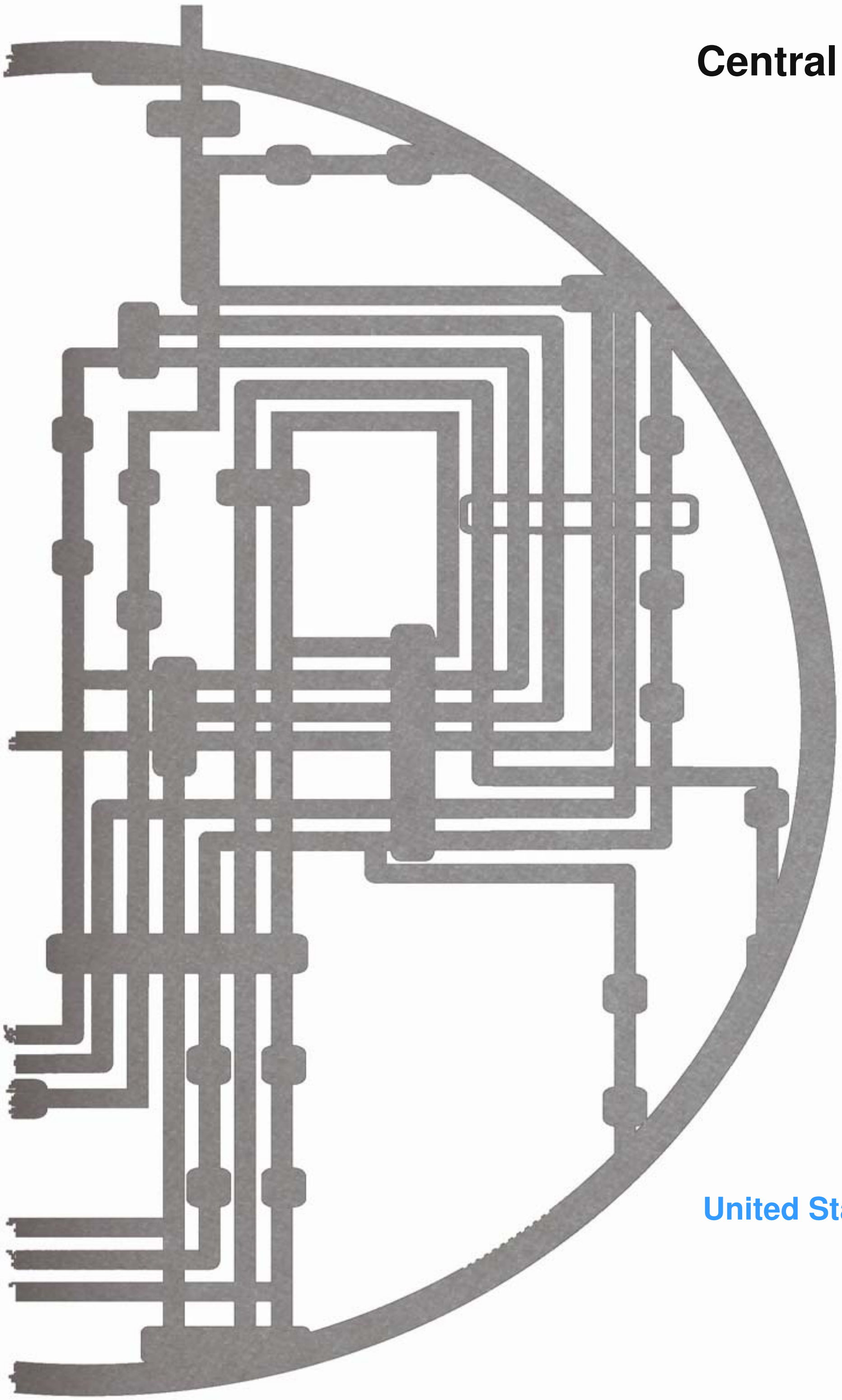
Energy Island
INTEGRATION STUDY



Completed for the
Central Corridor/Green Line
Study Area

In partnership with the

United States Department of Energy

Prepared by Ever-Green Energy

for District Energy St. Paul

in partnership with

April 2013

Photo demonstrates heat lost through industrial process.

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Section 1.0

EXECUTIVE SUMMARY

1.1 Introduction

Throughout the world, countries are seeking pragmatic solutions to increase the efficiency of their energy systems through the use of smarter energy distribution and the advancement of technology. The drivers for change vary from mandates to economics to environmental conditions. Within the United States, utilities are being required to integrate more renewables and increase the efficiency of the demand-side user.

Demand-side reductions and renewables are important investments for the overall system, but often times these foci result in a missed opportunity. Each day, millions of Btus[2] of thermal and electric energy potential are lost through wasted heat or stranded energy. Waste heat occurs when a process creates thermal energy as a by-product that must be disposed of using cooling water from rivers or other bodies of water, through cooling towers or otherwise exhausted to the atmosphere. Most often this heat is produced by industrial processes or electricity generation. Stranded energy includes waste heat and the excess capacity of existing production assets that are currently under-utilized due to the isolation of production facilities or limitations of existing systems.

According to the United States Department of Energy (DOE), "the U.S. industrial sector accounts for about one-third of the total energy consumed in the United States and is responsible for about one-third of fossil-fuel-related greenhouse gas emissions." Of these industrial energy inputs, 20-50% are lost as waste heat.[1] In addition to waste heat from the industrial sector, most electricity generation facilities lose an average of 50-70% of their fuel inputs to waste heat each year. Combined-cycle and combined heat and power (CHP) facilities greatly reduce these losses by increasing electricity production through additional turbine cycles or through the re-use of waste heat for heating and cooling applications, such as district energy. District energy is a thermal delivery system that connects energy users with a central (or shared) production facility.

The waste heat left behind by these facilities represents a clear opportunity to make better use of available fuel resources. In addition, this waste heat carries a value that can be placed in the market to displace fossil fuels and create financial opportunities for the producer and increase rate stability for the users. In order to maximize these opportunities, systems must be looked at with a new perspective that integrates the capabilities and needs of energy islands.

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[1]BCS Incorporated, Department of Energy, *Waste Heat Recovery: Technology and Opportunities in U.S. Industry*, http://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf (March 2008)

[2]For the purposes of this report, multiple energy units were utilized to estimate thermal energy potential depending on information sources and the type of energy measured. This includes Btu (British thermal units), mmBtu (one million Btu), watt (3.41214 Btu/h), kW (one thousand watts or one kilowatt), kWh (kilowatt/hour), kW_t (kilowatt thermal), MW (megawatt or one million watts), MWh (megawatt/hour), MW_t (megawatt thermal). Unless otherwise noted, all units are thermal equivalents.

Energy islands are the existing production facilities and aggregates of users operating independent of each other within a close proximity. Operating as islands, these systems could more effectively use their own resources. More importantly, these islands hold vast potential as integrated energy systems, with facilities possessing excess or waste energy resources that could connect users with matching demands for energy.

An integrated energy system is one that combines aspects of multiple systems and technologies to achieve greater efficiencies than any single system could ever achieve on its own. Integrated energy systems can help solve the challenges that prevent a renewable energy technology from reaching its full potential, thereby making it more viable and cost-effective. Consider the promising technology of solar thermal in which the sun's energy is used to heat water, which can then be used to heat buildings. Or, using a CHP plant to generate electricity and capture the excess steam to heat the water used to heat downtown buildings. Better yet, distributing the excess heat from local industrial processes and using the otherwise wasted heat to provide opportunities for neighboring businesses and jobs.

To substantiate the benefits of energy island integration, District Energy St. Paul (District Energy) partnered with its affiliate Ever-Green Energy, as well as the Department of Energy and Barr Engineering to evaluate the existing production facilities surrounding the Central Corridor Light Rail Transit (LRT) Project, referenced in this report as the Green Line or Green Line corridor. The Green Line corridor stretches between the downtown areas of Saint Paul and Minneapolis in Minnesota. Along this corridor are several existing fossil fuel energy production facilities of varying sizes and efficiencies, including campuses, hospitals, and industrial facilities. Each of those facilities operates independent of the other and most utilize fossil fuels as their primary source of energy, with the exception of District Energy St. Paul, which utilizes waste heat from a biomass-fired CHP plant and the Hennepin Country Energy Recovery Center, a waste-to-energy facility.

In addition, some of these facilities have excess capacity or generate waste heat from their processes that could be recovered and used to meet the heating needs of the surrounding community instead of being dumped to the atmosphere.

Although the study area features unique facilities and user groups, the core components of integration are similar to those in most towns, cities, and campuses throughout North America. By examining the types of producers and consumer loads that can be found in a snapshot of a metropolitan area, this study aims to provide a methodology for other regions to create an energy inventory and examine the potential for the region to integrate existing assets and energy sources into symbiotic systems.

The first phase of this project created an inventory of the energy islands/energy production facilities along the Green Line corridor that are reasonably contiguous to areas with a concentration of heating loads. The inventory assessed business districts, health care complexes, business parks, large places of assembly, government buildings, colleges and universities, and commercial and industrial facilities. The second phase examined the proximity of each of the district energy systems, load concentrations, and waste heat generators; assessed the potential of converting systems from fossil fuels to renewable energy; identified potential locations where solar thermal could be utilized; and studied the potential of developing an interconnecting network throughout the study area.

This study examines specific opportunities for integration of assets and also shares the approach to the evaluation. Components of a system were evaluated based on major development factors and then ranked by the complexity of these factors. Major components were defined as production assets, distribution systems, consumer load, renewable potential, and system integration. With integration as a priority, systems were also evaluated based on their potential to expand the reach and potentially connect with other major systems.

1.2 About the study area

The Green Line corridor stretches from downtown Saint Paul to downtown Minneapolis, spanning 11 miles and representing a $957 million infrastructure investment for the region (Figure 2). This corridor represents the core segment of the study area, which will feature eighteen light rail stations, and connect downtown Minneapolis, the University of Minnesota, the Midway commercial district, State Capitol complex, downtown Saint Paul and many diverse neighborhoods, businesses, and academic institutions in between.

Beyond the Green Line corridor, the study area encompasses a 90-square-mile study area (Figure 1) includes portions of Minneapolis in Hennepin County; the entire city of Saint Paul, portions of Lauderdale, Falcon Heights, and a small portion of Maplewood in Ramsey County; and a two-square-mile portion of Newport in Washington County.

The study-area boundary was drawn to include areas in the high-density core areas of Saint Paul and Minneapolis.

Areas of interest included industrial land uses and college and health care campuses. Redevelopment districts identified by the cities of Minneapolis and Saint Paul (Figure 3 - Section 2.0), as well as existing and future transit corridors, were deliberately included in the study area because they represented new, high-density developments where district heating could potentially be incorporated in new construction.

Three areas in Minneapolis and Saint Paul are already served by commercial district energy systems (Figure 1). Most of downtown Saint Paul is served by District Energy St. Paul. Much of downtown Minneapolis is served by NRG. The Energy Park area in Saint Paul is also served by a district energy system, which is owned by the Saint Paul Port Authority and operated by Ever-Green Energy.

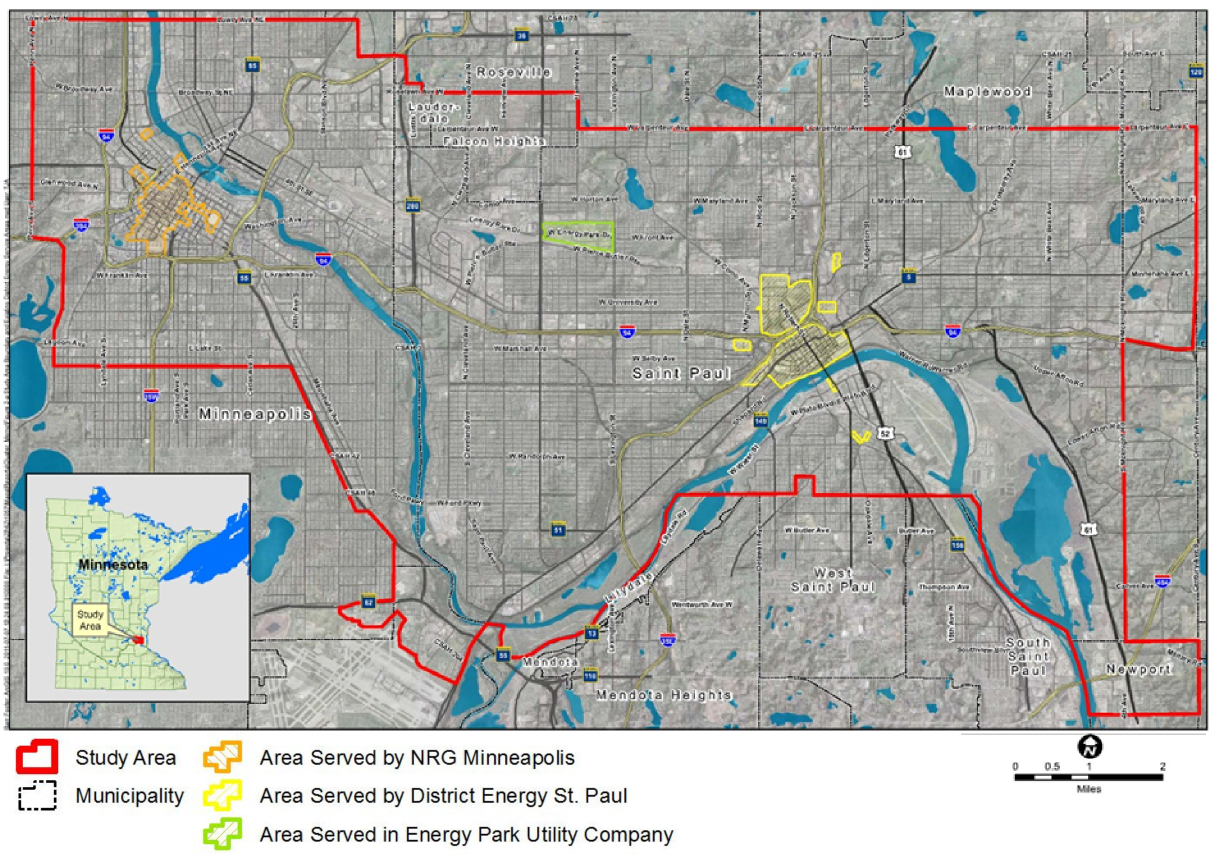

Figure 1. Study Area Boundary and Existing District Energy Service Areas

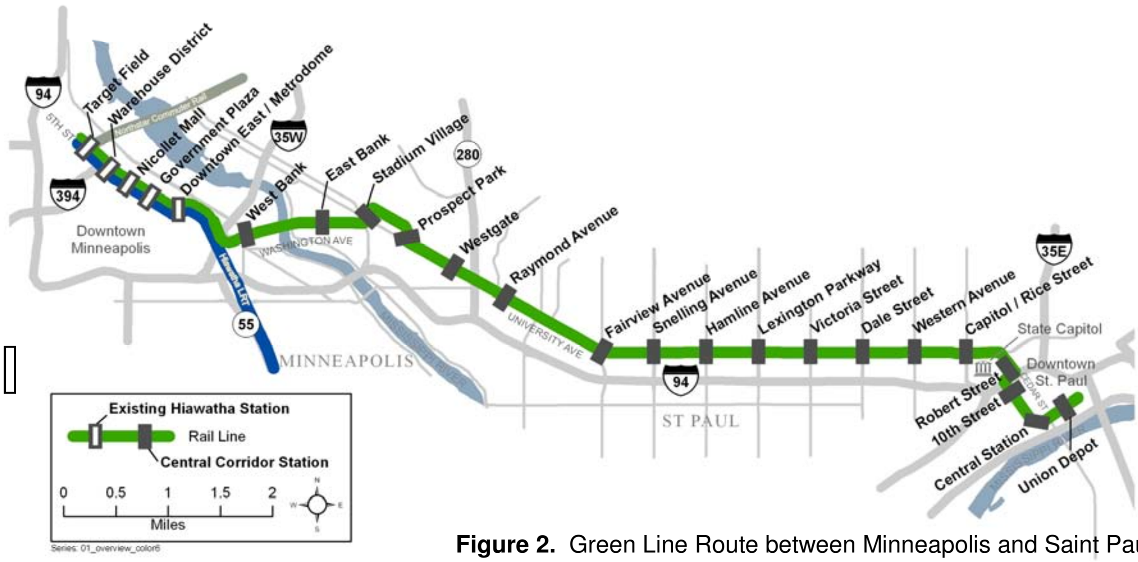

Figure 2. Green Line Route between Minneapolis and Saint Paul[3]

1.3 Utilizing the energy island study

This study was initially developed to advance the multitude of opportunities for district energy system expansion during construction of the Green Line corridor. A district energy system was not constructed during this major infrastructure project. However, placeholders in the form of casing pipes were installed under the tracks to preserve the opportunity for these energy islands to be developed in the future. Throughout preliminary discussions of a district system, a wide range of stakeholders lent their support to the development of an integrated energy system and continue to show interest in the environmental and economic benefits offered by these systems.

This report both explores the remaining potential for the original study area and develops a more robust approach to developing similar systems. By offering a pre-feasibility methodology, system planners can evaluate their own cities, regions, campuses, or other key areas for the development of integrated systems. By using the tools in this report to assess energy options, system planners can explore energy options concurrently with other major development and infrastructure projects or begin to build a database of information to verify the opportunities before investing in additional study.

District Energy St. Paul encourages parties to also explore the International District Energy Association's Community Energy Guide. The Community Energy Guide explores complementary opportunities to establish district systems utilizing new production assets, rather than existing. Economic and policy indicators are also highlighted.

Combined with this document's emphasis on stranded energy opportunities and system integration, system planners have new and improved tools to use to meet their energy, environment, and economic goals.

System planners may include but are not limited to the following parties:

- ⇒ City and regional planners
- ⇒ Economic development agencies
- ⇒ Local government units
- ⇒ Chambers of commerce
- ⇒ Departments of transportation
- ⇒ Developers
- ⇒ Architects
- ⇒ Engineers

For those in early stages of comprehensive planning, we have provided a checklist in Appendix A to serve as an abbreviated tool for analyzing your

[3] Image courtesy of Metro Transit.

Every region is at a different stage of development along this checklist. Depending on your stage in assessment, we would recommend spending more time in different sections of this study.

