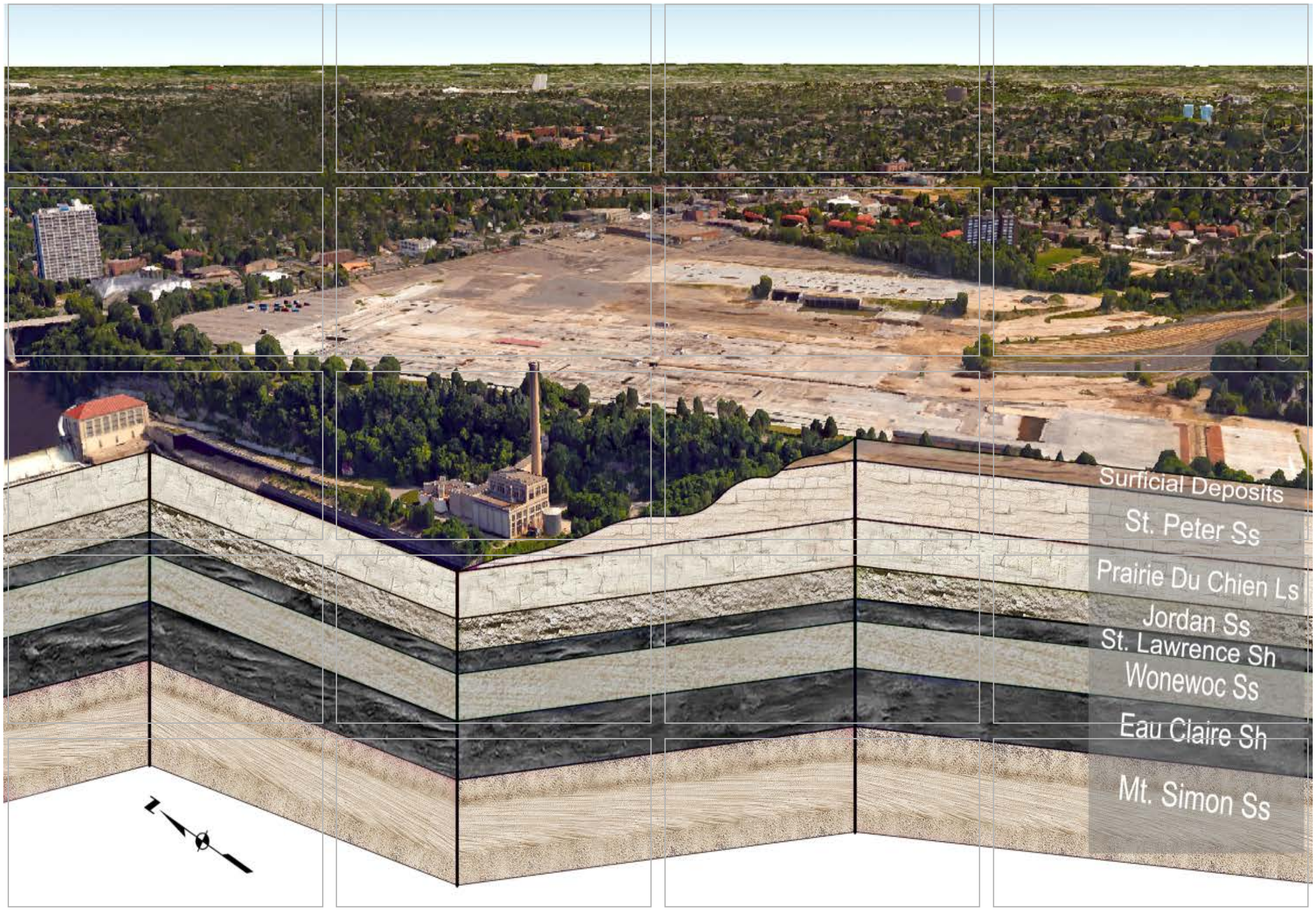

Final Report

Aquifer Thermal Energy Storage (ATES) Feasibility Study

Ford Site
Saint Paul, Minnesota

Prepared for:
City of Saint Paul

August 2016

www.underground-energy.com

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Applied Hydrogeology, Geothermal Innovation

Underground
ENERGY

Executive Summary

Underground Energy, LLC performed a feasibility study of Aquifer Thermal Energy Storage (ATES) for heating and cooling of the proposed redevelopment of the Ford Site in Saint Paul, Minnesota. ATES is a sustainable geothermal heating and cooling technology that can yield significant, large-scale energy savings for buildings and energy districts that have large heating and cooling requirements and that overlie at least one productive aquifer. ATES is an open-loop, low-temperature geothermal technology that uses high-capacity wells for both withdrawal and injection of groundwater on a seasonal basis. ATES is well suited to application in low-temperature district energy systems, and the technology is well established in the Netherlands, where over 2,500 ATES projects have been commissioned.

The Twin Cities area has excellent climatic and hydrogeologic conditions for ATES; cold winters and large summer cooling demands are well suited to the application of seasonal thermal energy storage, and the area is underlain by multiple aquifers capable of providing high well yields. ATES systems are carefully designed and operated so that temperature is the only characteristic of the water that is modified; no chemicals or additives are injected into the aquifer. Balance is a key characteristic of ATES systems, the injection and withdrawal rates are balanced, the hydraulic conditions in the aquifer are seasonally balanced, and the systems are typically designed so that net thermal balance on the aquifer is maintained.

The preferred aquifer for ATES beneath the Ford Site is the Prairie du Chien-Jordan aquifer, which typically yields more than 1,000 gallons per minute (gpm) to water wells, and occurs at depths between about 220 and 490 feet at the Site. Deeper aquifers could also be utilized for ATES projects but with decreased well yields (more wells needed to meet a given thermal capacity) and higher drilling cost.

Underground Energy's conceptual design for an ATES system uses an estimated maximum ATES well flow rate of 900 gpm per well (5,500 gpm aggregate), a diversified heating load of 53.6 million British Thermal Units per hour (MMBtu/h) peak and 115,800 MMBtu of annual energy consumption (excluding domestic hot water production), a diversified cooling load of 3,450 Tons peak and 66,900 MMBtu of annual thermal energy consumption. These loads are based on approximately 6.5 million square feet of conditioned space. More than 75% of the annual cooling demand can be met with direct cooling enabled by seasonal thermal energy storage.

The conceptual design is based on boundary conditions that assume the buildings are designed with low-temperature heating systems and high-temperature cooling systems, with each building having its own centralized or individual domestic hot water system(s). Our conceptual design comprises a total of 12 ATES wells (6 warm and 6 cold wells) connected to a 2-pipe groundwater loop that connects heat pumps in individual buildings to the warm and cold ATES wellfields.

An estimated investment cost of $33 million was calculated for both the ATES system and for the business-as-usual (BAU) scenario of a new, efficient four-pipe insulated district heating & cooling system with centralized gas boilers and electric chillers. Despite their comparable capital costs, the ATES system can provide savings on primary energy consumption of 41% and CO2 emission reductions of 36% compared to the BAU scenario, while eliminating 16 million gallons of water consumption. Due to the greater energy efficiency of ATES, the estimated operating cost of an ATES system was calculated to be about 17% lower than for the BAU scenario using recent energy prices.

While technical and financial measures of ATES feasibility at the Ford Site are strong, obtaining the necessary regulatory approvals will be an equally important component to development of an ATES project at the Ford Site. The salient regulatory issues lie within the jurisdiction of Minnesota Department of Health (MDH) under MR 4725.2050, which prohibits injection of any material into a well or boring in Minnesota. An exemption exists for smaller open-loop geothermal system (up to 50 gpm), but the only option for an ATES system, short of a change in law, is to seek a variance from the rule. There is precedent for a variance to that rule for an Aquifer Storage Recovery project, and MDH representatives have indicated a willingness to consider similar variances for ATES projects.

Underground Energy concludes that an ATES project is feasible at the Ford Site, where climate and aquifer conditions are ideal for this large-scale, sustainable heating and cooling technology. We recommend that pre-design activities include a phased, on-Site hydrogeologic study to confirm or modify the estimates of subsurface conditions that were the basis for our conceptual design, and to facilitate detailed design and financial analysis.

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General Report Disclaimer

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Table of Definitions and Acronyms

ags	Above ground surface
ASR	Aquifer Storage and Recovery
ATES	Aquifer Thermal Energy Storage
BAU	business as usual, the energy system to which ATES is compared
bgs	Below ground surface
Btu	British thermal unit
BTES	Borehole Thermal Energy Storage
CO2	Carbon dioxide
COP	Coefficient of Performance
CSM	Conceptual Site Model (hydrogeology)
CVOCs	Chlorinated Volatile Organic Compounds
CWI	County Well Index
°C	Degrees Celsius
°F	Degrees Fahrenheit
DH&C	District Heating and Cooling
DHW	Domestic Hot Water

DNR	Minnesota Department of Natural Resources
EPA	Environmental Protection Agency
ETS	Energy Transfer Station
EUIs	Energy Use Intensities
EQB	Environmental Quality Board
ft	feet
GIS	Geographic Information System
gpm	Gallons per minute
HDPE	High Density Polyethylene
HP	Heat Pump
kW_e	Kilowatt (electric)
kW_t	Kilowatt (thermal)
lbs	Pounds
LDC	Load Duration Curve
m	meter
MDH	Minnesota Department of Health
MFI	Membrane Filter Index
mg/L	Milligrams per liter
MGS	Minnesota Geological Survey
MMBtu	Million British Thermal Units
MMBtu/h	Million British Thermal Units per Hour
MR	Minnesota Administrative Rules (regulations)
MSL	Mean Sea Level (reference datum)
MW	Megawatt
MWh	Megawatt-Hour
MWh_t, MWh_e	Megawatt-Hour (thermal), Megawatt-Hour (electric)
O&M	Operation & Maintenance
PCA	Minnesota Pollution Control Agency
PCBs	Polychlorinated Biphenyls
SDI	Silt Density Index
sf	Square feet
SPF	Seasonal Performance Factor (avg. COP over heating/cooling season)
ΔT	Delta T, temperature difference
Ton_r or Ton	Ton refrigeration; 1 Ton = 12,000 Btu/h or 3.5 kW
UIC	Underground Injection Control
USGS	United States Geological Survey

1.0 Introduction

This Feasibility Study report has been prepared for the City of Saint Paul by Underground Energy, LLC. The objective of this ATES feasibility study has been to collect and analyze available data to assess the technical, regulatory and economic feasibility of Aquifer Thermal Energy Storage (ATES) for sustainable heating and cooling for the proposed redevelopment of the Ford Site in Saint Paul, Minnesota (the Site).

The Ford Site is 135-acres of land on the Mississippi River in Saint Paul, Minnesota for which a 21st Century Community is envisioned. Ford's former Twin Cities Assembly Plant will be redeveloped as a livable, mixed use neighborhood that looks to the future with clean technologies and high quality design for energy, buildings and infrastructure. A November 2015 Energy Study Report of the Ford Site by Ramboll and Krifcon Engineering identified ATES as a promising technology in a district energy concept that should be evaluated in more detail, which was the basis for Underground Energy's feasibility study.

Saint Paul is unique from a historical energy perspective, where it was the site of some of the earliest ATES research and pilot testing ever performed during the 1980s. The earlier high-temperature (150 °C) ATES tests were not viable for long-term operation, but the research pointed the way to the technical and economic benefits of low-temperature ATES, which was subsequently developed and commercialized in Europe. The Ford Site offers a unique and exciting opportunity for Saint Paul to realize the benefits of ATES coupled with district heating and cooling and to lead the nation in the commercial development and sustainable operation of ATES systems.

1.1 GeoExchange and ATES

GeoExchange technologies all utilize the subsurface as a low-temperature heat source for heating or as a heat sink for cooling, typically using geothermal heat pumps in this heat exchange. The most common GeoExchange installations are closed-loop geothermal systems that circulate a glycol solution in a closed-loop high-density polyethylene (HDPE) piping network between borehole heat exchangers installed in borings and heat pumps. Open-loop geothermal systems typically withdraw water from an aquifer and pass the water through a heat pump after which the heated (in summer) or cooled (in winter) water from the heat pump is discharged either back into the aquifer, or to surface water, or even into a municipal water system. The common feature of closed loop and "once-through" open-loop geothermal heating and cooling systems is that they use the earth as a heat sink or as a heat source. The primary difference between ATES and other GeoExchange technologies is that ATES uses the earth not as a passive heat sink/source, but as a thermal battery, where warm and cold water is stored in separate portions of the aquifer. These warm and cold stores are charged and discharged seasonally, resulting in significant energy efficiency improvements over other GeoExchange applications.

ATES is an open-loop geothermal technology that uses high-capacity wells for both withdrawal and injection of groundwater on a seasonal basis. ATES systems are optimized for thermal energy storage on a seasonal timeframe; it is possible to size an ATES system to meet (part of) the cooling demand with direct cooling, i.e. without running the heat pump. Normally, direct cooling can only be used by buildings on days when outside air temperatures are low, which, of course, is when cooling demand is low. ATES enables seasonal thermal energy storage, which allows chilled water injected and stored during winter to be recovered and used in summer for direct cooling. Because direct cooling with ATES is accomplished with circulation pumps rather than compression chillers, significant energy reductions can be realized, typically about 60% compared to conventional chillers. Similarly, warm return water in summer is injected to recharge the aquifer warm store, where it will be extracted the following winter. Because the warm store temperature is typically higher than ambient groundwater temperature, heat pumps operating in winter mode see a smaller “lift,” the temperature difference between the heat source and the heating supply temperature. As the lift required of a heat pump decreases, its energy efficiency increases.

At present, there are over 2,500 ATES systems operating in Europe, most in the Netherlands, where climate and aquifer conditions are well suited for ATES.

1.2 ATES Principle

An ATES system is a large open-loop geothermal system optimized and operated to realize seasonal thermal energy storage by reversing extraction and injection wells seasonally. The basic principle is explained below for an application in which ATES is used for heating and cooling.

Figure 1 displays the basic principle of an ATES system that is used for both cooling and heating. In summer, groundwater is extracted from the cold well(s) and used for cooling purposes, depleting the cold store over the cooling season. The warmed return water is injected in the warm well(s) to recharge the warm store. In winter the process is reversed: water is pumped from the warm well(s) and applied as a low temperature heat source for a heat pump. After the exchange of heat the chilled water from the heat pump is injected into the cold well(s), recharging the cold store for use the following summer.

