Biomass for Cooling System Technologies: A Feasibility Guide

May 2016

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The Community Assistantship Program (CAP) is a cross-college, cross-campus University of Minnesota initiative coordinated by the Center for Urban and Regional Affairs (CURA). Funds for CAP were generously provided by the McKnight Foundation and the Blandin Foundation.

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1. Acknowledgements

The Biomass Cooling Technologies: A Feasibility Guide represents the culmination of a successful collaboration with several partners and numerous contributors. Project funding and support is due in part to student research assistance provided by the Community Assistantship Program, a program of the University of Minnesota's Center for Urban and Regional Affairs (CURA) program as well as the University of Minnesota's Northwest Regional Sustainable Development Partnership (NWRSDP) and the Agricultural Utilization Research Institute (AURI). The participation of these organizations and Roopesh Pushpala is gratefully acknowledged.

The authors also thank the contributors to this project for their insight, guidance and patience during the writing of this report.

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Potential applications of biomass cooling systems may expand beyond industry usage. Other beneficiaries of the efficient, ecofriendly biomass cooling technologies may include shopping centers, quad homes, townhomes and groups of single-family houses.

Market growth for biomass cooling technologies is promising. While the target market for the product is small-to-medium scale industrial and commercial facilities, multi-unit housing facilities and malls may benefit from the technology. Institutions or industries that currently use absorption chillers can also convert their fuel source and use the biomass cooling system. Subsequently, the potential exists for market expansion that includes residential use, further strengthening the value chain.

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2. Executive Summary

Biomass cooling technologies currently exist but only on a large commercial scale. In response to climate change detailed in the Minnesota Public Radio's Climate Change Series (2015) and associated risks referenced in the *Risky Business Report: The Economic Risks of Climate Change in the United States (2015)*, acting now to mitigate the projected increases in energy costs is critical and necessary in planning for the future. For example, Gordon (2015) projects the Midwest in particular will see large energy cost increases due to expenditures associated with switching from heating demand to cooling demand (p. 5). Gordon also notes that on our current emissions path, residents of Minneapolis-St. Paul will see warmer winters and hotter summers, with 3 to 7 days over 95°F per year likely in the next 5 to 25 years (p. 37). As a result of these seasonal changes, Minneapolis-St. Paul residents will spend less on energy to heat their homes in the winter, but more to cool them in the summer—a switch from heating fuels like natural gas to electricity—resulting in overall energy cost increases of up to 18% by end of century (p. 38). The timing is ripe for exploring alternative renewable energy opportunities to utilize biomass for cooling.

The need to cool buildings is vital to many businesses; however cooling systems are energy intensive and costly. Biomass is currently separate from other vital sources of energy. However, a biomass-derived cooling innovation creates a natural, renewable energy source for cooling systems. This may be welcome news for small-to-medium sized commercial, industrial and residential units, as well as manufacturers and retailers of biomass boiler systems.

The intent of this research was to identify innovations that utilize biomass as the essential wellspring of energy for cooling systems. Research findings include identifying cooling systems processes and components transferable to a biomass system. One key component that runs the absorption chiller is the refrigerant, Lithium Bromide (LiBr), which generates the cooling effect. Currently, BSH Companies, Yazaki Energy Systems and Trane Systems (Thermax) have adapted their organization's current cooling systems to biomass cooling technologies and provide explanations of the system's operational principals in this report.

Existing data was obtained from mechanical contractors to assess the potential feasibility of utilizing a biomass cooling system. The analysis includes comparisons of biomass cooling systems to conventional, propane and natural gas controlled cooling systems. The research also examines costs associated with wood pellets and wood chips and their economic impact when utilized as a biomass fuel. The opportunity also exists to cost effectively utilize agricultural biomass as a solid fuel source based on availability.

The current economic data provided in this report substantiates biomass cooling is a viable option and worth consideration, particularly if constructing a new building or retrofitting a current system where piping is in place. Research findings support that biomass cooling is a proven technology with case studies that demonstrate the economical and operational feasibility of biomass cooling systems.

In considering operational concerns, case study evidence supports similarities of operations and maintenance for absorptive chiller and conventional technologies. While it may require a person on staff to monitor the systems, the long-term benefits of job creation, energy savings and increased employment in the biomass sector over time outweigh the operational demands. Additionally, biomass-derived cooling innovations will continue to bring added benefits.

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4. Introduction

New technologies are developing every day; nevertheless, the need for efficient and green energy is ubiquitous in our daily life. Biomass energy resources to operate an air unit are implementable through cooling technologies. These developments can result in an electricity free system to foster green energy worldwide by reducing the carbon footprint.

The concept of biomass energy stemmed from the growing concern and evidence carbon's adverse effects on the environment when generated by the combustion of coal or other fossil fuels. The use of biomass systems is beneficial because it uses agricultural, forest, urban and industrial residues and waste to produce heat and electricity with less impact on the environment than fossil fuels. This type of energy production has a limited long-term effect on the environment because the carbon in biomass is part of the natural carbon cycle; while the carbon in fossil fuels permanently adds carbon to the environment when burned for fuel.

Historically, before the use of fossil fuels in significant quantities, biomass in the form of wood fuel provided most of humanity's heating. Over time, other forms of biomass have also been employed for heating. In this regard and considering climate change projections, the Agricultural Utilization Research Institute (AURI) decided to explore biomass cooling systems available for use in small-to-medium scale commercial or industrial businesses and residential units. While some larger industries already use this technology, there is limited information available on the use by other aforementioned sectors.

In the process of attaining in-depth information about this opportunity, valuable information was gained regarding the working principle of the whole cooling systems, including different types of components, capacities of the system, and a better understanding of implementation opportunities. The intent of this report is to detail the existing biomass cooling technologies, associated installation and manufacturing costs, and related energy requirements in order to provide an economic comparison to current conventional cooling systems used in the United States. While the economics may not work for all biomass fuel types at a given time, the information provided in this report facilitates future planning for when the economics prove feasible. Estimated savings could have a significant impact on overall operational costs of commercial or residential units. In addition, the objective of this study is to identify commercial units available for biomass cooling along with identifying cooling capacities that are economically viable on a small scale.

5. What is Biomass?

Biomass is a term covering different types of organic material that can be processed and burned to produce energy. Examples of biomass include forest and agricultural residues or wood pellets, which are one of the richest sources of sustainable, environment-friendly fuels. Biomass is readily available in most parts of the country, but nearby sources often determines the exact type, such as wood products in forested regions and agricultural residues in farming regions.

The cost and scarcity of fossil fuels as well as a global focus on using more renewable energy has brought biomass energy to the fore. Although burning biomass releases carbon dioxide into the atmosphere, it is offset by the carbon dioxide absorbed in the original growth of the biomass. See Figure 1.

Thermal applications of biomass use two main forms of biomass materials: woody biomass and gas or liquid biofuels. For thousands of years, people have created heat by burning wood and other organic materials in their fireplaces, wood stoves, and campsites. This study focuses primarily on woody biomass and its feasibility of use in biomass cooling technologies. See Table 1 for examples of different fuel types and associated costs per million British thermal unit (Btu) and kilowatt-hour (kWh).

Table 1: Different Types of Fuel

Table 1
Different Types of Biomass Fuel

Fuel Type	Retail Cost (Minnesota)	kWh/lb	Btu/lb	Efficiency	Cost/Mbtu	Cost/kWh
Wood Chips*	$60/ton	1.76	4,300	0.75	$9.30	$0.03
Wood Pellets*	$160/ton	2.42	8,250	0.75	$12.93	$0.04
Natural Gas	$13.21/Mcf**	5.98	19,000	0.80	$15.73	$0.05
Propane	$2.60/gal	6.43	21,500	0.85	$33.49	$0.10
Corn Cobs	$60/ton	2.19	7,461	0.70	$5.74	$0.02
Heating Oil	$3/gal	4.93	18,104	0.70	$30.90	$0.11
Electricity	$.1135/kWh	-	3,412/kWh	0.97	$34.28	$0.14

Note. *Bulk; Mcf=Thousand cubic feet
**Peak summer average price.

The following figure illustrates the general use of agricultural biomass.

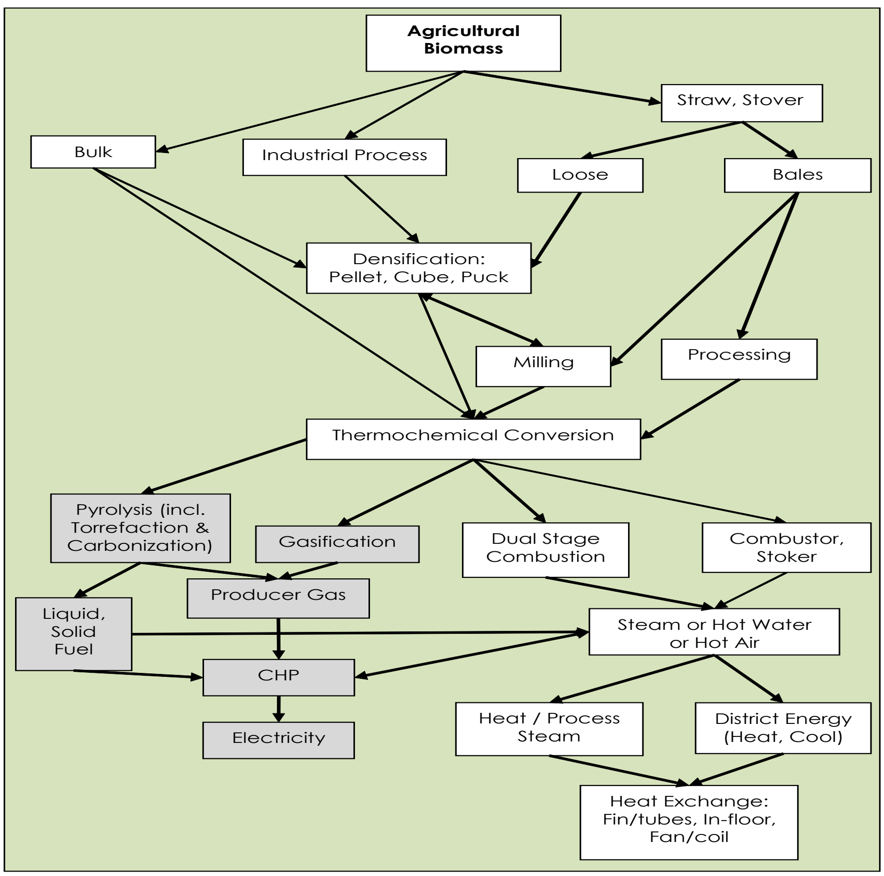

Figure 1. Agricultural Biomass Pathways.
This diagram illustrates the general usage of agricultural biomass. Reprinted from Friesen, D. L. (2012). *Minnesota Biomass Heating Feasibility Guide.* Agricultural Utilization Research Institute. Retrieved from http://www.auri.org/assets/2012/05/biomass-heating-feasibility-guide.pdf .
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For purposes of this project, wood pellets are the primary source of biomass fed into a boiler and burned to generate energy. The energy generated from the boiler flows to the cooling system, to cool the premises.

6. What are Cooling Systems?

With respect to this project, the cooling systems include air conditioning units for offices, industries and households, which run on energy generated by burning biomass. The absorption chiller generates the air cooling effect from the heat generated. The heat from the biomass is used to operate the absorption chiller to cool the air. The cooled air then circulates into different parts of the facility through insulated pipelines and is maintained at a consistent temperature throughout the premises. These cooling systems are identified as a potential replacement for conventional air conditioning systems which consume a significant amount of electricity or natural gas thus affecting environmental conditions.

7. Biomass Cooling System Equipment

A biomass cooling system contains multiple units functioning as a system.

7.1 Biomass Boiler

A biomass boiler is a wood-fueled heating system which provides both heat and hot water. Biomass boilers burn wood to provide a heat source for the buildings in which they reside. A biomass boiler can be the heat source for an absorption chiller as well.

Pellet and chip-fed boilers often use automatic fuel feeders, which refill from hoppers. Biomass boilers are particularly suited to community or district heating where one boiler heats more than one home. A biomass boiler provides an efficient heat source and, when burned, the wood fuel is a low carbon option as the carbon dioxide emitted is typically around the same as the amount that was absorbed while the plants were growing (Figures 2, 3 and 4).

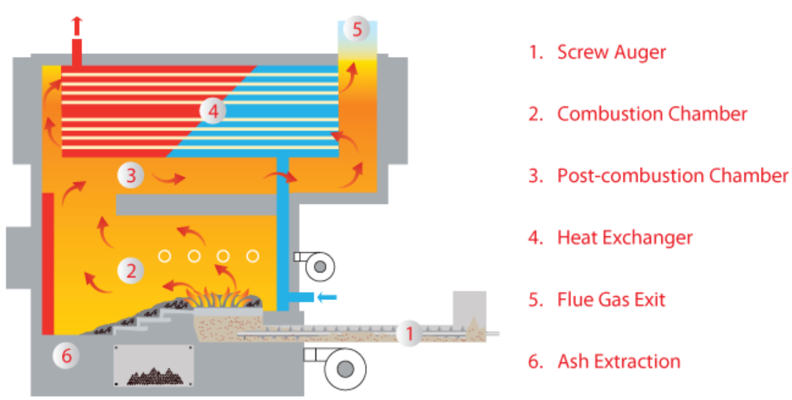

Figure 2. Stoker Boiler Diagram
This diagram illustrates a biomass boiler system. Reprinted from Friesen, D. L. (2012). *Minnesota Biomass Heating Feasibility Guide.* Agricultural Utilization Research Institute. Retrieved from http://www.auri.org/assets/2012/05/biomass-heating-feasibility-guide.pdf.
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Another type of combustor, shown in the following diagram, circulates air through a heat exchanger that receives heat from burned pelleted biomass fuel.