Section 2.0: Focused on beginning stages of analysis for regions that are preparing to inventory their assets or identify key geographic areas of focus. This is a particularly helpful exercise for comprehensive planning efforts.

Section 3.0-6.0: If your region has already inventoried clusters of energy density and identified opportunities, the production, consumption, distribution, and alternative energy sections may be most helpful.

Section 7.0: This section focuses on guiding your region through an integration discussion after your assets and needs have completed initial mapping.

1.4 About district energy

Throughout northern Europe, district energy has advanced to become a vast network of district heating and cooling systems and energy production facilities. Similar to District Energy St. Paul, many of these systems utilize renewable energy sources as their primary source of energy, and many of those systems have integrated the wasted energy recovered from industry and electricity generation. Networking the heating systems and wide variety of energy production facilities has significantly increased overall system efficiency, increased the use of renewable energy, stabilized rates, and decreased emission of greenhouse gases and air contaminants, all while increasing energy security. This study focused on district heating opportunities, but district cooling is noted where appropriate for consideration.

1.5 About the report contributors

District Energy St. Paul

District Energy St. Paul (District Energy) operates North America's largest hot water district heating system using energy from a biomass fired, combined heat and power plant fueled by Twin Cities' tree trimmings. A 501(c)3 non-profit utility, District Energy uses central heating plants, solar thermal, thermal storage, and a network of underground hot water distribution piping to serve the heating needs of over 31 million square feet in 195 buildings and 300 single family homes. Its customers include the Minnesota State Capitol Complex, four major downtown hospital complexes, the Warren Burger Federal Building, the City of Saint Paul, Ramsey County, the Science Museum of Minnesota, and a major hockey arena, convention center, and entertainment spaces. The system also serves Fortune 500 companies, start-ups, entrepreneurs, and landmark small businesses that thrive with the support of District Energy's stable and reliable heating and cooling services. According to the Building Owners and Managers Association's Experience Reports, Saint Paul consistently enjoys competitive energy rates compared to other major cities. Ecolab, Travelers, Securian, and Wells Fargo operate their businesses in Saint Paul, in part, because of the economic and environmental benefits provided by the district energy services.

To effectively serve this local economy, District Energy and its customers have relied on a remarkable 30-year history of providing affordable and stable energy costs. After adjusting for inflation, District Energy's customers pay less for heating service today than they did 30 years ago. District Energy has been at the forefront of Minnesota's movement towards sustainable energy solutions, and has been internationally recognized as a model for energy security, stabilizing energy costs, and reducing carbon emissions.

Ever-Green Energy

Ever-Green Energy is one of the country's foremost experts in advancing integrated energy systems. Developed through District Energy St. Paul, Ever-Green provides its clients with decades of experience in engineering, system development, and utility ownership and management. Along with consulting services, Ever-Green provides operations and management services to District Energy and District Cooling St. Paul, Duluth Steam, Energy Park Utility Company, Environmental Wood Supply, and St. Paul Cogeneration. Drawing from the experience gained with the flagship system, Ever-Green's industry-leading experience helps communities, universities, and government organizations advance the study, development, and operation of integrated and resilient energy systems.

Barr Engineering
Barr provides engineering and environmental consulting services to clients across the Midwest, throughout the Americas, and around the world. Barr has been employee owned since 1966 and traces its origins to the early 1900s. Working together, Barr's 700 engineers, scientists, and technical specialists help clients develop, manage, and restore natural resources.

Barr's project teams serve the power, mining, and fuels industries, natural-resource-management organizations, and others with complex problems. Their project sites range from South America, throughout the U.S. and Canada.

1.6 Study goals and findings

Goal: Create a blueprint for identifying energy island clusters.

Findings:

⇒ The study outlines a methodology for working with multiple public data sets to evaluate stranded energy opportunities, including industrial waste heat and excess facility capacity for anchor or supplemental production for new energy districts. This methodology utilizes a European philosophy for "thermal smart grids", that is less prevalent in North American planning.

⇒ Components of the energy system (production, distribution, consumption, and renewables) were evaluated through a complexity scale (low, medium, high). Complexity can be determined by an assessment of the most likely technical, financial, and market scenarios. The complexity scale allows system developers to determine the value of advancing an opportunity to the feasibility study stage.

Goal: Inventory energy production facilities and heat recovery opportunities in the study area.

Findings:

⇒ Public data sets can be used to identify potential contributors based on a minimum threshold for production assets (the availability of this information and its source may vary from state to state).

⇒ To verify the predictive modeling for production assets, a survey was conducted with the following results:

- ♦ Facility managers are looking for ways to cut costs or improve income streams and have considered one of the following options:
    - Increase the amount of on-site combined heat and power CHP or develop new CHP capabilities.
    - Bridge existing gaps in systems to reduce unnecessary equipment use.
    - Improve system efficiency.
    - Engage third party providers to manage their energy systems.
    - Utilize renewables in a more effective manner.
- ♦ The majority of production facilities in this region have excess capacity available to sell.
- ♦ The majority of facilities surveyed expressed interest in exploring energy uses beyond their own facility boundaries.

⇒ The production complexity scale is based on the quality and quantity of heat available from existing or potential facilities, the forecast for that heat's availability, the facility's willingness or interest in selling this heat, and the viability of the nearby consumer load.

Goal: Assess energy user potential based on load density and patterns.

Findings:

⇒ Public data sets can be used to identify potential energy users (the availability of this information and its source may vary by state or province).

⇒ The available public data provides building information, not energy usage. A methodology was developed for predicting the most likely energy profile for each building in the data set. It was determined that surveying the customer base to confirm data prediction was not practical for this study, so the results were compared to existing private data sets. This refined data was aggregated in order to map energy usage density in the two cities and identify favorable clusters for potential system development.

⇒ A consumer load minimum can be difficult to determine because a load's viability is heavily determined by the localized production and distribution potential.

⇒ The consumer complexity scale is based on the density of energy users, the age of the equipment, the conversion potential of the building HVAC, and their business interest in connecting to a district system.

Goal: Create a distribution system analysis.

Findings:

⇒ Prior to developing any distribution system analysis, system planners will benefit from an assessment of existing conditions, including soil conditions, size and location of right-of-ways, utility locations, building service entry locations, and access management provisions.

⇒ Pipe sizing is guided by the overall potential load of a given cluster and the most likely routing to reach key or dense user groups. Pipe sizing can be favored to the larger of the potential load options to ensure system growth and long-term cost savings; however, the pace of growth and market risk should be heavily weighed to avoid short-term and long-term difficulties with system maintenance and repair.

⇒ Pipe routing will be defined by existing conditions, regulatory requirements and permitting, and major infrastructure project planning. On average, district heating distribution projects can save up to 40 percent on distribution construction by co-locating the project with another major infrastructure effort. These cost savings could be used to coordinate financial packages for co-location or collaborative planning of multiple utility, transportation, or other infrastructure projects.

⇒ The complexity of distribution systems for this phase in project assessment is based on co-locating potential with other infrastructure projects, existing ground and utility conditions, pipe sizing, routing, and materials.

Goal: Assess the potential to convert fossil fuel users to renewable energy.

Findings:

⇒ The majority of production facilities surveyed are either developing or interested in developing a renewable energy source to complement their current energy profile.

⇒ Given the lack of adequate geothermal sources and the high electricity demand of heat pumps, no geothermal opportunities were identified.

⇒ College campuses and breweries were the most ideal solar thermal candidates with adequate installation space and facilities utilizing a consistent annual hot water load.

⇒ Only one biomass opportunity was determined to be highly viable. Viability was based on site size and potential to store or process biomass. Most facilities were interested in biogas purchase but no facilities that were surveyed were found to be viable for biogas production.

⇒ Most facilities surveyed had interest and technical capability to develop CHP.

⇒ Industrial facilities surveyed have high amounts of low-grade heat. These facilities remain viable as anchor facilities but may need additional heat pumps for heat to reach adequate temperatures for energy users or would be ideal for development of a micro-district with a commercial industrial user base requiring lower-grade heat. Examples of such users include laundries, breweries, bottlers, dairies, hotels, hospitals, greenhouses, and other process heat users.

Goal: Study the feasibility of system integration.

Findings:

⇒ System integration incorporates technologies, fuel sources, load aggregation, and connection through district systems. Integration opportunities were found within and between clusters, including but not limited to the following examples:

- ♦ The addition of micro-CHP to supply electricity and heat to the operations.
- ♦ Existing systems utilizing alternative energy resources and expanding their fuel intake to be more flexible and efficient.
- ♦ Expanding existing steam, hot water, and cooling district systems to serve additional users, particularly if it integrates new private users for the system.
- ♦ Adding satellite production to existing or potential systems, creating a thermal smart grid with multiple production facilities and expanded fuel choices (ex. capturing waste heat from production to back-feed an existing heating system).
- ♦ Connecting existing systems to unlock higher efficiency from production assets, distribution, and users.

⇒ Hot water systems offer the greatest integration potential for existing or potential systems.

⇒ Even highly developed areas are still undergoing major infrastructure investments and planning for increased density. Integration is most viable when incorporated into comprehensive planning and infrastructure projects.

⇒ Systems are best served by the recommissioning of existing production assets to meet heating needs and stabilize energy rates for development.

⇒ System development and integration was most viable where district systems were already in use. In these cases, the existing district could be optimized by expanding the system boundaries or customer base to serve new users. Expanding the boundaries of current systems accomplishes the following:

- ♦ Improves the efficiencies of under-utilized boilers.
- ♦ Creates a new source of income for existing system owners and managers.
- ♦ Allows customers access to a greater variety of alternative fuels.
- ♦ Energy rates can be stabilized by increasing and aggregating system users.
- ♦ Shares capital costs between a great number of customers.

⇒ From a review of dozens of potential energy islands, we confirmed a dozen islands in Minneapolis and Saint Paul that have viable energy providers and met the threshold for energy consumption and displayed interest in collaborative energy planning and multi-nodal system development.

Section 2.0

IDENTIFYING ENERGY ISLAND CLUSTERS INVENTORY & METHODOLOGY

2.1 Scope and purpose

This section provides an introduction to the criteria developed for identifying energy islands. These criteria were developed to identify opportunities in the Green Line corridor, but should be applicable in many regions. The identification of energy islands is the broadest step allowing for future examination of production assets, consumer groups, development districts, distribution areas, and incorporation of local renewables. By defining a major area of interest and subsequent clusters, system planners can begin to develop the components for improving and connecting these energy islands. We recommend each system planner consider this a step in other comprehensive planning efforts.

As noted earlier, energy islands are the existing production facilities and aggregation of users operating independent of each other within a close proximity. Operating as islands, these systems could more effectively use their own resources. These islands, or clusters, hold vast potential as integrated energy systems, maximizing their own integration, and connecting to the assets and needs of proximate users. By this definition, the study required that a potential energy island feature existing or potential energy production and energy consumers.

The original study boundaries were centered along the development of the Green Line corridor (referenced as the Central Corridor LRT Project during construction). This area represents a significant opportunity for development and also presented clusters for examination of industrial, commercial, residential, and mixed use of varying densities and character. As an aggregate it represents a unique region; however each cluster is indicative of the resources and existing assets that can be found in most communities and campuses.

We recommend system planners determine the scope of their study area in partnership with other planning organizations, including other economic development agencies. Wherever possible, boundaries should include major health care facilities or local colleges and universities who may have significant shared benefits from the study outcomes, as well as providing energy production and a consistent energy load potential.

District Energy presents the information in Section 2.0 as a product of the work commissioned on behalf of this study. This work was analyzed and compiled by Barr Engineering with guidance and input provided by the District Energy/Ever-Green Energy staff.

2.2 Process to develop energy island clusters

The identification and analysis of energy island clusters was a primary function of the study and crucial to determining the appropriate study area and unique areas of interest. Energy islands are areas that could potentially support a district heating system. Typically, within its boundaries as defined by this study, an energy island has three requirements: it includes one or more producers of excess energy (e.g., wasted heat or excess capacity), contains significant energy consumption, and has a relatively compact energy-use pattern or energy density. Multi-family, commercial, and institutional users are the potential consumers of this excess energy.

Energy islands were identified using a visual method that mapped three factors: energy consumption, energy production, and energy density.

These factors were used to identify and select energy islands through the following process:

1. Identification of the energy island study area
2. Estimate of total energy use (see Section 4)
3. Calculation of energy density
4. Delineation and verification of energy island boundaries

2.3 Identification of energy islands study area

The 90-square-mile study area shown in Figure 1, includes portions of Minneapolis in Hennepin County; the entire city of Saint Paul, portions of Lauderdale, Falcon Heights, and a small portion of Maplewood in Ramsey County; and a two-square-mile portion of Newport in Washington County, all within this central metro area of Minnesota.

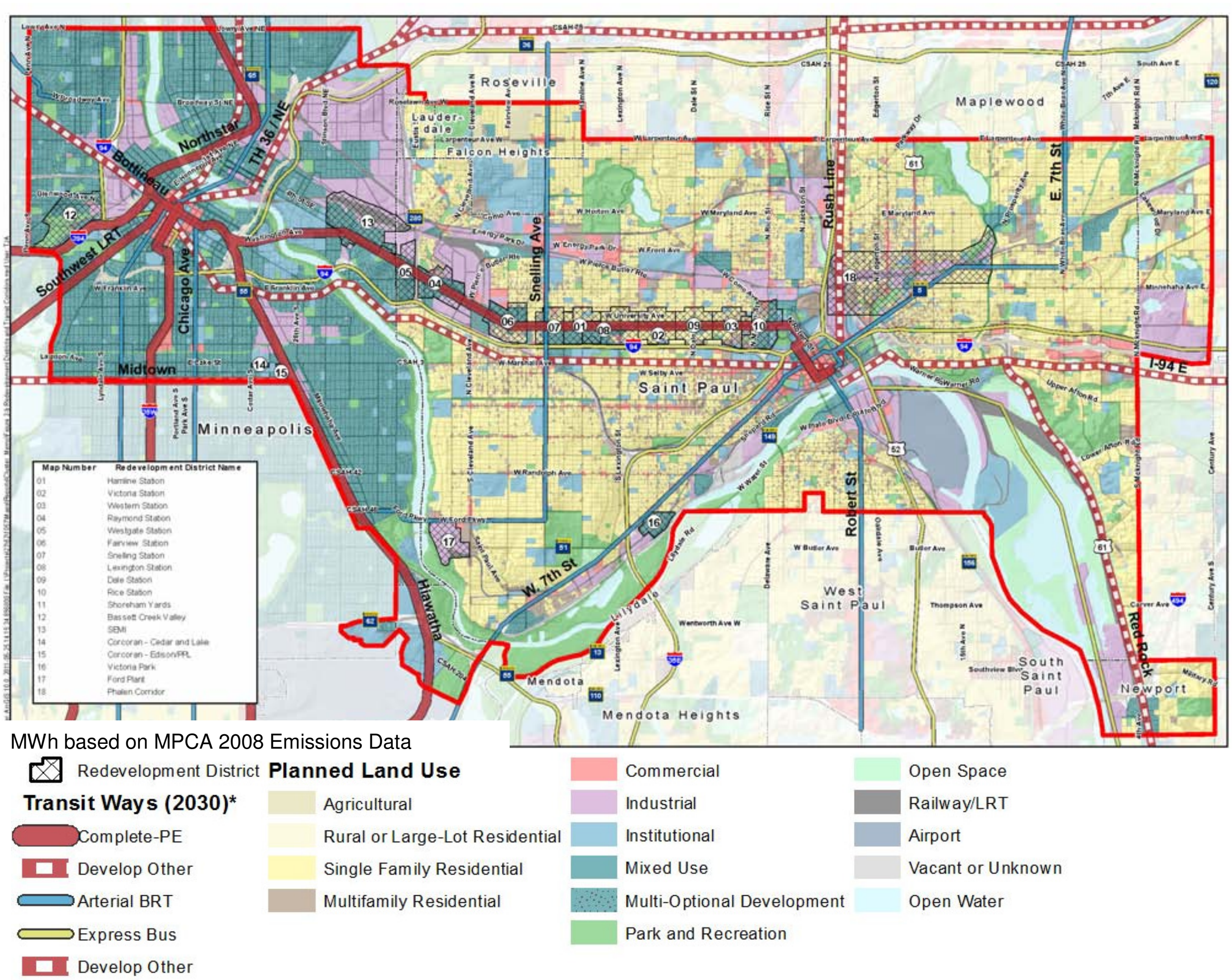

Figure 3. Future Land Use Redevelopment Districts and Transit Corridors

2.4 Calculation of energy density

The study-area boundary was drawn to include areas in the high-density core areas of Saint Paul and Minneapolis. Areas of interest included industrial land uses and college and health care campuses. Redevelopment districts identified by the cities of Minneapolis and Saint Paul (shown in Figure 3), as well as existing and future transit corridors, were deliberately included in the study area because they represented new, high-density developments where district heating could be incorporated in new construction.

Three areas in Minneapolis and St. Paul are already served by commercial district energy systems[4] (see Figures 1 and 7a, 7b, and 7c). Most of downtown Saint Paul is served by District Energy St. Paul. Much of downtown Minneapolis is served by NRG. The Energy Park industrial area in Saint Paul is also served by a district energy system. Although these districts were excluded from energy islands, they were included in the study area so that energy metrics, including estimates of energy used, energy produced, and energy density, could be calculated and compared.

In using a visual approach for identifying energy islands, total energy use is insufficient. Energy density is an indicator of compactness or proximity of energy consumers and is an important factor in the economic viability of energy districts. Thus, the third requirement of an energy island is a relatively compact energy-use pattern or energy density. Basing energy island selection only on total energy use would be misleading. The visual magnitude of energy use is skewed by parcel size. A very large parcel (ex. a major park) may have a large computed total energy while a small parcel may have the same energy use, but its significance will be less visually obvious due to its size.

