

Case Study 2: Solar Air Heat Enhances Competitiveness of Family Farm
Clean energy innovation for small farmers

Application: Hot air to heat soil for crops

Location: Frazee, Minnesota

Figure 4. Solar collectors outside of the Flynns' high-tunnel

Project Description: Dallas Flynn and his wife sell vegetables from a high-tunnel farming system on their property. Dallas wondered if it was possible to extend the farm's growing season by heating the soil year-round. In 2008, Dallas Flynn received assistance from the Minnesota Department of Agriculture to install a three collector solar system for his farm. The solar system heats air, which is then cycled through corrugated tile pipes underneath the soil of the high-tunnel. The high-tunnel is also covered by insulation to retain hot air inside the greenhouse. The hot air is circulated through the pipes by small fans, and returned to the solar collectors for re-heating. The heated soil enhanced the health of the Flynns' crops and expanded their growing season from 270 to 300 days.

Project Economics: The solar air heat system cost approximately $23,000 dollars. The Flynns received a $17,692 Sustainable Agriculture and Energy Grant from the Minnesota Department of Agriculture. The solar system enabled the Flynns to be the first-to-market with several high-value crops.

Lessons Learned:

- During the summer months, the heated air from the solar system became too hot, and damaged crops. The Flynns modified the system by adding temperature controls for the heated air circulation system.
- The Flynns' solar air heat system is highly replicable for small family farms, and an innovative method to increase the competitiveness of small growers. Several visitors have come to observe the Flynn's solar system to try to integrate similar techniques into their farming practices.

2.3 Transpired Air Heating

Transpired air heating systems (also called solar walls) are solar air systems that use corrugated metal panels installed along the side of a building's south wall to pre-heat ventilation air for buildings during the heating season (see Case Study 3). The solar preheated air is drawn into the heating, ventilation, and air conditioning (HVAC) system to provide ventilation air to the building. These systems are best suited for commercial and industrial buildings with high fresh-air ventilation requirements.[xii]

The dark façade of the solar wall absorbs solar energy on sunny days and a fan or blower draws ventilation air into the building through tiny holes in the collector and up through the air space between the collectors and the building's wall. Solar energy absorbed by the unglazed collector warms the air by as much as 40 degrees Fahrenheit. By pre-heating outdoor air with solar energy, transpired air heating systems remove substantial load from a building's conventional air heating system, thereby saving energy and money.[xiii]

While no technical potential estimates for transpired air heating systems have been made for this report, it is clear that there is good potential for solar walls in Minnesota. Case Study 3 describes the installation and operation of a typical transpired air heating system. The most cost-effective systems are installed in non-residential buildings that use expensive fossil heating sources, have high ventilation requirements, and have unshaded south-facing roofs or walls.

Case Study 3: Transpired Solar Collector Warms Police Station

Solar wall reduces energy costs

Application: Transpired air for heating

Location: Minneapolis, Minnesota

Figure 5. Solar wall on the south side of the 3rd precinct police station.

Project Description: The Minneapolis 3rd Precinct police station installed a 42 x 18 foot transpired solar collector as part of building renovations from 2003 to 2005. The collector was installed on the building's south-facing wall to reduce energy costs; it integrates with the station's updated mechanical and electrical systems. The solar wall is a passive solar system which uses dark galvanized steel panels to collect solar energy. Heated air in the panels is pulled into the ventilation system, and integrated with return air prior to returning into the conditioned space. The building's energy management system chooses between accepting outside air or air from the solar wall based the building's heating and cooling needs. The solar wall is expected to last a minimum of 20 years with little to no maintenance.

Project Economics: The 3rd Precinct solar wall cost approximately $22,000 to install. No state grants or incentives were used to fund the project. During a Minnesota State University monitoring study conducted from 2010-2011,[xiv] the solar wall saved the police station an average 39.4 MMBtus over the course of a six-month heating season, a 15.7% savings in energy. The estimated cost-savings were $418 per month, which resulted in a payback period of approximately 8.5 years.

Lessons Learned:

- Solar wall systems have a wide variety of applications for different building types. The Minnesota State monitoring study found significant energy and emissions savings from solar wall installations on institutional, municipal, and office buildings.
- Payback periods improve in regions with longer heating seasons. Additionally, providing modest incentives through the Conservation Improvement Program or other mechanism would improve payback times and make solar walls more attractive investments for businesses.

2.4 Solar Cooling

In addition to the heating applications described above, solar thermal technologies can also serve air conditioning applications. The market for solar cooling is small, with only 1,000 systems installed worldwide (as of 2012) – primarily in Spain, Germany, and Italy.[xv] While solar cooling technology has been successfully demonstrated, experts report that additional research and development (R&D) is needed to bring down costs and improve the efficiency and operation of solar cooling systems.[5]

Like the SHW system described above, solar cooling systems use solar collectors to capture heat from the sun. The captured heat is used to drive a thermal process such as those used in absorption chillers or desiccant systems resulting in cooling and/or de-humidification.[xvi] Absorption chillers replace the compressor needed in a typical cooling cycle with a more complex refrigerant absorption and transport system. In the absorption cooling system only a small pump and a heat source are needed to bring the refrigerant to the elevated temperature and pressure normally achieved by the compressor. The benefit of these systems is that the pump requires very little energy to elevate the pressure of the liquid refrigerant compared with compressing a vapor, and the heat can be supplied from external sources such as solar collectors. However, the disadvantages are that these systems are complex, bulky, and expensive. Solar de-humidification systems use a solid or liquid desiccant (like silica gel) to lower the humidity of outside air, then use heat from solar collectors to periodically re-generate the desiccant.

Minnesota stakeholders have expressed significant interest in solar cooling systems, in large part because of the potential of solar-driven cooling to address air conditioning load during periods of utility peak demand. However, the opportunity for solar cooling at this time appears to be limited. As described in Case Study 4, there is only one known solar cooling system currently operational in Minnesota – at the University of Minnesota Morris campus. While the University of Minnesota project has successfully demonstrated the technology, solar cooling continues to face challenging project economics. This mirrors international experience: despite cost reductions for solar cooling of approximately 50% over the last six years, the technology continues to face high upfront system costs and long payback periods.[xvii] With research and development and pilot scale deployment, however, solar cooling systems may become more competitive in the future.

[5] In particular, the International Energy Agency reports that systems require optimized thermally driven cooling cycles with higher efficiencies, lower costs, easier hybridization with other waste heat sources and integration with backup heating and cooling technologies. RD&D is needed in new materials and material coatings for heat exchange surfaces and new heat and mass transfer systems. It will also require the design of new thermodynamic cycle systems. See International Energy Agency (IEA). (2012). Technology Roadmap Solar Heating and Cooling. Retrieved from http://www.iea.org/.

Case Study 4: Pilot System Uses Sunlight to Cool Research Center

University of Minnesota-Morris' innovative solar system

Application: Solar heating and cooling

Location: Morris, Minnesota

Project Description: The University of Minnesota-Morris wanted to demonstrate the feasibility of solar heating and cooling in northern climates. The University installed a solar heating (53 kW) and cooling (35 kW) system at the West Central Research and Outreach Center. The solar thermal system uses 1,200 evacuated tubes, a chiller, a storage tank, and cooling tower. The building's heating and cooling load is monitored by a Honeywell building management system. Back-up heating and cooling is provided via ground source heat pumps.

Figure 6. Evacuated tube array outside of WCROC

During heating mode, solar-heated water is directed to a mixing valve where it is diverted to fan coils to heat the building or a tank for storing excess heat. During cooling mode, solar-heated water is directed into the chiller, where it heats up a refrigerant, thus enabling the chiller's compressor to run less or operate at a lower speed in order to cool the building. The solar heated water is then returned to the solar collectors in a loop. A mixing valve sends water over the coils to cool the building or to a storage tank depending on cooling needs.

Project Economics: The solar heating and cooling system cost approximately $340,000. The installation and monitoring system was funded in full by a grant from the University of Minnesota's Initiative for Renewable Energy and the Environment. Project managers report that the system was installed to serve as a demonstration project and estimates of project payback have not been calculated.

Lessons Learned:

- When heating and cooling loads are minimal, the solar thermal system will produce excess heat. It is important that systems are designed with a heat dissipation mechanism.
- The cooling tower requires regular maintenance to prevent bacteria from accumulating. Due to this, a solar cooling system may be more applicable for larger systems.
- The solar cooling industry is limited in the United States with only a handful of systems installed nationwide. Additional research is needed to develop cost-effective applications.

2.5 District Energy Applications for SHC Technologies

In addition to residential, commercial, and industrial applications described above, solar thermal technologies can also be integrated into district energy systems. District energy systems can efficiently connect multiple buildings to central or satellite sources of thermal energy, which distribute heat to users through underground pipes in the form of hot water, steam, or chilled water. Over the last century, a number of district energy systems were established in major cities and academic campuses across the U.S. In Minnesota, many of these systems remain in place, with improvements made over decades of operation to increase operating efficiencies and increase the flexibility of fuel inputs.

To operate effectively, district energy systems typically must aggregate thermal load, serve areas with high building density (or close building proximity), and supply facilities with diverse heating requirements. Integrating solar thermal with district energy is a natural fit, because they share many of these characteristics. For example, load aggregation enables solar thermal to be used year-round to meet the needs of users. Similarly, the need for load diversity presents opportunities to integrate solar thermal, matching solar production to serve a wide variety of applications, including but not limited to facilities such as breweries, bottling facilities, laundries, hotels, pools, cafeterias, and multi-unit residential buildings.