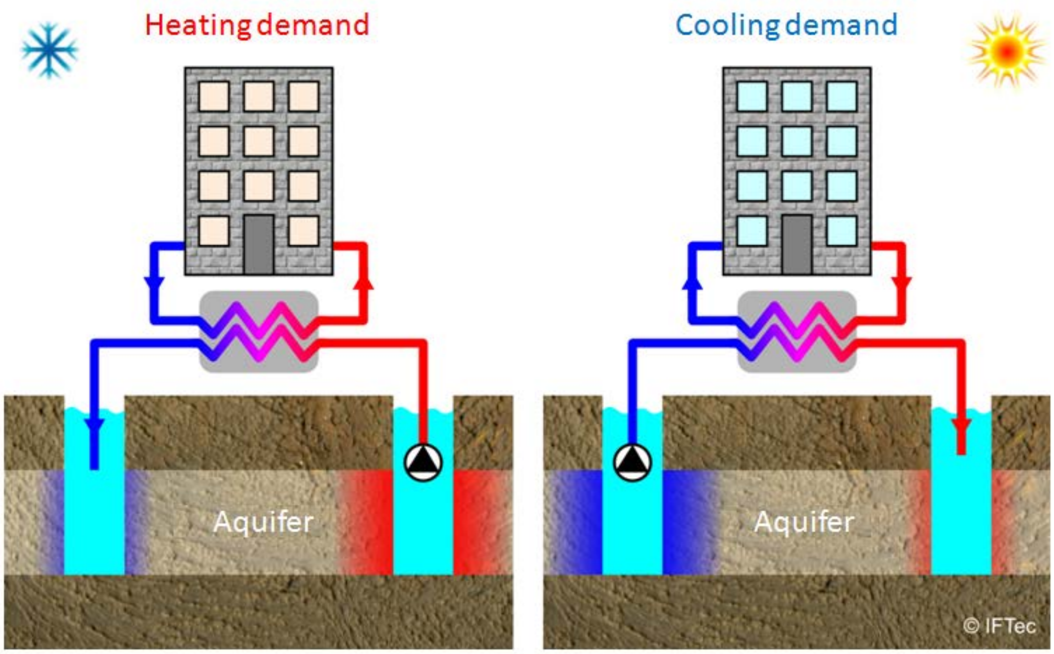

Figure 1 - Principle of ATES in heating (winter) and cooling (summer) mode

All the water extracted from the cold store is re-injected into the warm store. There is net extraction of groundwater, so despite the fact that ATES systems operate at high flow rates, there is no consumptive use of groundwater. ATES systems are carefully designed and operated so that temperature is the only characteristic of the water that is modified; no chemicals or additives are injected into the aquifer. Balance is a key characteristic of ATES systems, the injection and withdrawal rates are balanced, the hydraulic conditions in the aquifer are seasonally balanced, and the systems are typically designed so that net thermal balance on the aquifer is maintained.

ATES systems require a minimum distance between warm and cold wells, depending on site conditions and thermal capacity of the system. ATES systems require three primary site-specific physical characteristics: (1) an aquifer capable of yielding high flow rates to wells, (2) seasonally variable (and preferably, relatively balanced) heating and cooling requirements, and (3) large thermal loads, typically greater than 100,000 square feet (sf) of conditioned space. All three of these conditions exist at the Ford Site.

2.0 Methodology

This ATES Feasibility Study report for the Ford Site was prepared by a team that included Underground Energy, LLC and IF Tech USA LLP. Our team was supported by Ever-Green Energy, Inc. (Ever-Green), who provided estimated average heating and cooling loads and input on district energy system costs.

A hydrogeologic evaluation was performed using existing data, and potential yields of ATES wells were estimated. Estimated heating and cooling loads were provided by Ever-Green Energy, Inc. The well sizes and the loads are the design basis for a district-energy-based ATES system, for which a conceptual design was patterned after a conceptual layout prepared previously by Ramboll. A cost estimate was developed and the energy and economic benefits of ATES were compared to a district energy system with centralized gas-fired boilers and centrifugal chillers. Finally, a regulatory evaluation was performed, and Underground Energy participated in meetings with City of St. Paul staff and Minnesota regulatory officials.

3.0 Site Hydrogeologic Evaluation

3.1 Data Compilation and Review

3.1.1 Publically Available Hydrogeologic Data

The following sources of publically available information were useful in the development of a conceptual hydrogeologic model of the multi-aquifer setting of the Ford Site and of the Twin Cities region:

- Geologic Atlas of Ramsey County (1992),
- Metropolitan Council Twin Cities Regional Groundwater Flow Model V3 (2014),
- Minnesota Geological Survey (MGS) Report of Investigations 61 (2003),
- United States Geological Survey (USGS) Water Resources Investigations Reports, and
- County Well Index (CWI) database created and maintained by MGS.

A complete list of references reviewed is included in Section 11.0.

3.1.2 Site Specific Hydrogeologic Data

Site-specific hydrogeologic data were included in the Comprehensive Phase II Site Investigation Report that was prepared for Ford Motor Company by Arcadis U.S., Inc. (2015). The focus of the Phase II report was on soil and groundwater contamination at the Ford Site, which was primarily limited to the shallow portions of the unconsolidated glacial overburden at the Ford Site. The deepest bedrock unit investigated in the Phase II report was the St. Peter Sandstone, at the base of which is a confining unit that hydraulically separates the St. Peter Sandstone from the underlying aquifers considered for ATES in this feasibility study (Mossler, 1992).

Arcadis' Phase II report identified that some dissolved metals, diesel-range organics, cyanide and PCPs have been detected in the St. Peter sandstone aquifer at concentrations exceeding applicable regulatory screening values. However, these detections in St. Peter aquifer groundwater have been of low concentrations, isolated and not repeatable. (The source of the compounds had not been determined at the time of this report.) Chlorinated volatile organic compounds (CVOCs) are considered the contaminant of greatest concern to development of an ATES system because they are denser than water in their non-aqueous phase and tend to sink into deeper aquifers, because they are mobile and recalcitrant in groundwater, and because they pose significant human health risks and are difficult to remediate. No CVOCs have been detected in the St. Peter Sandstone beneath the Ford Site, and they are therefore unlikely to be detected in deeper aquifers. It is Underground Energy's opinion that the suitability for ATES of aquifers below the St. Peter sandstone at the Ford Site has likely not been affected by anthropogenic contamination from historic land uses at the Ford Site.

3.2 Conceptual Site Model

A conceptual site model (CSM) has been developed in the following sections to facilitate interpretation of hydrogeologic conditions at the Ford Site in Saint Paul. The CSM is based on Underground Energy's review and interpretation of published hydrogeologic and subsurface data in the vicinity of the site.

3.2.1 Site and Regional Stratigraphy

The Twin Cities area is underlain by a mantle of Quaternary age glacial deposits that range in thickness from zero (exposed bedrock outcrop) atop Mississippi River bluffs to over 400 feet in buried bedrock valleys. These glacial deposits unconformably overlie more than 1,000 feet of nearly horizontal Paleozoic age sedimentary rocks. These bedrock formations comprise multiple sandstone and carbonate aquifers separated by shale confining layers. These units are laterally extensive on a scale of tens to hundreds of miles. The bedrock units tend to be more fractured within about 200 feet of the top-of-bedrock surface, and the limestone and dolomite (carbonate) units of the Prairie du Chien group exhibit dissolution enlargement of vertical and horizontal fractures and karstic behavior with respect to permeability and groundwater flow.

Figure 2 presents a graphic depiction of the bedrock aquifers and shale confining units that underlie the Ford Site.

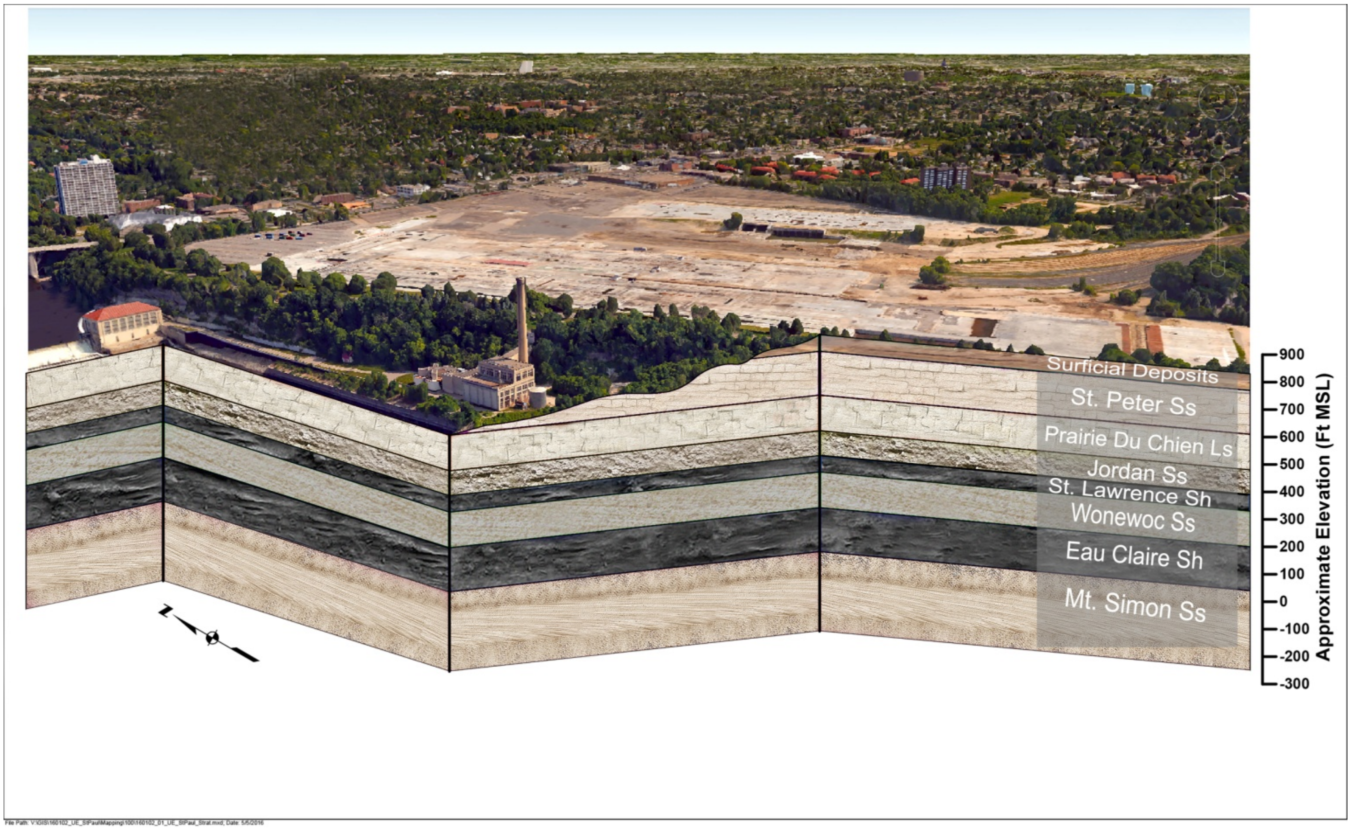

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Figure 2 – Graphic depiction of bedrock aquifers beneath the Ford Site

At the Ford Site, the unconsolidated glacial deposits range from zero to about 15 feet thick (Arcadis, 2015), and comprise both coarse-grained and fine-grained units. The glacial overburden deposits at the Ford Site are mapped as "stream sediment of Glacial River Warren" (Meyer et al., 1992). The overburden deposits may locally yield fairly large flow rates to properly constructed wells, but they are not considered suitable for ATES use at the Ford Site due to their thin nature and low transmissivity (which is the product of aquifer thickness and hydraulic conductivity). The surficial deposits overlie the uppermost late Ordovician bedrock formations at the Ford Site, either the Decorah Shale or the Platteville limestone/dolostone, which overlies the Glenwood shale. These upper bedrock units are not considered suitable for ATES use at the Ford Site due to low transmissivity. The Glenwood shale overlies the mid-late Ordovician St. Peter Sandstone, which can be a productive aquifer in southeastern Minnesota, however the St. Peter sandstone is not considered suitable for ATES at the Ford Site due to expected locally unconfined (phreatic) and unsaturated conditions and relatively low expected well yields. The base of the St. Peter sandstone in the Twin Cities area is comprised of shale and siltstone beds that are nearly continuous; these formations have a low permeability and are effective at confining the underlying Prairie du Chien aquifer and protecting it from contamination from above (Mossler, 1992).

The underlying bedrock aquifers and confining layers are described in more detail in the following subsections, in order of increasing depth and geologic age. Figure 3 (from Runkel et. al, 2003) depicts the stratigraphy and character of the Paleozoic formations near the Ford Site, including the higher degree of fracturing of the bedrock formations within 200 feet of the top of the bedrock surface and the dissolution features within the Prairie du Chien group.