In the delineation of energy islands, the compactness of the consumer's property is important since the length of piping is a critical financial factor in developing a district heating system. Therefore, the density of energy use is a significant parameter for valuing energy islands. The energy density of each cluster was determined by dividing the amount of energy used in a parcel by the parcel's area:

Energy Density (MWh/acre) = MWh per parcel/Parcel Area (acres)

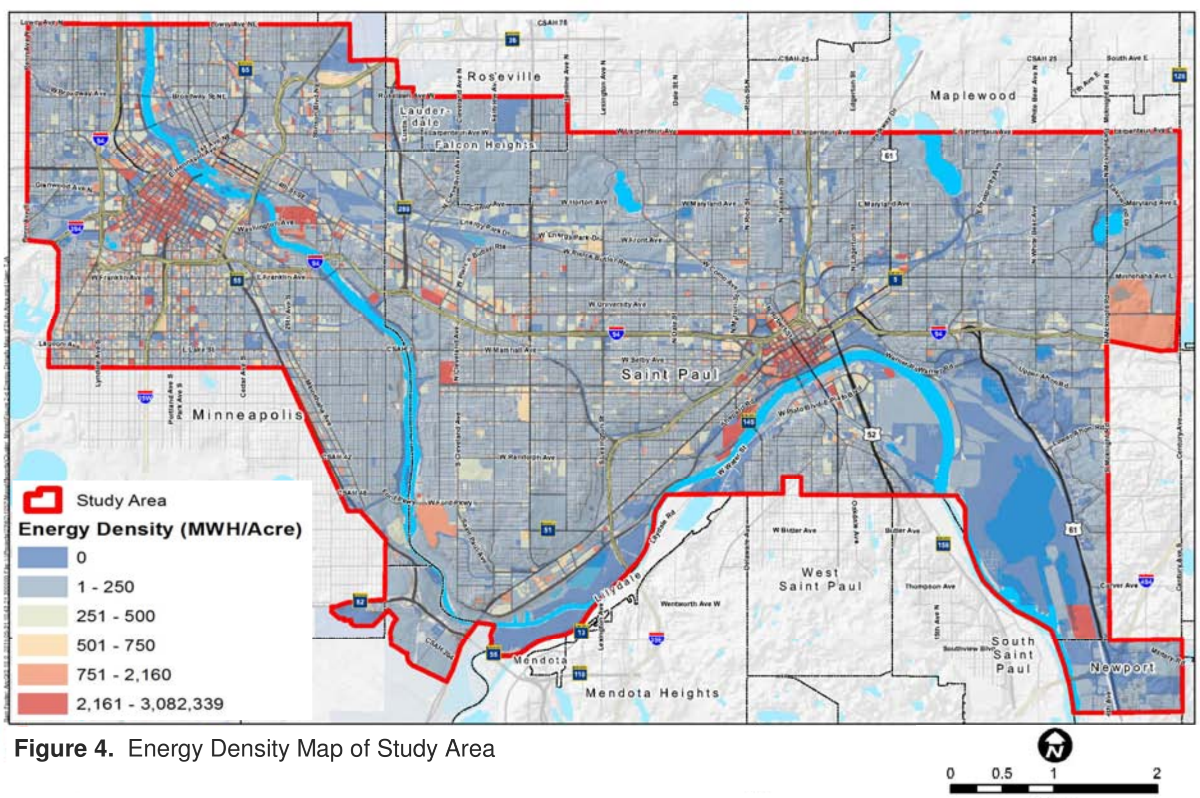

Figure 4. Energy Density Map of Study Area

[4] This summary of district systems does not include the hospitals, academic, and corporate campuses served by district heating systems.

Figure 4 illustrates how energy islands can be identified based on energy density. As an indication of the energy density of existing district energy systems, the study found thermal energy densities of approximately 300 MWh/acre, 1990 MWh/acre, and 780 MWh/acre for the existing Energy Park, NRG, and District Energy St. Paul systems, respectively.

2.5 Delineation and verification of energy island boundaries

Development of energy island boundaries was completed using a two-step process. In the first step, preliminary boundaries were developed through a visually guided qualitative mapping process. Parcels with high energy use and high energy density that were in relatively close proximity to each other (e.g., within a distance of one or two parcels from each other) were visually identified. Boundaries were drawn around these groups to identify clusters. In the second step, these preliminary energy island boundaries were verified and quantified using GIS spatial statistics. The final 25 energy islands are shown on Figure 5.

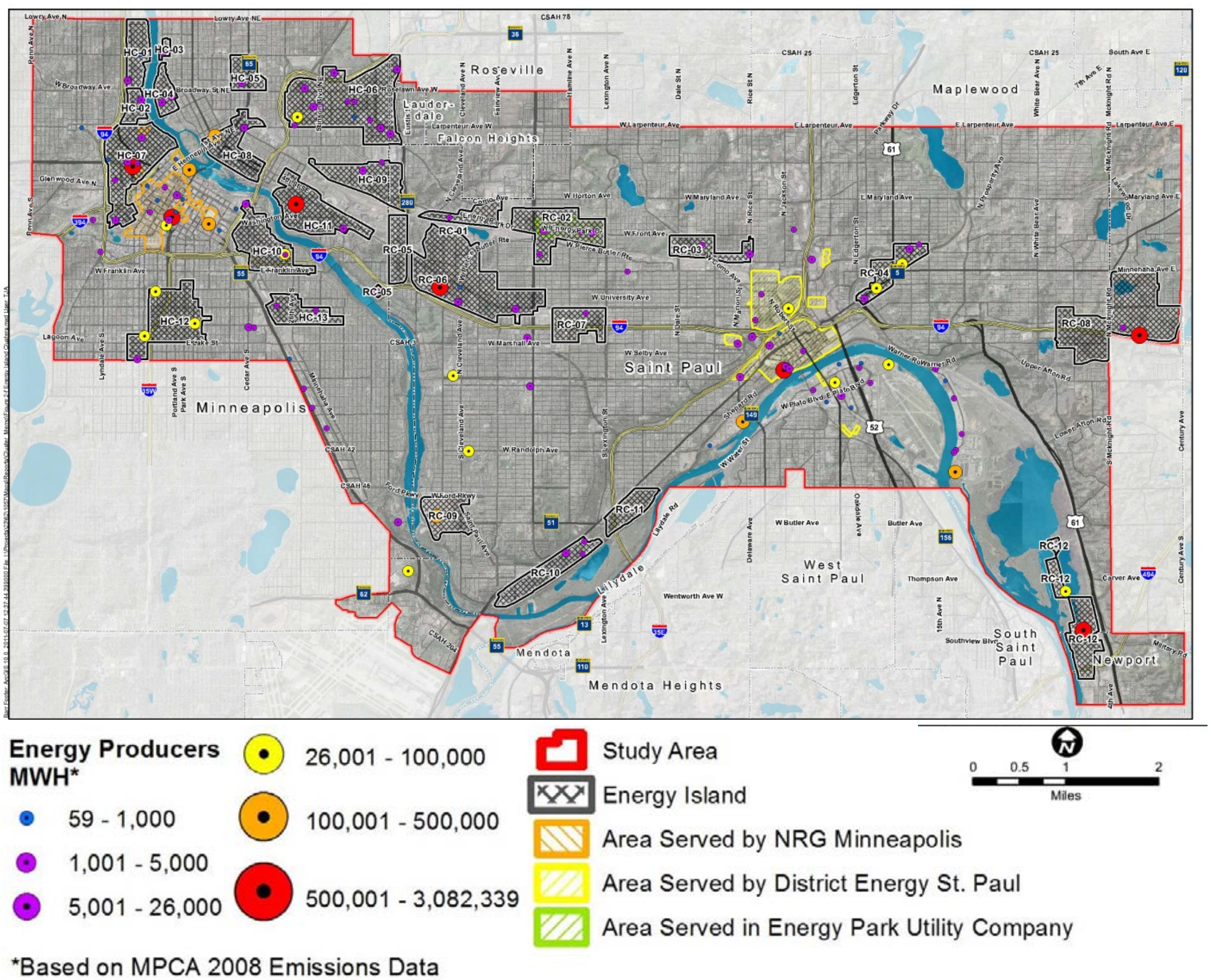

Figure 5. Energy Islands

2.5.1 Step 1: Preliminary energy island boundary development

Energy island boundaries were initially determined by visually identifying areas of potential high energy use. This qualitative process combined maps and parcel land-use data to display total energy use and energy density graphically for each parcel. The actual selection of boundaries considered several factors, including:

- Presence of at least one viable energy producer. With the potential to have excess capacity or wasted heat, a producer is important as both an anchor to and as a large energy customer for an energy district.
- Presence of high-energy density. A compact energy footprint is important for minimizing pipe length and hence improves economic viability of an energy district.
- Presence of redevelopment districts. Areas identified as priorities for redevelopment provide the potential for future energy use and increase the economic viability of an energy district.
- Use of existing parcel lines to define boundaries. Existing boundaries provide a practical approach for defining energy islands. Key data for determining and analyzing energy islands is contained within parcel data available from cities and counties.
- Residential areas with lower-density housing (< 4 units) were not considered. These types of low-density land uses have low energy use compared to other uses and are spatially dispersed, thus providing little opportunity for economic viability.
- Service areas of District Energy St. Paul and NRG in downtown Minneapolis were excluded. These are already energy districts and hence provide no opportunity for new energy districts.

Knowledge of and past contact with local industries and institutions also played an important role in boundary determination.

2.5.2 Step 2: Verification and refinement of energy island boundaries

Spatial statistics were used to help verify the visually drawn boundaries of the energy islands. Spatial statistics is the statistical analysis and modeling of spatial data. Observations, such as energy density, are obtained at spatial locations - in this case, parcels. Spatial statistics can help determine if feature attributes are randomly distributed, clustered, or evenly dispersed across the search area. The statistical results were used to determine if original visual boundaries drawn for the energy islands were correct and to identify other energy islands not identified previously.

Finding: The study outlines a methodology for working with multiple public data sets to evaluate stranded energy opportunities, including industrial waste heat and excess facility capacity for anchor or supplemental production for new energy districts. This methodology utilizes a European philosophy for "thermal smart grids," but is less prevalent in North American planning.

2.6 Statistics results and discussion

As shown in Figure 6, the hot spot analysis indicated potential energy islands close to those areas indicated by visual inspection of the data.
Hot spot analysis found clusters of higher energy-use density in downtown Minneapolis, downtown Saint Paul, and portions of the Green Line corridor connecting the downtown areas. Smaller clusters of high energy-use density were also found around industrial facilities and neighborhoods.

The energy density and hot-spot analysis found statistically significant clusters of high energy-use density in downtown Minneapolis and Saint Paul, as well as along sections of the Green Line corridor. Generally, residential areas were not found to be significant clusters; however, a mixed residential-commercial part of Minneapolis south of downtown did have significant clusters of high energy-use density. Industrial areas generally were found to be spatial outliers, with parcels of high energy-use density surrounded by clusters of low energy-use density or mixed-energy use.

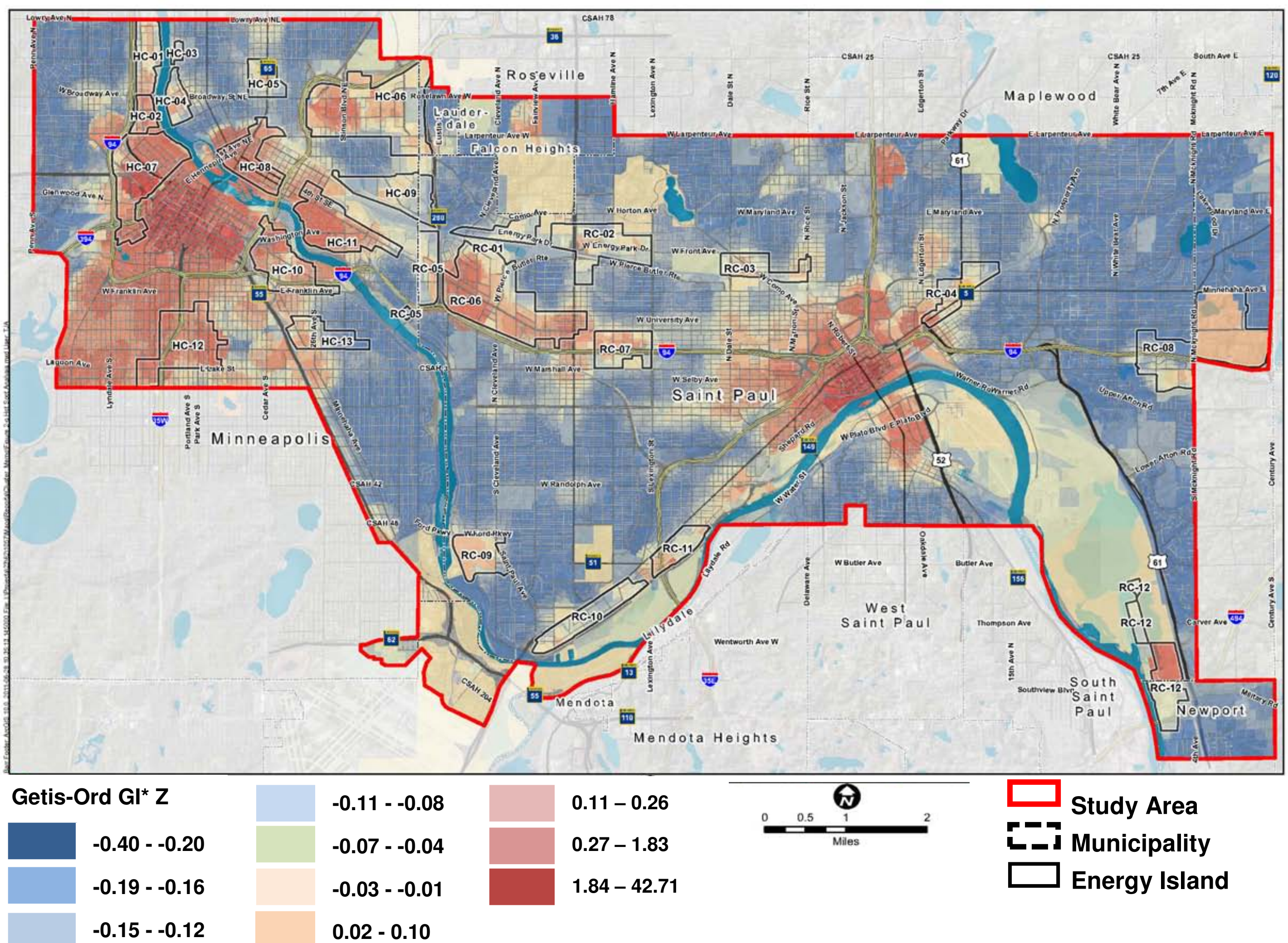

Figure 6. Hot Spot Analysis of Energy Use Density

2.7 Evaluation criteria

Four criteria were used to evaluate each energy island. A weight between one and five was assigned to the criteria to reflect their relative importance in assessing each energy island's value or overall viability. The four criteria, or energy estimates, used in evaluating energy islands include:

Existing Heating Load Energy Consumed by the Energy Island – Weight 5.0

This is the estimate of total energy use described in Section 2.2. Total energy use includes energy used by both consumers and producers. A large energy load is a primary driver of energy-district feasibility, and thus a weight of five was assigned to this criterion.

Existing Energy Production by the Energy Island – Weight 4.0

This is the same as the estimate of energy production discussed in Section 3.0. The presence of significant energy producers is considered an important factor and was given a weighting of four for several reasons. First, the presence of an energy producer is an indicator of opportunities for waste-heat recovery that can improve an energy district's economics by reducing the unit cost of delivered energy. Energy producers may also have excess capacity and/or physical plant space that could be used by an energy district. Energy producers with these characteristics may be suitable partners for establishing a new energy district.

Energy Density of the Energy Island – Weight 4.0

The compactness of the energy used within the energy island is important because the length of piping is a critical financial factor in developing a district heating system. Due to this relatively high level of importance, a weight of four was assigned to this criterion.

Future Energy Use for Redevelopment Districts – Weight 1.0

One consideration for evaluating each energy island is the potential for additional energy consumption due to future development activity. City planning data collected from Saint Paul and Minneapolis identified redevelopment districts within these cities. In most cases, plans for redevelopment districts included predicted land use and forecasts of square footage of buildings that may be constructed within the site. The method used for estimating heating load for existing land uses described was used for estimating future energy consumption. Because estimates of future energy use are uncertain and in some cases highly speculative, a weight of one was assigned to this criterion. Note that future energy use was not used in developing energy islands.

Finding: Components of the energy system (production, distribution, consumption, and renewables) were evaluated through a complexity scale (low, medium, high). Complexity can be determined by an assessment of the most likely technical, financial, and market scenarios. The complexity scale allows system developers to determine the value of advancing an opportunity to the feasibility study stage.

2.7.1 Scoring methodology

To complete the evaluation, each energy island was ranked based on a total score. To score each energy island, the energy data, or raw scores, collected for each criterion were converted into a normalized score. Normalized scores are between zero and one, where a normalized score of one is given to the highest raw score (energy data). All other energy data were assigned a normalized score representing the ratio of the raw score to the highest raw score. Estimated energy consumption and production and energy density, along with cluster weight are shown in Tables 1 and 2.

Finding: From a review of dozens of potential energy islands, we confirmed a dozen islands in Minneapolis and Saint Paul that have viable energy providers and dense energy users interested in collaborative energy planning and multi-nodal system development.

Table 1. Estimated Thermal Energy Consumption (Weight 5.0) and Production (Weight 4.0)				
Cluster Name	Estimated Thermal Energy Consumption	Normalized Score	Estimated Thermal Energy Production	Normalized Score
	(KWh_t)		(MWh_t)	
Industrial A	204,299	1.000	2,117,723	1.000
Campus A - Existing Systems	116,480	0.570	1,032,420	0.488
Corporate A	150,158	0.735	786,852	0.372
Hospital A	119,421	0.585	236,244	0.112
Industrial B	153,856	0.753	148,779	0.070
Industrial C	76,252	0.373	277,074	0.131
Mixed Use A	90,016	0.441	91,182	0.043
Mixed Use B	67,554	0.331	34,808	0.016
Commercial-Industrial A	41,816	0.205	15,998	0.008
Industrial D	66,778	0.327	10,958	0.005
Mixed Use C	43,712	0.214	24,846	0.012
Mixed Use D	41,291	0.202	0	0.000
Industrial D	44,034	0.216	182,742	0.086
Mixed Use E	7,476	0.037	15,881	0.007
Campus B - Existing Systems	68,955	0.338	39,555	0.019
Mixed Use F	46,205	0.226	2,364	0.001
Mixed Use G	39,782	0.195	94,108	0.044
Mixed Use H	22,016	0.108	15,060	0.007
Mixed Use I	34,969	0.171	6,036	0.003
Mixed Use J	32,398	0.159	11,113	0.005
Mixed Use K	15,699	0.077	23,499	0.011
Mixed Use L	43,789	0.214	9,690	0.005
Mixed Use M	27,867	0.136	16,584	0.008
Commercial-Industrial B	17,782	0.087	1,758	0.001
Industrial E[5]	N/A	N/A	N/A	N/A
Total	204,299		2,117,723	

[5] Industrial Cluster E was reviewed for one facility's waste heat production capacity. There is not an existing user group to receive the energy so a cluster boundary was not designated.