District energy systems also provide infrastructure for energy export, allowing solar thermal systems to be sized beyond single building capacity. For solar thermal, energy export via a district energy system is comparable to net metering on the electric grid, which enables on-site solar heat that would previously be unused to be distributed to other users via the grid. District systems also often seek diversity by utilizing multiple satellite heating facilities with feed-in options for multiple boilers, chillers, and fuels. By integrating solar thermal, district energy managers can further add to the fuel flexibility of the system. Additionally, because district energy systems consist of infrastructure that is primarily located underground, solar thermal offers managers a valuable asset that can be used to showcase the system to educate the community and users.

There are many advantages to integrating solar thermal into district energy systems, though successful solar thermal integration depends upon a variety of factors. While a full account of key development factors is beyond the scope of this report, the following scenarios describe key technical criteria for integrating solar thermal into district energy systems.

Scenario 1: Hot Water Distribution, Low Load Profile. District systems utilizing hot water for distribution are ideal for solar thermal integration. Unfortunately, the majority of the systems in Minnesota are steam based, not hot water based. Some of the existing steam systems do utilize smaller hot water loops in their system, however, which can also be used to integrate solar thermal within that district. Most new systems that are being constructed or considered do utilize hot water for main distribution.

When evaluating a district for solar thermal placement, sometimes the best host sites do not have heat load profiles that match the potential peak output of the solar array. In this scenario, the solar system can be designed to export hot water from the host building once the host building's hot water needs have been met by connecting it to a district hot water loop. Systems being considered for export should be modeled to meet or exceed the distribution system's lower set-point (year round) through higher efficiency collectors and building and system controls. The economic model of this type of installation may require assignment of separate retail and wholesale values for energy consumed onsite and energy exported. Examples of buildings with low load profiles include office, commercial, and government buildings with minimal domestic hot water needs.

Scenario 2: Hot Water Distribution, High Load Profile. It is common to find buildings on district energy systems with high hot water load profiles, whether for domestic hot water, space heating, or process heat loads. These buildings often anchor district systems by providing a consistent consumer of energy for the overall loop. Integration of solar thermal for these buildings can be focused on meeting the peak demands of the district system. Solar system sizing can be decreased or increased based on the compatibility with, and interest in, exporting heat the district system. When the array is closely matched to the building average load, export may still occur but will not play as large of a determining factor in panel selection, operating set-points, and economic valuation. These installations may benefit from the existing district energy mechanical interface and energy sharing, although these types of building applications are often ideal hosts for stand-alone solar thermal installations. Examples include restaurants, hotels, laundries, breweries, bottling companies, and incarceration facilities.

Scenario 3: Steam Distribution, Proximate Buildings. Considering the common occurrence of steam distribution in Minnesota (and the United States), it may prove valuable to explore the possibility of exporting from a hot water array and building system to a steam distribution system. To-date, there is not a working example to provide specifications or technical criteria. However, steam systems can still be candidates for solar thermal installations by utilizing an existing hot water loop in the system or by developing one for the solar export. Steam systems utilizing a hot water loop as a connection between users (such as the systems used by Macalester College and Duluth Steam) would be able to install a solar hot water array with export capability to the hot water loop. The array and export would need to be sized to the capacity of the hot water users on that loop, not the overall steam system. Evaluating the installation of a hot water loop should be determined by the capital infrastructure necessary to connect proximate buildings and the benefit of the overall operation of this hot water loop.

Scenario 4: Plant Production Pre-Heat. Regardless of the distribution medium (e.g. hot water, chilled water, or steam) plant production pre-heat is an option for integrating solar thermal into a district system. Most major district systems are producing energy every day of the year and can benefit from additional energy production added to the system prior to distribution leaving the plant. For systems utilizing hot or chilled water storage tanks, the solar thermal arrays could be directly linked to the tanks to increase or decrease temperatures.

Case Study 5: Solar Thermal System and District Heating

Saint Paul hosts the largest solar thermal system in the Midwest

Application: Space heating, hot water and district energy

Location: Saint Paul, Minnesota

Figure 7. The District Energy St. Paul is the largest solar project in the state

Project Description: District Energy St. Paul provides thermal energy to approximately 80% of St. Paul's central business district. The company wanted to test the feasibility of integrating renewable technologies into its district energy system to reduce its carbon footprint. In 2010, District Energy St. Paul installed 144 large-scale solar thermal collectors on the roof of the RiverCentre convention center. The installation generates just under 1 megawatt (MW) of energy. As the system is warmed by the sun, a glycol solution flows through the solar panels and collects thermal energy. The solution then flows through pipes to heat exchangers for the building's hot water system, and also serves the convention center's space heating load. If there is excess thermal energy, the system connects to District Energy St. Paul's existing hot water loop. When the RiverCentre's heating demand exceeds the supply of the solar thermal installation, the building receives heat from other generators in the district energy system. The installation is the largest solar thermal project in the Midwest, covering half a football field in area.

Project Economics: The District Energy solar thermal system cost approximately two million dollars. The system received a one million dollar Department of Energy (DOE) Solar Communities grant. District Energy St. Paul matched these funds. During 2011, the system exported up to between 0.01% and 1.5% of the 183-MW district energy system's load. Part of this variation is due to the change in heating needs of the host-site throughout the year.

Lessons Learned:

- Large-scale solar thermal systems require adequate space to store excess thermal energy. In the case of a district-energy connected system, the thermal system must be able to access the mechanical infrastructure to heat its host building and the district energy loop system. In the absence of a district energy system, storage tanks would be necessary for excess energy.
- District Energy St. Paul also had to locate a roof-site capable of supporting the weight of its solar project. The roofing material at the RiverCentre was nearing its end of life, and had to be replaced prior to the beginning of construction.
- Appropriate structural design is critical for roof-mounted installations. Ground-mounts could be considered as an alternative, if such roofs are not available.

2.6 Minnesota SHC Technical Potential

Solar thermal technical potential estimates reveal that there is significant potential for SHC technologies to displace fossil fuel consumption within the heating and cooling sector in Minnesota. As described below, these estimates take into account the major technical factors that limit development for solar thermal projects. They do not take into account economic considerations such as the LCOE or project payback. Economic performance of SHC systems are described in Section 3.

2.6.1 SHW Technical Potential

The solar hot water (SHW) technical potential analysis presents a high level estimate of the total domestic hot water demand that can be satisfied with SHW systems in Minnesota. The methodology used for this analysis is based upon a national 2007 analysis completed by NREL. Key variables in the technical potential analysis include:

- The total estimated hot water demand in Minnesota
- The percentage of a building's demand that can be satisfied by a SHW systems (the solar fraction)
- And the fraction of buildings roofs suitable for a SHW system (rooftop availability).

Using these key variables, the technical potential for Minnesota was calculated using the following equation:

SHW Technical Potential = Hot Water Demand x Solar Fraction x Rooftop Availability

Results from the analysis are described in Table 1 below.

Table 1. SHW Technical Potential Estimates for Minnesota

	Residential SHW	Commercial SHW
Total Potential	9.6 trillion Btus	2.4 trillion Btus
% of hot water demand	27.6%	38.4%

2.6.2 Solar Air Heating Technical Potential

The solar air heating technical potential analysis presents a high level estimate of the total heating demand that can be satisfied with solar air heating systems in Minnesota. The methodology used for this analysis is based upon a similar analysis completed for the New York State Energy Research and Development Authority (NYSERDA).[xviii] Key variables in the technical potential analysis include:

- The total estimated space heating demand in Minnesota,
- The percentage of a building's demand that can be satisfied by a solar air heating system (the solar fraction), and
- The fraction of buildings with that can support a solar air heating system.

Using these key variables, the technical potential for solar air heating in Minnesota was calculated using the following equation:

Solar Air Heating Technical Potential = Space Heating Demand x Solar Fraction x Eligible Buildings

Results from the analysis are described in Table 2 below.

Table 2. Solar Air Heating Technical Potential Estimates for Minnesota

	Residential Solar Air Heat	Commercial Solar Air Heat
Total Potential	6.2 trillion Btus	2.5 trillion Btus
% of total space heating demand	5.0%	6.4%

2.6.3 District Energy Technical Potential

The requirements for integrating solar thermal into district energy systems are complicated and can vary significantly from site to site. There is also uncertainty regarding the number, size, and type of district energy systems currently operational in Minnesota. As a result, this report does not attempt to generalize the technical potential estimates for integrating solar thermal into district energy systems.

Nonetheless, at this time, at least 24 known district energy systems are currently operational in Minnesota, all of which present some level of viability for solar thermal applications. Within the Twin Cities metro area, two district energy systems are operable, which use hot water distribution systems, which would appear to make good candidates for more detailed analysis for solar thermal. The other known district energy systems use a primary steam distribution system, which as described in Section 0, may also offer some opportunities for solar thermal integration.

3 Economics Solar Heating and Cooling Systems in Minnesota

Solar heating and cooling only supplies a small share of the heating and cooling demand in Minnesota. It is estimated that fewer than 150 solar hot water systems and 350 solar air heating systems have been installed in the state since 2008. The majority of these installations have been in the residential sector. Only 30 known commercial systems have been installed over the past five years.[6]

For accelerated solar thermal market growth to occur, policymakers and industry representatives will likely need to collaborate to improve the economic case for system installation. This section describes the economics of SHC in Minnesota. In particular, it describes the heating and cooling market, detailing the fuels most commonly used in the state. It describes the incentives supporting SHC, and provides levelized cost of energy (LCOE) calculations that compare the economic performance of SHC technologies with the performance of the most commonly used heating fuels in Minnesota: natural gas, fuel oil, propane, and electric heating.