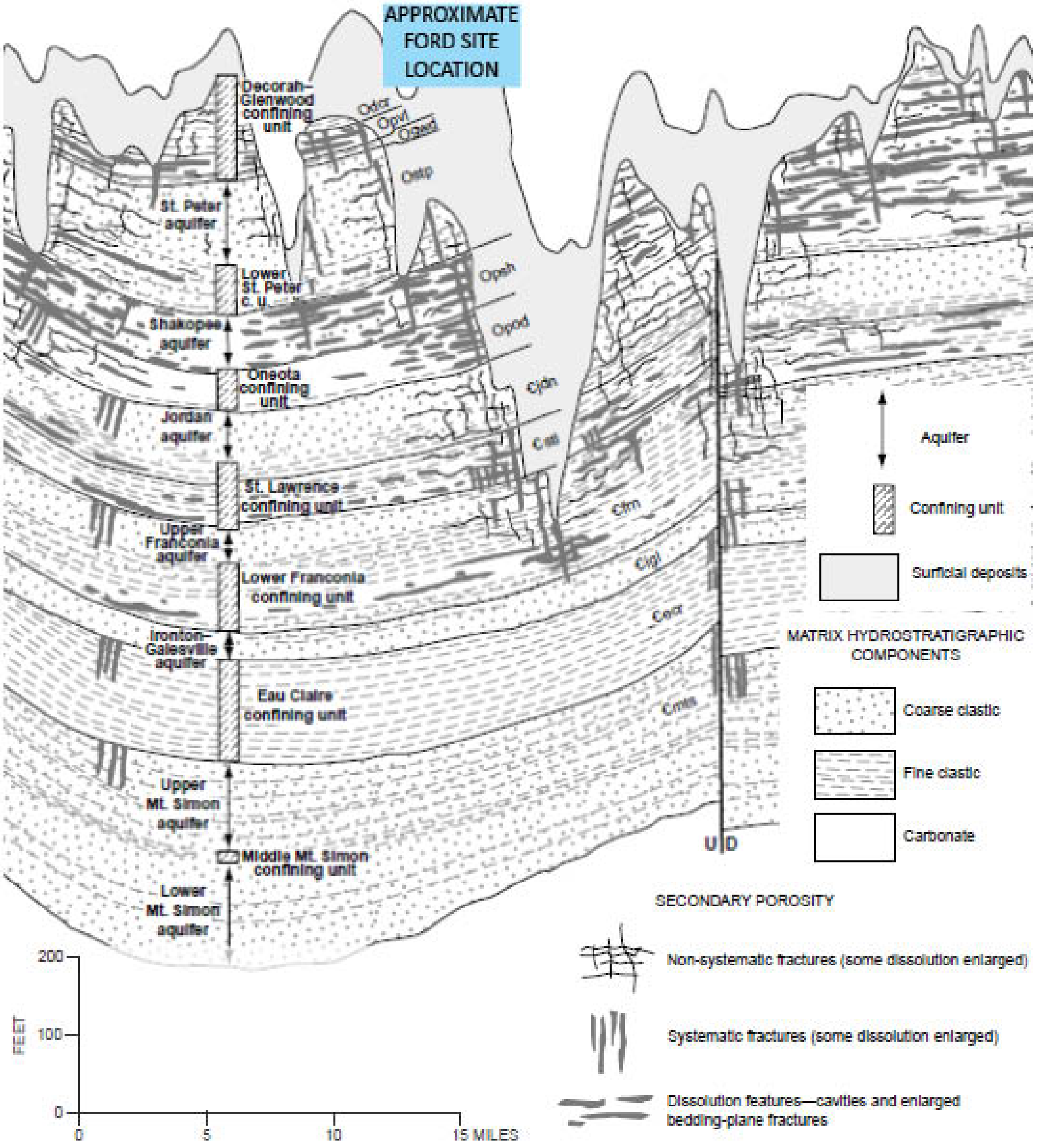

Figure 3 - Paleozoic bedrock stratigraphy near the Ford Site

Prairie du Chien-Jordan Aquifer

The Prairie du Chien Group and Jordan Sandstone together form the most heavily used aquifer in Ramsey County. The aquifer is overlain and confined by the shaly basal part of the St. Peter Sandstone. The early Ordovician Prairie du Chien Group is composed predominantly of dolostone; groundwater flows mainly through fractures, joints, and solution cavities. The total thickness of the Prairie du Chien Group is about 120-130 feet. The Jordan Sandstone (70 to 100 feet thick) consists of highly permeable, fine- to coarse-grained quartzose sandstone, and, unlike the Prairie du Chien aquifer above, most groundwater flow is through intergranular spaces rather than along fractures. Despite their difference in rock type, the Prairie du Chien Group and Jordan Sandstone function as a single aquifer because no regional confining bed separates them. Locally, however, small water-level differences may exist, owing to relatively impermeable beds of shale of limited extent. The Prairie du Chien-Jordan aquifer is a confined aquifer at the Ford Site.

In general, groundwater in the Prairie du Chien-Jordan Aquifer flows from areas with the highest hydraulic head in northeastern Ramsey County toward the Mississippi River. This flow pattern indicates that the Prairie du Chien-Jordan aquifer discharges into the river. Figure 4, from the Twin Cities Metropolitan Area Groundwater Flow Model (Metropolitan Council, 2014), depicts piezometric surface contours and groundwater flow directions as determined from a calibrated groundwater flow model. The piezometric surface shown in Figure 4 shows a flattening of the hydraulic gradient near the Ford Site, probably attributable to the impounded area of the Mississippi River north of Lock and Dam No. 1(formerly the Ford Dam). A reduced hydraulic gradient is beneficial for ATES, as the lower groundwater velocity increases storage efficiency.

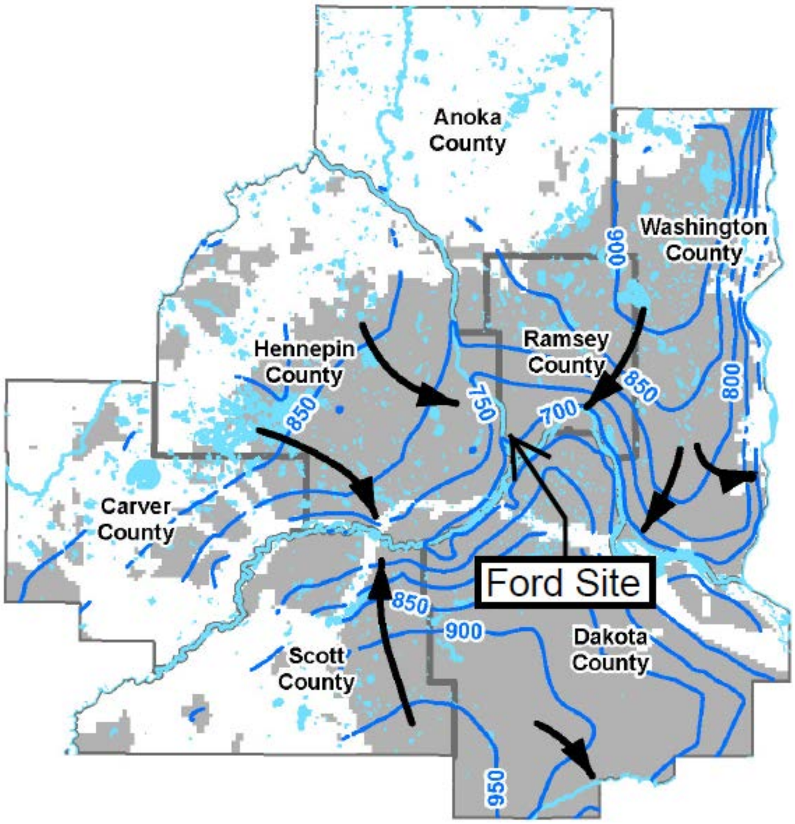

Figure 4 - Groundwater flow in the Prairie du Chien-Jordan aquifer

Wonewok Aquifer

The Wonewok aquifer (previously referred to in the literature as the Franconia-lronton-Galesville aquifer) underlies all of Ramsey County. The aquifer has three parts: (1) the upper part is the Franconia Formation, which consists of about 115 to 160 feet of feldspathic and glauconitic sandstone with some shale and dolomite; (2) the middle part is the 15- to 20-foot-thick Ironton Sandstone, which contains minor shale partings; and (3) the basal part is the 30- to 40-foot-thick Galesville Sandstone. All three bedrock units are hydraulically connected, although small hydraulic head differences may be found locally.

Ground-water movement in this aquifer, like that in the overlying Prairie du Chien-Jordan aquifer, is from areas having the highest hydraulic head in northern Ramsey County toward the Mississippi River. The difference in water level between wells in the Prairie du Chien-Jordan and wells in the Wonewok aquifer, which ranges from 20 to 80 feet (Fig. 1), demonstrates the effectiveness of the St. Lawrence confining unit.

The Wonewok aquifer is little used in Ramsey County. In the northwestern part of the county the aquifer is used in a few multiple-aquifer wells drilled into the deeper Mt. Simon aquifer.

The Eau Claire Formation consists of siltstone, shale, and silty sandstone and is about 60-I 10 feet thick. It has low hydraulic conductivity and thus hydraulically separates the Wonewok aquifer from the Mt. Simon aquifer.

Mt. Simon Aquifer

The Mt. Simon aquifer underlies the Twin Cities area. It is composed of fine - to coarse-grained sandstone with many thin beds of siltstone and shale in the upper part, and ranges in thickness from 250 to 330 feet in Ramsey County. Nearly all high-capacity wells in the aquifer are located either in the south-central or the northwestern part of the county.

Data on ground-water movement are very limited, but the pattern of flow in the Mt. Simon aquifer apparently differs greatly from the pattern in the overlying aquifers. The general movement of ground water is from east to west toward the cone of depression formed by the major pumping centers in Hennepin County.

3.2.2 Aquifer Physical and Hydraulic Properties

Major aquifer physical and hydraulic characteristics are summarized in Table 1. This table was compiled by Underground Energy following review of the documents listed in Section 11.0. The assumed elevation at the Ford Site is 830 ft above mean sea level (MSL), and most of the depth and aquifer thicknesses data in Table 1 were obtained from a 1,070-foot-deep observation well (well #792118), approximately 1,000 feet south of the Ford Site. This well was completed to the base of the Mt. Simon aquifer and logged by MGS on behalf of the Minnesota Department of Natural Resources (DNR).

Table 1 - Estimates of bedrock aquifer properties at the Ford Site

Parameter	**Aquifer System**				
	St. Peter	**Prairie du Chien**	**Jordan**	**Wonewoc**	**Mt. Simon**
Ford Site Ground Elevation	830 ft	830 ft	830 ft	830 ft	830 ft
Aquifer Top Elevation	770 ft	610 ft	480 ft	330 ft	40 ft
Aquifer Bottom Elevation	610 ft	480 ft	390 ft	200 ft	-250 ft
Saturated Thickness	160 ft	130 ft	70 ft	130 ft	290 ft
Groundwater head in aquifer	690-710 ft	700 ft MSL	700 ft MSL	740 ft MSL	640 ft MSL
Groundwater depth from ground surface	130 ft	130 ft	130 ft	90 ft	190 ft
Aquifer depth	60-220 ft 18-67 m	220-350 ft 67-107 m	350-440 ft 107-134 m	630-700 ft 192-213 m	800-1100 ft 244-335 m
K_h – Hydraulic conductivity – horizontal	20-30 ft/day 6-9 m/day	20-60 ft/day 6-18 m/day	20-50 ft/day 6-15 m/day	2-5 ft/day 0.6-1.5 m/day	5-25 ft/day 1.5-7.6 m/day
K_v – Hydraulic conductivity – vertical	3 ft/day 1 m/day	1 ft/day 0.3 m/day	3 ft/day 0.8 m/day	0.07 ft/day 0.02 m/day	3 ft/day 1 m/day
Aquifer transmissivity	3200-4800 ft^2/day 300-450 m^2/day	2600-7800 ft^2/day 240-730 m^2/day	1800-4500 ft^2/day 170-420 m^2/day	250-650 ft^2/day 24-60 m^2/day	1400-7300 ft^2/day 130-670 m^2/day
Aquifer specific storage	4.5 x 10^{-6} 1/m	3.2 x 10^{-6} 1/m	1 x 10^{-6} 1/m	1 x 10^{-5} 1/m	2 x 10^{-5} 1/m
Aquifer specific yield	0.2 %	0.2 %	0.2 %		
Hydraulic Gradient	1 x 10^{-2}	2 x 10^{-3}	2 x 10^{-3}	1.4 x 10^{-3}	6 x 10^{-4}
Aquifer Porosity	0.32	0.18	0.33	0.30	0.28
Ambient Groundwater Temperature	47° F 8.2° C	49° F 9.3° C	49° F 9.3° C		
Groundwater flow velocity	0.6- 0.9 ft/day 0.2-0.3 m/day	0.2-0.7 ft/day 0.07-0.2 m/day	0.1-0.3 ft/day 0.04-0.09 m/day	0.01-0.02 ft/day 0.003-0.007 m/day	0.01-0.05 ft/day 0.003-0.02 m/day

3.2.3 Aquifer Geochemical Properties

As discussed in Section 3.1.2, it is Underground Energy's opinion that the suitability for ATES of aquifers below the St. Peter sandstone at the Ford Site has likely not been affected by anthropogenic contamination from historic land uses at the Ford Site.

Reducing (anaerobic) groundwater conditions, favorable for ATES, are expected in the confined Prairie du Chien-Jordan, Wonewok and Mt. Simon aquifers.

Based on water quality analyses from the Prairie du Chien-Jordan aquifer reported in Ruhl, et al. (1983), the groundwater from this aquifer system is predominantly of a calcium magnesium bicarbonate type. A relatively low dissolved solids concentration of about 100-300 mg/l is expected from this aquifer at the Ford Site. Average iron and manganese concentrations in the Prairie du Chien-Jordan aquifer are 0.65 and 0.2 mg/L, respectively.

Based on water quality analyses from the Wonewok aquifer reported in Ruhl, et al. (1982), the groundwater from this aquifer system is predominantly of a calcium magnesium bicarbonate type. A relatively low dissolved solids concentration of about 200-300 mg/l is expected from the Wonewok aquifer at the Ford Site. Average iron and manganese concentrations in the Wonewok aquifer are 1.3 and 0.1 mg/L, respectively.

Based on water quality analyses from the Mt. Simon aquifer reported in Wolf, et al. (1983), the groundwater from this aquifer system is predominantly of a calcium magnesium bicarbonate type. A relatively low dissolved solids concentration of about 200-300 mg/l is expected from the Mt. Simon aquifer at the Ford Site. Average iron and manganese concentrations in the Mt. Simon aquifer are 0.9 and 0.01 mg/L, respectively.