Table 2. Estimated Thermal Energy Density per Cluster (energy island) – Weight 4.0			
Cluster Name	**Cluster Area**	**Thermal Energy Density**	**Normalized Thermal Energy Density**
	(Acres)	(MWh/Acre)	
Industrial A	765.7	267	0.790
Campus A - Existing Systems	366.4	318	0.941
Corporate A	742.8	202	0.599
Hospital A	419.8	284	0.842
Industrial B	804.4	191	0.566
Industrial C	250.4	304	0.901
Mixed Use A	315.4	285	0.845
Mixed Use B	226.8	298	0.882
Commercial-Industrial A	123.8	338	1.000
Industrial D	240.1	278	0.823
Mixed Use C	159.2	275	0.813
Mixed Use D	144.8	285	0.844
Industrial D	190.5	231	0.684
Mixed Use E	22.1	338	0.999
Campus B - Existing Systems	371.3	186	0.550
Mixed Use F	199.2	232	0.687
Mixed Use G	195.1	204	0.604
Mixed Use H	98.1	224	0.664
Mixed Use I	184.4	190	0.561
Mixed Use J	171.8	189	0.558
Mixed Use K	73.0	215	0.637
Mixed Use L	294.5	149	0.440
Mixed Use M	173.5	161	0.475
Commercial-Industrial B	130.8	136	0.403
Industrial E	N/A	N/A	N/A
Total		338	

2.8 Description of existing energy districts

Three energy districts exist in the Twin Cities area: the downtown Minneapolis system operated by NRG, the downtown Saint Paul system owned by District Energy, and the smaller Energy Park system owned by the Saint Paul Port Authority. The two latter systems are operated and managed by Ever-Green Energy. These three existing energy districts represent a broad range in both energy use and end-user characteristics. These districts are detailed on the following pages in order to provide a useful point of comparison in describing the identified high-priority energy islands resulting from the evaluation[6].

2.8.1 Energy Park

Energy Park is the smallest system at 182 acres with an estimated energy load of 55,500 MWh per year. The Energy Park system also has the lowest energy density of 300 MWh per year for each acre. Most of Energy Park's end users are concentrated in three sectors: office, multi-family, and industrial. While more than half (54 percent) of Energy Park's end users belong to the office sector, multi-family end users account for 23 percent and industrial end users 18 percent, making them significant sectors. The Energy Park system would receive a ranking of 19 (of 25) if it had been included in the scoring and ranking system for the energy islands.

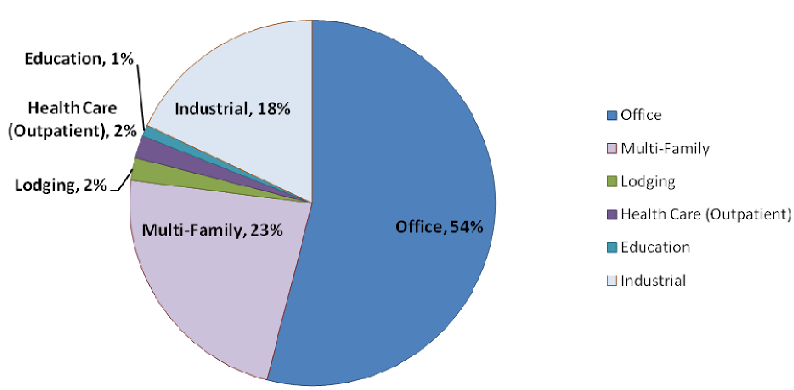

Figure 7a. Energy Park Building Profiles

2.8.2 Downtown Saint Paul

With a service area that covers 760 acres, the downtown Saint Paul energy system is the largest of the three systems. Total energy used in this area is estimated at 594,000 MWh per year and energy density is estimated at 780 MWh per year for each acre. While this density is over twice that of Energy Park, it is less than the estimated density of the downtown Minneapolis energy district. The downtown Saint Paul system, while dominated by office end users, includes a greater diversity of end users than the Energy Park system. Nearly 60 percent of the end users are office buildings. Lodging and multi-family sectors represent 14 percent and 8 percent of the system's end users respectively. The system also serves a wide variety of other end users, each representing 5 percent or less of the system's energy usage. The Saint Paul system would receive a ranking of six (of 25) if it had been included in the scoring and ranking system for the energy islands identified.

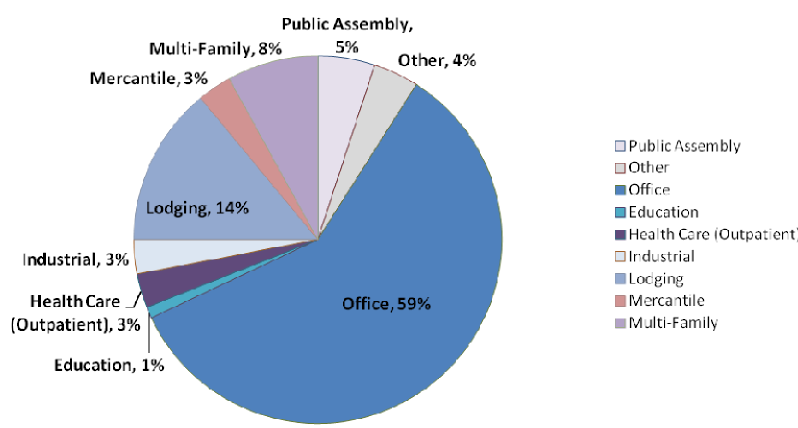

Figure 7b. Downtown Saint Paul Building Profiles

[6] Building use data is based on information available from city and county tax data. Square footages for in-patient hospital care are split between multiple uses.

2.8.3 Downtown Minneapolis

The service area of the downtown Minneapolis energy district is 413 acres and relatively compact compared to the Saint Paul system. With an estimated energy load of 824,000 MWh per year, the Minneapolis system has an estimated energy density of nearly 2,000 MWh per year for each acre. This is significantly higher than either of the other two energy districts. The downtown Minneapolis system has a customer profile similar to the Saint Paul system. The Minneapolis system is dominated by office users (61 percent) with the lodging sector at 8 percent. A wide variety of other sectors are present, each with 6 percent or less of the system's energy usage. The Minneapolis system would receive a ranking of 2 (of 25) if it had been included in the scoring and ranking system for the energy islands identified.

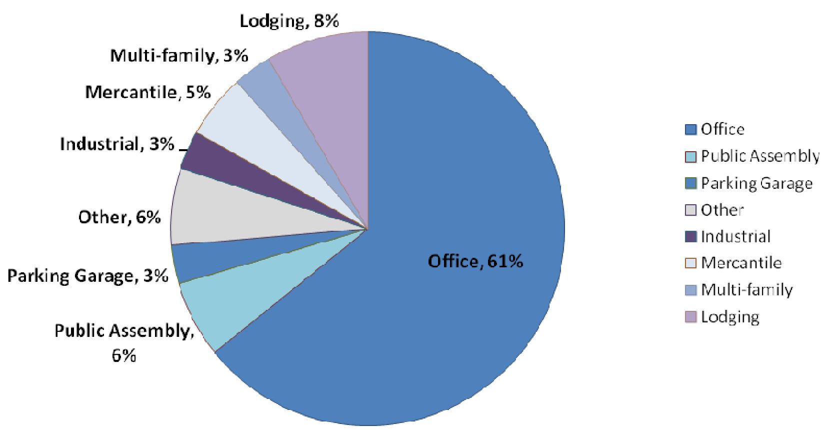

Figure 7c. Downtown Minneapolis Building Use Profile

Section 3.0

ENERGY PRODUCTION

3.1 Scope and purpose of energy production analysis

A primary requirement of an energy island is the existence of one or more energy producers. Producers are considered any facility with major on-site energy generation. Such facilities are typically associated with industrial activities or large commercial and institutional facilities. These facilities may have excess capacity or generate waste heat from the production process that could be used in a district heating system; however, in general, their energy use is consumption. The energy production of these facilities is an additional indicator of the energy size of each energy island. Once a producer's excess capacity or waste energy potential can be verified, it can be considered a potential contributor to a system.

Additionally, electricity producers can serve as major sources of heat by shifting to combined heat and power (CHP).[7] The recovery and reuse of waste heat using CHP offers an opportunity to improve grid reliability, increase efficiency, and produce thermal energy for a community, industrial processes, or both. Recovering and using wasted heat from industry in neighboring buildings is another opportunity available to communities desiring diversification and efficiency of energy supply.

This energy can be distributed as steam or hot water to buildings for space heating and cooling, heating domestic hot water, or to drive industrial processes. The scope of this energy export ranges from a single additional user to a campus or multi-use downtown district.

The development, improvement, or expansion of energy islands does not require the pre-existence of a contributing facility. New energy production assets are often developed to support economic growth and the start-up or expansion of district systems. For the purposes of this study, we primarily examined areas that could be supported by existing assets in order to accomplish the following goals:

- ⇒ Reuse existing capital investments.
- ⇒ Increase production efficiency by examining highest best use of existing assets (ex. increasing a boiler's current usage from 30-80% to increase efficiency).
- ⇒ Promote additional connections between islands and systems to increase opportunities and overall efficiencies.
- ⇒ Opportunities to capture waste heat from electricity production and manufacturing.
- ⇒ Reduce greenhouse gas emissions by unlocking efficiency gains.

[7] CHP is a process that recovers the waste heat that is produced when a fuel is converted to electricity.

Given these priorities, energy production was a slightly higher priority for examination of clusters, although consumer load analysis was completed almost concurrently. For a facility to be considered as a contributer, it needed to offer the potential to serve an existing load or future development. Some opportunities were not pursued because the chances of increased density, load, or development were considered too small.

The verification of load played a major part in final consideration of a production facility's viability. The complexity of developing any potential production assets is measured by the quantity and consistency of demand, quantity and consistency, of heat available from the facility, the forecast for energy availability, the cost to recover that energy, and the facility's level of business interest. For purposes of this study, these areas were generally examined with the exception of the cost to recover energy. All of the factors noted in a production assessment can be very technical and very specific to a facility and its service district and should be analyzed during the feasibility study stage.

System planners may consider engaging utility and industrial partners during an earlier phase of analysis or during their standard comprehensive planning efforts. Based on the results of this study effort, the following information should be aggregated for the consideration of energy island integration planning:

- ⇒ Industrial studies (increases or decreases in manufacturing, processing, or other industrial applications)
- ⇒ Utility resource plans
- ⇒ Comprehensive planning efforts that include food processing, breweries, or health care facilities (these tend to require consistent heat loads)

3.2 Examine study area and clusters for contributor facilities

During the first phase of the study, a 90-square mile study area was analyzed to identify the highest-potential production facilities for contribution to a system. The initial screen was a basic approach to gather additional data that would determine whether a facility stayed in consideration. The results of this initial screen identified over 100 potential facilities for further assessment.

This study was initiated to maximize the opportunity created by the construction of the major light rail corridor between the downtown areas of Minneapolis and Saint Paul. The research area was initially established within the city boundaries of Minneapolis and Saint Paul. Any facilities along the city boundaries were included in the study. Additional facilities were included in subsequent evaluations based on the potential valuation of their production assets and ability to contribute to a system.

3.3 Determine potential production (or contributor) facilities

3.3.1 Defining optimal production assets

Energy islands are defined by having either a major production facility or major energy consumer(s). Ideally the system has both, which can be connected for greatest benefit. In the absence of one or the other, production assets and user groups could be developed to maximize the opportunity for system efficiency.

In considering production opportunities, system planners should first consider what they already know about a given study area. Create an inventory of major facilities including industrial producers, hospitals, college campuses, major commercial hubs, transit centers, and other energy intensive applications. These facilities frequently utilize industrial-scale boilers or manufacturing equipment that could become a source for heating through the capture of stranded energy (waste heat or excess capacity).

These opportunities were initially evaluated by relying on Barr and District Energy/Ever-Green's decades of experience serving Saint Paul and contributing as a subject matter expert to energy projects throughout the Twin Cities metro. The initial list included 41 facilities within the study area.

3.3.2 Methodology for identifying energy producers

Production facilities were evaluated based on their ability to contribute to a system, which was secondarily assessed by the scale of existing production assets. Actual energy production data may not be publically available. System planners may choose to partner with local utilities to evaluate and develop energy islands. In these cases, production and consumer data could be made available by the utility. In other cases, local government units (LGUs) may require reporting of fuel usage, emissions, or other data that can be utilized during this phase of evaluation.

For this study, Barr Engineering evaluated air emissions data from the Minnesota Pollution Control Agency (MPCA, 2008) and used this as a proxy to identify facilities and to estimate energy production. Nitrogen oxide (NO_x) emissions were used as an indicator because NO_x is a product of conventional combustion that occurs across all fuel types. The amount of NO_x emitted by various fuel-combustion scenarios is well understood. MPCA data indicated that there are 138 facilities reporting NO_x emissions in the study area, 29 of which have estimated energy production exceeding 10 mmBtu/hr (~ 26,000 MWh/year).

The relationship between annual NO_x emissions and annual MWh used in the study follows:

Annual MWh = Annual NO_x Emissions (US tons) x 2,000 lbs/ton x 2.930 MWh/lb

This estimate relies on the correlation between NO_x emissions from natural gas–fired utility boilers and the amount of natural gas burned to provide a first-cut indication of significant energy production. The relationship above uses the assumption, based on a review of emissions data, that 0.1 lbs of NO_x was generated for each million Btu of natural gas consumed. The assumed relationship between NO_x and annual MWh production is less reliable for industrial process emissions that rely on heating equipment other than process boilers.

The energy use for each parcel calculated using NO_x emissions data was compared to the energy use estimate based on building square footage. The larger of the two values was assigned to the parcel on which the facility resides. The consumer-energy-use value was added to the producer-energy-use values to estimate total energy for each energy island.

Finding: Public data sets can be used to identify potential contributors based on a minimum threshold for production assets (the availability of this information and its source may vary from state to state).

3.4 Establishing clusters and viable contributors

The NO_x emissions analysis presented twenty-nine facilities that could potentially serve as contributors to an energy system. In order to narrow the field to the most viable candidates for evaluation, the consumer load was evaluated for the study area (see Section 4.0 Energy Consumers). Clusters were identified based on the presence of a contributor facility and proximate energy density. Energy density of district systems can vary widely. Three of the existing commercial district systems within the study area present densities of 300 MWh/acre, 1990 MWh/acre, and 780 MWh/acre for the existing Energy Park, NRG, and District Energy St. Paul systems, respectively. The functional density of each is based on the technical and economic integration of production, distribution, and consumer factors (see Section 7.0 Integration).

Once clusters were established, four production facilities were removed from consideration based on current user density and low potential for future development. Twenty-five facilities remained in consideration for evaluating contribution potential.

3.5 Evaluation of waste heat for system contribution

Waste heat is thermal energy created as a by-product of a process that is disposed of through cooling towers or otherwise exhausted to the environment. Utilizing wasted heat promotes the use of stranded energy and the conservation of fossil fuels.

There have been many past studies of sources of industrial waste heat. Waste heat is often captured for reuse in industrial processes like pre-heating process, boiler feed water, or make-up air. In our limited survey of commercial facilities in the study area, we found that many boilers are over twenty years old and do not have built-in economizers. These sites had the highest temperature exhaust gases and presented some of the better opportunities for recovery.

3.5.1 Viable waste heat recovery

Using waste heat in a district heating system has minimum technical requirements. To be technically viable, waste heat must be:

- ⇒ captured or lifted to a temperature to be reused by consumer buildings,
- ⇒ available consistently and predictably,
- ⇒ and the quantity and reliability of heat must justify the equipment necessary for recovery.

Temperature is a critical indicator in assessing potential for recovery. Using waste heat for district heating or district cooling directly depends on the standard design supply and return temperature of the district energy system of interest. If the waste heat is not at a higher temperature than the return temperature of the district system, then it cannot be used directly in the production of supply water. Rather, if it is still to be used in the district energy system somehow it must be used for preheating boiler feedwater or air, or the temperature must be boosted by boilers or heat pumps.

Table 3. Samples of Waste Heat[8]

Temperature Range	Example Sources	Temperature
High	Steel Electric Arc Furnace	2500°F
Over 1200°F	Aluminum reverberatory furnace	2000°F
	Glass melting furnace	2400°F
Medium	Steam boiler exhaust	450°F
From 450°F to 1200°F	Gas turbine exhaust	700°F
	Heat treat furnace	800°F
	Drying and baking ovens	450°F
Low	Process steam condensate	130°F-190°F
Under 450°F	Cooling water	80°F-200°F
	Exhaust gases from recovery units	150°F-450°F

[8] "Waste Heat Recovery: Technology and Opportunities in U.S. Industry." US Department of Energy, Industrial Technologies Program. 2008

3.5.2 Utilizing low-grade heat

Harvesting energy from waste heat sources can be a significant source of cost-effective energy for district heating operations. The energy captured from waste heat sources is often reduced to a lower grade or lower temperature than the initial process input and is often referred to as low-grade heat. Such sources include solar heat, incinerator and boiler waste heat, air or water cooled equipment, and exhaust gases from industrial processes.

Since the sources of low-grade water temperature will be limited by the maximum water temperature, the system will usually need to be supplemented with a higher water temperature source during colder weather to safely meet peak winter heating demands.

There should be a market for low-grade heat in new planned multi-use property development design and construction. Energy advisors can supply developers with key performance guidelines for the maximum and minimum district water service temperature and other pertinent information for the users terminal equipment selection.

Most district heating systems in North America are based on steam distribution and are to be considered high temperature (above 250°F). Steam district heating would not use waste heat directly to create steam but rather preheat boiler feed water or makeup air as in an economizer. Some district systems use hot water for energy distribution at temperatures between 250°F and 180°F. A hot water system operating under 180°F is to be considered low temperature. Medium and low temperature hot water systems would be more likely to use waste heat directly in distribution to consumers.

3.5.3 Heat pumps

Thermal energy sources are all around us. The challenge is matching the source with an equivalent use. When a thermal source like waste heat is at a temperature too low to be used directly, then an electronically driven heat pump may be able to boost the heat to a useful temperature.