3.1 Heating and Cooling Fuels and Price Volatility in Minnesota

Minnesota's heating market is primarily served by natural gas. A significant portion of the population also uses electricity or delivered fuels (propane and fuel oil) to serve their heating load. Figure 8 below illustrates the number of households in Minnesota using natural gas, electricity, propane (i.e. liquid petroleum (LP) or "tank" gas), and fuel oil. Additionally, a small portion of the population (approximately four percent) uses "other" heating fuels, which include, for example, wood, coal or coke, and solar.

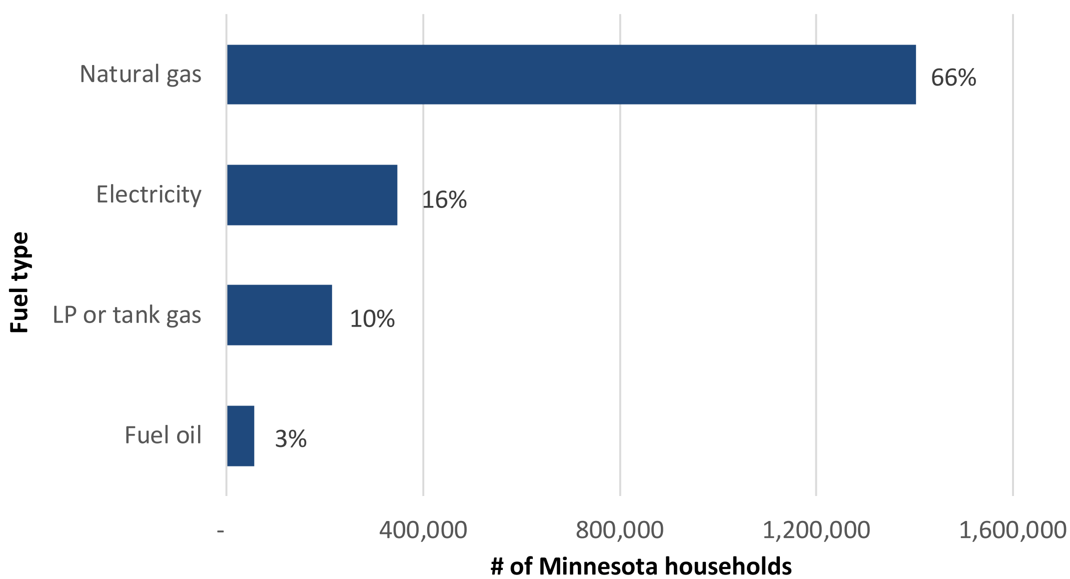

Figure 8. Household heating fuels in Minnesota (Source: U.S. Census, American Community Survey, 2011)

According to the U.S. Energy Information Agency (EIA), households heating with natural gas, propane, and electricity will experience higher prices for the 2013/14 heating season than they did for the previous winter. Homes heating with natural gas are expected to face the greatest price spikes, up 13 percent compared to the previous winter. Propane prices are expected to increase by nine percent, and

[6] These estimates are based on data collected from Minnesota Department of Commerce's rebate and financing programs as well as systems reported by installers.

electricity will increase by two percent. Fuel oil prices, on the other hand, are expected to decrease by approximately two percent.[xix]

In spite of expected price increases over the coming year, fossil fuel costs in Minnesota remain relatively low compared to historical prices. For examples, EIA reports that despite the expected increase in costs, 2013 natural gas prices are still expected to be lower than the *average* price over the previous five winters (2007 through 2012).[xx]

Nonetheless, price volatility, like the price spikes that will be experienced over the 2013/14 winter, is a serious concern. It is often difficult for business owners and homeowners to plan for or manage sudden shifts in heating and cooling expenditures. Businesses and homeowners using solar thermal can mitigate or eliminate the negative impacts of price volatility, because customers can "lock in" a portion of their heating costs by using free fuel (i.e. sunlight). Investment decisions for solar thermal energy are typically made by balancing the comparative cost of conventional heating fuels with the range of savings and benefits, such as fuel price hedging, that solar heating creates.

3.2 Federal and State SHC Policies

Solar thermal technologies are supported by federal tax incentives, but the technology has not benefitted from stable policy support in Minnesota. Several pilot programs have been implemented in the state, though longer-term policies or programs have only recently emerged. The following describes the state and federal policies that have at various times supported solar thermal.

3.2.1 Federal Tax Incentives

Solar thermal technologies are eligible for several federal tax incentives. This includes the federal business and personal investment tax credit as well as accelerated depreciation. Tax benefits and eligible solar thermal technologies are described in Table 3 below.

Table 3. Federal SHC tax incentives (Source: DSIRE, 2013)

Federal Tax Incentive	Eligible SHC Technologies	Description	Expiration
Personal Renewable Energy Tax Credit	Solar water heat[7]	The personal tax credit is equal to 30% of expenditures with no maximum credit. Solar pool-heating systems are not eligible. Reverts to 10% after expiration date.	12/31/2016
Business Investment Tax Credit (ITC)	Solar water heat, solar space heat, solar thermal process heat	The business tax credit is equal to 30% of expenditures with no maximum credit. Solar pool-heating systems are *not* eligible. Reverts to 10% after expiration date.	12/31/2016
Modified Accelerated Cost-Recovery System (MACRS)	Solar water heat, solar space heat, solar thermal process heat	Businesses may recover investments in certain property through accelerated depreciation deductions. SHW property can be depreciated over five years.	n/a

3.2.2 Minnesota policies and incentives

Rebate programs have been implemented in Minnesota by the state and by individual utilities to support solar thermal investment over the past several years. The State of Minnesota offered two sequential rebate programs for small solar thermal installations. The first program ran from 2008 until 2010, and was funded under a Renewable Development Fund (RDF) appropriation of approximately $200,000. A subsequent program, running from 2010 until 2012, was funded using federal ARRA funds, and paid out approximately $215,000 in rebates. The ARRA program offered rebates for solar air heat systems in addition to solar hot water. Minnesota's solar thermal rebate programs were undersubscribed.

In 2014, Minnesota Department of Commerce launched the *Made in Minnesota* solar thermal rebate program. This program provides rebates covering 25 percent of installed costs with a maximum of $2,500 for residential systems, $5,000 for multi-family systems, and $25,000 for commercial systems. The program has an annual budget of $250,000, approximately half of which is reserved for SHW systems and half for solar air projects. Collectors must be manufactured in Minnesota and be SRCC certified in order to be eligible for the rebate.[xxi]

Several utilities have also offered rebates for solar thermal installations. Minnesota Power, the investor-owned utility in northeast Minnesota, offered (through 2013) a rebate of up to $2,000 per installation for solar thermal systems within the company's service territory under the *SolarSense* program. The

[7] According to industry leaders, tax rules are not clear regarding the eligibility of residential solar air heating for the personal tax credit. Tax rules currently indicate that only solar water heating is eligible, though a number of legal analyses suggest that the original legislation was written to include other solar heating technologies (including solar air heating). In practice, a number of residential customers in Minnesota have successfully received the personal RE tax credit for residential solar air heating systems. Customers should consult with their tax attorney for guidance.

total *SolarSense* program budget for both PV and thermal rebates was capped at approximately $200,000. Solar thermal rebates are only available to customers using electric water heaters, which excludes many Minnesota Power customers in Duluth who use natural gas.

Three municipal utilities in southern Minnesota (Rochester, Owatonna, and Austin) offer solar thermal rebates at $15 per square foot of collector or up to $1,200 per system. The program is part of the *Conserve and Save* rebates, offering (in 2013) rebates for energy efficiency, PV, and solar hot water systems. The solar thermal rebate has been largely unused in Austin and Owatonna, and only a few systems installed in Rochester. Additionally, the Marshall Municipal Utilities offer a solar thermal rebate program at approximately $20 per square foot of collector or up to $2,000 per project.

In addition to the rebate programs, several hundred solar air heat systems were installed under the Sustainable Energy Resources for Consumers (SERC) grants offered by the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE). SERC grants are funds that were made available on top of normal Weatherization Assistance Program (WAP) funding levels. In 2009, as part of the American Recovery and Reinvestment Act (ARRA), the Minnesota WAP spent $1,034,288 on the installation of solar air heating systems on low-income households. At the completion of SERC, 371 collectors were installed on 220 households in the state.

3.3 SHC Levelized Cost of Energy (LCOE) Analysis

The following section provides a high-level assessment of the LCOE of solar hot water, solar air heat, and transpired air heating systems. Solar thermal scenarios – which estimate costs, production, and incentives for SHW, solar air, and transpired air heating systems – were developed to illustrate the potential impacts of the *Made in Minnesota* (or comparable) rebate program on the LCOE of each applicable technology relative to fossil fuel base cases.

3.3.1 Scenario Description

Solar thermal scenarios were developed for both residential and commercial SHC applications. It is important to note that considerable variability may exist in the installed costs of solar thermal systems, which can significantly impact cost-effectiveness. While this analysis cannot account for every possible scenario, it represents a reasonable starting point for evaluating the cost effectiveness of "typical" solar heating and cooling systems. The scenarios were developed using RETScreen Clean Energy Analysis software and were reviewed by solar thermal engineers, and validated against real-world SHC case studies in Minnesota where possible.

For each scenario, it is assumed that a conventional heating system already exists in the building, serving the heating and domestic hot water needs for occupants. The "new" SHC installed will produce heat that displaces a portion of the energy from the existing heating system.

Each scenario compares capital and operating costs of a solar system with the fuel costs of a conventional system. The LCOE is calculated by (i) calculating the capital and operating costs for a new solar thermal system (net incentives) divided by total energy generation, and comparing that with (ii) the fuel costs of the conventional heating system divided by total energy generation. Each system is assumed to have a 20 year project life. Fuel costs were discounted over the 20 year life of the system. For residential systems, the discount rate was assumed to be six percent. A 12 percent discount rate was used for commercial systems.