3.3 ATES Well Sizing

ATES wells differ from conventional water-supply wells because they are designed to operate as withdrawal wells during heating or cooling season and as injection wells during the opposite season. Because injection wells are subject to plugging from fines, colloids and mineral precipitates in the recharge water, typical practice in the United States has been to double the well screen length, if possible, or operate them at one half or less of the maximum flow rate of a similarly constructed groundwater withdrawal well (Driscoll, 1986). To size ATES wells operating in withdrawal mode, Dutch ATES practioners utilize a maximum approach velocity at the borehole wall, $V_{b,\,max}$, developed by IF Technology (2001). To calculate maximum infiltration flow rate from ATES wells, the calculations require measurement of Membrane Filter Index (MFI), a technique developed in the Netherlands that is used to predict the plugging performance of ATES wells. It is similar, but not identical, to the Silt Density Index (SDI) method. The Dutch practice is to size ATES wells based on the lower of the two calculated well flow rates. Because MFI data are collected by testing a production well, no MFI data are available for the aquifers beneath the Ford

Site, although the consolidated Paleozoic-age aquifers at the Ford Site suggest that MFI values will be low compared to similar values from unconsolidated aquifers. Therefore, the preliminary ATES well sizing used in this feasibility study was based on the IF Technology approach velocity method.

For production (withdrawal) mode, the maximum approach velocity at the borehole wall is used to estimate maximum ATES well flow rate, Q_{max}, using the following equations:

$$v_{b,max} = K/12$$
$$Q_{max} = A_b v_{b,max}$$
$$A_b = \pi D_b L_s$$

where: $v_{b,max}$ = maximum production flow velocity on the borehole wall (m/hour);
K = formation hydraulic conductivity (average over the screened interval; m/day); and
A_b = area of the borehole along the screen length (m^2); and
D_b = diameter of the borehole (m); and
L_s = length of the screened interval (m).

Table 2 presents the data used to calculate Q_{max}, for the aquifers that underlie the Ford Site. From Table 2, the combined calculated flow rates for the Prairie du Chien and Jordan aquifers ranges from 430 to 1,200 gallons per minute (gpm). A maximum ATES well yield value of 900 gpm from the Prairie du Chien-Jordan aquifer was used in the conceptual design.

Table 2 - Conceptual ATES well design by aquifer at the Ford Site

	Aquifer System				
	St. Peter	**Prairie du Chien**	**Jordan**	**Wonewoc**	**Mt. Simon**
Well Depth	220 ft 67 m	350 ft 107 m	440 ft 134 m	700 ft 213 m	1100 ft 335 m
Well Screen Length	90 ft 27 m	130 ft 40 m	90 ft 27 m	130 ft 40 m	150 ft 46 m
Well Screen Depth Interval	130-220 ft 40-67 m	220-350 ft 67-107 m	350-440 ft 107-134 m	630-700 ft 192-213 m	950-1100 ft 290-335 m
Borehole Diameter	36 in	36 in	36 in	36 in	36 in
Well Casing Diameter	20 in	20 in	20 in	20 in	20 in
Max. Approach Velocity on Borehole Wall	0.5-0.8 m/hr	0.5-1.5 m/hr	0.5-1.3 m/hr	0.05-0.1 m/hr	0.1-0.6 m/hr
Well Flow Rate	180-260 gpm 40-60 m^3/hr	255-760 gpm 60-170 m^3/hr	176-441 gpm 40-100m^3/hr	14-34 gpm 3-8 m^3/hr	73-370 gpm 15-85 m^3/hr
Maximum Injection Pressure	4 ft ags	13 ft ags	21 ft ags	38 ft ags	49 ft ags

3.4 Proximity to Public Supply Wells

Underground Energy obtained public supply water well information from the County Well Index (CWI) database maintained by the MGS. The CWI well data were analyzed using Geographic Information System (GIS) software to identify nearby public supply wells by their use codes, which are:

- *PC – Community Supply*
- *PN – Public Supply/non community-transient*
- *PP – Public Supply/non-community-non-transient*
- *PS – Public Supply/non-community*
- *MU – Municipal*
- *LN – Licensed Non-Public Water Supply*

Figure 5 depicts public supply wells within about two mile of the Ford Site, labeled according to their completion depth and by the reported aquifer from which they withdraw groundwater. The nearest public supply well that obtains water from the Prairie du Chien-Jordan aquifer is at the Minnesota Veterans Home approximately 1,200 feet west of the Ford Site. This is a deep well and obtains water from multiple aquifers. The next nearest public supply wells that obtain water from the Prairie du Chien-Jordan aquifer are located approximately 1.5 miles to the southeast of the Ford Site. All of the nearest public supply wells are located at distances from the Ford Site that are significantly greater than the maximum isolation distance of 300 feet for water supply wells as set forth in Minnesota Rules 4725.4450-4500.

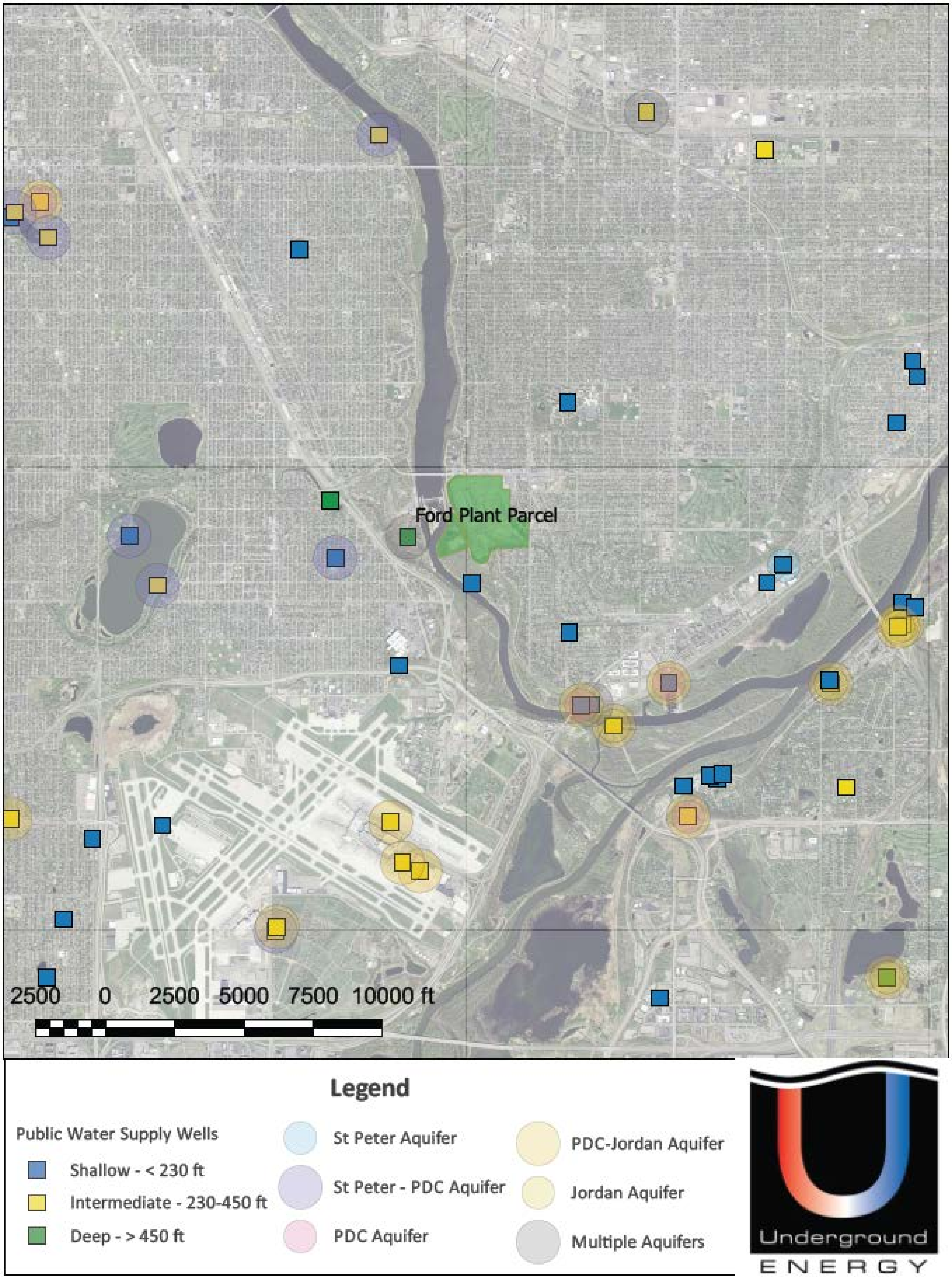

Figure 5 - Area Public Supply Wells

4.0 Building Information and Building Loads

4.1 Building Information

The Ford Site Draft 1 Conceptual Development Plan, prepared by the City of Saint Paul for the purpose of technical analyses and studies of potential redevelopment needs, impacts and costs, shows about 6,570,000 sf (610,000 m^2) building conditioned floor area, mainly consisting of medium-high density residential buildings. The approximate floor space per building type is presented in Table 3 below.

Table 3 - Building information

Building type	**Conditioned floor area** **sf**	 **m^2**
Low density residential	890,000	83,000
Medium density residential	780,000	72,000
High density residential	3,450,000	320,000
Mixed use/retail	275,000	25,000
Retail	640,000	60,000
Civic buildings	300,000	28,000
Office buildings	235,000	22,000
Total	**6,570,000**	**610,000**

Source: E-mail from Ever-Green Energy dated March 11, 2016.

4.2 Building Loads

In order to develop a concept for a District Heating & Cooling (DH&C) network including ATES and to evaluate the feasibility of this concept, the peak demand and annual energy use of the future buildings on the Ford site has to be estimated. To predict the loads at this level of analysis, Energy Use Intensities (EUI's) have been used by Ever-Green Energy for both cooling and heating. EUI's are defined as thermal peak demand or annual energy per unit floor area. It has been assumed that all buildings meet the energy efficiency standards according to the Minnesota Sustainable Building Code 2030.

The heating and cooling loads were developed based on the building areas given in Table 1. The diversified heating load for the Ford site is estimated to be 53.6 MMBtu/hr peak and 115,800 MMBtu of annual energy consumption (excluding domestic hot water production). The diversified cooling load for the Ford site is estimated to be 3,450 Tons peak and 66,900 MMBtu of annual energy consumption. The estimated energy loads for the various building types are summarized in Table 4.

Table 4 - Building thermal energy demands

Building type	Heating demand		DHW demand		Cooling demand	
	MMBtu/y	MWh/y	MMBtu/y	MWh/y	MMBtu/y	MWh/y
Low density residential	13,600	3,980	0	0	6,800	1,990
Medium density residential	15,800	4,640	3,960	1,160	7,900	2,320
High density residential	70,600	20,700	17,650	5,180	35,300	10,350
Mixed use/retail	4,300	1,250	430	120	4,200	1,250
Retail	7,400	2,170	740	220	7,400	2,170
Civic buildings	2,400	700	130	35	3,500	1,020
Office buildings	1,700	510	290	85	1,800	510
Total	**115,800**	**33,950**	**23,200**	**6,800**	**66,900**	**19,610**

Source: E-mail Ever-Green Energy dated March 11, 2016.

Table 5 indicates the total peak loads and the diversified total peak loads. The latter loads take into account that the peak loads of all homes, apartments and buildings do not coincide. This implies that the peak load of the overall system will be lower than the sum of the peak loads of the individual thermal energy consumers. For this study a diversity factor of 0.75 has been assumed.

Table 5 - Building thermal peak loads

Building type	Heating peak load		DHW peak load		Cooling peak load	
	MMBtu/h	MW	MMBtu/h	MW	Tons	MW
Low density residential	8.49	2.49	0	0	514	1.81
Medium density residential	9.90	2.90	1.13	0.33	600	2.11
High density residential	44.12	12.93	5.04	1.48	2,674	9.42
Mixed use/retail	2.36	0.69	0.13	0.04	295	1.04
Retail	4.11	1.20	0.09	0.03	121	0.43
Civic buildings	1.33	0.39	0.04	0.01	290	1.02
Office buildings	1.16	0.34	0.09	0.03	132	0.47
Total	**71.5**	**20.9**	**6.5**	**1.9**	**4,600**	**16.3**
Total diversified load	**53.6**	**15.7**	**4.9**	**1.4**	**3,450**	**12.2**

Figure 6 and Figure 7 below show the assumed load-duration curve (LDC) for the estimated heating and cooling loads, respectively. These curves are estimates and included only for explanatory reasons. A LDC indicates, on an annual basis, the time that loads are less and/or greater than a given value in a typical year. LDC's are useful tools for visualizing a load profile throughout the year; they show, amongst other things, that peak demand only occurs for a very short time.

LDCs also assist with sizing energy source options and estimating the energy that each source would contribute on an annual basis. The area under the load duration curve represents the energy demand from the buildings. For example, an energy source with a higher capital cost but a lower operating cost would be sized at typically 35-50% of the peak load but supplies 80% or more of the annual energy for the system. The remaining energy could be provided by an energy source with a lower capital cost and a higher fuel cost, as it is used very little and is required for backup in any event (see Section 6.0 on ATES system sizing).