Heat pumps at a very simple level are air-conditioners running in reverse. Heat is concentrated in a heat sink by using a refrigerant evaporation-condensation cycle. Most heat pumps available in the US have an output temperature of 140°F. Some models emerging on the market can reach 179°F. Heat pump performance is often measured as a Coefficient of Performance (COP). This means for every unit of electricity used in the heat pump, more units of thermal energy are produced. A heat pump COP of 3 indicates 3 units of thermal energy are produced from 1 unit of electricity consumed.

3.5.4 Consumer HVAC system considerations

For district heating, waste heat might be most feasible in cases where the designed supply temperature is under 180°F. Special circumstances would be needed where buildings served by the low temperature district system were designed specifically to operate on a low temperature system. Converting an existing building with a "typical" hydronic system that requires a supply temperature of 180°F could be cost-prohibitive in some cases, but new buildings or HVAC systems can be designed to utilize lower temperatures. Fan coils generally need more rows to utilize lower temperatures effectively, for example. However, with a lower temperature system more sources of waste heat would be available and higher temperature sporadically available sources could be exploited through thermal storage.

3.5.5 Availability of high quality, high volume waste heat

If waste heat temperatures above 250°F were consistently available, a medium temperature district heating network could be developed without a total overhaul of most types of existing commercial building HVAC systems. Waste heat at these temperatures in useful quantities usually occurs in heavily industrial areas such as near steel mills, metal foundries, glass factories, or cement kilns. Heavy industrial zoning usually means there are fewer users available to take advantage of the waste heat used in a hypothetical district heating system.

3.5.6 Waste heat identified in Green Line corridor

Within the energy island study area, multiple facilities surveyed had technical capability to capture waste heat for system contribution. Some posed challenges for capturing a high enough grade of waste heat for a major system. This configuration would require boilers or heat pumps or other temperature boosts to meet the export requirements. Others had a high enough grade but did not have an existing or dense enough user group to justify short-term development of the production asset.

Industrial clusters A and B indicated the right balance of available heat and proximate demand to warrant further exploration of their waste heat assets.

3.5.7 International example of waste heat for district heating

In Sweden, waste heat accounts for approximately 22 percent of the source energy for district heating, according to the Swedish District Energy Association. As examples, two of the district heating systems use waste heat to serve Swedish municipalities and the third is used at a large car manufacturing campus. The two municipal utilities receive 194°F supply water from the refineries and 120°F return water. The manufacturer receives 266°F water and returns 194°F water.

3.6 Evaluation of excess capacity (stranded energy) for system contribution

One of the key research concepts in this study is determining if large commercial or industrial facilities with excess capacity can export energy to neighboring users. In many systems, this excess capacity is not only under-utilized but the current system curtails or disallows any use of that capacity. By evaluating its potential, facility managers and system planners can determine the value of that capacity and determine the potential for expanding or integrating the system for higher, better usage.

This study defines excess capacity as any existing heating equipment that is beyond what a given facility needs to safely meet its peak seasonal demand.

There are four primary steps to determining excess capacity for a facility or existing system:

- ⇒ Estimate building peak thermal demand.
- ⇒ Inventory existing energy production equipment.
- ⇒ Calculate building firm capacity.
- ⇒ Calculate excess capacity where firm capacity is in excess of peak demand.

3.6.1 Building operations and peak demand

Excess capacity ultimately depends on the peak demand of the facility or system. A building's maximum or peak heating demand will occur at the coldest time of the year. In the northern hemisphere, this is often in the month of January. Firm, or N+1 [9] capacity, refers to the existing equipment capacity available when the largest boiler is not available for dispatch. Peak demand is safely met when a building's firm capacity meets or exceeds it.

Peak demand can differ annually depending on winter weather. Determining peak demand involves looking at past fuel consumption for heating and speaking with building operators to get an idea of how the building's physical plant operates under heavy load conditions. It is important to note that peak demand is an estimate that will depend on winter conditions and occupancy requirements that may vary from year to year.

Every building operates differently depending on its use. A facility may have existing excess capacity, but future market conditions may cause the amount of available excess capacity to shrink or expand accordingly. Operating conditions change with occupancy, operating objectives, or conservation initiatives.

3.6.2 Example of an excess capacity evaluation

A 200,000 ft^2 office building has two 1 mmBtu/hour high pressure steam boilers and one 1.5 mmBtu/hour boiler. Its peak heating demand in January is 1.3 mmBtu/hour. If its largest boiler is unavailable at a period of peak demand, there are still two boilers (total 2 mmBtu/hour) that can handle the building load. Excess capacity in this case is firm capacity less the peak building demand.

$$\text{Excess Capacity} = \text{Firm Capacity} - \text{Peak Heating Demand} = 2\ \frac{\text{MMBtu}}{\text{hr}} - 1.3\ \frac{\text{MMBtu}}{\text{hr}} = \mathbf{0.7}\ \frac{\textbf{MMBtu}}{\textbf{hr}}$$

$$\text{Firm Capacity} = \left(1\ \frac{\text{MMBtu}}{\text{hr}} + 1\ \frac{\text{MMBtu}}{\text{hr}} + 1.5\ \frac{\text{MMBtu}}{\text{hr}}\right) - 1.5\ \frac{\text{MMBtu}}{\text{hr}} = \mathbf{2}\ \frac{\textbf{MMBtu}}{\textbf{hr}}$$

[9] N+1 is a method of analyzing system redundancy. N represents the components necessary for the system and +1 represents the independent backup component.

3.6.3 Benefits of multiple facilities or systems in contributing to excess capacity

In a system where two or more facilities are connected by a district heating network, an increase in excess capacity can occur if both facilities can produce energy that is exportable on the system.
If the building in the previous calculation is connected to another building of the same size, equipment configuration, and load profile, excess capacity increases with the additional firm capacity gained by running both buildings as one larger system.

Network Firm Capacity

Building A Total Capacity + Building B Total Capacity – Largest Boiler

$$=3.5\ \frac{\text{MMBtu}}{\text{hr}} + 3.5\ \frac{\text{MMBtu}}{\text{hr}} - 1.5\ \frac{\text{MMBtu}}{\text{hr}} = \mathbf{5.5}\ \frac{\textbf{MMBtu}}{\textbf{hr}}$$

Network Excess Capacity = Firm Capacity – Total Peak Heating Demand

$$=5.5\ \frac{\text{MMBtu}}{\text{hr}}\quad 2.6\ \frac{\text{MMBtu}}{\text{hr}} = \mathbf{2.9}\ \frac{\textbf{MMBtu}}{\textbf{hr}}$$

By linking the two buildings' heating equipment through a district energy network, the effective excess capacity is increased; in this example, from 0.7 mmBtu/hr to 2.9 mmBtu/hr.

3.7 Additional feasibility considerations

Once excess capacity or waste heat potential is identified and confirmed through additional data collection, system planners should consider a feasibility study to confirm assumptions. If the information is readily available, system planners should gather additional information about economic conditions.

3.7.1 Policy conditions and regional Markets

Each state, region, and individual market or project will have unique market considerations that may benefit the project economics. Many states now have thermal energy policies that may be benefit to waste heat or excess capacity applications. Additionally, variability in fuel markets and economic conditions should be closely considered before proceeding with development.

3.7.2 Evaluation of demand (market penetration)

Demand evaluation is reviewed in Section 4.0 Consumer Load. For the purposes of production and integration analysis, a market penetration of 60 percent was considered the minimum threshold.

3.7.3 Estimating additional costs:

- ⇒ Collect current equipment and material quotes for production, distribution and service line equipment through virtual bidding or institutional information
- ⇒ Collect labor and installation estimates for equipment and materials
- ⇒ Estimate additional cost factors, including financing, legal, administrative, design, operation, and maintenance
- ⇒ Extrapolate long-term costs
- ⇒ Annual change value
- ⇒ Capital costs
- ⇒ Outage percentages
- ⇒ Thermal storage
- ⇒ Cost based rates
- ⇒ Franchise fees

3.8 Weighing the potential for additional study

Section 3.9 showcases the results of a production facility study completed for potential contributors within the Green Line corridor. In addition to applying the production study process above, facilities were evaluated to determine the validity of the production estimating techniques as well as the actual viability of using the facility as an anchor or satellite facility for an extended or new district. This allowed our research team to identify four facilities with the best technical and economic scenarios based on the potential energy contribution and the estimated consumer load. The additional evaluation of these clusters is discussed in Section 7.0 Integration. The work represented in the survey summary and integration section may require additional resources and engineering expertise. We recommend using the survey and integration efforts as a milestone to consider additional technical and economic partners for pursuit of a feasibility study.

Findings:

⇒ Public data sets can be used to identify potential contributors based on a minimum threshold for production assets (the availability of this information and its source may vary from state to state).

⇒ The production complexity scale is based on the quality and quantity of heat available from existing or potential facilities, the forecast for that heat's availability, the facility's willingness or interest in selling this heat, and the viability of the proximate consumer load.

3.9 Green Line production survey

3.9.1 Survey approach

A survey was developed as a means of documenting a production facility's ability to be a contributor. Twenty-five facilities were initially identified for survey. Sixteen facilities were surveyed with varying degrees of data collected. The methodology includes development, process, data collection, and survey results.

3.9.2 Survey – Phase 1

The intent of the survey was to test the initial evaluation process used to identify potential contributor facilities. The base information required was:

- ⇒ Facility Name
- ⇒ Facility Manager (Contact Name)
- ⇒ Size of area served (ft^2)
- ⇒ Equipment that consumes the majority of the fuel and their capacity, fuel used
- ⇒ Purpose or process for the equipment
- ⇒ Peak usage of each major piece of equipment
- ⇒ Amount of each fuel consumed last year

3.9.3 Survey – Phase 2

If initial survey results were promising and the survey participant was interested, a facility site visit was conducted. Additional information was collected to determine the interest of the facility, to further test hypothetical information, determine fit for a case study, and explore system integration.

Our research team determined that facility tours helped clarify misunderstandings and inconsistencies in the survey. Additional questions and clarifications would inevitably develop during the facility tour. It was common for a facility contact to miss or misrepresent their capacity. Following are examples.

Table 5. Examples of Survey Results[10]

Facility	Source	Comments
Foundry	Electric Melting Furnace	Waste heat available. Additional study needed to determine recovery method.
	Heat Treat Furnace	Waste heat available. Additional study needed to determine recovery method. Vents to open room.
	Make-Up Air Unit	Small heater. No obvious opportunity for recovery.
	Boiler	This is a small office boiler. No obvious opportunity for recovery.
	Pre-Heat Oven	Opportunity for excess capacity recovery. The 10 mmBtu/hr burner is only used 16% of the time.
Steel Mill	Reheat Furnace	27.5 mmBtu/hr could be recovered in the exhaust 24/5.
	Heat Treat Oven	There is an abundance of waste heat. Vents to open room.
	Ladle Pre-Heater	High heat but intermittent operation.
	Oxy Fuel Burners	High heat but intermittent operation.
	Hot water discharge	Additional data needed.
Paper Mill	Boilers	Medium temperature with opportunity to recover.
	Dryers	High flow high humidity (65% RH)
Electroplating	Condensing Boilers	Low temperature clean exhaust.
	Make Up Air Units	Small heater. No obvious opportunity for recovery here.
Water Treatment	Incinerator W/Boiler	Low temperature exhaust. They have 3000 LB/HR of extra steam available.
Electricity Generator	CHP	Opportunity for combined heat and power.
College Campus A1	Boilers	Multiple campuses with varying resource statuses. Sub-campus 1 offered an opportunity for CHP development to fulfill heat needs.
College Campus A2	Boilers	Sub-campus 2 offered excess capacity potential.
College Campus C	Boilers	Excess capacity offered potential.
Hospital	Boilers	Multiple boilers showed high temperature clean exhaust available for recovery and medium temperature with opportunity to recover.
Museum	Boilers	Medium temperature with opportunity to recover.

[10] Facilities are named by their primary function. Not all facilities have a direct correlation to the name provided for identified energy islands.

3.9.3.1 Equipment verification for waste heat

In the load estimate calculations the survey results are evaluated. The equipment capacity, load, and annual fuel consumption were analyzed and it was determined if the numbers balanced out, within reason. It was normal for energy and power to be represented using many different units. This included but was not limited to, Btu, mmBtu, kWh, MWh, Bboiler horsepower, pounds/hour steam, mmBtu/hr, MW, etc.

3.9.3.2 Case Study: Industrial Facility D

Utilizing the study methodology and follow-up survey, Industrial Facility D's natural gas consumption for the previous year was determined to be 5.12 E+04 mmBtu.

Table 6. Industrial Facility D equipment capacities and utilization

Utilization	Source	Annual Contribution
70%	Heat Treat Oven	3.53 E+04 mmBtu/Year
16%	PreHeat Oven	1.34 E+04 mmBtu/Year
60%	Make-Up Boilers	5.04 E+03 mmBtu/Year
Total		5.38 E+04 mmBtu/Year

- ⇒ **A foundry plant manager completed a survey prior to our team touring the facility. During the tour it was discovered that there was a 10 mmBtu/hr pre-heat oven that wasn't captured on the original survey completion. This oven was only used about 16 percent of the time leaving a good opportunity for capturing excess capacity.**
- ⇒ **A steel mill plant manager completed a survey prior to the plant tour. The original survey indicated the heat treat oven had a total capacity of 60 mmBtu/hr. During the tour it was determined that their heat treat oven had twenty (20) burners at 60 mmBtu/hr.**

Finding: To verify the predictive modeling for production assets, a survey was conducted with the following results:

- ⇒ The majority of facilities surveyed expressed interest in exploring energy uses beyond their own facility boundaries.
- ⇒ The majority of production facilities in this region have opportunities for selling excess heat.
- ⇒ Facility managers are looking for ways to cut costs or improve income streams and have considered one of the following options:
  - ♦ Increase the amount of on-site combined heat and power (CHP) or develop new CHP capabilities.
  - ♦ Bridge existing gaps in systems to reduce unnecessary equipment use.
  - ♦ Improve system efficiency.
  - ♦ Engage third party providers to manage their energy systems.
  - ♦ Utilize renewables in a more effective manner.

Section 4.0

ENERGY CONSUMERS

4.1 Scope and purpose of energy consumer analysis

Producers and consumers are clearly a critical component of energy island analysis and integration. Section 3.0 identified the approach and findings for production analysis. The energy consumer section establishes the methodology for analyzing consumer load, findings from the cluster analyses, and concepts for taking the complexity ratings and methodology into consideration for additional project development.

According to the Department of Energy 2011 Quadrennial Technology Review, buildings are responsible for just over 40 percent of all energy consumption in the United States. Energy consumption and production are directly linked. Matching efficient energy generation with corresponding use is critical. If there is no use for the energy then there is no reason to create or enhance energy production. The energy island concept of harnessing underutilized energy sources depends on where energy consumption exists to take advantage of it. A critical piece of the study involved researching and understanding energy consumption rates across the study area.

System planners may be able to establish consumer information during a pre-feasibility planning effort.

In developing the energy island inventory the consumer load sections of this report, the research team relied on the public information available to most system planners and development agencies, including the following:

- ⇒ City comprehensive plans and zoning overlays
- ⇒ Neighborhood plans
- ⇒ Station area plans for the Green Line
- ⇒ City and county tax databases
- ⇒ National databases for building consumption averages (also available from state and regional planning offices)

The planning and zoning documents allowed our team to make assumptions about the future development or market potential for an area. Areas targeted for increased development, which is an indicator for energy density, were considered higher potential for market saturation and consumer load viability. Tax databases establish building square footages but should only be used during pre-feasibility efforts. Advanced system planning requires the confirmation of the tax data and verification of actual building space, usage, and consumption.

The consumer analysis is an essential component of any development. We recommend that system planners work closely with industry partners when considering additional feasibility efforts. This may include business organizations, facility management organizations, planning and economic development agencies, engineering firms, or local utilities.

4.2 Considerations for property developers and designers

District energy services are often located in dense urban areas and medical and university campuses. Urban property developers and designers are sometimes unaware of the existence of district energy systems in new areas they serve.

Due to this potential gap, property developers and designers were surveyed to gain insight into energy decisions during the design process. We asked developers at what point in the design process is energy taken into account? Does the developer have any knowledge or experience dealing with district energy utilities? What are the current trends in urban property development? Are there circumstances where district services work better than others?

Property developers are highly attuned to the markets they serve. As in any decision, up-front capital costs and longer term operation and maintenance costs all impact the choice of heating service. These costs were emphasized in conversations with developers during the study. State building codes are also a large influence on the final design of a new building. If exceeding building codes by using high performing materials increases initial costs, the short and long term financial impacts are closely weighed.

4.3 Market saturation

Whether during pre-feasibility analysis or advanced system planning, market saturation can play a key role in developing the system economics. For the purposes of this study, 60 percent market share was used most commonly to evaluate the load potential. This assumes 60 percent of available load will connect to a district energy system if available. Each project will have a different economic and technical tolerance level for this market saturation rate.

Case Study B – This cluster was evaluated under multiple scenarios with final analysis completed for 60 and 100 percent market saturation. The 60 percent scenario equates to approximately 12,180 kW and would exceed the available energy from the primary contributor facility in the cluster. The following considerations would be needed for feasibility planning and economic analysis:

- ⇒ **What percentage of the existing load is easily converted to a hot water district system?**
- ⇒ **What is the likelihood of additional short-term development?**
- ⇒ **Based on density, distribution, and price/kW, what is the ideal threshold for system start-up?**
- ⇒ **What is the potential to increase production capacity from the anchor contributor? Or what satellite facilities could also contribute?**

Finding: A consumer load minimum can be difficult to determine because a load's viability is heavily determined by the localized production and distribution potential.

4.4 Energy consumption within the study boundaries

For the purposes of this study, estimates were primarily based on building square footage and available information for average energy usage. Natural gas energy use for each parcel was estimated by multiplying natural gas use per square foot times the building square feet. Estimates of natural gas use per square foot for different building-activity types were provided by the 2003 Commercial Buildings Energy Consumption Survey (CBECS) produced by the Energy Information Administration/ U.S. Department of Energy (DOE) and the 2009 Minnesota Gas Energy Efficiency Potential study produced by Navigant Consulting. Building activities were reconciled and attributed to land-use descriptions provided on county parcel data (Table 7).