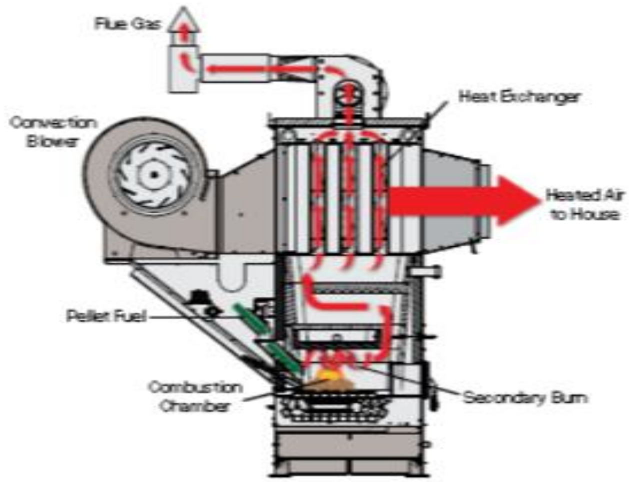

Figure 3. Biomass Furnace Diagram
This diagram illustrates a combustor. Reprinted from Friesen, D. L. (2012). *Minnesota Biomass Heating Feasibility Guide.* Agricultural Utilization Research Institute. Retrieved from http://www.auri.org/assets/2012/05/biomass-heating-feasibility-guide.pdf.
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Still another burner method is to feed the biomass up from the bottom through an auger feed system.

Figure 4. Central Lower Biomass Feed System
This diagram illustrates a burner method. Reprinted from Friesen, D. L. (2012). *Minnesota Biomass Heating Feasibility Guide.* Agricultural Utilization Research Institute. Retrieved from http://www.auri.org/assets/2012/05/biomass-heating-feasibility-guide.pdf.
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7.2 Absorption Unit

Absorption chillers use heat to drive the cooling cycle. The units produce chilled water while consuming a small amount of electricity to run pumps. Absorption chillers generally use heat (low-grade energy) to drive a lithium bromide (LiBr) refrigeration cycle, rather than using electricity (high-grade energy). The energy source may be steam, hot water, or waste heat like exhaust gases from an engine.

The heat generated from the biomass boiler can be an effective heat source for an absorption chiller. Absorption chillers use a refrigerant with a very low boiling point (less than 0 degrees Fahrenheit (−18 degrees Celsius). When the refrigerant evaporates, some heat dissipates, providing the cooling effect. The key factor to the process is utilizing a liquid refrigerant, which results in a repetitive cycle.

7.3 Cooling Tower

A cooling tower is a heat rejection device, which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. The type of heat rejection in a cooling tower is termed "evaporative" in that it allows a small portion of the water to evaporate into a moving air stream to provide significant cooling to the rest of the water stream. Evaporative heat rejection devices, such as cooling towers, commonly provide significantly lower water temperatures.

Pumps move water heated by an industrial process or in an air-conditioning condenser to the cooling tower through pipes. The water sprays through nozzles onto banks of material called "fill," which slows the flow of water through the cooling tower, and exposes as much water surface area as possible for maximum air-water contact. As water flows through the cooling tower, its exposure to air pulled through the tower by an electric motor-driven fan causes evaporation and creates a cooling action. A pump then directs the cooled water back to the condenser or process equipment where it absorbs heat. Water is then moved back to the cooling tower to be cooled once again (see Delta Cooling Towers, 2016, for varying models).

7.4 Delta Cooling Tower

Shell

The shell is a seamless engineered polyethylene cylindrical (HDPE) molded shell with HDPE blower duct plastic welded onto the shell wall. The shell has an inspection port with a removable HDPE cover located above the integral cold sump water level for accessibility to the automatic make-up valve and adjustable float.

Sump

The sump is a liquid containment which is integrated with the cooling tower shell, creating a one-piece seamless structure.

Water Distribution System

A water distribution system is a totally enclosed non-corrosive polyvinyl chloride (PVC) internal riser spray tree/nozzle distribution system. The PVC threaded nozzles are interchangeable and can be substituted, in most cases, with a larger diameter orifice for increased flow conditions without increasing inlet pressure. All nozzles will accept flow rate increases at higher inlet pressures.

Wet Decking and Drift Eliminator

A non-corrosive polyvinyl chloride (PVC) wet decking and drift eliminator is spirally wound and bonded for maximum film cooling efficiency. Non-corrosive, PVC hand straps secured to the wet decking and drift eliminator sections provide easy removal.

Blower

A blower is a forward-curved centrifugal blower, statically and dynamically balanced, constructed of heavy-duty carbon steel. It is corrosion protected with a dipped and baked alkyd finish.

Motor

The motor is a totally enclosed fan-cooled (TEFC) variable frequency drive (VFD) rated motor with a 1.15 service factor. It is designed for 208 or 230/460 volt three-phase, 60-cycle operation and suitable for outdoor service. The motor comes with a five-year motor manufacturer's warranty.

Fitting Connections

The fitting connections are non-corrosive polyvinyl chloride (PVC) bulkhead fittings with neoprene gaskets for inlet, outlet, overflow, drain and make-up Floating Roof Tank (FRT) connections. All outlet fittings for pump suction applications have a vortex breaker.

7.5 Control System

The control system integrates the biomass boiler, absorption chiller and the cooling tower to control the functioning of all three as a single unit. The control system has several sensors and electronic circuits to monitor functions according to capacities to ensure optimal execution. The cooling capacity is proportional to the temperature difference of the water at the inlet and outlet. Indicators of load changes are based on the rise or fall of the water temperature at the inlet. The outlet-chilled water temperature varies with the inlet-chilled water temperature. A Resistance Temperature Detector (RTD) sensor notes this change in temperature. This temperature signal feeds into the Programmable Logic Controller (PLC). An inbuilt software Proportional–Integral–Derivative (PID) control loop processes this signal with respect to the chilled water set point. A control output signal of 4 to 20 milliampere (mA) is sent to the current to pressure (I/P) converter. The I/P controller converts the 4 to 20 mA electrical signal to a 2.8 to 14.5 pounds per square inch (psi) pneumatic signal, which controls the position of the hot water control valve. As the load increases, the hot water control valve also opens, and vice-versa, thus regulating the quantity of heated and cooled water entering the machine (see ABCO Automation, 2016 for details on control systems).

The control panel includes the components of:

- Programmable Logic Controller (PLC)
- Panel view operator interface
- Power circuit for pumps

7.6 Pipelining

The cooling effect obtained from the absorption chillers is circulated by pipelines into the facilities and evenly distributed based on space capacities. These pipelines are similar to the ones currently in use in conventional systems. As a result, currently installed pipelines used to circulate the cooling effect or heating effect are also usable for the circulation from the cooling system with slight modifications (See Energyland, 2015, for details on district cooling systems).

8. Working Principle

A pump sends diluted lithium bromide (LiBr) solution from the absorber to the generator where the heating medium circulating through the generator heat exchanger boils it. Refrigerant (water) vapor, liberated from the diluted solution, flows to the condenser heat exchanger where it is condensed to a liquid state by the rejection of heat to the cooling water circuit. Due to the partial separation of the LiBr solution and water during boiling in the generator, the portion of LiBr in the remaining solution increases. This concentrated solution flows from the generator to the absorber where it will flow over the surface of the absorber's exchanger coil.

Since cooling water from the cooling circuit is circulating through the absorber coil, there is low vapor pressure in the common room of the evaporator and absorber due to the high concentration of the LiBr solution. This is the environment the refrigerant liquid coming from the condenser encounters as it flows over the coil into the evaporator. Concentrated solution absorbs refrigerant vapor from the evaporator as the liquid refrigerant changes its state to vapor, taking energy from the vaporization of the chilled water circulating through the evaporator exchanger. This heat extraction results in the production of chilled water.

The concentrated solution returns to a diluted state as the refrigerant vapor is absorbed. In its relatively cool condition, the concentrated solution is collected in the absorber sump and thereafter forced by the solution pump to return to the generator for boiling again, thus perpetually repeating the cooling cycle (see Yazaki Energy Systems, 2015, for a diagram of the working principle).

With a Trane system, absorption systems use heat energy to produce a refrigerating effect. In these systems, the refrigerant (i.e. water) absorbs heat at a low temperature and low pressure during evaporation and releases heat at a high temperature and high pressure during condensation.

Figure 5 shows the process of maintaining the system at a high vacuum, which would allow the water to flash cool itself upon interaction with the water refrigerant. The water refrigerant is then sent into the system to balance the heat generated through warm water, generating vapor.

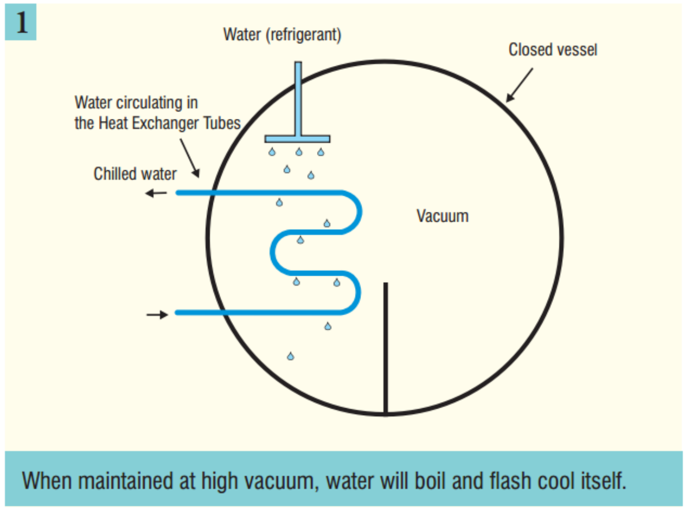

Figure 5. Trane (Thermax) Cooling System – Refrigerating Effect.
This diagram illustrates the vaporizing effect of the water refrigerant. Reprinted from http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/absorption-liquid/hotwaterdrivenabsorptionchillers.pdf.
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Figure 6 illustrates the process as the LiBr solution absorbs the vaporized refrigerant obtained in the previous stage. This absorption is done by passing the LiBr solution through the chilled water pipelines, which initiates the ability to absorb the refrigerant vapors. The evaporation of the refrigerant takes place at a low pressure. The diluted solution, which contains the absorbed refrigerant vapor and LiBr solution, experiences higher pressure when heated.

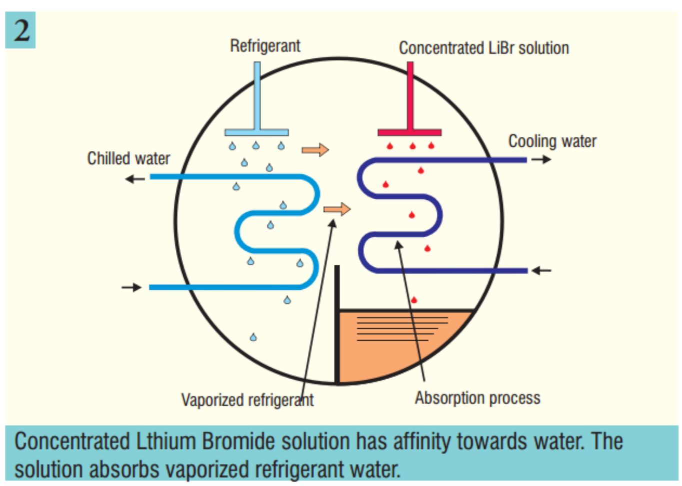

Figure 6. Trane (Thermax) Cooling System – Concentrated LiBr
This diagram illustrates LiBr absorbing the vaporized refrigerant. Reprinted from Trane. (2016). Trane Commercial Heating and Air Conditioning. Trane University. Retrieved from http://www.trane.com/commercial/north-america/us/en.html.
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This leads to the vaporization of the refrigerant, which loses its capacity. In Figure 7, the refrigerant is concentrated using additional heat produced by the external heat source and thus, the restoration of the solution to its original concentration is attained for future usage. The cycle keeps repeating itself to give the desired chilling effect through the vapors or LiBr and water refrigerant.

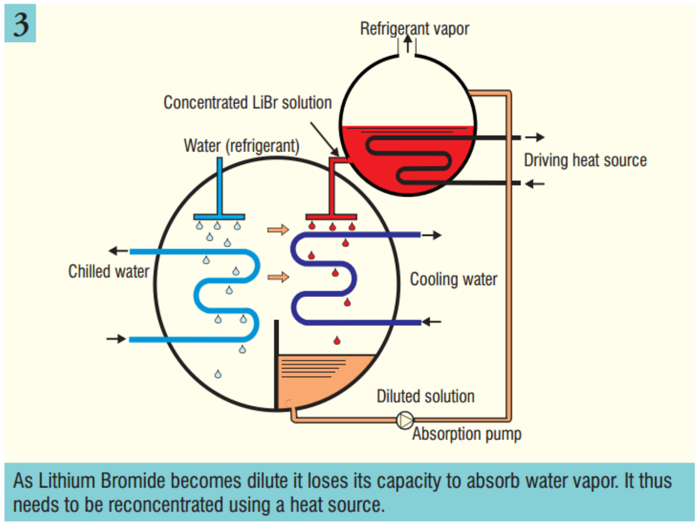

Figure 7. Trane (Thermax) Cooling System – Reconcentrated LiBr
This diagram illustrates the reconcentration of the LiBr solution. Reprinted from Trane. (2016). Trane Commercial Heating and Air Conditioning. Trane University. Retrieved from http://www.trane.com/commercial/north-america/us/en.html.
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Figure 8 illustrates the process of cooling the absorbed refrigerant in vapor form in an external chamber, which is recycled to be the liquid refrigerant used in Step 1. In ProChill (twin design) absorption machines, the hot water first passes through a high-pressure generator and then through a low-pressure generator to enhance the efficiency of the cycle.