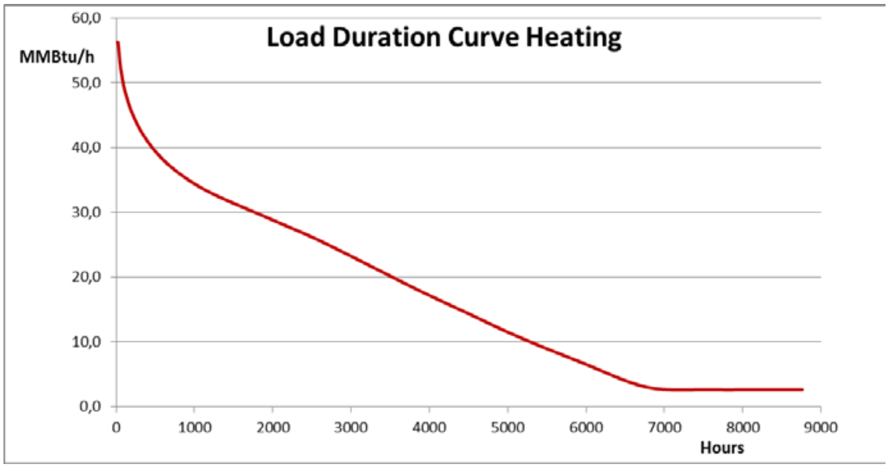

Figure 6 - Heating load duration curve for the Ford Site

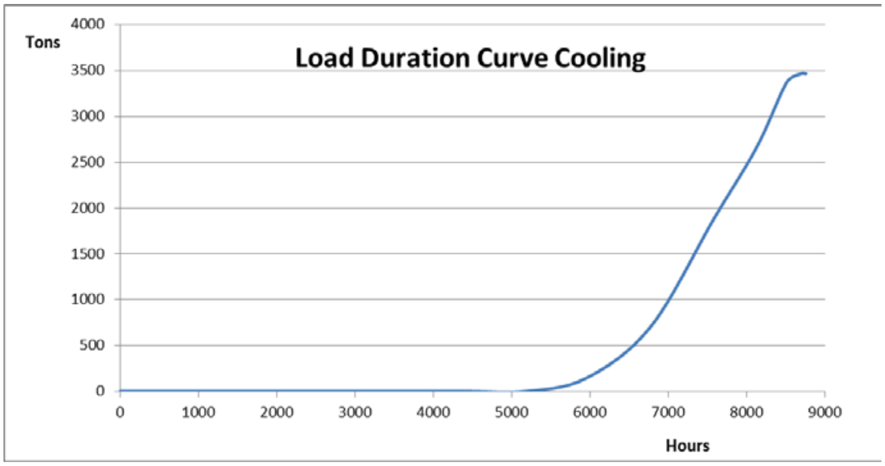

Figure 7 - Cooling load duration curve for the Ford Site

In order to be able to apply an ATES system combined with heat pumps for heating and cooling of the buildings on the Ford site, there are some boundary conditions that have to be taken into account. This study is based on the assumption that the following boundary conditions are met:

- The buildings, homes and apartments have a low temperature heating system, enabling the application of heat pumps. Assumed heating supply and return temperature under design conditions 120-100 °F (48.9-37.8 °C).
- The buildings, homes and apartments have a high temperature cooling system, enabling the application direct ATES cooling in combination with heat pumps. Assumed cooling supply and return temperature under design conditions 45-60 °F (7.2-15.6 °C).
- The homes and apartments have a centralized domestic hot water (DHW) system per residential building or individual DHW production with a booster heat pump using the ventilation air or the heating/cooling return.

5.0 ATES System Conceptual Design

5.1 Configurations for ATES based DH&C Systems.

Utility scale ATES projects consist of a well field with several groundwater withdrawal and recharge wells (open-loop system), groundwater transport/distribution piping, heat pumps as well as warm and chilled water distribution piping. The system is providing heating or cooling, or simultaneous heating and cooling to several buildings. The groundwater circuit is hydraulically separated from the heating and cooling circuits inside the buildings by plate heat exchangers.

From the thermal energy distribution perspective, several system configurations can be distinguished (Table 6).

Table 6 - Distribution system configurations

Heat pump location	Distribution System Groundwater	Distribution System Chilled and Warm Water
1. In centralized plant room for all buildings together.	Between well field and central plant room. Single, uninsulated piping (water is flowing either from warm to cold wells or from cold to warm wells).	Supply and return piping for warm and chilled water between central plant room and buildings, and inside buildings. Four-pipe system, insulated. Remark: DHW supply requires special attention.
2. In central plant room per building (also group of houses/apartment block). Remark: Best suited for aquifer seasonal thermal energy storage application.	Between well field and buildings. Two- or four-pipe system, piping not insulated.	Supply and return piping for warm and chilled water inside buildings. Four-pipe system, insulated. Remark: DHW make-up might be integrated in building plant room.
3. Distributed heat pumps in the buildings. Remark: Central heat exchanger per building is recommended for hydraulic separation.	Between well field and buildings. Two pipe system (supply and return), piping not insulated.	Two-pipe system (supply and return) inside buildings between heat exchanger and distributed heat pumps. Piping insulated. Supply and return piping for warm and chilled water after heat pumps. Two- or four-pipe system.

The majority of the utility scale ATES projects in Europe provide heating and cooling. Most of the utility scale ATES projects are providing heating and cooling applying the distribution configuration according to #2 in Table 6. This configuration will be discussed in more detail hereafter. Although this paragraph is focusing on ATES based systems, the approach is not limited to this type of system. Especially utility scale systems based on borehole thermal energy storage (BTES) will have similar issues when selecting the distribution system configuration.

5.2 Groundwater Distribution Options for ATES based DH&C Systems.

In the case of an ATES based utility scale DH&C system with a mechanical room in each of the buildings (configuration #2 in Table 6), the selection of the distribution system between the wells and the building plant rooms is summarized as a flowchart in Figure 8. If there is no simultaneous demand for heating and cooling (all buildings are either demanding cooling or heating), a two-pipe groundwater system (supply and return) will suffice. The two-pipe system provides either warm water or chilled water to the building plant rooms.

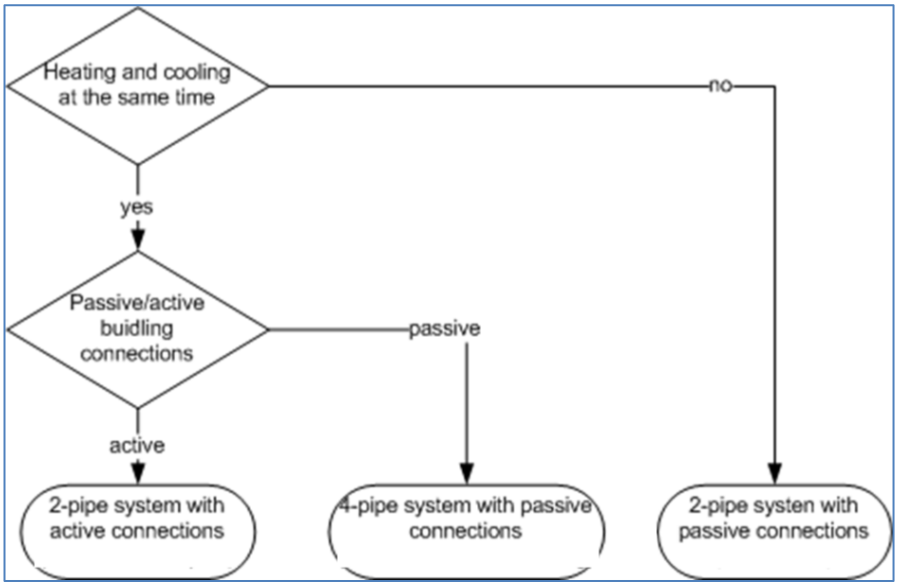

Figure 8 - Distribution system selection flowchart

In the case of simultaneous heating and cooling demand, which is the most common situation for ATES-based systems, both a two-pipe and a four-pipe groundwater distribution layout are possible.

Figure 9 and Figure 10 show a schematic representation for the four-pipe and two-pipe configurations.

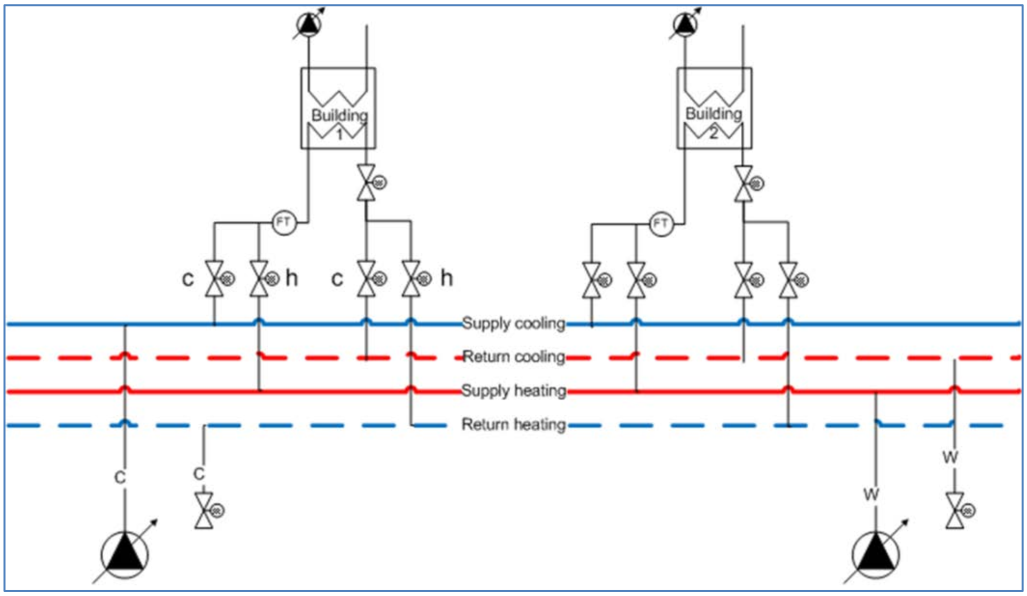

Figure 9 - Four-pipe groundwater distribution, passive building connections

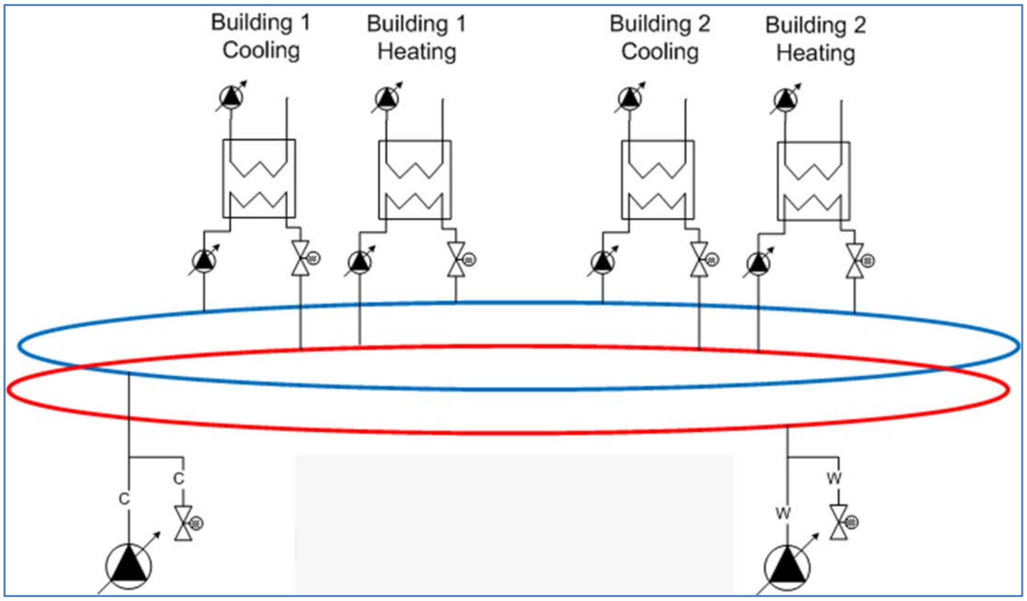

Figure 10 - Two-pipe groundwater distribution, active building connections

In both the four-pipe system and the two-pipe system the flow of the groundwater in the ATES system is driven by the well pumps. In the four-pipe system, these well pumps also provide the pressure drop over the heat exchangers in the central building plant rooms. This is realized by maintaining a constant pressure difference between supply and return pipes of the groundwater loop. This building connection is defined as a passive building connection, see also Figure 9. By opening/closing valves, the building is connected to either warm water supply and return or chilled water supply and return. A separate control valve in the building connection controls the flow over the building heat exchanger by maintaining a pre-set return temperature or temperature difference between supply and return.

In the two-pipe system, the well pumps in combination with the valves in the discharge wells maintain an equal pressure in the warm and chilled water loop. Each building has its own pump to take water from the chilled water loop and return it to the warm water loop and vice versa (active building connection). The flow rates of the building connection pumps are controlled by the temperature of the return water, see Figure 11. In this example schematic the building is taking water from the chilled water pipe and returning it to the warm water pipe at a minimum temperature of 15 °C (59 °F). It is important that this pre-set temperature condition is met, because a neighboring building might be taking water from the warm water pipe at the same time and the minimum supply temperature has to be guaranteed by the energy supply entity.

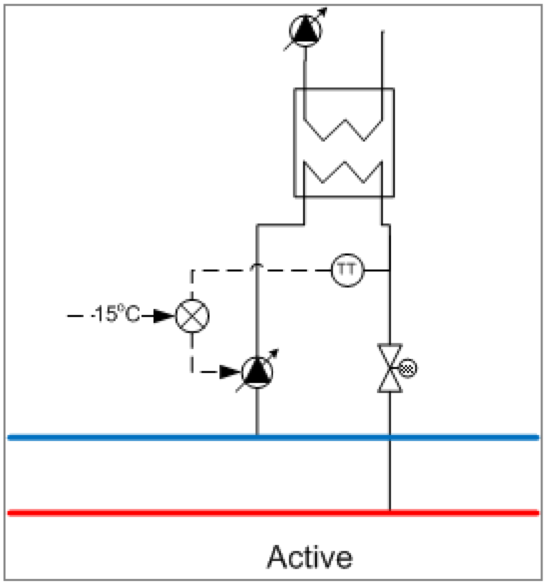

Figure 11 - Active building connection

The two-pipe configuration is more complex regarding building connections and controls. The piping cost, however, is significantly lower than for the four-pipe distribution system. Because the piping cost increases with the overall capacity of an ATES based district heating and cooling system (larger distances, larger diameters), the two-pipe system tends to be the preferred option for the larger scale ATES applications (ATES capacity > 5.0 MW, 1,500 tons) with a limited number of building connections. In this ATES feasibility study, the two-pipe system is analyzed in more detail.

5.3 ATES based DH&C Network for the Ford Site

Figure 12 and Figure 13 depict the conceptual design of an ATES system integrated with new building systems and with a new local District Heating and Cooling loop. This configuration uses a two-pipe groundwater loop with active building connections (configuration #2 in Table 6).

The principle of operation for a building in winter mode and the ATES system in winter mode (ATES system heating mode and charging operation for the cold ATES well field) is displayed in Figure 12.

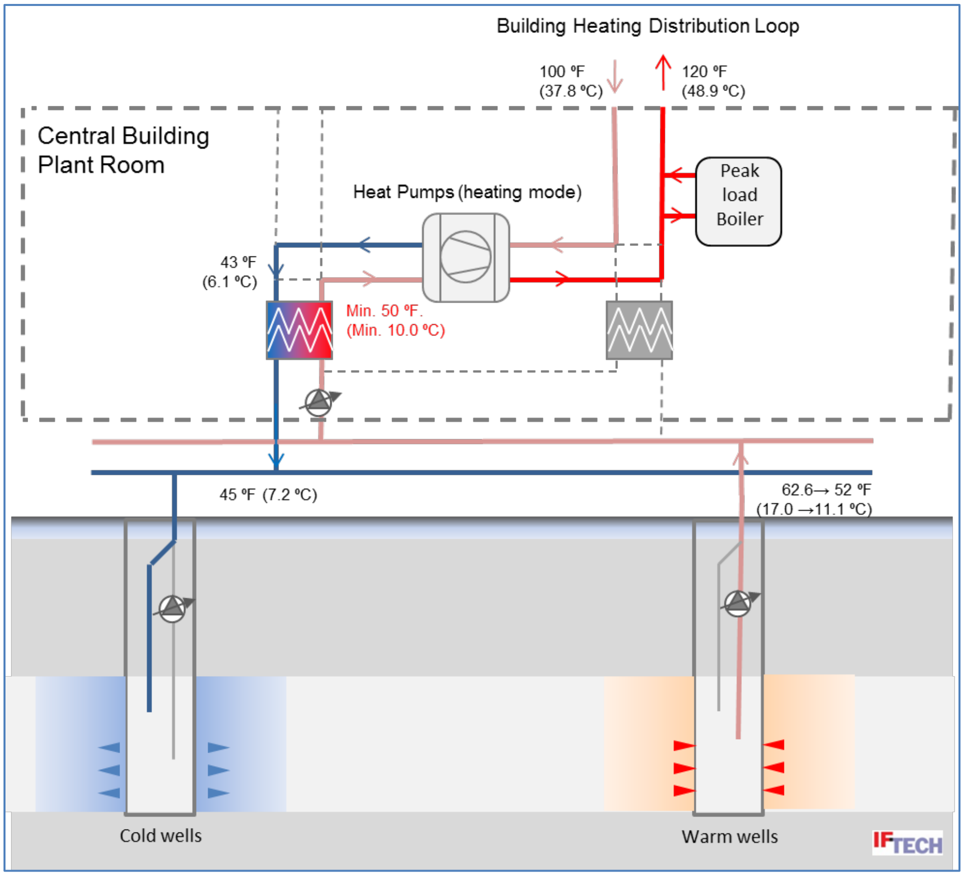

Figure 12 - Principle of ATES system in heating mode (winter operation)

In winter mode, groundwater is pumped from the warm wells to the cold wells and the warm water is used by heat pumps as a low temperature heat source. The water that is cooled down by the heat pumps is discharged into the cold wells. The heat pumps provide heating for the buildings in winter operation.

Note that with this winter mode configuration:

- Some buildings can still be in cooling mode while the remainder are in heating mode. In heating mode of the ATES system, the net flow in the groundwater loop will be from the warm wells into the cold wells.
- The warm well discharge temperature indicated in Figure 12 is resulting from the summer operation, see hereafter.

The principle of operation for a building in summer mode and the ATES system in summer mode (cooling operation) is displayed in Figure 13. In cooling mode (discharging operation for the cold ATES well field) groundwater is pumped from the cold wells to the warm wells. Direct cooling to a building in cooling mode is supplied by thermal energy exchange over a plate heat exchanger.

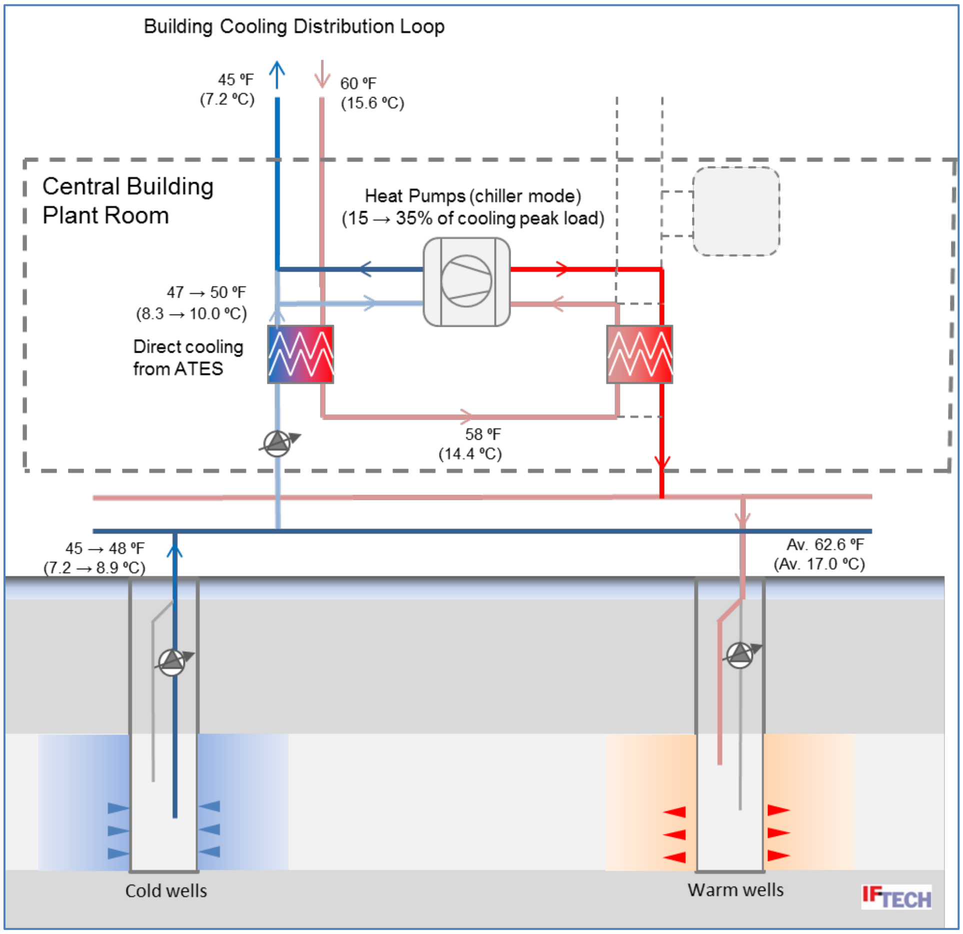

Figure 13 - Principle of ATES system in cooling mode (summer operation)

At the start of the cooling season, when the cold wells are fully charged, the extraction temperature from the cold wells will be close to the charging temperature. As a result of the temperature drop over the plate heat exchanger (2.0 °F - 1.1 °C) both during charging and discharging, the temperature supplied to the building distribution loop will be 47 °F (8.3 °C). During summer operation the extraction temperature from the ATES wells will gradually rise.

The heat pump(s) in the central building plant room are utilized in chiller mode for additional cooling in order to have a guaranteed cooling capacity and temperature. In the conceptual design according to Figure 13, the heat rejected into the aquifer in ATES cooling mode is about 70,300 MMBtu/y (20,600 MWh/y). If the full annual heating demand were provided by heat pumps, the heat pumps abstract about 104,400 MMBtu/y (30,600 MWh/y) from the aquifer. These energy figures are calculated using the efficiencies given in Table 4. In order to maintain a thermal energy balance for the aquifer and to avoid low abstraction temperatures in heating mode, part of the heating is not supplied by heat pumps but by peak load gas boilers. These gas boilers are located in the plant rooms of the buildings.

5.4 Energy and Water Savings and Emissions Reduction Estimate

An energy savings estimate for the application of the ATES/HP system described in Section 5.3, as compared to the reference system, has been made. Savings on energy also result in a reduction of CO2 emissions.

The reference system (or business as usual, BAU) for the energy savings estimate consists of a 4-pipe DH&C network with a central chiller and boiler plant with heating supply and return temperatures of 180-130 °F and cooling supply and return temperatures of 42-56 °F.

In the ATES/HP system, part of the heating is provided by the heat pumps and part by the gas boilers. Because the total heat pump capacity is about 38% of the diversified peak heating capacity (see Section 6 – Initial ATES System Sizing), the heat pumps will be able to provide about 75% of the annual heating demand (see Figure 6). In a similar way, part of the cooling is provided by direct ATES cooling and part by the heat pumps operating in chiller mode. Because the minimum direct cooling capacity is about 65% of the diversified peak cooling capacity (see Section 6), the ATES direct cooling will be able to provide over 75% of the annual cooling demand (see Figure 7). The 75% contribution of heat pump heating and ATES direct cooling has been taken into account for the energy savings estimate.

A graphic presentation of the thermal energy flows in the ATES/HP system is shown in Figure 14.

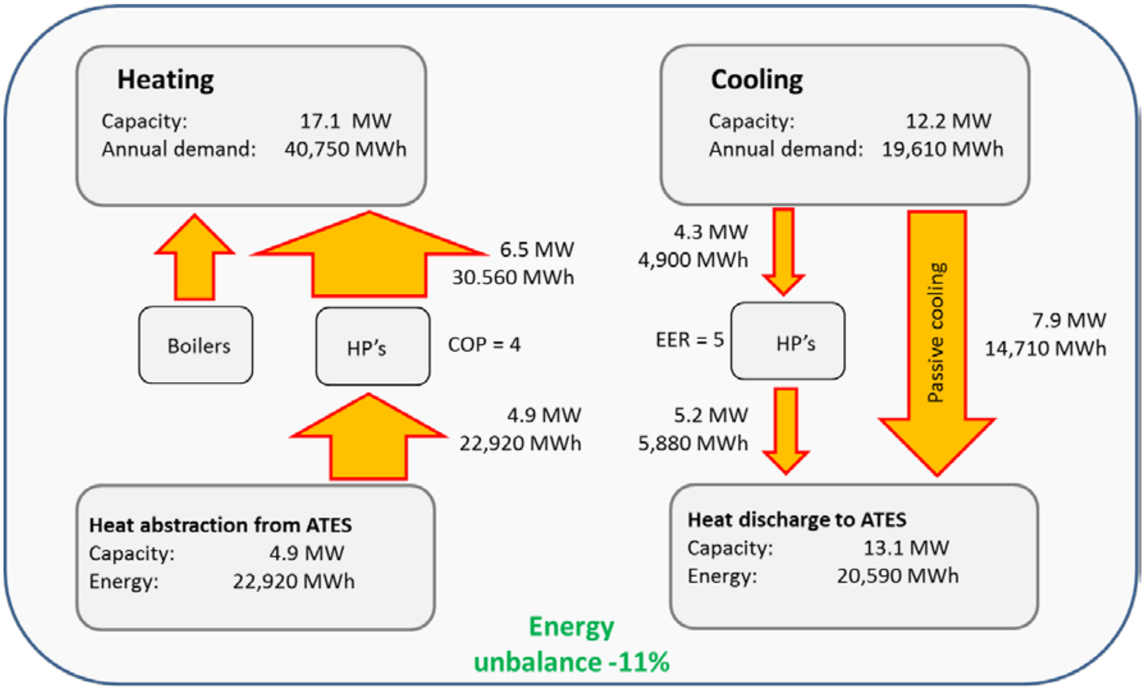

Figure 14 - Energy flows in ATES/HP system (without distribution losses)

To calculate the energy consumption of the ATES/HP system and of the reference BAU system, an estimate has to be made for the annual (seasonal) efficiencies for the various system components. The values applied in this study for these efficiencies, also called Seasonal Performance Factor (SPF) or seasonal Coefficient of Performance (COP), are shown in Figure 14.

Table 7 - Estimated annual efficiencies

	Annual Efficiency	Unit	Annual Efficiency	Unit
Gas boiler (condensing)	0.95	$MMBtu_{out}/MMBtu_{in}$	0.95	MWh_{out}/MWh_{in}
Centrifugal chiller, incl. pumps cooling tower, condenser and evaporator	0.65	kW_e/Ton	5.4	MWh_t/MWh_e
Screw heat pump-cooling operation, incl. pumps condenser and evaporator	0.70	kW_e/Ton	5.0	MWh_t/MWh_e
Screw heat pump-heating operation, incl. pumps condenser and evaporator	0.25 0.875	kW_e/kW_t kW_e/Ton	4.0	MWh_t/MWh_e
Well pumps	0.0875	kW_e/Ton	40	MWh_t/MWh_e
Distribution pumps	0.05	kW_e/Ton	70	MWh_t/MWh_e
Distribution efficiency (loss) groundwater loop	0.95	$MMBtu_{out}/MMBtu_{in}$	0.95	MWh_{out}/MWh_{in}
Distribution efficiency (loss) heating loop	0.90	$MMBtu_{out}/MMBtu_{in}$	0.90	MWh_{out}/MWh_{in}
Distribution efficiency (loss) cooling loop	0.95	Ton_{in}/Ton_{out}	0.95	MWh_{out}/MWh_{in}
Electrical power plant	0.40	MWh_e/MWh_t	0.40	MWh_e/MWh_t

Table 8 below summarizes electricity, natural gas and water consumption as well as carbon dioxide (CO2) emissions for the ATES/HP system as well as the BAU scenario.

Table 8 - Annual energy use, water use and CO2 emissions for BAU and ATES scenarios

Energy Requirement	BAU		ATES/HP	
	Electricity	**Gas**	**Electricity**	**Gas**
Heating: gas boiler (condensing), incl. distribution losses		47,180 MWh 147 MMBtu		10,730 MWh 33.5 MMBtu
Heating: heat pump-heating operation, incl. pumps condenser and evaporator			7,640 MWh	
Distribution pumps/well pumps	640 MWh		600 MWh	
Cooling: chillers, incl. pumps cooling tower, condenser and evaporator and distribution losses.	3,810 MWh			
Cooling: ATES direct cooling, incl. distribution losses (well pumps only)			530 MWh	
Cooling: heat pump-cooling operation, incl. pumps condenser and evaporator			980 MWh	
Distribution pumps	290 MWh			
Total	**4,740 MWh**	**47,180 MWh** **147 MMBtu**	**9,750 MWh**	**10,730 MWh** **33.5 MMBtu**
Total primary energy consumption		**59,030 MWh** **184 MMBtu**		**35,100 MWh** **110 MMBtu**
Total CO2 emissions	**12,400 metric ton per year**		**7,900 metric ton per year**	
Total water consumption	**60,300 metric ton per year** **16,000,000 gallons per year**		**0**	

From Table 8 it can be concluded that the ATES/HP system provides savings on primary energy consumption of about 40% as compared to the BAU scenario.

The annual reduction of CO2 emissions of about 35% is based on an average emission of 1290 pounds (lbs) of CO2 per MWh or 586 metric ton CO2/MWh electricity for the grid electricity sources in Minnesota. Natural gas sources consist of 132 lbs of CO2 per MMBtu fuel or 0.204 metric ton CO2/MWh fuel (Ramboll, 2015, Table 27).

An ATES/HP installation will also reduce the water usage because no evaporative cooling towers will be installed. For water savings we have assessed the total make up water for evaporative cooling towers to 2.3 gal/TR-hr (consisting of 1.8 gal/TR-hr for evaporation+drift and 0.5 gal/TR-hr for blow down).

6.0 Initial ATES System Sizing

An important factor for the sizing of an ATES system is the achievable well yield for extraction and injection of groundwater. The maximum well yield depends on local hydrogeology and well dimensions (depth and diameter). Based on the available information on hydrogeology (Section 3.0) it is currently considered that 900 gpm (200 m^3/h) is about the maximum sustainable yield that can be obtained from an ATES well completed in the combined Prairie du Chien-Jordan aquifer.

The initial sizing of the ATES/HP system is presented below in Table 9.

Table 9 - Initial ATES/HP system sizing

	Value	Unit	Value	Unit
System heating capacity, incl. DHW	58.5	MMBtu/h	17.1	MWh
System cooling capacity	3,450	Tons	12.2	MW_t
Depth wells	440	ft	135	m
Screened section	165	ft	50	m
Maximum well yield	900	gpm	200	m^3/h
Number of doublets (pair of wells)	6	-	6	-
Minimum distance between warm and cold well clusters	650	ft	200	m
Maximum flow rate groundwater system	5,500	gpm	1,250	m^3/h
Ambient groundwater temperature	49	°F	9.3	°C
ATES storage and abstraction temperatures in winter and summer operation	Figure 7 and 8	°F	Figure 7 and 8	°C
ATES/HP heating capacity	22.2	MMBtu/h	6.5	MWh
Total boiler capacity	36.3	MMBtu/h	10.6	MWh
Annual heating demand supplied by ATES/HP system	75	%	75	%
Annual heating demand supplied by boilers	25	%	25	%
ATES direct cooling capacity	2,230	Tons	Min. 7.9	MW_t
Total HP cooling capacity	1,220	Tons	4.3	MW_t
Distribution system length, mains	1,650	ft	503	m
Distribution system length, laterals	1,340	ft	408	m

In principle, the wells can be located everywhere along the district loop, taking into account sufficient distance between the wells. It is assumed that the well field consists of two clusters of 3 warm wells each and two clusters of 3 cold wells each. There is a minimum distance required between a cluster of cold wells and a cluster of warm wells to avoid thermal breakthrough between the wells. To have some preliminary insight on the required well distance a simple calculation has been performed, according to which the distance between the clusters should be at least 200 m.

Figure 15 shows the routing of the district loop and proposed location of the wells, along with conceptual building configurations from Figure 6 of Ramboll (2015).

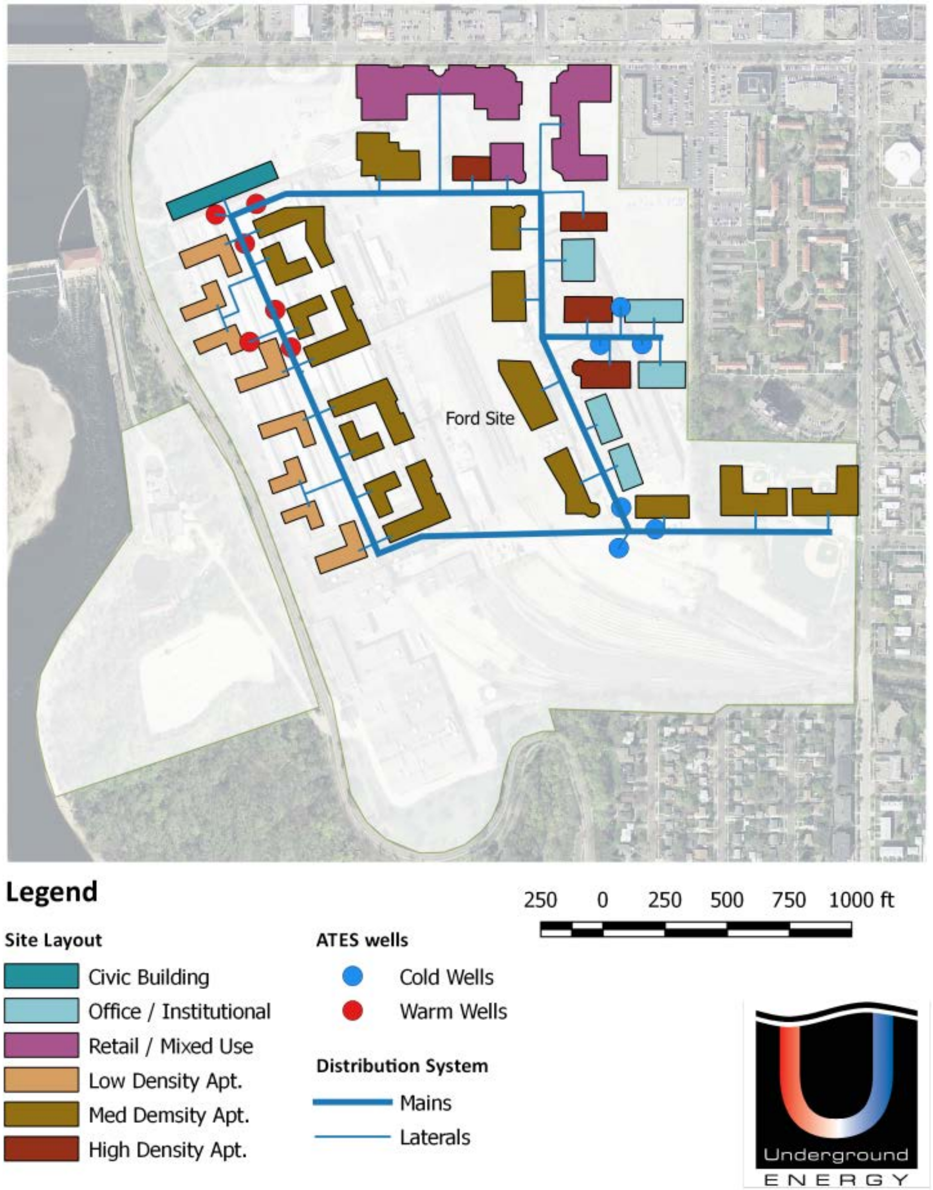

Figure 15 - Conceptual Site Layout

7.0 Financial Analysis

7.1 Investment Cost Estimate

The following assumptions and limitations have been used in the cost estimate:

- All costs are considered pre-feasibility study level given the scope of work assigned.
- All costs are 2016, 1st quarter, US Dollars and exclusive of taxes.
- General contractor OH&P, bonding, permitting, insurance and construction management & supervision are allowed for at 20%.
- Engineering, testing and commissioning are allowed for at 10%.
- The scope of this feasibility study did not allow for an investigation of well locations and routing of the groundwater piping. The well locations and piping routing assumed for the investment cost estimate are as shown in Figure 14.
- The wells will be drilled with cable tool or reverse flow rotary drilling equipment to minimize aquifer clogging due to drilling fluid.
- The well vaults will be partly underground and partly above ground (about 2 ft).
- For each of the well clusters, power for the well pumps is available from one of the building plant rooms nearby. Power and control cabling is in the piping trench.
- Trenching is assumed to be in green field. Trench depth allows for 2 - 3 feet of cover to the top of the pipes.
- Given the temperatures of the groundwater in the ATES distribution piping, the “cold” piping is HDPE piping with insulation, the “warm” piping is uninsulated HDPE piping. Piping for the BAU scenario is insulated steel and PEX piping for hot water and insulated HDPE piping for chilled water.
- The costs for ground and plant rooms (including external utilities) are not included in the estimate. The central plant room (BAU) and building plant rooms (ATES/HP) are on ground floor and/or basement level.
- The site wide heating and cooling capacity and demand are more or less equally divided over the 38 building connections.
- Redundancy for main components (chillers, boilers, heat pumps and wells) is N+1.

- The cost for the gas distribution network to the central plant room (BAU scenario) and the building plant rooms is not included.
- Distribution of thermal energy from the Energy Transfer Station (ETS) or central plant room in the building to the individual consumers is not included.

A breakdown of the estimated investment cost is shown in Table 10 below. The investment cost for the ATES/HP option turns out to be almost equal to the investment cost for the BAU option.

Table 10 - Estimated investment costs (excluding taxes)

	BAU	ATES/HP
Site investigation incl. test well (first borehole) and three monitoring wells, analysis of results, EIA	$ 0	$ 600,000
Thirteen additional boreholes 36”diameter, 440 ft depth, incl. development and tests	$ 0	$ 4,200,000
Well housings and well M+E equipment, incl. installation	$ 0	$ 900,000
Piping incl. trenching, DH&C distribution, and cabling (BAU) and groundwater distribution (ATES/HP)	$ 5,200,000 (a)	$ 1,800,000
M+E equipment central plant room (BAU) and 38 building plant rooms (ATES/HP), incl. controls and installation	$ 9,200,000 (a)	$ 13,300,000
Energy transfer station	$ 6,600,000 (a)	$ 0
Subtotal BAU and ATES/HP system	***$ 21,000,000***	***$ 20,800,000***
Engineering, main contractor overhead, bonding, insurance 30% (excluding site investigation)	$6,300,000	$ 6,100,000
Contingency 30% (including site investigation)	$ 6,300,000	$ 6,200,000
Total BAU or ATES/HP system	***$ 33,600,000***	***$ 33,100,000***

(a) Source: Ever-Green Energy, 2 June 2016

7.2 Estimated Financial Benefit

Because of the fact that the investment cost for both options is almost the same, the financial comparison is reduced to the comparison of the operating cost of the BAU scenario and the ATES/HP scenario. This comparison is presented in Table 11. The following assumptions were made to develop Table 11:

Variable operating costs:

- The utility electricity rate applied is $55.00/MWh. This is the weighted average of the on peak and off peak rate (Ramboll, 2015, Section 5.7).
- The utility gas rate applied is $16.5/MWh (Ramboll, 2015, Table 21).
- The water rate applied is $4.0/1,000 gal ($1.1/metric ton). Costs for chemicals and disposal to sewer have not been included.
- No economic value has been assigned to the reduction of CO2, although it is likely that some form of greenhouse gas regulation will be implemented in the coming years.

Fixed operating costs:

- Operation and Maintenance (O&M) cost of 3% of the investment for M+E equipment and wells and 1% of the investment for buried piping and cabling.

Table 11 - Estimated operating costs per year (excluding taxes)

	BAU	**ATES/HP**
Electricity consumption	$ 260,700	$ 536,300
Natural gas consumption	$ 778,500	$ 177,000
Water consumption	$ 66,300	$ 0
Operating and maintenance cost	$ 615,000	$ 720,000
Total BAU or ATES/HP system	***$ 1,720,500***	***$ 1,433,300***

Table 11 shows a 17% saving on operating cost for the ATES/HP system as compared to the BAU scenario, to a large extent a result of savings on energy and water consumption when applying an ATES/HP system.

8.0 Regulatory Evaluation

While technical and financial measures of ATES feasibility at the Ford Site are strong, it is Underground Energy's opinion that obtaining the necessary regulatory approvals is an equally important consideration to development of an ATES project at the Ford Site. A draft of this regulatory evaluation was provided by the City of St. Paul Department of Planning and Economic Development to members of the Minnesota Environment Quality Board (EQB) and the Minnesota Department of Health (MDH) for their review in advance of meetings about regulatory feasibility of ATES at the Ford Site on 23 May and May 31, 2016, respectively. The salient regulatory issues lie within the jurisdiction of MDH, as discussed in Section 8.4.

8.1 Underground Injection Control

The primary federal regulation that applies to an ATES system is the Underground Injection Control (UIC) program administered by the US Environmental Protection Agency, Underground Injection Control Program (USEPA-UIC). ATES wells are Class V injection wells under the UIC program. An ATES system that discharges non-contact heating and cooling water without chemical additives must register with USEPA-UIC. ATES systems are designed and operated in such a manner that temperature is the only regulated parameter that is modified from ambient groundwater conditions. The discharge must meet all drinking water and other health-based standards. The US EPA has primacy in Minnesota over the Underground Injection Control program and a Class V geothermal well registration is a relatively simple process.

8.2 Minnesota Pollution Control Agency

As discussed in Section 3.1.2, it is Underground Energy's opinion that the suitability for ATES of aquifers below the St. Peter sandstone at the Ford Site is unlikely to have been affected by anthropogenic contamination from historic land uses at the Ford Site. Underground Energy therefore assumes that ATES project development will not be burdened by groundwater contamination issues. As such, Minnesota Pollution Control Agency (PCA) regulations or other regulations related to oil and hazardous material in the environment are excluded from consideration in this feasibility study.

8.3 Minnesota Department of Natural Resources

An appropriation permit for a groundwater withdrawal exceeding 10,000 gallons per day or one million gallons per year is required from the Minnesota Department of Natural Resources (DNR).

Because an ATES system withdraws groundwater concurrently with injection, the net flow rate in the aquifer is zero and there is no consumptive use of the groundwater resource. In this situation, many other state agencies have indicated they would waive a similar permit requirement. However, in Minnesota the DNR permits required by law are for appropriation, not consumption.

8.4 Minnesota Department of Health

8.4.1 Prohibition of Underground Injection

The MDH regulates Wells and Borings under Minnesota Administrative Rules Chapter (MR 4725), which were adopted according to and must be read in conjunction with Minnesota Statutes, chapter 103I, relating to wells, borings, and underground uses. Under MR 4725.2050, injection of any material into a well or boring in Minnesota is prohibited.

One exception is contained in Minnesota Statutes, section 103.621, which establishes a permit system for groundwater thermal exchange devices, which are defined as heating and cooling systems that withdraw groundwater from a well and inject into the same aquifer. These permits are limited to a maximum flow rate of 50 gpm, which is too low a threshold for an ATES system. The only option for an ATES system, short of a change in law, is to seek a variance from the rule pursuant to MR 4725.0400.

MDH can issue variances and has done so for an Aquifer Storage and Recovery (ASR) project. In that case, the applicant was a public water supplier, and the water will be ultimately withdrawn and used for potable purposes. The purpose of the ASR request was to maximize water treatment capacity, not for thermal energy storage or space heating and cooling. While there will be differences for an ATES project, many of the MDH concerns and requirements would be the same including the quality of the injected water, potential to mobilize contaminants, contaminant plume impacts, and potential effects on drinking water supplies.

The fee for processing a variance is currently $235, and a variance will typically be subject to conditions such as hydraulic and geochemical monitoring. A variance request application is provided in Appendix A. Underground Energy has reviewed three variances issued by the MDH and it is our opinion that any such conditions would probably be consistent with the monitoring we would normally recommend for an ATES project.

In summary, MR 4725.2050 is a regulatory obstacle to an ATES project in Minnesota, but there is precedent for a variance to that rule and regulators have indicated to Underground Energy a willingness to consider similar variances for ATES projects.

8.4.1 Mt. Simon Aquifer Prohibition of New Appropriations

Minnesota Statutes Section 103G.271 4(a) prohibits new permits for appropriation and use of water from the Mt. Simon aquifer. At present this is not considered an obstacle to ATES development due to the high cost of installing ATES wells in this deepest aquifer beneath the Ford Site. Underground Energy notes that, given the nonconsumptive nature of ATES and the potential to utilize ATES wells also as ASR wells, an opportunity may exist to develop ATES/ASR projects that could beneficially restore lowered groundwater elevations in the Mt. Simon aquifer that were the basis for this prohibition.

9.0 Conclusions

9.1 ATES Feasibility Summary

It is Underground Energy's opinion that ATES is feasible at the Ford Site, and that an ATES system with a two-pipe District Heating and Cooling system can meet the City of St. Paul's objectives for redevelopment of the Ford Site, provide a significant, large-scale energy and financial benefit, long-term operational flexibility and a hedge against future fuel cost increases.

The overall feasibility of an ATES project has several facets, the most important of which is usually financial. Underground Energy's opinion on the multi-faceted feasibility of ATES at the Ford Site is summarized below in Table 12, where one to three check marks are assigned to criteria depending on how well each criterion is suited for an ATES project.

Table 12 - ATES Feasibility Summary

Feasibility	Feasibility Criteria	Summary
✓✓✓	Financial	Similar investment cost to BAU, 17% operating cost reduction
✓	Regulatory	Underground injection prohibited by rule, variance required
✓✓✓	Climate	Cold winters/warm summers well suited for seasonal energy storage
✓✓✓	Hydrogeology	High well yields, multiple aquifers, good hydraulics expected
✓✓✓	Geochemistry	Contamination unlikely, stable redox conditions expected
✓✓✓	Facilities Integration	Master planning and new construction best suited for ATES

9.2 ATES Benefits

The advantages and benefits of an ATES system design at the Ford Site include:

- Compared to a new, efficient four-pipe district energy system with a central plant, ATES can achieve annual savings of
  - 24,000 MWh per year of primary energy (41% reduction);
  - 4,500 metric tons CO2 per year (36% reduction); and
  - 60,000 metric tons (16 million gallons) of cooling water (100% reduction).
- An ATES system can be powered by renewable electricity, displacing the combustion of fossil fuels for heating and for grid electricity, and potentially facilitating net-zero development.
- An ATES system would provide a hedge against future fuel cost increases.
- An ATES system can be completed in phases as the Ford Site is redeveloped, allowing developers and tenants to develop a high level of confidence in the technology as the project is built out.

- Undertaking an ATES project at the Ford Site can accelerate the rate of adaptation of ATES elsewhere in Minnesota and in the US marketplace, with resulting large-scale CO2 reduction along with local and regional economic benefits and improved resiliency.

9.3 ATES Technical and Regulatory Feasibility

ATES is feasible at the Ford Site from a technical perspective. Multiple transmissive aquifers lie beneath the Ford Site, thermal loads are fairly well balanced, and ATES can meet approximately half of the cooling demand for approximately 6.5 million square feet of conditioned space with direct cooling from seasonally stored chilled water. The Prairie du Chien-Jordan aquifer has high transmissivity and can provide good well yields, but the karstic conditions in the Prairie Du Chien carbonate aquifer may result in high natural groundwater flow velocity unacceptable for ATES.

Obtaining the necessary regulatory approvals will be required for development of an ATES project at the Ford Site. The salient regulatory issues lie within the jurisdiction of MDH under MR 4725.2050, which prohibits injection of any material into a well or boring in Minnesota. An exemption exists for smaller open-loop geothermal system (up to 50 gpm), but the only option for an ATES system, short of a change in law, is to seek a variance from the rule. There is precedent for a variance to that rule for an Aquifer Storage Recovery project, and MDH representatives have indicated a willingness to consider similar variances for ATES projects.

If the full energy, economic and environmental benefits of ATES are to be realized in Minnesota, where climate and aquifer conditions are ideal for this large-scale, sustainable heating and cooling technology, consideration should be given by Minnesota's policy makers how best to responsibly embrace this technology, as the Dutch have done so successfully.

9.4 ATES Financial Feasibility

ATES is feasible at the Ford Site from a financial perspective. The estimated investment cost for an ATES system of \$33.1 million is similar to the estimated cost of a 4-pipe district heating and cooling system of \$33.6 million. The more efficient ATES system would reduce operating expenses by an estimated additional 17% compared to the BAU scenario.

10.0 Recommendations

Given the favorable findings regarding ATES feasibility at the Ford Site, Underground Energy recommends that a phased hydrogeologic investigation be performed at the Ford Site to confirm or modify the estimates of subsurface conditions that were the basis for our conceptual design, and to facilitate detailed design and financial analysis. Underground Energy recommends that the design of a hydrogeologic testing program consider the following elements:

- Borings and (smaller diameter) monitoring wells are needed for hydraulic and geochemical testing.
    - Three wells are needed in an aquifer in order to measure groundwater elevations and estimate the piezometric surface (3 points define a plane, which is a first approximation of the piezometric surface). This allows calculation of hydraulic gradient, groundwater velocity and flow direction.
    - Because groundwater flow in the Prairie du Chien aquifer is through karstic dissolution-opened fractures while groundwater flow in the Jordan is through porous media, it will be important to evaluate groundwater velocity separately in the Prairie du Chien and Jordan aquifers. This would require a minimum of six wells, three in the Prairie du Chien aquifer and 3 in the Jordan aquifer.
- A larger diameter boring/well will be needed for aquifer pump testing to size and design the ATES wells.
    - An evaluation of the vertical distribution of hydraulic conductivity down from the top of the Prairie du Chien group to the base of the Jordan. Underground Energy recommends packer tests in a moderate-sized boring to accomplish this task. The boring could be completed as a well and used later for a combined Prairie du Chien-Jordan aquifer pumping test while monitoring hydraulic effects separately in these two formations with the six observations wells.
- Geochemical testing is needed, with the scope to be determined pending discussion with regulators.
- Hydraulic testing is needed, and initial efforts can focus on the smaller-diameter monitoring wells.

The City of Saint Paul and project proponents should continue the productive dialogue that was begun with the EQB and MDH in meetings in May 2016. We recommend that work plans for any subsurface investigation activities be coordinated with experts at the Minnesota Geologic Survey and MDH.

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APPENDIX A

Minnesota Department of Health Variance Request Application

Minnesota Department of Health
Well Management Section
625 North Robert Street
P.O. Box 64975
St. Paul, Minnesota 55164-0975
651-201-4600 or 800-383-9808
www.health.state.mn.us/divs/eh/wells

Protecting, maintaining and improving the health of all Minnesotans

MEMORANDUM

DEPARTMENT: Health

TO: Variance Applicants

FROM: Alex M. Martell, Hydrologist
Well Management Section
P.O. Box 64975
St. Paul, Minnesota 55164-0975

PHONE: 651-201-4595

SUBJECT: **Completing the Variance Request Application Form**

The attached **VARIANCE REQUEST APPLICATION** form may be used to apply for a variance from any requirements of Minnesota Rules, Chapter 4725 (Wells and Borings) and Minnesota Rules, Chapter 4727 (Explorers and Exploratory Borings). Variances cannot be granted to state statute, including Minnesota Statutes, Chapter 103I (Wells, Borings, and Underground Uses). Variances must have only future effect, so cannot be granted "after the fact."

A variance request must be submitted in writing on the attached application form, and must include the $235 nonrefundable variance fee. The variance fee is in addition to any applicable permit or notification fee. The fee may be paid by check or money order payable to the Minnesota Department of Health or by credit card using the attached Credit Card Payment Information form.

On "average," a variance application takes approximately two weeks to process. In order to avoid delays in processing of your variance request, please be sure that your application includes all of the following:

- A completed and legible **VARIANCE REQUEST APPLICATION** form.
- The site map specified in Part I of the application.
- Signatures of all affected parties, which may include the property owner(s), well owner, well contractor, sewer contractor, or others.
- The nonrefundable variance fee.

You will be notified in writing of the Minnesota Department of Health (MDH) decision regarding your variance request. Variances may only be granted in writing by the MDH.

An approved variance usually includes several conditions which must be satisfied in order for the variance to be valid. These alternative measures or conditions which are attached to a variance have the force of law and effect of applicable rule. Failure of the applicant to comply with alternative measures and conditions of the variance will result in immediate expiration of the variance and the party will be subject to enforcement actions and penalties provided in the applicable law or rule.

If you have any questions on variances or need additional variance application forms, please contact me at 651-201-4595 or visit the MDH Well Management Section at Orville L. Freeman Building, 625 North Robert Street, St. Paul, Minnesota 55155-2538.

AMM:kad
Attachments

origs\variance application memo.docx   10/28/2015R

PRINT Clear Form

VARIANCE REQUEST APPLICATION

MINNESOTA DEPARTMENT OF HEALTH
Well Management Section, 625 North Robert Street
P.O. Box 64502, St. Paul, Minnesota 55164-0502
651-201-4600 or 800-383-9808
Fax 651-201-4599

MDH USE ONLY
Date Received ____________________________
Amount Received _________________________
TN Number ______________________________
Deposit No. ______________________________
Receipt Codes: General Program - 4921
Disclosure Program - 4932

The party requesting the variance must complete this Variance Request Application and submit to the above-listed address, along with the nonrefundable $235 application fee.

ID No. of Water Well Status Report (if applicable) __________________________

In counties or governmental units which currently have a well program delegation agreement, the variance request must be submitted to both the Minnesota Department of Health and to the delegated program for review.

The variance request must contain the following information. (Please print or type.)

A. Name of Applicant (i.e. well/boring/sewer/other owner)		Company Name (if applicable)	
Street Address			
City	State	ZIP	Telephone No. (including area code)

B. Name of Property Owner (if different from above)		Company Name (if applicable)	
Street Address			
City	State	ZIP	Telephone No. (including area code)

C. Name of Contractor (if applicable)	Company Name (if applicable)		Company License No.
Street Address			
City	State	ZIP	Telephone No. (including area code)

D. Well or Boring Location	Fraction ¼ ¼ ¼	Section No.	Range No.	Township No.	Township Name	County
Street Address of Well or Boring						
City	State	ZIP	Fire No.	MN Unique Well No. (if known)		

E. Rule(s) from which variance is requested (cite specific rule[s]).

F. Reason(s) rule cannot be met (include supporting evidence).

G. Alternative or additional protective measures to be taken to assure a comparable degree of protection to health or the environment.

H. Well Information	Estimated Depth	Casing Depth	Casing Diameter	Casing Type	Method of Drilling
	Depth to Water	Grout Materials			
	Description of Construction Methods and Anticipated Geologic Conditions.				

I. A scaled map showing the location of the well or boring in relation to property lines, structures, utilities, and contamination sources (use additional sheets as necessary and note distances from contamination sources and wells on adjacent properties).

Please include the following information for a variance request from isolation distances.

J. Description of the age, design, size, and type of construction of any existing or potential contaminant sources (such as septic system; petroleum storage; unused, unsealed wells; etc.). Include contamination sources on adjacent properties.

K. Other relevant information, such as any testing, inspection, or certification data (please attach reports or data).

Incomplete applications cannot be processed and will be returned to the applicant. Please submit a complete application including application fees, scaled map, and signatures of well owner and contractor (if applicable). Please include with this request any relevant information necessary to properly evaluate the request and a copy of any review of any contamination sources by a local or state unit of government under other applicable regulations.

The nonrefundable variance fee of $235 along with the variance application, signed by the applicant and the contractor, with supportive information, must be returned to the Well Management Section, Minnesota Department of Health, P.O. Box 64502, St. Paul, Minnesota 55164-0502

This variance is conditioned upon the applicant's acceptance of, and compliance with the conditions of this variance. Failure by the applicant to comply with the conditions prescribed in this variance will result in the immediate expiration of this variance.

If the variance is granted, I agree to comply with any conditions required by the Minnesota Department of Health.

Date	Applicant Name (print)	Applicant Signature
Date	Property Owner Name (print)	Property Owner Signature
Date	Contractor Name (print)	Contractor Representative Signature

PRINT Clear Form

Minnesota Unique Well No.	MN Well and Boring Sealing No.
	H

Minnesota Department of Health, Well Management Section
625 North Robert Street, P.O. Box 64502, St. Paul, Minnesota 55164-0502
651-201-4591 or 800-369-1290 and Fax No. 651-201-4599

Please complete and return this form if payment of fee(s) is by credit card. **NOTE**: If the *notification form* already has the preprinted credit card information box **DO NOT** use this form.

Fee Type: ☐ Monitoring Well Permit Application ☐ Elevator Boring Permit Application ☐ Variance Application
☐ VHE/Groundwater Thermal Exchange Permit Application ☐ License/Registration and/or Rig Registration
☐ Maintenance Permit

Credit Card Type: ○ Visa ○ MasterCard ○ Discover Expiration Date: ______________________

Total Amount to be Charged: ________________

Print Cardholder Name: ____

Credit Card Number: ______________________________ 3-Digit Security Code ____________
(Printed on back side of card.)

Authorized Signature: ____