The DOE CBECS data has the benefit of surveying many facilities across many climate zones. The data used for this study are for Climate Zone 1 that includes Minnesota. However, other climate zones apply to areas across the United States. Land-use descriptions were obtained from county parcel data. Parcel data were collected from Ramsey, Hennepin, and Washington counties for the study area. Land-use categories included in parcel data are not standardized across counties. These land-use descriptions were reclassified into 17 classes for consistency across the study area (Table 7).

Building square footage was obtained from Ramsey and Washington counties and the city of Minneapolis. Counties and cities keep track of building square footage to determine estimated market value for tax purposes. Parcel data may be available from local government entities in other areas considering this research.

In a few circumstances, building square footage data and/or land descriptions were not available. Land use for parcels missing assigned land-use classification was determined using 2010 aerial photography (Minnesota DNR) and/or internet searches. Where building square footage was not available in the city or county building data, building height and footprint information were obtained from the National Geospatial-Intelligence Agency (NGA, June 2007). The NGA estimated building outlines and heights using feature-extraction software and GIS-based LiDAR elevation data acquired prior to the Republican National Convention, held in Saint Paul in 2008. In cases in which parcels were located outside of the area that NGA data were available, the building footprint was digitized from aerial photography.

Using the building square footage and energy-usage data, energy use per parcel was estimated using the following relationship:

Parcel Energy Use (natural gas, ft^3) = Building ft^2 x DOE and Navigant natural gas use per square foot for different building types

Annual MWH per parcel = Parcel Energy Use (natural gas, ft^3) x 0.000293 MWh/ft^3 natural gas

> *Finding:* Public data sets can be used to identify potential energy users (the availability of this information and its source may vary from state to state).

4.5 Other energy consumption models

The DOE CBECS survey data used in this study were compared to other building energy use models, such as the State of Minnesota sustainability building guideline, Sustainable Building 2030. It sets goals of reducing energy usage in new buildings and major retrofits that the state is constructing or funding. Note that on-site natural gas consumption and use depends on the efficiency of energy conversion from fuel to useful space or water heating. An 80 percent conversion efficiency was assumed and the reduced quantity was defined as “energy use” as distinguished from energy consumption. Newer boilers will average close to 80 percent efficiency. Older boilers may average 70 to 75 percent efficiency or lower.

Table 7. Energy Consumption Models (kBtu/sq ft)		
Occupancy Type	2003 CBECS Consumption	Estimated Use (80% of CBECS Consumption)
Education	53	42.4
Grocery	63.8	51.0
Restaurant	40.5	32.4
Inpatient Health	114	91.2
Outpatient Health	63.8	51.0
Lodging	55.5	44.4
Mercantile Non-mall	46.1	36.9
Mercantile Mall	42.2	33.8
Office	48	38.4
Public Assembly	49.7	39.8
Public Order/Safety	55.5	44.4
Religious Worship	49.2	39.4
Service	70.9	56.7
Warehouse	34.5	27.6
Parking		
Multi-family Residential	41.9*	33.5
Industrial	60*	48.0

A commercial property owner was generous in providing energy use data from four commercial properties within the study area. We were able to compare two years of usage data with the CBECS data and based on the actual occupancy and the projected use from the CBECS model, there were discrepancies but not enough to discern a trend or bias. We also noticed that the owner's building square footage differed from the county property record, which also affects the output of the energy model estimates.

Finding: The available public data provides building information, not energy usage. We developed a methodology for predicting the most likely energy profile for each building in the data set. We determined that surveying the customer base to confirm data prediction was not practical for this study, so the results were compared to existing private data sets. This refined data was aggregated in order to map energy usage density in the study area and identify favorable clusters for potential system development.

4.6 Energy consumption in district heating systems

Buildings connected to district energy systems are not substantively different in construction or operation. However, the method which energy is converted for use at district energy consumer buildings differs subtly but importantly from on-site energy generation. District heating production, distribution, and use influence each other in critical and iterative ways. These relationships will be discussed in the following sections:

- ⇒ District hot water system temperature 4.7
- ⇒ Customer connections 4.8
- ⇒ Building heating systems 4.9

4.7 District hot water system temperature

Water-based energy distribution systems are frequently called hydronic systems. The HVAC and energy utility industries have settled on a few temperature range classifications for hydronic systems based on design considerations related to equipment generation, temperature, piping arrangement, controls, and pumping. These temperature ranges include:

1. High Temperature Water System (HTW) operating at over 350°F and typical pressure of approximately 300 PSI.

2. Medium Temperature Water System (MTW) operating between 250°F and 350°F, with typical pressure not exceeding 150 PSI.

3. Low Temperature Water System (LTW) operating at 250°F or less, with maximum allowable working pressure of 160 PSI.

Central water systems serve many purposes. Loads commonly served are heating, domestic water heating, process heating and cooling, and steam generation for process use. The proportion and duration of these loads can be a major factor in determining the type of distribution system provided as part of a community energy system.

4.8 Consumer connections

Thermal energy produced at the central plant is transported in a distribution network and extended to the consumer building equipment room. The building systems may be connected directly or indirectly to the district heating distribution system. With direct connection, the district heating water is distributed within the building to directly provide heat to terminal equipment such radiators, unit heaters, and heating coils in the central station air handlers.

Direct connection of the customer's terminal heating equipment to the network distribution system is sometimes more economical than the indirect method. No heat exchangers, pumps, or water treatment systems are required, thereby reducing the capital investment costs. There is also the potential for getting lower district heating return water temperature. Direct connection is sometimes prohibitively expensive. Direct connection should especially be considered in new development areas where building heating systems could be designed for direct connection. Direct connection is most suitable for smaller district heating systems or where the static head in the distribution system is low, which is the case in areas with relatively flat ground and low rise buildings. Most urban areas with district heating systems serving large buildings will be the indirect type because of the diversity in building elevations and pressure limits in the existing buildings will make direct systems impractical.

Indirect connections involve a heat exchanger in the customer building that transfers energy from the district distribution system (primary side) to the building distribution system (secondary side). The rate of energy extraction in the heat exchanger is governed by the control valve that responds to the energy demand. The control valve modulates in order to maintain the temperature set point on one side of the heat exchanger.

Major advantages of indirect connections include:

- ⇒ the static head pressure effects in high rise buildings are eliminated.
- ⇒ the building and energy distribution systems. are kept separate, not exposing the building to the relatively high pressure and temperature in the district energy system.
- ⇒ the customer maintains their own building loop make-up water and chemical treatments.
- ⇒ the customer manages their building loop temperature tailored to their operational needs.

4.9 Building heating systems

Hydronic systems are used in a majority of large building heating systems and significant number of industrial process heating applications. This can be attributed to certain advantages of properly designed hot water systems over alternative heating systems. Hydronic heat provides faster and more uniform responses to load changes using minimum pipe sizes. Resetting the system supply water temperatures with the outdoor air temperature means matching system heat output to the load requirements of the building and minimizing energy consumption, space overheating, and fuel waste.

In sensible heating applications where the load consists entirely of space heating and domestic water heating requirements, the type of system and its operating temperature range are mostly economic decisions. In those cases, low temperature systems have an advantage. Low temperature systems have the added benefits of more easily integrating heat recovery from process loads, solar thermal, and other renewable energy sources.

The principal economic consideration in any heating system is balancing initial system construction costs with future operating expenses. Initial capital expenditures include generators, distribution system materials, and the terminal equipment as determined by system load requirements and supply and return system temperature. The cost of the distribution system is directly impacted by the volume of water necessary to handle the designated thermal load including a margin of safety. Generally, the greater the difference between supply temperatures provided by the plant and return temperatures received by the plant, the more efficient the distribution system will be in both thermally and financially. Higher supply temperatures allow for greater energy delivery at smaller system flow rates. Additionally, greater supply and return temperature differences allow for smaller heat exchangers at the point of use due to the smaller surface areas required for full energy transfer. Smaller heat exchangers reduce overall capital costs. For example, a system could be designed with a supply water temperature of 250℉ to the primary side of the heat exchanger, a secondary side supply water temperature of 180℉, and a secondary return temperature of 150℉. This would result in a conventional water temperature difference of 30℉ on the secondary side allowing the primary distribution piping to be sized for a 100-degree water temperature drop. Heat exchangers are available from a few manufacturers that can provide thermal capacity at lower flow rates.

4.9.1 Heating units for space heating

Many types of terminal units are available for closed loop hydronic systems. Some units are suited to a specific design scheme while others may be used in many types of systems.

- ⇒ Natural convection units include radiators, cabinet convectors, baseboard and finned tube radiation. The typical use in residential units involves in-floor heating and other radiant equipment. Many of these systems are used with water flow rates that generate a maximum 20-degree temperature drop.
- ⇒ Forced convection equipment such as fan coil units, unit heaters, induction units, central station units, and unit ventilators can be less costly to install and operate due to lower flow rates and greater operating temperature range. Forced convection equipment can reach temperature drops of up to 50℉ even in low temperature systems.
- ⇒ Radiators and radiant panel systems all transfer some heat by convection. Such units are generally used for heating with low grade temperature water systems. However, special designs of overhead radiant surfaces use higher temperature water systems to take advantage of the lowered surface requirements that are achieved through the use of high surface temperature.

4.9.2 Producing domestic hot water

Hot water can be produced from district heating services at nearly the same rate as it is consumed in a building. Similar to heating services, domestic hot water is generated through heat exchangers. Though it can be produced rapidly, most domestic hot water still relies on storage tanks.

Hot water stored in a tank is heated to a predetermined temperature at a rate somewhat less than the maximum demand. The tank is recharged to full during periods of low demand and it is drawn down during periods of high demand.

4.10 Utilization hours

Annual energy use in buildings alone does not indicate how much peak heating demand a building will need. The analysis used a formula based upon typical heating degree days per year in the Minneapolis - Saint Paul metropolitan area and the number of hours this translates to given a building purpose. For most buildings 1700 utilization hours approximates the amount of energy used at the peak demand. Based on operations, hospitals are about 2200 utilization hours and hotels have 1900 utilization hours. Using this methodology, the utilization hour formula can be used to estimate annual energy use of a building if peak energy demand is available, or to estimate peak demand if annual energy use is available.

Estimated Peak Energy Demand (kW) = Annual Energy Use (kWh) / 1700 Utilization Hours

4.11 Diversity factor

One of the main positive features of a central plant is the use of several large units that have combined total capacity including increased reserve capability that is significantly less than the combined sum of individual dispersed building units. Individual buildings have different construction, operating patterns, and climatic exposure. The aggregated effect is a staggered peak-load demand and the accumulation of redundant margins of safety.

Often called the coincidence or diversity factor, it is defined as the ratio of measured maximum load at peak periods from different separate building to the coincident maximum demand of all demand of the group on the central plant. A diversity factor will increase with the added increase in the user connected buildings to the central heating plant. It is a figure equal to or greater than the given unit.

Findings:

⇒ We did not develop an ideal consumer load minimum because the load's viability is heavily determined by the localized production and distribution potential.

⇒ The consumer complexity scale is based on the density of energy users, the age of the equipment, the conversion potential of the building HVAC, and their business interest in joining a system.

4.12 Green Line survey, interviews, and findings

During the evaluation of the energy islands, the primary tool used for determining consumer loads is detailed in the process information in Sections 4.1-4.11. In order to substantiate this methodology, our research team completed a series of follow-up exercises to confirm consumer load information and to gauge building owner, building manager, and developer opinions about integrated district systems. Appendix C includes the survey utilized with building developers and a summary of comments from those interviewed for this study.

Additional information about consumption in the study area is presented in Section 2.0, including energy densities and building use profiles. Table 8 offers a summary of the total and future energy potential determined for each energy island and the total study area. This was calculated using the study consumer formula and the information available through the public tax databases.

Table 8. Total Thermal Energy Consumption for Energy Islands

Cluster Name	Current Demand	Projected Future Demand
	(kWh_t)	(kWh_t)
Industrial A	204,299,166	244,999,996
Campus A - Existing Systems	116,480,444	126,429,252
Corporate A	150,157,713	150,157,713
Hospital A	119,421,303	119,421,303
Industrial B	153,855,988	153,855,988
Industrial C	76,252,135	76,252,135
Mixed Use A	90,016,116	90,016,116
Mixed Use B	67,553,867	67,553,867
Commercial-Industrial A	41,815,786	41,815,786
Industrial D	66,778,492	66,778,492
Mixed Use C	43,712,398	80,196,748
Mixed Use D	41,291,303	52,306,103
Industrial D	44,033,875	68,630,305
Mixed Use E	7,475,768	7,475,768
Campus B - Existing Systems	68,955,049	68,955,049
Mixed Use F	46,204,643	54,033,810
Mixed Use G	39,781,867	40,694,226
Mixed Use H	22,016,091	22,016,091
Mixed Use I	34,969,117	34,969,117
Mixed Use J	32,398,210	32,398,210
Mixed Use K	15,698,539	15,698,539
Mixed Use L	43,789,027	48,862,222
Mixed Use M	27,866,991	27,866,991
Commercial-Industrial B	17,782,224	17,782,224
Total	204,299,166	244,999,996

Section 5.0

DISTRIBUTION SYSTEM ANALYSIS

5.1 Scope and purpose of distribution system analysis

The purpose of this section is to identify the baseline criteria necessary for developing and reviewing the physical and economic viability of installing a hot-water district heating system in an existing, developed area.

Given the complexity of distribution analysis, this work may be more challenging during a pre-feasibility phase. By partnering with public works, engineering firms, and other local experts, system planners can use the following criteria to begin gathering data for a potential project and have an early sense of the complexity level and associated costs of a project.

The following information was considered for each of the energy islands evaluated as full case studies. This information was evaluated based on information available in the public domain and only to the extent that a distribution system could be determined viable enough to consider the case study for additional feasibility analysis. During the process of this analysis, our team was able to validate the four energy islands identified as case studies and create findings for future research (Section 5.9)

5.2 Existing condition analysis

Prior to developing any distribution system analysis for a particular area, it is important to note key factors that may impact the development and implementation of a hot-water district heating system. Factors such as the presence and capacity of a production facility, customer loads, and energy demand are addressed in other sections of this report. Factors that are distribution system specific include surface topography, soil conditions, size and location of right-of-ways, utility locations, building service entry locations, and access management provisions.

5.2.1 Soil conditions

Soil conditions are critical for identifying adequate areas for pipe installation. Some soils, such as sands and silts, are ideal for installing subsurface utilities. Other materials, such as peat, clay, and bedrock, require more effort or remediation for excavation and bedding of piping materials.

In many urban areas, especially where industrial processes presently occur, or have occurred in the past, contaminated soils are likely to exist. Soils may have varying levels of contamination, requiring various amounts of remediation. Some contaminated soils with low levels of contamination can remain in-place or re-used for backfill material. Other materials may need to be hauled offsite and disposed in a manner permitted by the governing pollution control agency. Remediation of contaminated soils, if not fully known prior to beginning a project, can quickly become the most expensive part of a project, and result in extensive cost overruns.

5.2.2 Right-of-way

Identifying the presence and location of public right-of-way in a potential district heating service area is an important step in determining where a system can be installed. Existing right-of-way may include roads, railroads, easements, and other utilities. Installing piping in existing right-of-way provides a number of economical benefits, including not having to purchase easements, streamlined permitting and design reviews, and full-time access to facilities for future repairs or upgrades.

5.2.3 Utilities

The presence and location of adjacent utilities, both public (water main, sanitary sewer, storm sewer, traffic signals, etc.) and private (electricity, gas, cable television, telephone, etc.) can become a key factor in the design of a new district heating system.

Utilities may exist in public right-of-way as long as certain installation requirements are met. These requirements may include providing access to adjacent utilities for future maintenance, relocating in the event of a public utility needing use of the right-of-way space, or making accommodations for other future or concurrent utility installation.

5.2.4 Building layouts & density

The proximity and location of buildings to the right-of-way and each other, as well as the location of individual mechanical rooms, is an important consideration when looking at the viability of a district heating system. For instance, in areas of higher density, where buildings are built close together and near the street or right-of-way, such as in central business districts or older downtown centers, the distance of a service line extension in a district heating system is much shorter than for buildings built back from the right-of-way, which reduces the cost of installing heating services. For older or historic buildings, mechanical rooms were placed along an outside wall, close to the location of fuel delivery, such as along an alley or street. Newer buildings may have their mechanical rooms further into the building, requiring more internal piping work in order to install a district heating connection.

5.2.5 Access management

Access management consideration should be given to the installation of a district heating system, and include a review of both individual property and building access, as well as the displacement of the general public in the form of pedestrian, vehicular, or other traffic. Maintaining access becomes critical when working with potential customers and obtaining the necessary construction permits for installation work. Failure to adequately manage access in the area of construction can result in increased costs and potential loss of customer contracts.

5.3 Material considerations

There are select types of materials that can be utilized for piping in a hot water district energy system. Critical material design components include the carrier pipe (steel, copper, or cross-linked polyethylene (PEX)), insulation (polyurethane foam), and external jacket (high-density polyethylene (HDPE)). The selection of materials should be based on the pipe sizing and operating temperature requirements of the hot water district energy system.

To determine a material cost estimate for a hot water district energy system, it is important to identify some specific design criteria for the system. Certain criteria may include:

- ⇒ Operating temperature
- ⇒ Pipe sizing
- ⇒ Service locations
- ⇒ General system layout
- ⇒ Length of pipe segments
- ⇒ Expansion elements (bends, anchors, compensators, etc.)
- ⇒ Isolation and valve requirements

Once system criteria are identified, it becomes simpler to determine material quantities and begin cost estimation. Separating a system into segments may further simplify estimation, and allow for more flexibility in evaluating different material type and quantity scenarios.

Findings:

- ⇒ The study establishes baseline criteria necessary for developing and reviewing the physical and economic viability of installing a hot water district heating system in a developed urban area. The criteria are used to evaluate the complexity of the potential distribution and to help the system developer determine whether a feasibility study is warranted.

- ⇒ Prior to developing any distribution system analysis, the study outlines the baseline assessment of existing conditions, including surface topography, soil conditions, size and location of right-of-ways, utility locations, building service entry locations, and access management provisions.

- ⇒ Pipe sizing is guided by the overall potential load of a given cluster and the most likely routing to reach key or dense user groups. Pipe sizing can be favored to the larger of the potential load options to ensure system growth and long-term cost savings; however the pace of growth and market risk should be heavily weighed to avoid short-term and long-term difficulties with system maintenance and repair.