Table 4 below illustrates the SHC scenarios developed. Detailed assumptions are provided in Appendix A.

Table 4. Minnesota SHC scenarios for LCOE analysis

SHC Technology	Residential Scenario	Commercial Scenario
Solar Hot Water	SHW system for 4-person, single-family home	SHW systems for 32 resident commercial apartment building
Solar Air Heat	Solar air system for 4-person, single-family home	Not modeled
Transpired Air Heat	Not modeled	Solar wall for pre-heating ventilation

The LCOE analyses for the solar thermal systems here show the impact of the following important variables:

- **Installed cost ranges:** high and low installed costs estimates were developed for each scenario. Cost ranges were calculated based upon historical Minnesota Department of Commerce rebate data as well as estimates from regional installers.
- **Federal incentives:** each scenario assumes that all available federal (tax) incentives are monetized by project owners. This includes the ITC and MACRS for commercial systems and the personal tax credit for residential systems. For residential solar air heating systems, for which the eligibility of federal tax incentives is currently unclear, the LCOE results were calculated both with and without the federal tax incentive.
- **Impacts from the *Made in Minnesota* or a comparable solar thermal rebate:** where applicable, scenarios illustrate the impacts of the *Made in Minnesota* solar thermal rebate on the project LCOE. The *Made in Minnesota* rebate is only applicable for solar air heat and solar hot water systems using collectors manufactured in Minnesota and for customers of investor owned utilities. However, an analysis of what a comparable state or utility incentive that reduces installed costs by 25 percent would do for transpired air heat is considered for illustrative purposes. This enables policymakers to evaluate the potential impact of a state rebate that covers a wider range of customers (e.g. those using fuel oil and propane) for a wider range of solar thermal technologies (e.g. transpired air heat systems) than would currently qualify for the *Made in Minnesota* rebate.

3.3.2 Residential LCOE Analysis

Residential SHW systems showed higher LCOEs than all of the conventional heating alternatives. This scenario includes the value of the 30 percent personal tax credit. As illustrated in Figure 9 below, the addition of the 25 percent *Made in Minnesota* rebate significantly improves the LCOE for SHW systems. However, at current installed costs and heating fuel prices, the rebate is not sufficient to bring the LCOE of SHW systems below those of conventional heating fuels.

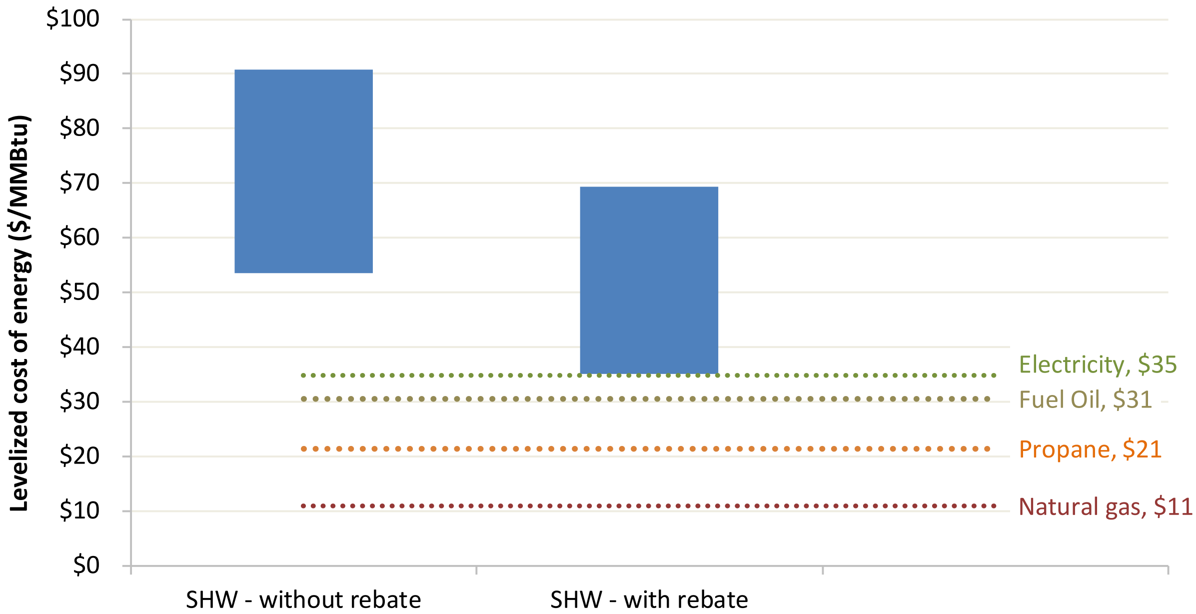

Figure 9. Residential solar hot water (SHW) LCOE analysis

Compared to SHW systems, the residential solar air heat systems illustrated in Figure 10 below can achieve considerably lower LCOEs. It is worth noting that there is some ambiguity with regard to the eligibility of residential solar air heating systems for the 30 percent personal tax credit. For this analysis, the LCOE analysis was calculated both with and without the impact of the personal tax credit, resulting in a larger spread of potential LCOE estimates. With the 25 percent *Made in Minnesota* rebate factored in as well as the impact of the personal tax credit, residential solar air heat systems are cost competitive with electric heating systems, fuel oil, and in the best cases, propane.

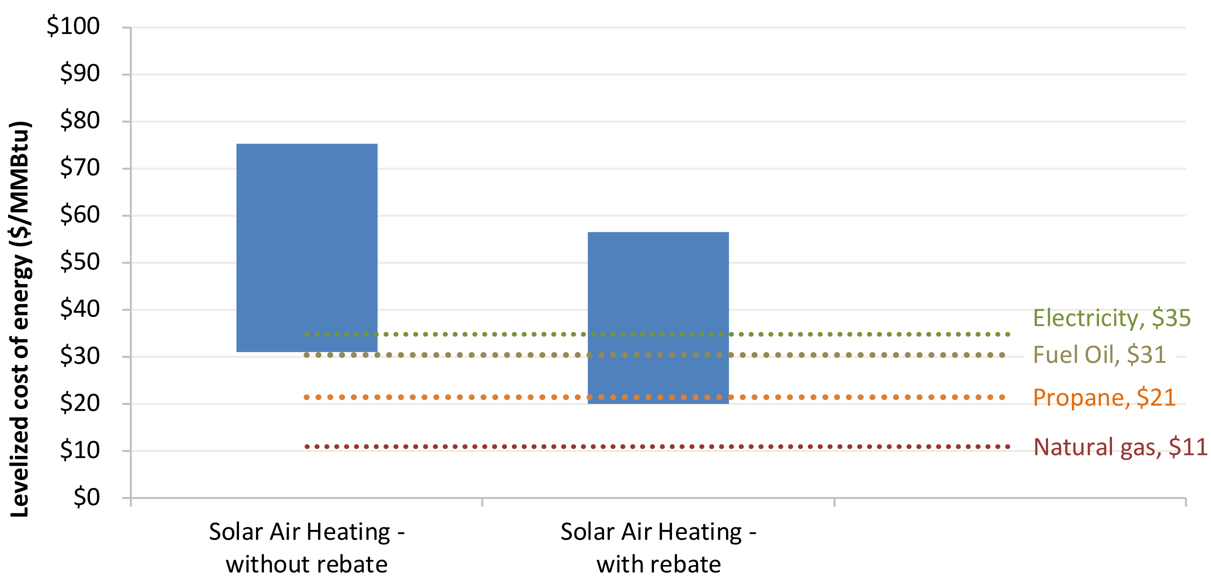

Figure 10. Residential solar air LCOE analysis

3.3.3 Commercial LCOE Analysis

Before the state rebate is factored in, commercial SHW systems show higher LCOEs than all of the conventional heating alternatives. This scenario includes the value of the 30 percent ITC in addition to the financial benefits of accelerated depreciation (MACRS). And as illustrated in Figure 11 below, the addition of the 25 percent rebate improves the LCOE for SHW systems, bringing the LCOE on par or below the commercial LCOEs for fuel oil, electric, and propane heating. However, at current installed costs, the rebate is not sufficient to bring the LCOE of commercial SHW systems below that of natural gas.