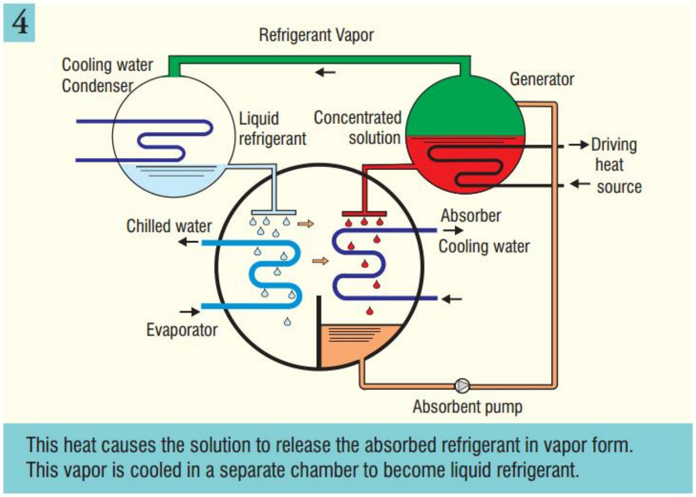

Figure 8. Trane (Thermax) Cooling System – Liquid Refrigerant
This diagram illustrates condensation of the vapor to be reused as the liquid refrigerant. Trane University. Retrieved from http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/absorption-liquid/hotwaterdrivenabsorptionchillers.pdf.
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The refrigerant then goes through a series of processes to complete the cooling cycle (see Figure 9). This is a repeatable process which generates the cooling effect from the absorption chiller. Processes include evaporation, absorption, pressurization, vaporization, condensation, throttling and expansion. During this cycle, the refrigerant absorbs heat from a low temperature heat source and releases it to a high temperature heat storage unit. A cooling tower is typically used to expose the low heat source (water) to the temperature of the atmosphere to cool it.

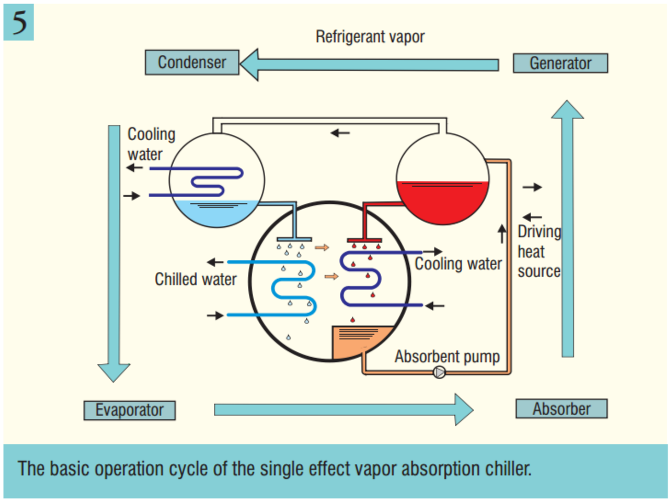

Figure 9. Trane (Thermax) Cooling System – Single Effect Vapor Absorption Chiller
This diagram illustrates the basic operation cycle of the single effect vapor absorption chiller. Reprinted from http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/absorption-liquid/hotwaterdrivenabsorptionchillers.pdf.
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9. Hybrid Systems

In the case of a hybrid model, the primary source of fuel is the thermal energy generated by the biomass and the secondary source of fuel could be a gas like propane. The primary source results in generating energy for the base load, while the secondary fuel satisfies the peak load when consumption and external climatic conditions warrant additional energy needs. Figure 10 illustrates a hypothetical situation of daily energy demand. The estimated load determines the change between the primary and secondary source of fuel. An electric closed loop circuit senses the load quantity and augments energy needs accordingly.

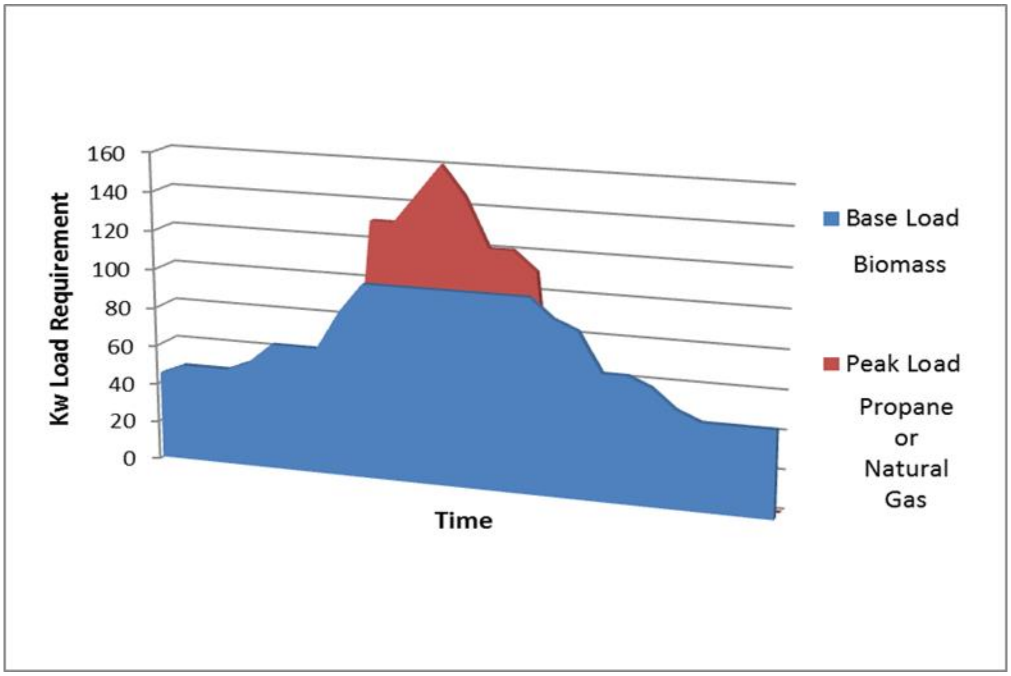

Figure 10. Base and Peak Load
This diagram shows the comparison of the kilowatt load requirements of the base and peak loads of biomass and propane or natural gas.

10. Biomass Cooling System Companies

10.1 BSH Innovative Heating and Cooling Solutions

BSH biomass boilers offer carbon savings when used in commercial and industrial organizations. Since biomass is a secure, reliable fuel source, price volatility is minimized, which can be an advantage against oil and gas. The reduced input cost risk can have a huge impact on overall operational costs. BSH has invested significantly in developing biomass boiler systems that can reduce fuel costs through practical and effective provision of a cooling system from a low carbon fuel source. This chilling system, in combination with a biomass boiler, is a suitable renewable energy alternative for residential units and office buildings as well as a wide range of commercial properties.

10.2 Yazaki Energy Systems

Combining the BSH biofuel generators, Yazaki uses the thermal energy to generate and retain cooling via absorption chillers. The absorption chilling process uses a chemical solution called Lithium Bromide (LiBr).

The absorption chiller developed by Yazaki, is a major component of the BSH cooling system. It effectively utilizes an external control system by SIME to integrate Yazaki's absorption chiller and the BSH boiler unit. BSH also develops its own circulating system.

10.3 Trane Systems (Thermax)

Trane, a brand of Ingersoll Rand, is a world leader in air conditioning systems, services and solutions. Trane provides innovative solutions that optimize indoor environments through a broad portfolio of energy-efficient heating, ventilating and air conditioning systems; building, contracting and energy services; parts support; and advanced controls for homes and commercial buildings. Trane systems and services have a reputation for reliability, high quality and advanced innovation. Trane (Thermax) manufactures absorption chillers which operate via an external energy source. When integrated with a biomass boiler, this system supplies heat to the absorption chiller to enable the reaction of LiBr solution.

11. Comparison of Biomass Cooling and Conventional Systems

11.1 Analysis of Fuel Source Cost

Biomass can offer a competitive energy cost alternative. It is a sustainable and often cheaper alternative to oil, with some customers reporting a 50 percent reduction in cost compared to heating oil. Refer to Table 1 to view the potential current cost benefits of utilizing a biomass fuel compared to some fossil fuels.

11.2 Analysis of Wood Pellets as the Primary Source of Energy (per month)

- Average electricity consumption: 911 kWh
- Average Btu or British thermal unit (dry matter basis): 3,108,332
  (NOTE: Dry matter basis is a calculation excluding moisture)
- Wood pellet efficiency: 0.75
- Pounds of wood pellets used (dry matter basis): 502.36
- Cost per month: $40.18

11.3 Analysis of Electricity of Conventional Air Conditioning Unit (per month)

- Average electricity consumption: 911 kWh
- Residential electricity rates in Minnesota average: 11.35 ¢/kWh

- Coefficient of Performance (COP) for electrical cooling (range 1:2 to 1:4)
- Average electrical cost per month: $51.70/month (COP=1:2) to $25.85/month (COP= 1:4)

11.4 Analysis of Hybrid (Biomass + Natural Gas)

The table below shows the maintenance of a hybrid system on an average hour in a day. The average kilowatt and kilowatt hour values through the usage of biomass and natural gas have been estimated by averaging the distribution over the day with reference to the Figure 10 hypothetical scenario. The mean distribution of the load is attained to be 143.9 Kw with a standard deviation of 40.08.

Table 2: Hybrid System Maintenance

Table 2

Hybrid System Maintenance

		Load Distribution		Usage Actual*	
	Average Load (kW)	Biomass(kW)	Natural Gas (kW)	Biomass (kWh)	Natural Gas (kWh)
Hour	143.9	100.0	44.0	26.4	11.6
Day	3,445.0	2,400.0	1,055.0	632.8	278.2

Note. *Usage actual is based on typical residential household of 911 kWh/month

Table 3: Economic Details of Usage

Table 3

Economic Details of Usage Per Month

	KWh	Btu	Retail Cost	Avg Btu/lb	Efficiency	lbs	Cost ($)
Base Load (wood pellet)	633	2,159,182	$160.00/ton	8,250	0.75	349	27.92
Peak Load (natural gas)	278	949,143	$13.21/Mcf	19,000	0.80	62	14.93
Total Cost							$42.85

11.5 Analysis of Natural Gas System

Table 4: Economic Details of Natural Gas System

Table 4

Economic Details of Natural Gas System

Btu Equivalent for 911 kWh	Natural gas ($/Mcf)	Efficiency	Natural Gas (cubic feet used)	Total Cost
3,108,332	13.21	0.8	3,701.37	$48.90

- Average electricity consumption: 911 kwh
- Average Btu: 3,108,332
- Natural Gas efficiency: 0.8
- Cubic feet of Natural Gas used: 3,701.37
- One pound of Natural Gas = 18.10 cubic feet
- Cost per month: $48.90

11.6 Analysis of Propane System

Table 5: Economic Details of Propane System

Table 5

Economic Details of Propane System

Btu Equivalent for 911 kWh Residence	Propane ($/gallon)	Efficiency	Propane (gallons used)	Total Cost
3,108,332	2.60	0.85	40.11	$104.30

- Average electricity consumption: 911 kwh
- Average Btu: 3,108,332
- Propane efficiency: 0.85
- Gallons of Propane used: 40.11
- One gallon of Propane = 4.24 pounds
- Cost per month: $104.30

12. Absorption Chiller Dimensions

The dimensions of the smallest absorption chiller (biomass boiler, cooling tower, control system) follow: length - 20 feet, width - 6 feet; and height - 8 feet. See Figure 11.

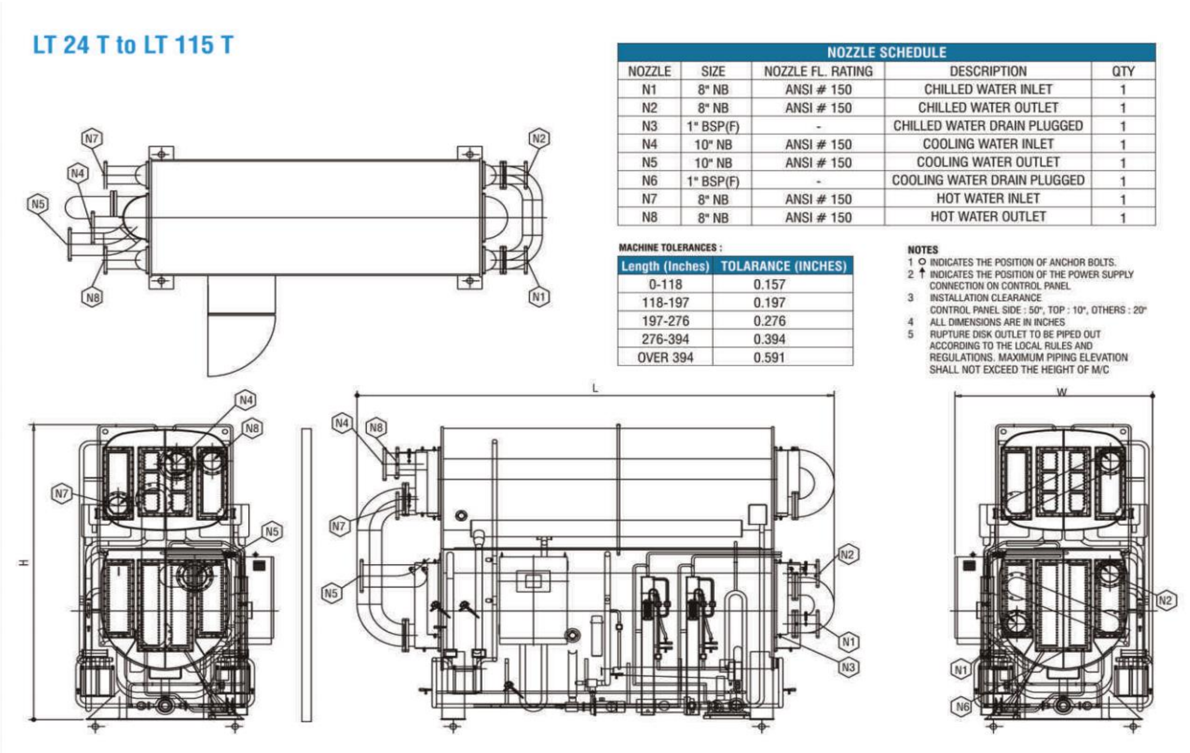

Figure 11. Dimensions of the Absorption Chiller
This diagram illustrates the dimensions of the smallest absorption chiller. Reprinted from Trane. (2016). Trane Commercial Heating and Air Conditioning. Trane University. Retrieved from *http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/absorption-liquid/steam_drivenabsorptionchillers.pdf.*
Reprinted with permission from Thermax USA.

13. Integration of Biomass and Cooling Systems

Absorption chillers utilize a heat source from the biomass boiler in a thermodynamic cycle for the cooling process. Possible heat sources are district heating plants based on fossil or renewable fuel, waste heat or solar heat. The thermodynamic cycle of absorption chillers is due to a refrigerant and a solvent. The refrigerant must be completely soluble in the solvent. Absorption chillers based on lithium bromide and water achieve cold water temperatures of 102.2 degrees Fahrenheit (39 Celsius) while the minimum temperature of the heat source needs to be 167 degrees Fahrenheit (75 degrees Celsius). To achieve lower temperatures with absorption chillers, the application of ammonia as the refrigerant and water as the solvent, along with higher temperatures of the heat source are required.

The achievable temperature difference between the feed and return flow of a district cooling system is considerably lower compared to district heating systems. District heating and/or cooling is a centralized system used to supply multiple buildings. The air conditioning of buildings, which is the most relevant cooling application, requires feed temperatures of approximately 42.8 to 53.6 degrees Fahrenheit (6 to 12 degrees Celsius). Hence, the flow rate in district cooling systems increases and larger pipe diameters are required compared to district heating networks. Furthermore, the investment costs and the operational costs increase due to pipe size and increased pumping. The trend of the daily cooling demand of a district cooling system typically shows rather high short-term peak loads. The integration of storage tanks is a feasible option to meet the peak cooling needs.

14. Economics of the Technology

Table 6: Capital Costs

Table 6

Capital Costs of 30 Ton Cooling System

Item	Cost
Biomass boiler	$ 68,378*
Absorption chiller	65,000**
Control system	14,000
Cooling tower	5,040***
TOTAL	$152,418

Note. *(G. Gagner, personal communication, June 8, 2016)
**(M. Spresser, personal communication, June 6, 2016)
***(HVAC Brain, Inc., 2016)

Installation and Pipelining Cost

A typical system requires the installation of piping to distribute the hot or cooled water. The pipe size and quantity needed vary depending on the size of the heating and cooling system needed. Based on general market analysis, estimated piping and installation costs are $173,391.

Summary

Taking into consideration the total capital/product costs, piping and installation costs, the overall system cost is calculated at $325,809.

Capital/Product Costs	$152,418
Pipelining & Installation Costs	$173,391
GRAND TOTAL:	$325,890

15. Potential Application of a Cooling System

Cooling systems can have a broad usage for industry or households for cooling purposes. The usage of cooling systems is not limited to industry, as shopping centers are also a key target to implement the efficient and ecofriendly technology of a biomass cooling system. Additional key implementations of a biomass cooling system could include:

- Small scale industries
- Strip malls
- Quad homes
- Townhomes
- 3-4 single family houses together

16. Operating A Biomass System—A Case Study Testimonial

According to Pinecrest Maintenance Supervisor David Vandermissen, despite differences, operating a biomass heating and cooling operation is not difficult. For more than 20 years, the Pinecrest Medical Care Facility in Powers, Michigan, has heated their campus using a biomass heating system. Pinecrest added an absorptive chilling system in 2001 to cool their facilities using wood chips.

Pinecrest offers medical care, Alzheimer's care, physical, occupational, and speech therapy. The campus can house up to 160 residents.

The facility heats 170,000 square feet across four buildings using a low-pressure steam district energy system. Biomass also cools about 144,000 square feet of space. An absorption chiller, which cools salt water to 42 degrees Fahrenheit (5.6 degrees Celsius), provides cooling.

In a recent interview conducted by freelance writer Daniel Lemke of Spirited Communications, Pinecrest maintenance supervisor David Vandermissen reported the initial installation of the biomass heating system at Pinecrest Medical Care Facility was a learning experience as the contractors at the time had never installed a similar system. The team struggled to implement the engineer's designed into practice and it took the facility time to get everything right. However, after clearing the hurdles, the system has worked well with the cooling system operation being relatively smooth from the start.

Pinecrest Medical Facility's initial motivation to install a biomass system was the rising cost of natural gas. The Pinecrest Medical Facility's biomass system currently runs four times cheaper than burning natural gas due in part to the availability of biomass wood products.

Because the biomass system is different from a traditional gas or fuel oil boiler, the initial responses from operators can be less than enthusiastic. However, Vandermissen says operating the system is not much different than operating a gas-powered boiler.

"The technology is there and it basically runs by itself," Vandermissen said. "It just looks intimidating because there is more involved with things like augers and controllers."

When first installed, Vandermissen had to understand the system's technology, and then had to learn the machine. Having ascertained the system, he says operation and maintenance are not much different for the absorptive chiller than for other more conventional technologies.

"The absorption chiller is no different than a screw chiller or a diesel-powered chiller," Vandermissen added. "You still have to maintain the cooling tower and do other small maintenance. It isn't that hard."

Vandermissen says maintenance, which takes an average of an hour per day, is minimal when the system is managed properly. That's about twice what is need for a natural gas boiler. Part of the maintenance requirement is ash disposal. Vandermissen says with good, clean burning wood, the system generates enough ash to fill a 55-gallon barrel every week. That's after burning about 40 tons of wood chips.

Per manufacturer recommendations, part of the system needed rebuilding after operating for 28,000 hours. The system currently has more than 36,000 hours of operation under its belt.

Vandermissen says adding the biomass burner and absorptive chiller has been an interesting project. He sees no reason why Pinecrest won't continue heating and cooling with biomass.

"A new person coming in will see only problems." Vandermissen noted, "There will be problems, but once the system gets going, the boiler will burn like gas. It may require a person on staff to watch more things, but it creates jobs, saves energy and is putting people to work in the woods. There are long-term benefits associated with it." (See Cook, 2015, for details of the biomass system).

Additional details regarding Pinecrest Medical Care Facility's biomass system is available at: http://msue.anr.msu.edu/uploads/234/69992/Pinecrest-2015.pdf.

17. Present Market

Presently, the target market of biomass cooling systems is small-to-medium scale industrial and commercial facilities, multi-unit housing facilities, and strip malls. The extension of residential usage of this technology could be focused in the future when the system dimensions match the capacities for other facility sizes.

Additionally, institutions or industries already using absorption chillers can become a biomass air cooling institution by converting the fuel source. This conversion represents the targeted market value in Minnesota. Additionally, the technology is extendable into the neighboring states like Wisconsin, North Dakota and South Dakota as these states have predominance for commercial strip malls over shopping complexes. Once the market is established, it can be expanded by developing a more economical system for residential use, which would increase the scope to produce or service a variety of fields.

Evidence supports the progressiveness of biomass-derived cooling innovations. For example, Thermax's Director of America's Rajesh Sinha notes, "Thermax, Inc. has 300 absorbers currently in operation in the United States. Most of which are driven by waste heat, either directly or indirectly. In roughly 30 percent of the cases, Thermax offers the hot water driven absorber with the hot water source being heat recovered from a prime mover electricity source or from district heating loops to generate cooling using its advanced high efficiency absorption chillers. While it is difficult to quantify the number of units, there are instances where heat is recovered from solid biomass combustion." (personal communication, June 1, 2016).

18. Conclusion

Biomass offers a competitive and often lower cost alternative to traditional energy sources. It is sustainable and a competitive alternative to oil, with some customers reporting a 50 percent reduction in cost compared to using heating oil. When compared to propane, the cost savings is currently $64.12 per month. When compared to conventional electricity, utilizing wood pellets as a primary energy source results in various cost savings or losses based on the Coefficient of Performance (COP) rating along with the electrical cost. Inefficiencies of electrical generation and transmission are accounted for within the retail price. Lastly, Agricultural biomass sources, such as corn cobs, would provide similar cost savings as wood biomass depending on availability and pricing.

The economic data provided in this report demonstrates that biomass cooling is a viable option and worth consideration depending on the situation, and particularly if constructing a new building or retrofitting a current system where piping is in place. Biomass cooling is a proven technology with case studies that demonstrate the economical and operational feasibility of biomass cooling systems. Biomass cooling systems are also currently being implemented in Europe, specifically by Swedish companies.

Information detailed in this study guide can be utilized to make informed decisions on the feasibility of utilizing a biomass system, whether as a main source of heating and cooling or as an auxiliary system. It serves as a potential opportunity to reduce heating and cooling cost, especially if the current energy source being used is propane or fuel oil. While the economics may not work for all biomass fuel types at a given time, the information provided in this report facilitates future planning for when the economics prove feasible. The greatest potential benefit for cooling, however, is realized when waste heat or steam are also utilized.

As with all AURI research initiatives, the ultimate goal is application and implementation. With the research data presented in this guide, a full economic feasibility assessment of the rate of return on a biomass cooling system should be more easily conducted by manufacturers and retailers, commercial and industrial businesses, organizations or the residential sector.

19. Bibliography

- ABCO Automation. (2016). *Control Systems*. Retrieved from http://wgr3.net/abco/frames/4competencies/14controlssystems/controlsystemsframes.html.
- Climate Change. Minnesota Public Radio (2015) http://www.mprnews.org/topic/climate.
- Cook, B. (2015). *Michigan District Energy Facility Case Studies*. *Michigan State University*. Retrieved from http://msue.anr.msu.edu/uploads/234/69992/Pinecrest-2015.pdf.
- COPs, EERs, and SEERs - How Efficient is Your Air Conditioning System? (2016). Power. Knot LLC. http://www.powerknot.com/how-efficient-is-your-air-conditioning-system.html

- BSH Innovative Heating & Cooling Solutions. (2014). Retrieved from http://www.bsh-limited.com/biomass-cooling.
- Delta Cooling Towers. (2016). *Cooling Towers*. *Delta Cooling Towers, Inc.* Retrieved from - http://deltacooling.com/products/cooling-towers/.
- Energyland. (2016). *Energyland District Cooling System*. Retrieved 25 May 2016, from http://www.energyland.emsd.gov.hk/en/building/district_cooling_sys/dcs.html.
- Friesen, D. L. (2012). *Minnesota Biomass Heating Feasibility Guide.* Agricultural Utilization Research Institute. Retrieved from http://www.auri.org/assets/2012/05/biomass-heating-feasibility-guide.pdf.
- Gordon, Kate; Mathew Lewis; Jamesine Rogers; and Fiona Kinniburgh, *Risky Business: The Economic Risks of Climate Change in the United States – Heat in the Heartland: Climate Changes & Economic Risk in the Midwest*. Risky Business Project, 2015. Pages 5, 37 and 38.
- Gundersen Envision. (2016). *Fueling the Future*. *Gundersen Envision*. Retrieved from http://www.gundersenenvision.org/renewable-energy/biomass-combined-heat-and-power.
- HVAC Brain, Inc. (2016). *Protec PCT-30 Cooling Tower.* Retrieved from http://www.hvacbrain.com/. Protec-PCT-30-p/pct-30.htm.
- Industrial Quick Search. *Absorption Chiller Manufacturers Information*. *IQS Directory*. Retrieved from http://www.iqsdirectory.com/absorption-chiller/?gclid=CjwKEAjw9Zu5BRCS_OuVibujhQ0SJAD7t4KrmWXpnWPehB8BgKBon68qEeS2hZtgs77ap4Kk7_hHPhoCgyrw_wcB.
- Loopnet. (2016). *Minnesota Shopping Centers and Malls for Sale on LoopNet.com*. *Loopnet*. Retrieved from http://www.loopnet.com/Minnesota_Shopping-Centers-For-Sale/.
- The Engineering ToolBox; http://www.engineeringtoolbox.com/cooling-heating-efficiency-d_410.html
- The Home Depot. (2016). *Natural Gas Boilers and Heaters*. *Products and Services*. Retrieved from http://www.homedepot.com/b/Heating-Venting-Cooling-Heaters-Boilers/Natural-Gas/N-5yc1vZc4m2Z1z0z72l.
- Trane. (2016). *Trane Commercial Heating and Air Conditioning*. *Trane University*. Retrieved from http://www.trane.com/commercial/north-america/us/en.html.
- Yazaki Energy Systems. (2015). *Water Fired Single-Effect Chiller "How to Works"*. *Yazaki Energy Systems, Inc*. Retrieved from http://www.yazakienergy.com/waterfired.htm.