- ⇒ Pipe routing will be defined by existing conditions, regulatory requirements and permitting, and major infrastructure project planning. On average, district heating distribution projects can save up to 40 percent on distribution construction by co-locating the project with another major infrastructure effort. These cost savings could be used to coordinate financial packages for co-location or collaborative planning of multiple utility, transportation, or other infrastructure projects.

- ⇒ The complexity of distribution systems for this phase in project assessment is based on co-locating potential with other infrastructure projects, existing ground and utility conditions, pipe sizing, routing, and materials.

Section 6.0

ALTERNATIVE ENERGY OPTIONS

6.1 Scope and purpose of alternative energy options analysis

The initial scope of this study called for an analysis of renewable energy options for energy island development and transition. The majority of the study area is currently supplied by fossil fuel energy sources and holds great potential for localizing energy and improving alternatives. The following facilities are the primary alternative energy exceptions for thermal energy systems.

- ⇒ Hennepin County Energy Recovery Center: waste-to-energy — transition of electrical-only plant to CHP is under consideration
- ⇒ St. Paul Cogeneration (District Energy affiliate): biomass/wood chips — CHP
- ⇒ District Energy Solar Thermal Project: flat plate solar collection — thermal only

Two of the three systems integrate thermal energy into a district heating system. There is current exploration for the Hennepin County facility to capture thermal heat from its electricity generation to supply a district heating system.

Existing residential scale solar thermal and geothermal applications were deemed outside the scope of this project.

In evaluating other opportunities, there are key indicators for facilities or loads that could support or benefit from alternative energy options.

Finding: College campuses and breweries were the most ideal solar thermal candidates with adequate installation space and facilities utilizing a consistent annual hot water load.

The intent of this analysis was to explore the specific applications of alternative energies for the facilities and clusters explored in the study. Solar thermal was explored for two facilities and biomass for one facility. Insufficient data was readily available to solidify the potential of biomass and solar for a specific facility but complexity levels are explored in associated technology sections.

Of the options explored, waste heat was deemed the most available and efficient source of alternative energy. Waste heat is not currently classified as a renewable energy source in the State of Minnesota statutes. However, it meets the study definition of alternative energy options by decreasing the use of fossil fuels, decreasing greenhouse gas emissions, and increasing the efficiency of energy systems.

Finding: For purposes of this study, the "renewable" definition included industrial waste heat, waste heat from combined heat and power, solar thermal, geothermal, and biomass .

Of the eight industrial facilities surveyed, five had industrial processes or on-site electricity generation that could be applied to a thermal grid .

Table 9. Preferred Conditions and Facilities for Alternative Energy

Alternative Energy	Summary of preferred conditions	Preferred facilities
Solar thermal	Low grade heat demand Consistent heat demand Year-round heat demand Structure was built "solar-ready" Unconstrained exposure to the southern horizon Exploring roof replacements	Commercial kitchens, breweries, food processors, bottling companies, restaurants, residential facilities with domestic hot water load, clinics, nursing homes, and systems connected to hot water district heating, including college campuses
Biomass	CHP improves economics for biomass by creating two energy products for each unit of fuel input Partnership with a fuel processing partner Existing plans for boiler upgrades or expansion, preferable including CHP	Manufacturing facilities with on-site fuel processing space and CHP potential, campuses, and utilities
Waste/Heat &CHP	Discussed in Section 3.0	Varies by technology

**Wind and solar PV were not examined so the focus could remain on thermal sources. Geothermal was not examined due to a lack of readily available information regarding site conditions.*

Finding: The majority of production facilities surveyed are either developing or interested in developing a renewable energy source to complement their current energy profile.

Despite the support of the facilities, there were technical hurdles to developing alternatives for specific sites. Although some were unique to each facility, the major hurdles were fairly common:

Table 10. Hurdles to Developing Alternative Energy

Alternative Energy	Hurdles to Development
Solar thermal	Lack of structural support on-site Blocked exposure to the southern horizon Inconsistent heat load on demand-side Lack of capital Age of roof
Biomass	Lack of access to delivery routes Lack of space for processing fuel Significant boiler upgrade or replacement needed to combust the biomass Permit limitations
Waste Heat &CHP	Conversion costs for current facility Lack of consistent consumer demand

6.2 Solar thermal

Solar thermal technology has been meeting the needs of hot water users for decades in the United States. Although there has been past consideration for municipal hot water supplies, the majority of the systems have been developed for residential scale domestic hot water, space heating, and pool heating. In recent years, fluctuating gas prices and additional incentives for thermal energy have increased the scale and frequency of solar thermal projects. Gatorade-Pepsicola has utilized Arizona thermal energy credits to complete three phases of a solar thermal project used to supplement heat for bottle washing. The project is projected to achieve over 2 MW (thermal equivalent) peak production. North Carolina based solar developers are leveraging state tax incentives and utility rebates for solar thermal projects around the country, including dairy, bottling, and brewery facilities with predictable thermal demands. And in Saint Paul, a 1.2 MW (thermal equivalent peak system is supplying solar energy for space heating and domestic hot water production and exporting excess energy to the district energy system.

Continued market penetration of solar thermal will depend on both technical and business attributes of system potential. Key attributes include building density, hot water demand, and commonality of ownership (either through the building owner or utility). Academic, corporate, and hospital campuses are prime examples of target user groups.

Areas already utilizing district heating systems would serve as ideal candidates. There are hundreds of heating and cooling systems across the country that may potentially be able to utilize solar thermal.

District steam systems could consider multiple solutions to system integration. Across the country, district steam systems are considering partial or full conversions to hot water. This would create immediate opportunities for solar or broader renewable integration. Solar applications are still feasible with steam systems. Such applications would rely on demand side sizing and could possibly integrate with adjacent buildings to maximize production and usage.

6.2.1 Considerations for energy island integration:

- ⇒ Structural vulnerabilities may contribute significant additional costs. Solar projects should be identified prior to construction for optimal savings. Post-construction, projects could be selected based on structural integrity and lowest reinforcement costs. Ideally, ground standing projects will save the most on capital and engineering if soil conditions and southern exposure are ideal.
- ⇒ Roof age should be taken into consideration. Solar projects are ideally planned with new construction or a reroofing project.
- ⇒ Maximum crane access to the installation site minimizes time constraints, planning, and construction costs. The handling and storage of large collectors can also pose a challenge if not considered into site evaluation.
- ⇒ Ideally, installation should be scheduled between April and October for Midwestern United States climates.
- ⇒ Future installations should maximize controls integration between existing building controls and additional solar controls. If the systems are well-integrated the conventional system could be programmed to anticipate and to a greater extent accommodate solar energy and maximizing available energy. Metering and controls can be a costly portion of the system and possibilities but investments should be maximized for the potential energy return.

⇒ Instrumentation redundancy and data collection is ideally planned at the onset of a project. A set of commonly needed data points should be determined by all parties involved.

⇒ Ideally, projects with multiple roof installations should target matching elevations to avoid challenges with filling, venting, and isolation.

⇒ Although there are many high-performing international manufacturers, shipping and unloading large collectors can be a challenge. Project developers should identify local offsite delivery points for pickup and delivery by the contractor. This can avoid unnecessary delays and hidden costs associated with import, ocean transport, rail, and unplanned storage.

6.3 Biomass

6.3.1 Biomass focus for the Green Line study

Biomass carries broad and sometimes unique definitions in different regions, often defined in state legislatures in support of energy policy. Statutes in the State of Minnesota acknowledge multiple biomass sources, including wood residues, agriculture residues, municipal solid waste (MSW), refused-derived fuel (RDF), and biogas from anaerobic digestion, landfill gas, and other sources. Facilities utilizing MSW and RDF are often referred to as waste-to-energy facilities.

Within the study area, biomass is regularly in use at the District Energy St. Paul (waste heat from woody biomass) and Hennepin County Energy Recovery Center (waste-to-energy). Facilities within the study area have also incorporated agricultural residues, landfill gas, and biomass/biogas from wastewater treatment. Although these are all viable technologies within specific applications, woody biomass was the focus of this area of review because of availability, fuel processing, and interest expressed by facility managers. Other stakeholders continue to develop these biomass projects and have compiled independent research, implementation, and operational data for applications within their facilities.

6.3.2 Woody biomass

Wood residuals, including tree trimmings and clean industrial and construction debris, become a benefit instead of a disposal challenge when utilized as a renewable, biomass fuel.

Within the greater Minneapolis-Saint Paul area, wood suppliers and producers already haul logs, brush, and other woody materials to local processing sites. A portion of the current supply is used for landscaping mulch. Approximately 280,000 tons is used to supply the combined heat and power facility affiliated with District Energy St. Paul. Some vendors choose to drop off wood residuals that have already been processed into mulch. The facility team grinds or screens the product in a final sizing process before transporting it to the CHP plant for boiler fuel. The main wood processing site and remote sites provide temporary storage for wood waste delivered by suppliers. To sustain the Saint Paul CHP facility, trucks transport the boiler fuel to the CHP plant over a 12- to 16-hour period seven days a week.

Recent studies have shown two factors that could lead to great opportunities for the region and would increase the likelihood of biomass integration for the study area.

1. There is a bounty of diverse wood resources that could be harvested for biofuel usage. The primary challenge in bringing this wood to market is the lack of infrastructure for woody biomass processing. Environmental Wood Supply (EWS) has established supply chains and is equipped to work within the existing infrastructure. EWS sources biomass for the CHP facility in Saint Paul and is an established industry-leader providing this service to the metro area, generating jobs, and adding economic benefit to the local economy.

2. Invasive species have created a new urgency for resource management of waste wood and wood fuels. Wood material infested with Emerald Ash Borer is best managed by combustion. Minnesota can utilize this diseased wood as a resource. This region has opportunities to develop expertise managing these wood resources and supply chains.

Finding:

- ⇒ Only one biomass opportunity was determined to be highly viable. Viability was based on site size and potential to store or process biomass. Most facilities were interested in biogas purchase but no facilities that were surveyed were found to be viable for biogas production. Most facilities were interested in biogas purchase but no facilities that were surveyed were found to be viable for biogas production. There is also potential to purchase biogas from the grid.

6.3.3 Examples of wood supplies:

- ⇒ Municipal and private tree/brush collection sites
- ⇒ Storm damage
- ⇒ Construction debris and pallets
- ⇒ Commercial tree trimming and removal
- ⇒ Land-clearing
- ⇒ Understory thinning and habitat restoration
- ⇒ Forest residuals

6.3.4 The benefits of woody biomass

Biomass fuel in the form of wood residuals supports to the local economy by keeping a valuable renewable resource out of the waste stream, creating jobs in the recycling and transportation industries, and keeping energy dollars in the local community. The use of wood residuals as fuel also helps to keep fuel prices stable, providing the opportunity for longer -term business planning.

Biomass can be utilized on its own, but is also used as a supplement to conventional fossil fuels. This process is known as co-firing, and may combine biomass resources and coal or biomass and natural gas.

6.3.5 Consideration for energy island integration

- ⇒ Availability of biomass feedstock
- ⇒ Market drivers for availability and cost
- ⇒ Competition
- ⇒ Environmental incentives or restrictions for biomass utilization
- ⇒ Transportation to the facility
- ⇒ Existing boiler design

6.4 Industrial waste heat and combined heat and power

Industrial waste heat and CHP are discussed at length in Section 3.0 Production. As noted, industrial facilities were interested and showed early viability for the capture of waste heat. Non-industrial facilities, including college campuses were interested in the potential to develop on-site electricity production with CHP playing an integral part of the efficiency and economic metrics of these proposals.

Findings:

- ⇒ Most facilities surveyed had the interest and technical capability to develop CHP.
- ⇒ Industrial facilities surveyed have high amounts of low-grade heat. These facilities remain viable as anchor facilities but may need additional heat pumps for heat to reach adequate temperatures for energy users or would be ideal for development of a micro-district with a commercial industrial user base requiring lower-grade heat. Examples of such users include laundries, breweries, bottling, and other process heat users.

Section 7.0

SYSTEM INTEGRATION

7.1 Scope and purpose of system integration analysis

In order for the energy island analysis to create effective opportunities, system integration is a necessity. System integration can apply within an energy island by improving the resilience and adaptability of an existing or potential system. Or system integration can be applied across energy islands to improve multiple systems and have an even greater positive impact on a region. During our examination of each cluster and the potential anchor facilities, our research team weighed the opportunities for integration both internal and external to the cluster. The criteria for analysis and results are discussed within this section.

7.2 Integration within an energy island

In reviewing the conditions of the twenty-five energy island clusters in the study area, each cluster provided some opportunity to integrate a technology, utilize alternative fuels, capture wasted energy from the system, or optimize the system through improved distribution. The summary of these opportunities within each cluster is shown in Table 11.

7.2.1 Technology integration

Technology integration from the perspective of a facility or a campus can be quite broadly defined. For the purposes of this study, our primary focus for technology integration was the potential for combined heat and power. As discussed in Section 3.0 Production, combined heat and power can range in scale from micro-CHP to supply electricity and heat to the facility and its operations or it can be utilized to for an entire cluster. Both approaches increase efficiencies for production and distribution and increase the energy independence and resilience for producers and users. Out of the clusters examined, seven facilities were identified for combined heat and power development, based on the current electric demands of the facility and the cluster and the potential to use the heat derived from the power production (see Table 13).

7.2.2 Utilize alternative fuels

The incorporation of alternative fuels is a priority for energy planning both for facilities and the broader system. Incorporation of alternative fuels enables a facility to be more fuel flexible, which leads to greater economic independence from fuel markets and an overall increase in stability for a facility’s energy budget.

For the broader system, integration of alternative fuels allows more systems to locally source fuels. This increases the independence of each energy system, improving energy security and resilience in the long-term.

Within the study area, at least eight of the energy island clusters showed potential to develop an alternative fuel. Only two of the anchor facilities surveyed within a cluster did not present the potential to develop alternative fuels based on limited space, structural limitations, or lack of interest. The other seventeen clusters were not examined in enough detail to confirm which alternative fuels could be incorporated. Our research team recommends additional research in this study area to determine the full potential of alternative fuel integration.

7.2.3 Applying waste heat

For the purpose of this study, waste heat was examined primarily as a product of industrial facilities, including the processing of raw products and recycling. Of the energy island clusters examined, six facilities presented the opportunity to capture waste heat from a manufacturing or process load. To be considered viable, the waste heat needed to meet the criteria detailed in Section 3.0 Production, including temperature and consistency of the available energy.

Three additional clusters may be viable for utilizing waste heat but would need future examination. Industrial cluster D was not researched based on the facilities lack of response to the survey. The two remaining clusters with industrial facilities are in transition. Industrial Cluster C is an area that is transitioning towards higher mixed-use development. There are two industrial facilities in the cluster. One is considering a move due to permitting issues. The other is in the process of being decommissioned. This cluster still has high potential for district energy development based on density and a nearby utility production facility. Industrial Cluster D is primarily anchored by a large manufacturer that has ceased manufacturing since the study was initiated. The cluster still has potential based on existing density and the current plans for the reuse of the site occupied by the manufacturer.

7.2.4 Sharing excess capacity

Excess capacity is a key indicator for integration that is often overlooked in facility and system planning. For example, a facility serving a campus and with an excess of capacity, may consider itself more prepared for growth. However, it is not common for that same campus to consider sharing the excess capacity or integrating their system with other users or other systems. Sharing this excess capacity with other users in the cluster (or with other clusters) optimizes the utilization of an existing asset.

In order to take full advantage of excess capacity, a facility or campus needs to consider the following:

- ⇒ Is there enough information about the facility's use of energy to confirm the excess capacity? Facilities and systems should plan based on energy trends over multiple years and normalize based on weather conditions. If this data is not readily available, improved collection and analyzing of data should be a priority step in planning.
- ⇒ Is the excess capacity a long-term condition? If the on-site users are using energy more efficiently and the growth plan is conservative, it is likely that the excess capacity can be considered available for other users.
- ⇒ How well does the excess capacity match the potential demand within the cluster or with adjacent clusters? Is the available energy sufficient to develop connections with adjacent users?
- ⇒ Are there multiple facilities that could serve as anchor facilities and satellite facilities within a more highly integrated system? One facility may not have enough capacity to warrant integration, but multiple facilities within a cluster or an area of study could aggregate their capacities to more effectively serve a broader system.

Within the Green Line corridor study area, six facilities presented the opportunity to share excess capacity (represented in four clusters). Four of the six facilities were central plants serving college or university campuses.

As noted above, the excess capacity currently available on each campus needs to be vetted against the long-term plans of the campus. Additional building development may require utilization of the existing assets. It is important to note that most of these campuses have excess capacity due to conservation efforts on the campus and changing weather conditions.

Each of the facilities identified with excess capacity expressed an interest in developing system integration with other nearby users. In the case of the academic campuses, the excess capacity was most suited for local commercial districts but could be considered for larger system integration with other local satellite contributors.

> *Finding:* Systems are best served by the recommissioning of existing production assets to meet heating needs and stabilize energy rates for development.

7.2.5 Connecting assets through district heating networks

Alternative fuels, waste heat, and excess capacity offer advantages to independent facilities, however, the highest, best use of these applications is achieved through district heating integration. Applying an element of integration to the facility will improve the profile of the facility's performance but connecting the facility to other users will maximize the asset for the system.

Integrating a hot water district heating network will allow the facilities to share capacities and will provide the following benefits to the system:

- ⇒ District heating networks account for the needs of multiple users, which improves access to energy options (waste heat, excess capacity, CHP, and alternative fuels).
- ⇒ Integrating fuel options into a district system helps avoid fuel market volatility and increases financial stability for energy budgets.
- ⇒ Reduce boiler inefficiencies from providers and individual users.
- ⇒ Provide production facilities the distribution system and market for selling their heat product.
- ⇒ Minimize long-term costs of heating for the users (rate stability).
- ⇒ Increase the security, adaptability, and resilience for the system.
- ⇒ System planners can coordinate district heating with other infrastructure investments to reduce installation costs and bring additional financial stability to projects.
- ⇒ Reduced operation and maintenance stressors for building owners and managers, providing more usable on-site space and higher reliability.

7.2.6 Optimizing existing district systems

As discussed in previous sections, many clusters offer potential to develop new district heating networks, however, there are already district systems in operation that offer the potential for greater system optimization. Systems can be improved by integrating the technologies and energy sources described in 7.2. Additionally, the systems can be improved by increasing the service territory of the existing systems.