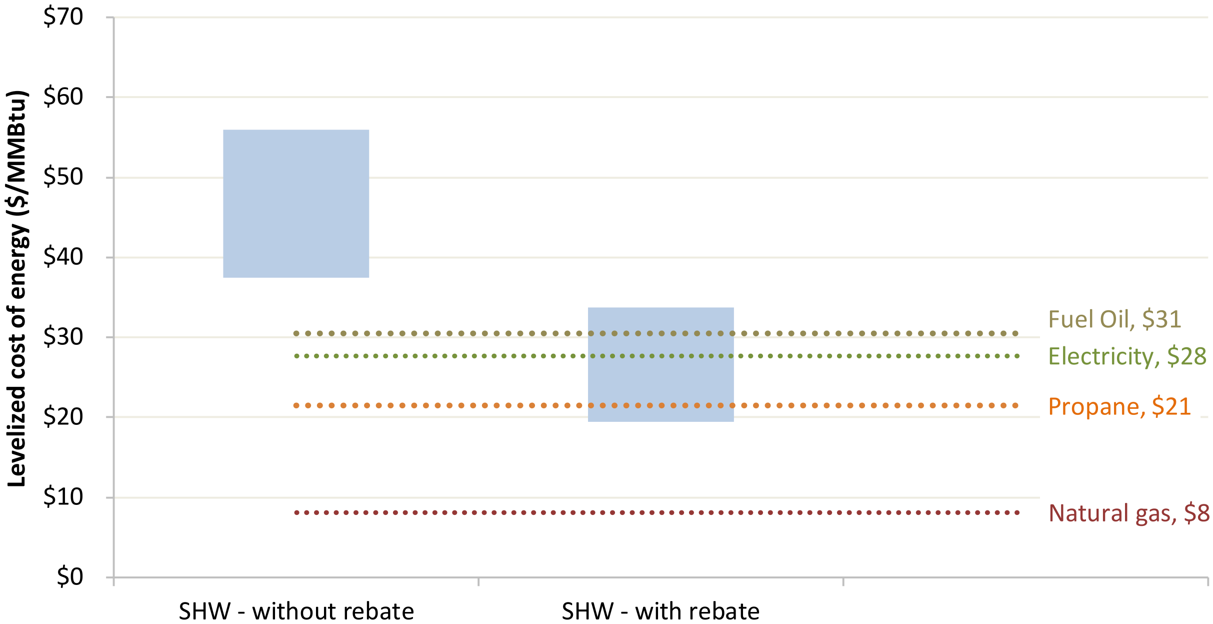

Figure 11. Commercial solar hot water (SHW) LCOE analysis

Like commercial SHW systems, commercial transpired air heating systems show higher LCOEs than all of the fossil fuel alternatives before a hypothetical 25 percent incentive is factored in. This scenario also includes the value of the 30 percent ITC in addition to the financial benefits of accelerated depreciation (MACRS). As illustrated in Figure 12 below, the addition of a 25 percent rebate significantly improves the LCOE for transpired air heating systems, bringing the LCOE on par or below the LCOEs for fuel oil, electric, and propane heating. However, at current installed costs, this incentive level is not sufficient to bring the LCOE of commercial transpired air heating systems below that of natural gas.

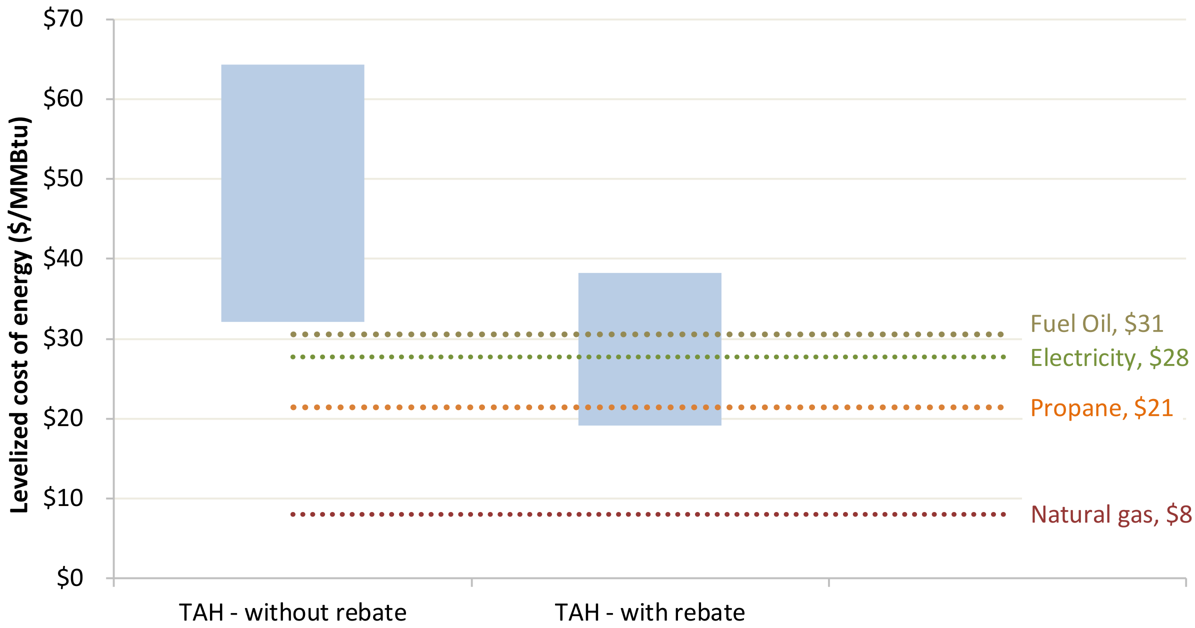

Figure 12. Commercial transpired air heat (TAH) LCOE analysis

3.3.4 Conclusions of LCOE Analysis

Most solar thermal technologies do not present compelling project economics at the residential scale at current conventional heating prices, SHC installed costs, and rebate levels. If solar air heating systems are eligible for the personal federal tax credit, then they can achieve attractive LCOEs in some cases at the residential scale.

At the commercial scale, due in part to improved economies of scale, federal tax incentives (ITC and MACRS), as well as the *Made in Minnesota* rebate (or a hypothetical 25 % incentive for transpired air heat), both SHW and transpired air heating systems can offer cost-competitive heating alternatives to Minnesota consumers that use fossil fuels. Solar thermal LCOEs are particularly compelling when compared against delivered fuels (fuel oil or propane) or electric heating.

A number of factors can alter project economics for solar thermal technologies. For example, SHC installed costs are a major driver of the LCOE calculation. Additionally, the SHC eligibility for federal tax incentives (e.g. tax credits and/or MACRS) also has a significant impact on the LCOE. Similarly, the economics for SHC technologies are greatly influenced by the comparative conventional heating fuel prices. While a sensitivity analysis assessing the impacts of each of these factors is beyond the scope of this report, policymakers may wish to analyze these factors in greater detail in the future.

4 Solar Heating and Cooling Market Barriers

The goal of this study is to explore opportunities for SHC technologies to advance Minnesota's climate and energy goals. A key component of this effort is to assess barriers constraining market growth of SHC technologies. The Project Team engaged stakeholders in Minnesota via a series of workshops and interviews to identify major market development barriers. SHC market development barriers include: (i) high upfront costs and inadequate financing options, (ii) poor public awareness of SHC benefits, particularly in high-value markets, (iii) inadequate metering standards, (iv) high certification standard costs, (v) opaque regulatory requirements, and (vi) need for workforce development. This section describes each of these barriers and discusses the presence (or lack thereof) of policies or programs in Minnesota that currently seek to address them.

4.1 High Upfront Costs and Inadequate Financing Options

High upfront costs are a significant barrier to development of Minnesota's solar thermal market, even when the lifetime fuel savings should justify the cost. For example, typical residential SHW systems cost $8,500 to $13,500. The high cost is particularly a barrier because SHW systems cannot provide 100 percent of a home's domestic hot water or space heating load; residents must also have a dispatchable heating system in place for when on-site solar hot water storage is exhausted. As a result, solar thermal systems are an additional cost outlay, rather than a substitute outlay for heating. Customers pay significantly more upfront than they would if they only installed a high efficiency, fossil fuel heating system. Solar air heat and transpired air heat systems also face high first cost challenges, requiring customers to make large, additional investments.

Tools that can overcome the upfront cost barrier include loan programs that match payments with savings, and rebates (or other incentives) that directly reduce the upfront cost. In Minnesota, however, financing options for solar thermal installations are limited, and Minnesota has not historically offered rebates or incentives over the long-term to encourage development of the solar thermal market.

In 2013, the Minnesota Legislature passed a bill authorizing the Department of Commerce to develop the *Made in Minnesota Solar Thermal Rebate Program*. This program will launch in 2014 and will run for ten years. The rebates will cover up to 25 percent of the installed costs for solar thermal installations.[xxii] Though the *Made in Minnesota* program is an important step to encourage development of the Minnesota solar thermal market, stakeholders point out that the program will likely suffer from several challenges. In particular, the *Made in Minnesota* solar thermal program has a limited annual budget – currently capped at $250,000 a year – which may not provide the magnitude of support required to sustain robust solar thermal market development.

The *Made in Minnesota* rebate program will also have a limited scope within the state. The rebate program is funded via surcharges on investor owned utility gas and electric bills.[8] As a result, only utility customers paying into the programs are currently eligible for the *Made in Minnesota* rebate. This prevents residents using delivered fuels like propane or fuel oil from participating in the program, thus eliminating participation of high-value customers who can capture strong project economics (see Section 3.3.4) and significantly reducing energy and cost-saving opportunities for Minnesota residents.

Stakeholders also indicated that there is a need to offer comprehensive, low-interest financing in order to spread the capital costs of solar thermal over time. In particular, stakeholders identified a need for publicly-supported financing mechanisms, such as low or zero-interest loan programs, revolving loans,

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[8] This includes the public utility's Conservation Improvement Program and the Xcel Energy Renewable Development Fund.

PACE financing, or on-bill financing, among others. A few financing programs mention solar installations as an eligible option, though they have not supported many solar thermal installations to date.[9] Some federal and state programs targeting rural development have been used to support agricultural solar thermal installations, but these are unlikely to scale the statewide SHC market on their own.[10]

4.2 Poor Public Awareness of SHC Benefits

Many policymakers and consumers are unfamiliar with the potential benefits of SHC systems. In particular, there is poor awareness of the cost-saving, GHG reduction, hedging, and other social and environmental benefits of solar thermal.

Solar thermal has not historically been widely marketed. Though the industry peaked in Minnesota during the 1970s oil crisis, stakeholders report that it has since suffered a sharp decline. Solar installers commonly offer solar thermal services as an ancillary business line (in addition to core business services like solar PV installation), and as a result, have not developed robust marketing campaigns for solar thermal. On the consumer side, solar thermal is commonly confused with more popular renewables like solar PV, which receive more attention from industry groups and policymakers.

Minnesota has basic information on the different types of solar and associated resources on the Minnesota Department of Commerce, Division of Energy Resources website, and advocacy organizations have similar information available. However, stakeholders report that more active and focused marketing and education campaigns will be essential to solar thermal market development in Minnesota.

4.3 Inadequate Metering Standards

Stakeholders report that residential and small commercial solar thermal systems are commonly not metered, making it challenging for customers to "see" cost-savings or ensure that the system performs adequately over time. This compounds challenges in making customers aware of solar thermal benefits, and creates difficulties for determining the cost effectiveness of rebate or incentive programs. It is particularly problematic in the residential sector, where the costs of metering can be disproportionally high, accounting for approximately ten percent of total installed costs (depending upon the quality of the meter installed). Stakeholders report that commonly accepted industry standards and state level guidance for solar thermal metering is needed to grow the market and ensure customers can monitor system operation.

Minnesota has not developed a standardized approach for metering small solar thermal systems. A number of technical questions need to be resolved, including how to measure energy, accuracy of metering systems, where to measure benefits (at the storage tank or on the DHW system as a whole), and other issues. New Hampshire is one of the first states engaged in developing SHW metering standards, which may offer important lessons for Minnesota in the future. Additionally, industry leaders at the International Association of Plumbing and Mechanical Officials (IAPMO) are developing a Heat Metering Standard that will provide technical guidance and standards for heat metering.

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[9] This includes the Center for Energy and Environment Home Energy Loan Program and the Minnesota Housing Finance Agency Fix-up Loan Program.

[10] This includes, for example, the Minnesota Sustainable Agricultural Loan Program.

4.4 Certification Standard Costs

Minnesota requires that systems receiving the *Made in Minnesota* rebate be certified by the established Solar Rating and Certification Corporation (SRCC) in keeping with state code requirements.[xxiii] However, solar thermal manufacturers in Minnesota report challenges and significant expense in certifying solar thermal collectors, noting that certification could become more expensive if national certification organizations – like the SRCC and the International Association of Plumbing and Mechanical Officials (IAPMO) – do not to coordinate efforts. In addition, solar thermal manufacturers express frustration that each solar thermal product must be certified. For example, manufacturers note that a scalable certification system would give them greater flexibility to manufacture products of varying sizes (e.g. 4x10 collectors, 8x20 collectors, etc.) without having to go through a costly and time-consuming certification process for minor product adjustments. Stakeholders state that redundant standards requirements increase the cost of the collectors and delay the development of new products.

It is not reasonable to expect Minnesota to unilaterally change national or international certification standards. However, the state could develop proxies that allow variations in collector sizing to use an existing certification for qualifying for Minnesota-specific standards. The state could also engage and convene manufacturers and certifying bodies in order to encourage development of standards that reduce or streamline certification costs and requirements while still ensuring product performance.

4.5 Opaque Permitting Requirements

Regulatory and permitting requirements in Minnesota are often unclear, especially in local jurisdictions where building inspectors may be unfamiliar with solar thermal technologies and installation practices. While estimates vary, installers indicate that local permitting can account for up to 20 percent of residential installed costs, especially if it is necessary to engage structural engineers or acquire land use permits. Reducing the cost of permitting and other soft costs can significantly reduce the overall installed costs of solar thermal in Minnesota.

Minnesota has developed specific best practices for permitting solar energy systems, some of which are directly applicable to solar thermal systems. However, the state does not have an ongoing, proactive effort to ensure that local officials consider and use the state's permitting best practices. A variety of methods have been used by other states to standardize permitting and ensure that the costs are transparent and predictable. Methods include active education efforts for local officials on best practices, creating statewide guidance documents, providing municipalities with technical assistance to support permitting reform, and legislatively standardizing procedures.

4.6 Workforce Development Challenges

Some stakeholders report that contractors lack knowledge of best practices for SHC installation, which creates quality control concerns for the industry. Solar thermal remains a niche market in Minnesota, which is often served by contractors that view solar thermal as an "ancillary" offering rather than a core business. There are also only a handful of North American Board of Certified Energy Practitioners (NABCEP) solar thermal installers in the state.[11] Ensuring that employers and consumers have access to a skilled and qualified solar thermal workforce will be important for market growth in the future.

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[11] NABCEP offers certification and certificate programs to renewable energy professionals throughout North America. Within the solar thermal sector, it provides the Solar Heating Installation certification for professionals. For more, see www.nabcep.org/.

Stakeholders note that there is an opportunity to integrate the plumbing and pipefitting trades into the emerging solar thermal market in Minnesota; however, there has not been broad participation among contractors, unions, and other potential solar thermal installers in the state historically. Several colleges and trade schools in the state offer training in PV installation, but there are not comparable training programs for solar thermal. Establishing sound training and certification opportunities for solar thermal installation will be important if the industry is to grow significantly in the future.

5 Recommendations and Proposed Next Steps

Development of a robust solar thermal market requires that policymakers, industry leaders, building owners, and other stakeholders adopt strategic and targeted approaches to market development. A strong solar thermal market requires the implementation of policies and programs that improve project economics, build market demand, and increase consumer confidence and awareness.[xxiv] Policies and programs must also address the underlying barriers that inhibit growth of the solar thermal market and focus on the heating and cooling market sectors that afford the greatest opportunities.

In the short-term, there is a significant opportunity to deploy solar thermal in high-value applications. High value applications include those applications where solar thermal is close to or already economically viable if currently available incentives are used. It additionally includes opportunities where additional policy support for solar thermal could be worthwhile, because it supports or complements other state objectives (e.g. energy affordability or economic development goals). In particular, potentially high-value solar thermal applications and market sectors in Minnesota include: commercial customers heating with high cost fuel sources such as electricity, propane, or fuel oil; agricultural applications where load characteristics coincide with solar resources; low-income housing where the effects of natural gas price volatility are particularly risky; and other applications where solar provides multiple benefits.

In the long-term (within the next ten to 20 years), Minnesota has a number of additional opportunities to significantly increase the use of solar thermal applications and other renewable heating and cooling fuels. To capture long-term opportunities, however, Minnesota should consider enabling policies today that encourage innovative development of solar thermal technologies and infrastructure across the residential, commercial, industrial and district energy sectors. This could include development of community aggregation solar thermal purchase programs, investment in new technological applications such as solar cooling, and integration of solar ready construction into mainstream building practices.

Capturing broader solar thermal potential will be especially important to meet Minnesota's goal to reduce statewide greenhouse gas emissions by 30 percent in 2025 and 80 percent by 2050. As European policymakers have found, renewable heating and cooling technologies represent the missing link in climate policy, and robust market development of solar thermal and other renewable heating and cooling technologies is essential to achieve significant climate reductions.[xxv] With this in mind, it is recommended that Minnesota policymakers develop policies now that will support robust, long-term growth of the solar thermal and broader renewable thermal market.

This section includes recommendations designed to stimulate Minnesota's solar thermal market and contribute to the achievement of Minnesota's energy and climate goals. Recommendations have been developed to build on the analysis in previous sections and to respond directly to the market barriers described in Section 4. An overview of recommendations is provided in Table 5 below. Detailed descriptions are included in the following section.

Table 5. Overview of recommendations for Minnesota's SHC market development

Recommendation	Description
5.1 Create or Expand Incentive Eligibility for High-Value SHC Customer Segments	• Target high-value customers for SHC incentives, including farmers, delivered fuel consumers, and low-income housing authorities, and commercial users. • Increase opportunities for cost-effectively installing SHC technologies in Minnesota
5.2 Implement "Solar Ready" Building Standards	• In the short-term, require all new construction and renovated buildings to incorporate "solar ready" design guidelines • Decrease complexity and reduce installed costs for future SHC retrofits
5.3 Require Solar Thermal in Public Buildings and/or the Building Code	• Over long-term, require all new construction and major building renovations to incorporate solar thermal or other renewable heating and cooling technologies • Reduce building energy use and enable the state to meet its long-term GHG emission reduction goals (e.g. 80% reduction by 2050)
5.4 Explore Innovative Financing Options to Reduce SHC Upfront Costs	• Increase access to solar thermal financing to reduce burden of high upfront costs to customers • Conduct a detailed study to examine the benefits, drawbacks, and resources available to develop a comprehensive solar thermal financing program in the state
5.5 Reduce SHC Soft Costs by Streamlining Permitting	• Reduce permitting and zoning soft costs, which can account for 20 percent of installed costs for residential SHC systems • Conduct outreach and education to local jurisdictions to implement SHC best practices across the state
5.6 Reduce SHC Soft Costs by Implementing a Community Aggregation Purchase Program	• Reduce customer acquisition costs and create demand for SHC technologies by implementing a Solar Thermalize campaign similar to those in Milwaukee, Massachusetts, and Vermont, which can reduce installed costs by 20 percent or more. • Pilot community outreach, marketing and thermalize customer aggregation campaign in communities using delivered fuels
5.7 Create an Online, Community-based Outreach and Information Campaign	• Create government and industry driven outreach campaign to overcome poor public awareness of SHC benefits • Create online platform with SHC building tool and social media engagement tools to inform and engage prospective customers of SHC installation options

Recommendation	Description
5.8 Create SHC Advisory Group on Metering, Certifications, and Standards	• Create Minnesota forum that enables industry leaders and market experts to discuss SHC technical issues and create solutions to overcome them • In near term, focus on heat metering policy as well as installation and manufacturing certifications
5.9 Engage Delivered Fuel Providers to Explore SHC Opportunities	• Encourage engagement between SHC and delivered fuel industries in order to create new market opportunities • Engage in structured dialogue, conduct market opportunity analyses, and provide grants to support delivered fuel providers entering the SHC market
5.10 Assess Potential for Integrating Solar Thermal into District Energy Systems	• Depending upon characteristics of district energy systems, solar thermal can provide significant system benefits by increasing load diversity and reducing GHG emissions • Conduct study of district energy systems across the state to identify high-value systems to demonstrate benefits for solar thermal integration

5.1 Create or Expand Incentive Eligibility for High-Value SHC Customer Segments

The following high-value solar thermal applications and market sectors in Minnesota have been identified:

- Commercial customers heating with high cost fuel sources such as electricity, propane, or fuel oil;
- Agricultural applications where load characteristics coincide with solar resources; and
- Low-income housing where the effects of natural gas price volatility are particularly risky.

Minnesota could target incentive programs to support these particular market segments. Specifically, Minnesota could identify funds to allow customers heating with delivered fuels (e.g. propane and fuel oil) to benefit from the incentives. As discussed in Section 4.1, only ratepayers of investor owned utilities paying the Conservation Improvement Program (CIP) and Renewable Development Fund (RDF) surcharges are eligible for the *Made in Minnesota* rebate. This prevents many customers who could cost-effectively install SHC technologies from participating in the rebate program. Minnesota could explore the potential for a solar thermal rebate program that is fuel neutral, enabling all residents and businesses in the state to participate in the program. Additionally, the state may consider expanding the *Made in Minnesota* rebate budget beyond the modest amount of $250,000 reserved each year.

Alternately, Minnesota could explore the potential for establishing and funding new rebate programs for solar thermal, funded by a surcharge on delivered fuel. There also may be opportunities for the state to collaborate with the rural electric cooperatives in order to develop pilot rebate programs, which could encourage the development of cost-effective SHC installations in agricultural communities.

SHC can be a valuable addition in market sectors highly sensitive to fuel price volatility, such as entities providing affordable housing. The primary goal of these entities (public housing authorities, community development corporations, affordable housing finance entities) is providing housing at a cost that is affordable to the residents. Increases in costs, even small increases, frequently cannot be recovered from the residents, as the contribution of the household is usually fixed. Unforeseen small changes in cost can push housing costs over the threshold from affordable to unaffordable and threaten the long-term sustainability of projects. As a result, the state could market incentive programs – and explore potential for further increasing incentives – to low-income housing authorities.

In many cases, such policy would coincide with other state priorities. For example, the Greater Minnesota Housing Fund requires many of the projects that it finances (thousands of housing units in Minnesota) to meet its Green Communities standards.[xxvi] These standards address energy efficiency and other affordable housing concerns, which SHC technologies could support.

5.2 Implement "Solar Ready" Building Requirements

Installed costs for SHC technologies can be significantly reduced if buildings are designed to be "solar ready." Existing building stock has not been traditionally designed to enable solar energy retrofits. Roof structure, building orientation, choices about the location of mechanical systems and building design elements can increase the complexity of solar thermal installations, leading to unnecessary expense and higher installed costs. By making a few fairly simple changes in the way that buildings are designed and constructed, builders can significantly simplify solar thermal retrofits, making SHC installation more predictable and less costly.[xxvii] Several jurisdictions have already implemented solar ready policies for solar thermal technologies, including California, Colorado, New Jersey, and Guam. [xxviii]

Solar ready buildings are those designed and constructed to enable installation of solar energy systems at some time after the building is constructed.[xxix] The three basic components of solar thermal ready buildings include:

- A place on the roof of the building that has unrestricted solar access, is free of obstructions such as rooftop equipment or plumbing vents, and is structurally designed to accommodate the weight, wind, and drift loads that the system might impose;
- An internal chase or other means for connecting the solar system to the building's mechanical system;
- Space within the building that is readily convenient for the installation of key controls and components such as hot water storage tanks.

Solar ready guidelines have already been developed for the Twin Cities region.[xxx] Similarly, Energy Star's Renewable Energy Ready Home (RERH) specifications[xxxi] for solar hot water also provide good guidance. In the short-term, Minnesota should consider requiring these guidelines be applied to all new construction and major renovations in the state if the goal is to reduce complexity and costs for SHC systems in the future. As reported in a 2010 document prepared for the Minnesota Department of Commerce, compliance costs for new construction are expected to be minimal.[12]

5.3 Require Solar Thermal in Public Buildings and/or the Building Code

Building codes and statutes that require the public and/or private sector to use renewable heating technologies like solar thermal can be highly effective in increasing public awareness, reducing fossil fuel usage, and reducing GHG emissions. Several jurisdictions in the U.S. and internationally have already mandated the use of solar thermal technologies in order to achieve state goals. For example, in 2009 Hawaii passed legislation requiring all newly constructed single family homes to install SHW systems.[13] The mandate was passed as part of the Hawaii Clean Energy Initiative, which will accelerate development of energy efficiency and renewable energy technologies in support of Hawaii's goal to derive 40 percent of its energy needs from clean energy sources by 2030.

Similarly, in order to achieve aggressive GHG emission reduction and energy efficiency goals, European Union countries must ensure that all new construction and major building renovations are "nearly net-zero." In order to achieve nearly net-zero building requirements, new construction and building renovations must consider integration of renewable heating and cooling technologies – including solar thermal – among other alternative energy or advanced energy efficiency technologies.

This could be rolled out in phases, focusing on public sector buildings first and eventually expanding to incorporate the private sector. The groundwork for comparable requirements has already been established in Minnesota. All buildings receiving public funding for replacement of heating and cooling systems must consider use of geothermal and solar thermal applications during pre-design review.[xxxii] In addition, new construction and major renovation of public buildings must include designs which use active and passive solar energy systems, earth sheltered construction, and other alternative energy sources where feasible.

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[12] Compliance costs for builders are expected to be approximately $1,000 for two-story residential buildings and $5,000 to $7,500 for a three-story mixed use buildings for new construction. Costs are estimated to be significantly higher to retrofit existing buildings to meet solar ready requirements. See: Lunning Wende Associates, 2010.

[13] Home construction plans that lack a SHW system will not receive a building permit.

Over the long-term, Minnesota should consider tightening these public building requirements and also incorporate them into the state's building code, thus ensuring that all new construction and major renovations (in the public and private sector) incorporate solar thermal or other cost-effective renewable heating and cooling technologies. Proactive measures like this will likely be necessary in order for the state to achieve significant GHG emission reductions by 2050.

5.4 Explore Innovative Financing Options to Reduce SHC Upfront Costs

Increasing access to innovative and low cost financing will be important to address barriers like high upfront costs for solar thermal market. A number of innovative financing programs have been created in the U.S. to reduce the burden of solar thermal's high upfront costs. Three promising options were emphasized by Minnesota stakeholders, which could be deployed to finance solar thermal in the state. These include development of publicly supported loan programs, commercial PACE programs, and on-bill repayment programs.

Publicly supported loan programs for solar thermal must offer more favorable terms (e.g. lower interest rates) than those available in the private sector to be successful. The Minnesota Housing Finance Authority *Fix-up Program* offers financing for energy conservation (including solar thermal) and other basic home improvements to residential properties. Loan amounts range between $2,000 and $50,000 with interest rates currently between three and six percent. The program has not been widely utilized for financing solar thermal installations in part because the interest rate is in line with commercial loan rates and because of income limits for participation. It will be important to share lessons learned from this program, as well as other solar thermal loan programs administered across the U.S., in order to develop solar thermal financing for high-value solar thermal market sectors. Stakeholders suggested that the *Sustainable Agricultural Loan Program*, administered by the Minnesota Department of Agriculture, could be utilized to finance more solar thermal projects for farmers across the state.

Commercial property assessed clean energy (PACE) programs could be deployed to support solar thermal installations across Minnesota. The Saint Paul Port Authority will manage a statewide $10 million program to fund a commercial PACE program that lends money to businesses and nonprofits to implement energy efficiency and renewable energy projects. The money will be repaid through a special property tax assessment, which Minnesota cities will collect from the borrowing business or non-profit.[xxxiv] This program could also be deployed to support solar thermal projects in commercial buildings.

Additionally, the Department of Commerce could consider working with utilities to offer an on-bill repayment program to finance solar thermal projects. In such a case, customers could borrow funding from approved lenders to finance solar thermal projects and make loan payments via their monthly utility bill payment. By leveraging utilities' unique relationship with energy consumers, on-bill financing programs can provide customers convenient access to funding for energy efficiency and solar thermal investments. According to the American Council for an Energy Efficient Economy (ACEEE), credit losses for both consumer and commercial utility bills tend to be far lower than for other obligations, and if structured properly, on-bill repayment can substantially reduce the cost of and improve access to financing.[xxxv]

A variety of other financing options could also be developed to address the high upfront costs of solar thermal technologies and support robust market development. It is recommended that Minnesota Department of Commerce conduct a detailed study to examine the benefits, drawbacks, and resources available to develop a comprehensive solar thermal financing program in the state.

5.5 Reduce SHC Soft Costs by Streamlining Permitting

Stakeholders report that solar thermal technologies are sometimes subject to high permitting, zoning, and inspection costs, especially when it is necessary to engage structural engineers or acquire land use permits. While estimates vary, solar installation companies indicate that permitting can account for up to 20 percent of installed costs for residential systems. By integrating permitting best practices across local jurisdictions in the state, Minnesota can reduce the installed costs and improve economics of solar thermal systems, especially within the residential sector.

Minnesota has already developed statewide guidance for permitting solar systems, many of which are directly applicable to solar thermal systems. For example, the Minnesota Department of Commerce in cooperation with the Department of Labor and Industry developed standard tables that outline limitations for the placement of rooftop solar thermal systems on existing single and multi-family dwelling structures. These best practices encourage safe and structurally reliable systems while reducing costs associated with unnecessary structural review for many residential applications.[xxxvi] Going forward, Minnesota should encourage adoption of this guidance by local jurisdictions. This can be achieved by implementing educational workshops for local officials, providing incentives or technical assistance to communities, and/or legislatively standardizing procedures.

In addition to permitting concerns, Minnesota should also address barriers posed by zoning and homeowners associations. In some cases, stakeholders report homeowners' association contracts expressly prohibit solar structures. Accordingly, the state could create an "as-of-right" installation standard for solar thermal.

5.6 Reduce SHC Soft Costs by Implementing a Community Aggregation Purchase Program

To capture long-term opportunities, Minnesota will need to address customer acquisition costs, especially in the residential sector. Customer acquisition costs can make up a significant portion of installed costs for residential systems and could be decreased by implementing a community-based marketing and aggregation initiative. Solar Thermalize campaigns provide comprehensive consumer education on solar thermal technologies and aggregate demand in the residential sector, thus enabling significant reductions in installed costs.

Many states and organizations across the U.S. have already implemented "solarize" campaigns to drive development and customer demand in the solar PV industry. These initiatives aggregate customers, creating bulk demand for solar, which in turn drives down installation costs. Building on lessons learned from solarize campaigns for PV, Minnesota could implement a comparable campaign to drive demand, increase consumer awareness, and reduce installed costs in the residential solar thermal sector. A Thermalize initiative could be particularly compelling in communities that heat with delivered fuels or electricity. As discussed previously, these customers frequently have limited access to alternative heating fuels and pay a substantial premium to heat their properties compared to similar homes with natural gas heating systems.

Past thermalize pilot projects have reduced installed costs for solar thermal and other renewable heating technologies by five to 30 percent.[14] By encouraging competition between installers while

[14] Known solarize-style pilot projects that have supported solar thermal and other renewable thermal technologies include the Minnesota Renewable Energy Society's "Make Mine Solar Hot Water" program, the "Solar Addison

simultaneously driving demand for solar thermal installations, the thermalize campaign could substantially reduce soft costs and stimulate the solar thermal market in the residential sector.

5.7 Create an Online, Community-based Outreach and Information Campaign

To address the barrier of low public awareness, Minnesota could work with industry leaders and trade groups to establish a comprehensive and interactive social media and online marketing campaign to increase consumer awareness of SHC technologies. This could consist of an online platform that actively engages potential customers and provides them with user friendly descriptions of SHC case studies as well as technology performance data. Additionally, it could consist of a robust and interactive online tool that enables customers to enter site specific building data in order to evaluate the potential for various solar thermal technologies on their properties, estimating system size, installed costs, annual energy production, and project economics. For example, the New York City Solar Map[15] estimates rooftop solar potential using a computer model that calculates the incoming direct and diffuse solar radiation for the City of New York, providing users with a wide range of solar production, capacity, and cost information. While it currently focuses only on solar PV, it provides a good model for Minnesota policy-makers and industry leaders that are exploring potential to educate consumers of solar thermal options.

Minnesota could also explore development of an interactive communication platform that enables stakeholders to engage with technical experts via email, webinars, blogs or other social media tools. These efforts should additionally complement in-person workshops and community events, wherein community members engage industry leaders, market experts, and policymakers in order to identify the most compelling opportunities to install solar thermal technologies.

5.8 Create SHC Advisory Group on Metering, Certifications, and Standards

Industry leaders report a number of metering, certification, training and technical challenges in the solar thermal marketplace. However, currently no forum exists where industry leaders in Minnesota regularly meet to discuss such market barriers and develop common solutions to address them.

Minnesota could create a solar thermal advisory forum that brings together manufacturers, installers, policymakers, educational leaders, and other stakeholders in order to identify common priorities and develop solar thermal working groups to address them. In particular, installers report that standards need to be developed in the state to address metering requirements. As a starting point, policy-makers may wish to review IAPMO's pending solar metering guidance and determine the appropriateness for adopting them in Minnesota. In addition, code and certification requirements could be addressed by this body, streamlining installation and manufacturing certifications across the state or making recommendations to national and international certification bodies regarding solar thermal technical standards. In addition, forum stakeholders could reach out to local community colleges or vocational schools in order to develop training programs in order to attract new talent to the industry once there are mechanisms in place to create a market.

5.9 Engage Delivered Fuel Providers to Explore SHC Opportunities

Due to high costs of propane and heating oil, delivered fuel customers often represent high-value customers for the solar thermal industry. Minnesota could support collaboration and engagement between the SHC industry and delivered fuel providers.

County" program run by the Vermont Public Interest Research Group (VPIRG), and the "Model Neighborhood Project" offered by the Northern Forest Center.

[15] See http://www.nycsolarmap.com/.

Delivered fuel providers represent an important industry in Minnesota and could play a role in supporting solar thermal market growth. Delivered fuel providers also often install and maintain oil and propane heating equipment and have substantial knowledge of HVAC equipment, building systems, the supply chain for fuel distribution, as well as an established customer base. Similarly, SHC technologies could provide propane and oil heat dealers a new market opportunity, providing them a means to diversify product offerings and enter a growing market.

Minnesota policymakers and industry leaders could evaluate potential for future collaboration with propane and oil heat distribution companies as an avenue for increasing solar thermal infrastructure. In particular, they could investigate opportunities, challenges, and needs of distributed fuel companies, especially those that are interested in expanding product offerings to include solar thermal. Policymakers could consider the potential to facilitate focused dialogue with key stakeholders, conduct market opportunity analyses for the industry, and offer grants to support delivered fuel providers to develop infrastructure and receive technical and sales training in order to enter the SHC market.

5.10 Assess Potential for Integrating Solar Thermal into District Energy Systems

As described in Section 0, depending upon characteristics of district energy systems, solar thermal can provide significant system benefits by increasing load diversity and reducing GHG emissions. Currently, there are at least 24 known district energy systems are currently operational in Minnesota, all of which present some level of viability for solar thermal applications. Within the Twin Cities metro area, two district energy systems are operable, which use hot water distribution systems and that would likely make good candidates for more detailed analysis for solar thermal. The other known district energy systems use a primary steam distribution system, which as described in Section 0, may also offer some opportunities for solar thermal integration.

Minnesota could provide funding to support feasibility studies of district energy systems across the state. Because the requirements for integrating solar thermal into district energy systems are complicated and can vary significantly from site to site, the state could establish high level pre-feasibility criteria (e.g. fuels displaced, heating distribution requirements, load characteristics, etc.) for applicants, thus ensuring that feasibility studies are more likely to lead to project implementation.

6 Conclusion

The study represents the first step to assess the value of solar thermal in relation to the state's energy and climate goals. By developing policies and programs that enable solar thermal market development, Minnesota can provide businesses and residents with a cost-effective means to meet key state goals, including the reduction of GHG emissions and per capita fossil fuel use in the state. Solar thermal can also improve long-term energy security by contributing to the development of a sustainable energy system in the state.

To achieve these goals, Minnesota will have to address a number of barriers that currently constrain the state's solar heating and cooling market. A strong solar thermal market requires implementation of policies and programs that improve project economics, build market demand, and increase consumer confidence and awareness. The recommendations in this report are designed to break down market barriers and scale up the solar thermal market over the short- and long-term. It additionally focuses on high-value market sectors and applications, which could scale up to provide climate and clean energy benefits in the short-term. The analysis and recommendations in this report provide a starting point for exploring the role and potential of solar thermal among other renewable heating and cooling technologies to contribute to Minnesota's energy and climate goals.

Appendix A: Modeling Assumptions

Scenario	**Residential SHW (DHW)**	**Commercial SHW (DHW)**	**Residential Solar Air Heating**	**Commercial Transpired Air Heating**
Technology	SHW	SHW	Solar air	Transpired air heat
Sector	Residential, DHW	Commercial, DHW	Residential, space heating	Commercial, space heating
Gallons/day	63	1,432		
Annual DHW heating use (MWh)	4	94	6	520
Solar System Parameters				
Solar fraction	72%	47%	25%	15.7%
# of collectors	2 panels	24 panels	2	
Collector square footage (ft2)	64	767	65	1,200
Storage (gallons)	81	969		
Solar Production				
Heating delivered (MWh)	3.0	44.2	2.1	923,995.7
Heating delivered (MMBtu)	10.2	150.9	7.2	77.0
Electricity used (MWh)	0.1	0.7	0.1	6.5
Electricity used (MMBtus)	0.2	2.5	0.3	65.4
Installed Costs				
$ per square foot	$135 to $230	$106 to $158	$70 to $125	$30 to $50
Total installed costs ($)	$8,627 to $14,697	$81,000 to $121,532	$4,550 to $8,125	$36,000 to $60,000

Endnotes

[i] U.S. Energy Information Administration (EIA). (2009). Household Site End-Use Consumption in Midwestern Region, Totals and Averages, 2009. Residential Energy Consumption Survey. Retrieved from www.eia.gov.

[ii] Minn. Stat. § 216H.02 (2008)

[iii] Minn. Stat. § 216C.05 (2007)

[iv] Minn. Stat. § 216C.05 (2008)

[v] U.S. Energy Information Administration (EIA). (2009). Household Site End-Use Consumption in Midwestern Region, Totals and Averages, 2009. Residential Energy Consumption Survey. Retrieved from www.eia.gov.

[vi] Minn. Stat. § 216C.416 (2013)

[vii] Mauthner, F. and Weiss, W. (2013). Solar Heat Worldwide. Solar Heating and Cooling Programme International Energy Agency. Retrieved from http://www.iea-shc.org/data/sites/1/publications/Solar-Heat-Worldwide-2013.pdf.

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