> *Finding:* System development and integration was most viable where district systems were already in use. In these cases, the existing district could be optimized by expanding the system boundaries to serve new users. Expanding the boundaries of current systems accomplishes the following:
>
> - ⇒ *Improves the efficiencies of under-utilized boilers*
> - ⇒ *Creates a new source of income for existing system owners and managers*
> - ⇒ *Allows customers access to a greater variety of alternative fuels*

System planners must consider the distribution system's role in maximizing efficiency. During development of North American district heating systems in the early 1900's, steam was most commonly utilized due to lack of access to electricity for pumps and engineering expertise. Increasingly, these systems are considering a steam to hot water transition to unlock the benefits seen in hot water networks operating in Europe and in Saint Paul.

Major academic campuses are shifting from their original steam infrastructure to an upgraded hot water distribution system. This upgrade should increase the application of renewable fuels and the efficiency of their overall system by minimizing losses and reusing more of the energy available in a closed-loop hot water system.

Within the study area, the majority of the district systems are steam and would be best served by transition to a hot water distribution system for optimal integration and to meet efficiency goals.

7.2.7 Summary of opportunities to integrate within energy islands

Given the opportunities and priorities described above, our research team found potential for integration within the energy islands examined within the study area as shown in Table 11. Thirteen of the clusters were not surveyed and would need additional research to determine their best opportunities for integration within their cluster.

7.3 Integrating multiple energy islands

Initially, it was proposed that the systems be connected via a single major arterial between the downtowns, following the light rail transit corridor. Each system would be connected by vertical networks that could aggregate existing loads and potentially pick up additional users between major hubs. This type of thermal network is very common in Denmark, Sweden, Germany, and other European countries that rely on a major hot water distribution system to connect facilities and users across hundreds of miles.

After the opportunity was lost to install the major arterial during Green Line construction, our research team reexamined the energy island clusters to determine other opportunities for integrating multiple clusters. Ideally, future infrastructure planning will identify new opportunities to better connect clusters throughout the study area. In order to make this possible, we studied more immediate opportunities to integrate proximate clusters. Creating more interconnection between clusters will offer improvements to the systems and will improve the planning process for future cluster connections.

Table 11. Summary of Opportunities to Integrate within Energy Islands

	Integrate a technology	Utilize alternative fuels	Waste heat	Excess Capacity	Improved Distribution
Industrial A	CHP	solar	waste heat	excess capacity	district heating
Campus A - Existing Systems	CHP	solar, biomass		excess capacity	steam to hot water transition
Hospital A		solar		excess capacity	steam to hot water transition
Industrial B			waste heat		district heating
Mixed Use B	CHP	biomass	waste heat		district heating
Campus B - Existing Systems	CHP	solar, biomass		excess capacity	steam to hot water transition
Mixed Use I	CHP				
Mixed Use J	CHP		waste heat		district heating
Mixed Use K			waste heat		district heating
Commercial-Industrial B					district heating
Industrial F[1]	CHP		waste heat		district heating

During our examination of the study area, nineteen of the independent clusters were identified for integration with another energy island. The criteria for integration are shown in Table 12. Not all of the clusters were surveyed so integration viability was determined by information available in the public domain. Additional information would be necessary to confirm integration potential for those clusters.

7.3.1 Proximity to other clusters

Connecting multiple systems is usually determined by technical and economic viability. Hot water systems are technically viable to stretch across tens of hundreds of miles as long as they are designed to pick up heat from satellite facilities, or in this case other anchor facilities in a cluster. An interconnected network would also depend on other distribution criteria described in Section 5.0. For the purposes of this study, economic viability was the more prominent factor. If a cluster ranked low for energy density or for energy production and was not within 1 mile of another cluster, it was not considered for immediate integration due to proximity. This assumption should be examined for future studies.

7.3.2 Development timing

As with most major metropolitan areas, Minneapolis-Saint Paul is evolving to meet changing priorities and community needs. Development in the area is in multiple stages varying from comprehensive planning to infrastructure construction. Timing of the development of new buildings or community improvements offers a window to make connections between systems without requiring major infrastructure changes. It also offers an opportunity to incorporate network connections into comprehensive planning efforts.

7.3.4 Infrastructure improvements

Some cluster connections would require or benefit from major infrastructure projects, such as transit projects, utility relocations or upgrades, or street improvements.

7.3.5 Interest in co-development

As part of our research, our team met with many planners and system decision-makers. Of the nineteen clusters identified for this level of integration, we were able to confirm interest in co-development from eight.

Table 12. Short-Term Potential Integration with Other Energy Islands

Cluster Name	Proximity to other clusters	Development timing	Infrastructure projects	Interest in co-development
Industrial A	X	X	X	X
Campus A - Existing Systems	X	X	X	X
Hospital A	X		X	X
Industrial C	X	X	X	TBD
Mixed Use A	X	TBD	TBD	TBD
Mixed Use B	X	X	X	X
Commercial-Industrial A	X	TBD	TBD	TBD
Industrial D	X	TBD	TBD	TBD
Mixed Use C	X	X	X	X
Mixed Use D	X	TBD	TBD	TBD
Mixed Use E	X	TBD	X	TBD
Campus B - Existing Systems	X	X	X	X
Mixed Use F	X			X
Mixed Use G	X	X	X	X
Mixed Use H	X	TBD	X	TBD
Mixed Use J	X	TBD	X	TBD
Mixed Use K	X	TBD	X	TBD
Mixed Use L	X	TBD	X	TBD
Commercial-Industrial B	X	X	X	TBD

7.4 Integration of highest ranked energy islands

After considering the opportunities within the twenty-five energy islands, our research team identified two clusters that presented the most immediate potential for additional development and integration. Below are the profiles of those clusters with summaries of our findings.

7.4.1 Case Study A: Industrial Cluster A

Description: Industrial Cluster A is anchored by a major manufacturing plant that recycles and processes paper, relying on heavy use of energy for its own equipment operation. The cluster is a mix of industrial, commercial, and residential zoning and building usage and is adjacent to the Green Line corridor. The cluster is approximately 765.7 acres.

Production: The anchor facility has a central power plant fueled primarily by natural gas that generates high-pressure steam. The plant does use some combined heat and power to generate electricity for its own processes. The heat byproduct is used for process load, heating the plant, and tempering the ventilation air. Additional industrial facilities operate in the cluster, also utilizing natural gas as a primary fuel. From our examination, this facility displayed potential to serve as an anchor through the capture of additional flue gas heat recovery, process waste heat recovery, and potential excess capacity in the central plant.

Consumer Load: This cluster has an estimated total thermal energy load of 204,000 MWh, making it the highest energy consumption cluster in the study. It should be noted that this includes the anchor facility, which is clearly a major user of energy in the cluster. The energy density of the cluster is ~260 MWh/acre with future potential of ~320 MWh/acre based on development planning for the area.

Alternative Energy Options: As noted in production, CHP, waste heat, and excess capacity could all be viable energy options for the development of a district system for this cluster. This cluster has previously been examined for renewable fuel integration and biomass was deemed to be technically viable but economically challenged during 2008 study conditions. Solar thermal was not examined for this cluster but could be integrated into a district hot water system and used for on-site process heat loads.

Distribution: A distribution system was found to be viable in this district, although challenged by the light rail transit infrastructure and major transects from a highway and railway.

Integration: This cluster was confirmed for integration potential of technologies and distribution network within the cluster. This cluster is proximate to six other clusters that could be integrated in the short-term based on potential of the distribution system, the excess capacity and waste heat available, and the advantage of aggregating the loads.

7.4.2 Case Study B: Mixed Use B

Description: Mixed Use Cluster B is anchored by an electricity generating facility, owned by a public entity, which sells its electricity to the local utility provider. The cluster is a mixture of zoning, featuring commercial, residential, light-industrial, and entertainment building stock. The cluster is directly adjacent to another local light rail transit line. The area is approximately 226.8 acres.

Production: The anchor facility currently has a power purchase agreement with the local electric utility to generate 33.7 MW of renewable electricity from municipal solid waste. Although some of the excess steam from the facility is already serving users, combined heat and power development for this facility would generate enough heat to provide approximately 124,000 MWh per year.

Consumer Load: The consumer load within the full cluster boundaries is ~68,000 MWh. Its energy density is ~300 MWh/acre with future density increasing with construction currently in progress. This load does not include the anchor facility usage.

Distribution System: A distribution system with a supply temperature of 200° to 250°F would be optimal for the estimated service territory and recoverable steam from the combined heat and power process. Snow melt and floor radiant heating could use a lower temperature loop between 90° to 250°F.

A major infrastructure project is planned for this cluster in the next eighteen months and provides an ideal opportunity to implement a system and reduce overall distribution costs from shared planning, excavation, and colocation efforts.

Alternative Energy: The contributor facility utilizes a renewable fuel as its primary fuel source. Additional energy would be recouped through combined heat and power providing a significant reduction in greenhouse gas emissions for the cluster as a whole. If 60 percent of the thermal users transitioned from on-site natural gas to district heating from this source, it would equate to a greenhouse gas emission reduction of 13,479 metric tons (see Table 13 for more detail).

Integration: With two proximate district heating systems and major development plans for this area, integration presents many potential opportunities.

7.5 Reaching sustainability goals through integration

Through discussion with facility managers and energy decision-makers, we also learned how important greenhouse gas emission reductions would be in system planning. In particular, the campuses and municipal facilities presented the highest interest in developing energy efficiency and alternative energy scenarios that would reduce their use of fossil fuels and increase overall system adaptability.

In order to understand the potential of system integration to meet these sustainability goals, we calculated the potential greenhouse gas (GHG) reductions for a sampling of facilities, based on integration of combined heat and power CHP.

Table 13. Estimated GHG Reductions Based on CHP Integration

	Recoverable Waste Heat	Recoverable Waste Heat	60% market share	80% market share	100% market share
	(mmBtu/hr)	(MWh_t)	(MTe as CO2)	(MTe as CO2)	(MTe as CO2)
Mixed Use B	223	111,075	12,060	16,080	20,100
Campus A - Existing System	28	13,844	1,503	2,004	2,505
Industrial A	48	23,909	2,596	3,461	4,326
Industrial F	28	13,947	1,514	2,019	2,524
Conversion Assumptions					
Natural Gas	53.02	kg CO2/mmBtu			
Heat Content	3,413	Btu/KW			
Heat Content	3.413	mmBtu/MW			
CO2 Equivalent	180.96	kg CO2/MW			
CO2 Equivalent	0.1810	MTe CO2/MWh			
Annual demand	1700	hours			

Section 8.0

CONCLUSIONS

8.1 Applying the research

The Energy Island Integration Study has evolved since its original inception. Throughout the evolving conditions of the study area and the application of the research, the original hypotheses of the study were maintained at the foundation of the research.

- ⇒ What efficiencies can be gained by evaluating energy islands and their potential to be integrated?
- ⇒ How can system planners evaluate existing assets to anchor a more effective network of energy systems?
- ⇒ How can district heating serve as the connection between isolated systems and unlock the potential of stranded energy?

In addition to answering these questions, our research team found overwhelming evidence that increased planning, system integration, and connections through district energy networks would increase overall system efficiency, increase economic stability, and develop greater environmental benefits within the study area. The detailed answers can be found in the study findings and throughout the report sections.

As our team examined these questions, we made a concerted effort to track our methodology. The process details found in the report are intended to provide a specific roadmap to the system planners in the Minneapolis-Saint Paul area, but also provide a tool for system planners in any region.

8.2 Advancing projects to feasibility studies

The scope of this study varies between pre-feasibility and advanced feasibility principles. Given our research team's experience with examining system potential, we were able to evaluate some technical areas to a greater extent. Other areas required very specific site-related or proprietary detail that could only be gained during a collaborative feasibility discovery process. The initial information discovered in the research identified seven areas that present the best potential to be considered for in-depth feasibility analysis. Feasibility analysis is currently moving forward for four of those clusters.

System planners using the lessons learned and the methodology within this report will be armed to study and advance clusters during various stages of development. They may choose to apply the base recommendations to their comprehensive planning efforts, as a tool to educate other stakeholders and install placeholders for future system integration. System planners with greater access to technical information may choose to consider applying the more advanced research methods for measuring and evaluating elements of a system or a system as a whole. We encourage system planners and other energy system decision makers to consider reaching out to both technical and development partners to advance their studies to a feasibility analysis.

We recommend starting the feasibility process with an engineering firm with district energy experience or your local utility.

8.3 Additional resources

Ever-Green Energy and District Energy St. Paul – These affiliate organizations led the research and development of this study and report. The companies provide technical resources on their web sites and can be contacted for additional planning and technical information, including system feasibility analysis and system development.

www.ever-greenenergy.com
www.districtenergy.com

Department of Energy – The Department of Energy has a deep resource pool for system planners, including the Community Renewable Energy Deployment project.

International District Energy Association – IDEA promotes energy efficiency and environmental quality through the advancement of district heating, district cooling, and cogeneration. Through their staff and membership, they provide access to research and resources for system planners. The recently published Community Energy Development Guide is a complementary document to the Energy Island Study.

Barr Engineering – Barr Engineering's staff has unique capabilities for evaluating production and consumer load information and producing GIS designated infographic information.

8.4 Acknowledgements

Our team would like to thank Congresswoman Betty McCollum for her efforts to explore greater efficiencies in our energy system, including but not limited to the expansion of combined heat and power, district heating, and an alternative energy infrastructure.

Special thanks to the following partners:
Barr Engineering for their contributions to the study methodology, data collection, and infographics used in the report.

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Appendix A – System Planner Checklist

Identifying Energy Islands for Comprehensive System Planning

Check all of the following that are operational in your region:

- ☐ electricity production facilities
- ☐ college campus
- ☐ hospital campus
- ☐ major manufacturer
- ☐ metal foundry
- ☐ district heating system
- ☐ district cooling system
- ☐ bottling facilities

Does your community host a district heating system?

☐ Yes ☐ No

If so, is it a steam or hot water system?

☐ Yes ☐ No

Have any of the major facilities considered combined heat and power?

☐ Yes ☐ No

If so, are they working with other facilities to complete a resource assessment?

☐ Yes ☐ No

Has your community completed an assessment of energy needs for users?

☐ Yes ☐ No

If so, does it include a plan for reducing fossil fuels?

☐ Yes ☐ No

If so, does it include a plan for reducing greenhouse gas emissions?

☐ Yes ☐ No

Do any of the regional planning documents account for inventory and integration of energy systems?

☐ Yes ☐ No

Appendix B – Glossary of Common Terms

The nature of this report necessitates the use of technical terminology. The following definitions are provided for those unfamiliar with energy system terminology:

British Thermal Unit (Btu) – The amount of heat required to raise the temperature of one pound of water 1 degree Fahrenheit. The Btu is a small amount of heat equivalent to the heat released by a burning matchstick. For district heating systems, heat is often measured in million Btu (mmBtu) which is equivalent to one million Btu.

Community energy system – A thermal energy delivery system that connects a significant portion of a community and permits technologies and energy sources to be deployed on behalf of the entire community as a result of economies of scale of the system and the adaptability advantages of the distribution network.

Condensate – Water produced by the condensation of steam

Customer conversion – The equipment in a customer building mechanical room that transfers thermal energy from the district heating system to the building systems to allow the heat to be distributed throughout the building. The customer conversion usually consists of heat exchangers, pumps, piping, control sensors, and control valves to enable heat to be efficiently transferred from the higher temperature district heating system to the lower temperature building system.

Differential temperature (dT, delta T) – The difference between the supply temperature and return temperature of the district heating water delivered to users. This is an indication of the amount of energy delivered to the customer.

District energy – A thermal energy delivery system that connects energy users with a central or shared production facility.

Diversified load – The actual peak load on an energy system. The diversified load is less than the sum of the peak loads of individual users due to the difference in time of day that each individual user realizes their peak load.

Dual pipe – A district energy system that consists of a two-pipe distribution network - a supply pipe that carries hot water to the customer and a return pipe that returns the cooler water to the production facility for reheating.

Distribution system – The underground piping network that delivers hot water from the production facility (the Duluth Steam Plant) to the customer buildings. Hot water is circulated through this distribution system using pumps that are located at the production facility.

Domestic water – Potable water that is heated for use in faucets, showers, laundry, and similar uses.

Heat exchanger – A pressure vessel that contains plates or tubes and allows the transfer of heat through the plates or tubes from the district heating system water to the building heat distribution system. A heat exchanger is divided internally into two separate circuits so that the district heating system water and the building heat distribution system fluids do not mix.

Heating coil – A heating element made of pipe or tube that is designed to transfer heat energy to a specific area or working fluid.

Hot water supply and return lines – The district heating system piping that distributes hot water for heating purposes to customers (supply) and returns the cooler water to the Plant for reheating (return).

Megawatt-hour (MWh) – The megawatt is equal to one million watts. A watt is defined as one joule per second. A MWh is equal to 3.413 mmBtu .

Non-diversified load – The sum of the peak loads of individual users. This is a theoretical maximum system peak load.

Normalized – Adjusted annual data of monthly building usage values measured on different monthly heating degree scales to a common scale prior to averaging.

Service line/service piping/customer connection – The segment of the district heating distribution system that extends from the main lines to the inside of the customer building. The service line is typically sized to meet the peak hot water flow requirements for the individual building served by the piping.

Terminal equipment – Heating equipment such as heating coils, radiators, unit heater, or air handlers that transfer heat from water to the building air space.

Thermal energy – Energy that is generated and measured in the form of heat.

Variable frequency drive – an electronic controller that controls the speed of an electric motor by modulating input frequency and voltage to match motor speed to the specific demands of the work being performed.

Appendix C — Producer Survey

Company Name:
Address:
Contact Name:
Phone:
email:
website:

Type of facility:

Size of facility:

Technically feasible to export (y/n):

Business interest in export (y/n):

Additional considerations for facility development:

Facility Profile facility (number of buildings, type of buildings, square footage, etc):

Type of power plant/boiler equipment:

Size of power plant/boiler operations:

What portions of the facility/campus does the plant/boiler operations serve:

Capacity of power plant/boiler operations:

Facility/campus peak energy needs:

Excess capacity (y/n):

Temperature range:

Frequency:

Waste heat (y/n):

Temperature range:

Frequency:

Previous efforts to capture wasted energy:

Opportunities to capture wasted energy:

Total potential (or available) energy for export:

Additional limitations for energy contribution: