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An Overview of Efforts Towards Utilizing Geothermal Energy in Interior Alaska

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ABSTRACT

The extreme cold temperatures in Interior Alaska put a significant amount of stress on heating and energy systems utilized by the local communities. A failure of heating systems can lead to severe consequences because of the dangerously low temperatures. As an in-situ thermal resource, geothermal energy/resource would increase resilience in both supply and energy systems, but Interior Alaska's unique geologic and environmental conditions introduce uncertainty in the prospecting and development process for both deep and shallow technologies. This requires development of novel techniques as well as considerations specific to extreme cold regions lacking high temperature thermal resources. This paper gives a holistic view of Department of Defense (DoD) efforts towards the identification and evaluation of the possibility of utilizing geothermal resources in Interior Alaska at its installations. This includes prospecting for low enthalpy, radiogenic thermal resources, and considerations for shallow technologies in extreme cold environments. Additionally future development is considered, including discussion of existing knowledge gaps and ongoing efforts towards deployment of geothermal district heating and cooling (GDHC) with underground thermal energy storage (UTES) at Fort Wainwright. Demonstration of geothermal technologies in the unique conditions of Interior Alaska would significantly de-risk utilizing geothermal in the region and other cold regions, which would be of great benefit to cold regions communities.

1. INTRODUCTION

Interior Alaska is an extremely harsh environment encompassing a large area of land. The region is functionally land locked because of its sheer size to the east and west and bordering mountains, the Alaska Range (south) and Brooks Range (north). It is largely inaccessible by ground outside of a few major roads and railways (Figure 1). Despite this remoteness, there is a significant population in the region, several military installations, and interest in economic activities such as resource extraction, making energy needs significant. Most energy comes from utilization of imported carbon fuels, like the coal-fired combined heat and power plant (CHP) at Fort Wainwright, Alaska. In winter temperatures can drop below -40°C, making a failure of heating systems or energy supply a life-threatening challenge. Up to 70% of the total energy budget goes towards heating (Wiltse et al. 2017).

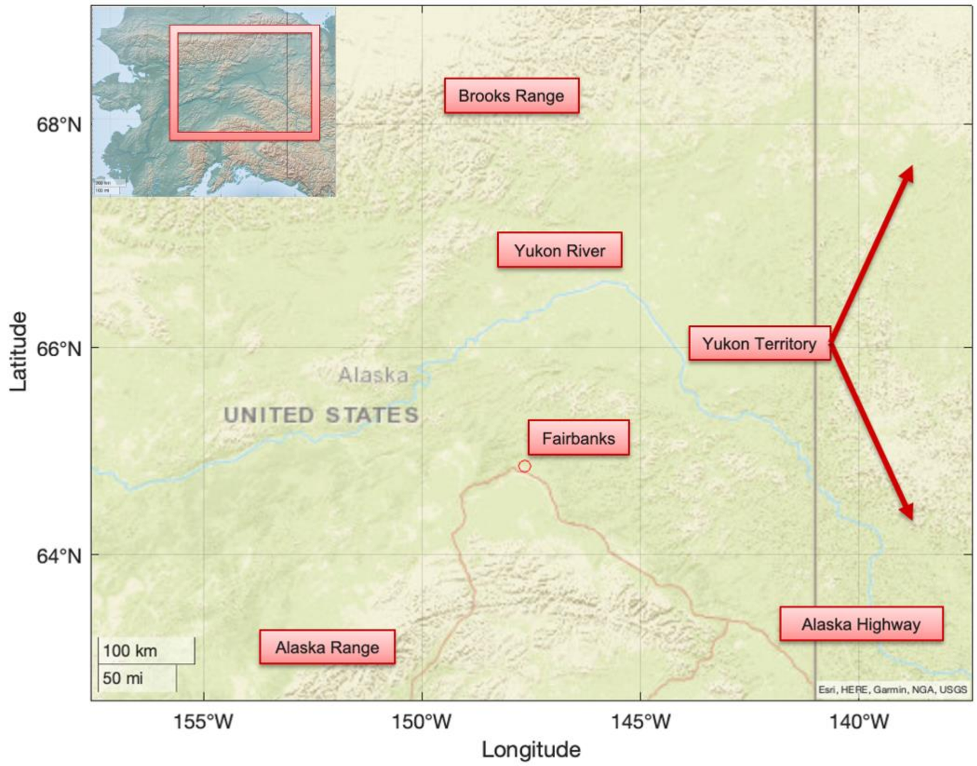

Figure 1: Interior Alaska map with relevant geographic features labeled.

Because of the importance of heating and the fragility of supply lines, geothermal, as an in-situ thermal resource, would be an ideal energy source for installations in the region if able to be harvested at community scale. Prior study indicates Interior Alaska may have high average ground heat flow at the regional scale, but data is too sparse to make specific determinations at local scale (Batir et al. 2016). For example, Interior Alaska is a region classified as containing discontinuous permafrost (Jorgensen et al. 2008), or permanently frozen ground. This implies there are known, heterogeneous extremes in heat flow, at least in the near subsurface, and the range of possible heat flows at the local scale is between harvestable geothermal resources and frozen ground.

Many measured high heat flow data points come from a series of disconnected springs known as the Central Alaska Hot Springs Belt (CAHSB). These springs may be heated by radiogenic igneous intrusions referred to as high heat producing (HHP) granites or plutons (Kolker, 2008). The only operating geothermal power plant in Interior Alaska is installed at Chena Hot Springs (Holdmann 2008), one of the spring systems in the CAHSB. Chena and the other springs are relatively low-temperature, low-enthalpy systems. It is conceivable that zones of harvestable high heat without surface manifestations could exist across Interior Alaska, but this is speculative and systematic approaches to identifying geothermal indicators specific to these heat sources are needed (Gisladottir et al. 2023).

There is limited deployment of small-scale shallow geothermal systems for heating and cooling, most notably in the largest population center, Fairbanks. Sustainable maintenance of ground heat is critical; thermal degradation of the ground because of unbalanced heating loads can cause performance losses over time and in extreme cases induce freezing of equipment and ground formation (Meyer et al. 2011; Garber-Slaght et al. 2017). Demonstrations pairing shallow geothermal with other systems, such as solar thermal collectors, has shown promise for better helping maintain ground heat (Garber-Slaght and Keays 2014).

Deploying geothermal at scale in Interior Alaska requires consideration of the extreme environment, remoteness, and these unique geological and hydrological factors. New data gathering from a pilot shallow system to serve as a baseline for system response and advancing prospecting methodology tailored to identifying low-enthalpy resources for direct use or power in these unique conditions would both increase the feasibility of district scale geothermal deployment and provide data for other types of prospecting in the region. District scale deployment would significantly increase energy resilience in installations and communities. To date the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and National Renewable Energy Laboratory (NREL) have conducted multiple studies aiming to address these uncertainties and de-risk geothermal development in Interior Alaska. The remainder of this paper focuses on these efforts related to DoD installations. Figure 2 shows the approximate area of interest for DoD studies.

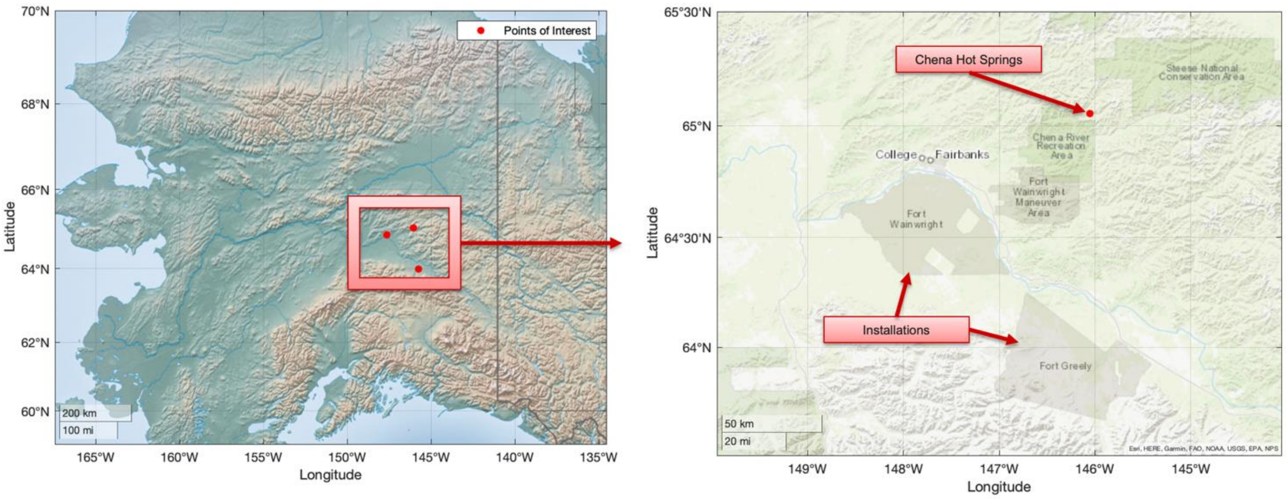

Figure 2: Topographic map of Alaska and the area of interest for these studies (left). Fort Wainwright, Fort Greely, and Chena Hot Springs are marked within the area of interest (right).

Gisladottir et al. (2023) conducted initial pre-feasibility study for assessment of geothermal opportunities at Fort Greely. In a follow-on study, Zody and Gisladottir (2023) conducted a review of district scale systems with underground thermal energy storage (UTES) in cold regions for potential implementation of similar systems at Fort Wainwright. An ongoing study in collaboration with NREL includes case study and potential demonstration of geothermal heat pumps (GHP) coupled with borehole thermal energy storage (BTES) at Fort Wainwright, Alaska. Continued development of geothermal technologies in Interior Alaska is of benefit to the DoD and residents of Interior Alaska and similarly harsh cold environments.

2. PRE-FEASIBILITY STUDY FOR GEOTHERMAL OPPORTUNITIES AT FORT GREELY

In cold regions thermal energy resilience is critical for adaptability and survivability during extreme disruptions. In pursuit of increasing thermal energy resilience at installations in Interior Alaska, a pre-feasibility study for geothermal development opportunities near Fort Greely, Alaska was conducted by Gisladottir et al. (2023). This serves as a comprehensive desk study to (1) begin developing a systematic approach for locating and characterizing geothermal resources in Interior Alaska; (2) provide a preliminary assessment of the opportunities to develop geothermal technologies at Fort Greely; and (3) to guide potential future exploration efforts at Fort Greely like field study and thermal gradient drilling. A modified version of the phased geothermal project risk reduction process as advised by the World Bank (Hervey et al, 2014) was used to plan project steps (see Figure 3, modified from Gisladottir et al. 2023). In this case, the pre-feasibility study has three phases because of the higher risk searching for unconventional thermal resources: Phase I) desk study, Phase II) field study, and Phase III) thermal gradient drilling. Ultimately, it was determined that the prospects survive the elimination test. However, when transitioning into phase II field study to fill in knowledge gaps, the higher risk in comparison to geothermal plays in different geological regions (i.e. due to new methodology and sparse existing data) should be considered.

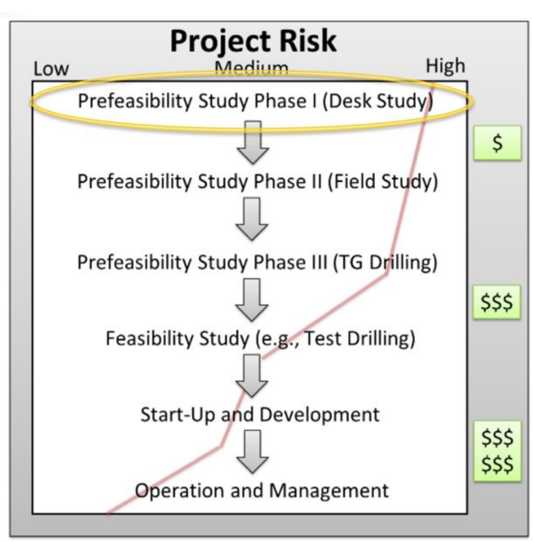

Figure 3: Geothermal risk reduction process modified from Hervey et al. 2014 and published in Gisladottir et al. 2023.

During Phase I, all relevant existing data and literature about the geology and geophysics of Interior Alaska was collected and assessed. Focus was placed on identifying indicators for radiogenic heat sources given the use of such a system at Chena for power generation and the widespread occurrence of springs related to such heat sources. For Interior Alaska, this would require a customized prospecting method. To our knowledge, there does not exist a systematic approach to resource location for such a play, and this work represents first steps towards the development of such a methodology. Potential tailored prospecting methods theorized to be worth studying include steps such as looking at radiogenic element concentrations from rock samples and leveraging cryo-hydrologic structures such as aufeis for indication of subsurface heat flow (note: aufeis is winter growth of surficial ice masses due to transport of subsurface liquid water under excess pressure to the surface via fractures or other channels). Table 1 shows potential geothermal resource types near Fort Greely.

Table 1: Most likely geothermal opportunities in Fort Greely area (Gisladottir et al. 2023).

Geothermal Resource Type	*Uses*	*Likelihood of Existing at Fort Greely*	*Risk*
Aquifer or ground source in permafrost-free zone	GHP	High	Low
Conduction-dominated intracratonic basin (sedimentary)	Direct use	Medium	Medium
Concealed convection-dominated radiogenic hydrothermal	Direct use Electricity generation < 1 MW	Low to medium	High
Concealed convection-dominated deep circulation or magmatic hydrothermal	Direct use Electricity generation > 1 MW	Low	High

To move forward with a phase II study, field study to fill in knowledge gaps, we propose four key types of missing data to target: 1) localized temperature logging of water wells, 2) rock sampling and core collection, 3) gravity surveys, and 4) permafrost and aquifer mapping. Completion of phase II would inform phase III, targeted thermal gradient well drilling at Fort Greely. Continued study would be scientifically valuable for the purposes of standardizing an Interior Alaska play methodology but high risk from an economic standpoint. The focus of subsequent projects has been on shallow technology for now.

3. SHALLOW GEOTHERMAL OPPORTUNITIES AT FORT WAINWRIGHT

While energy resilience is usually considered through the lens of electrical energy, a focus on thermal energy can yield significant improvements in resilience and efficiency in all climates and installations. In a warmer climate, a system installed at a DoD installation in Albany, GA, showed a 47.5% reduction in energy consumption compared to a conventional heating/cooling system (Hammock and Sullens 2017). Furthermore, a new GDHC system in central Finland was modeled to achieve 60% efficiency within ten years. Early data collected in 2019 from that system indicates that it is matching the modelled data, and subsurface temperatures have risen more than 10 ℃ in its first year of operation (Arola et al. 2021).

Given the uncertain nature of developing resource for power generation in the region, we expanded our focus to include viability of district scale shallow systems and their integration into greater energy systems at installations, like Fort Wainwright. Retrofitting geothermal to the existing power infrastructure, which includes a 65-year-old coal fired CHP, could result in significant increases to installation resilience. GDHC systems do not require any particular subsurface temperature to be effective; they can function in most settings where subsurface temperatures are above the freezing point (Garber-Slaght and Peterson 2017; Eslami-nejad and Bernier 2012). The extreme cold climate of Interior Alaska would provide a test bed that is on the extreme end of where a GDHC would function. While a GDHC in Fort Wainwright would be more efficient than currently available heating and cooling options, milder cold climate locations would see even better efficiency, especially ones with existing CHP distribution infrastructure.

Deployed geothermal heating and cooling systems in Interior Alaska are small in scale. These systems can have issues related to degradation of the thermal resource under unbalanced load conditions. A district scale system with UTES or other components integrated could help mitigate these losses by 1) not relying only on diurnal cycling, and 2) coupling the system with thermal storage. At Fort Benning, Georgia, a system tailored to a cooling dominant load is deployed with excellent results (Hammock and Sullens, 2017). In Interior Alaska the system would be tailored to extreme cold instead of extreme heat, but the concept is similar in that both have extremely unbalanced seasonal heating and cooling loads. Demonstrations with corresponding data gathering at the two extreme ends end of the spectrum would be valuable in derisking these types of energy systems.

In preparation for site selection and technical analysis of examining feasibility of such a system at Fort Wainwright, a desk study was conducted to 1) survey existing district scale systems employed in cold regions, and 2) identify existing data and knowledge gaps relevant to such systems. The goal is to work towards feasibility of a district scale system by first conducting analysis and demonstration of a smaller scale system feeding into only a couple of buildings. Figure 4 shows the idealized version of a modern geothermal district heating and cooling (GDHC) system integrated into a military installation (Zody and Gisladottir 2023).

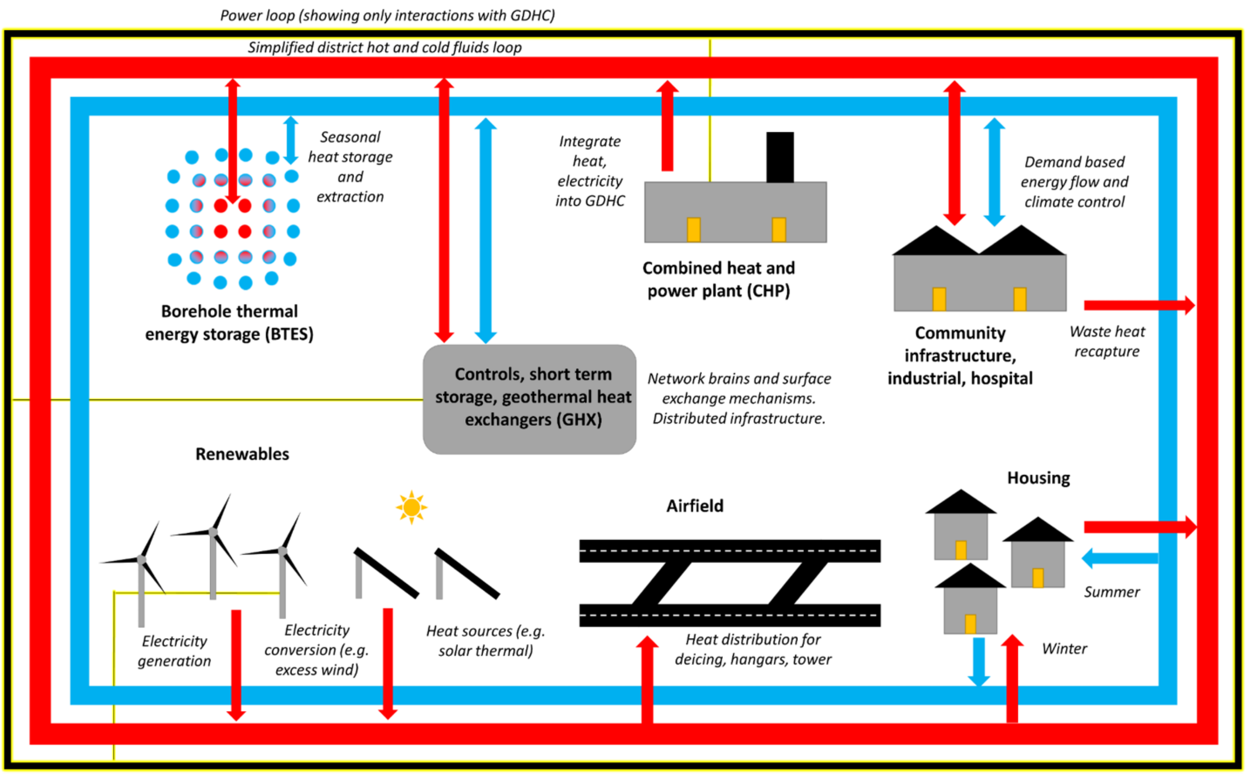

Figure 4: Idealized version of an installation scale GDHC with UTES (Zody and Gisladottir 2023)

Systems at the scale of all, or part of, a military installation with coupled UTES exist in cold regions around the world including Canada, northern Europe, China, and the U.S. To our knowledge, there is no such system at this scale deployed in regions with intermittent permafrost like Interior Alaska. Table 2 shows a modified version of deployed systems identified in the survey from Zody and Gisladottir (2023).

Table 2: Deployed GDHC systems with UTES elements truncated from Zody and Gisladottir 2023

Location	*Technology Elements*	*Year Built*	*Citation*
Albany, Georgia, United States	UTES using boreholes. GHPs coupled to UTES storage. Interconnected with building HVAC. Adiabatic coolers help to release excess heat.	2017	Hammock and Sullens 2017
Chifeng, China	UTES using boreholes. Integrated into district heating systems. Solar thermal collection. Industrial waste heat integrated. Short term thermal storage tanks.	2013	Xu et al. 2021
Heerlen, the Netherlands	GDHC with demand-based acceptance and rejection of hot/cold. UTES at district level using boreholes and abandoned mine cavern storage. Individual GHPs at building level.	2008/2013	Verhoeven et al. 2014; Boesten et al. 2019

	Poly-generation with bio-CHP, solar, waste heat, and cooling towers.		
Drake Landing, Alberta, Canada	UTES using vertical boreholes. Integrated into community heating and energy system. Control for acceptance and rejection based on demand. Solar thermal collectors. Short term thermal storage tanks.	2006	Mesquita et al. 2017; Kallesoe and Vangkilde-Pedersen 2019

Extreme conditions and cryohydrologic factors would present additional challenges for deployment of such a system in Interior Alaska, but we believe it would be feasible because of the ubiquity of such systems around the world, existence of systems tailored to extreme heat load imbalances, and the disproportionate benefit of such systems in remote extreme cold environment. The geohydrology around Fort Wainwright is “extremely complex” and “difficult to predict the direction and rate of ground water flow” (Lawson et al. 1996) and geochemical studies in the area provide evidence for communication between surface flow activities between surface flow and shallow ground transport (Hinzman et al. 1999; Verplanck et al. 2008). Surveying of existing wells and targeting permafrost free terrain would likely be a critical component tailored to deploying these systems to meaningful depth in Interior Alaska.

4. SHALLOW GEOTHERMAL DISTRICT HEATING COUPLED WITH UNDERGROUND THERMAL ENERGY STORAGE

Completed studies have culminated in targeting a district scale geothermal system to enhance thermal energy resilience in extreme cold regions installations. Since such a system hasn’t been deployed in an extreme cold region, a scalable transfer of existing technologies first needs to be proven. Leveraging existing GDHC and UTES technology tailored for deployment in extreme cold regions may mitigate thermal degradation caused by unbalanced heating loads (Figure 5). Unlike extraction systems alone, thermal storage allows for maintenance of the ground heat and presents opportunity to recover heat from additional sources such as solar thermal collectors and industrial processes.

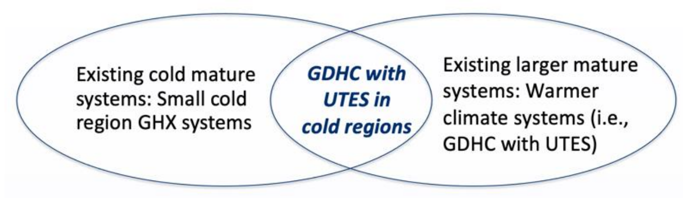

Figure 5: Technology development opportunity for GDHC with UTES in extreme cold regions

Demonstrating performance of a small-scale GDHC system coupled with UTES, first via modeling and later via potential installation, provides critical data on shallow geothermal system response in cold conditions. This may provide proof-of-concept in future planning of large-scale-systems in cold regions. By demonstrating feasibility in the most extreme conditions the viability of deployment in other cold regions is also shown.

In an ongoing case study, we focus on implementing a BTES system to couple with the heating systems in two buildings at Fort Wainwright, here referred to as buildings 1 and 2 (Figure 6). The buildings were selected because they are relatively new buildings with in-floor low temperature hydronic heating systems, and thus are suitable for heat pump retrofitting and conceptually scalable to a larger heat distribution system. Additionally, there is significant green space near the buildings suitable for placement of a potential borehole field.

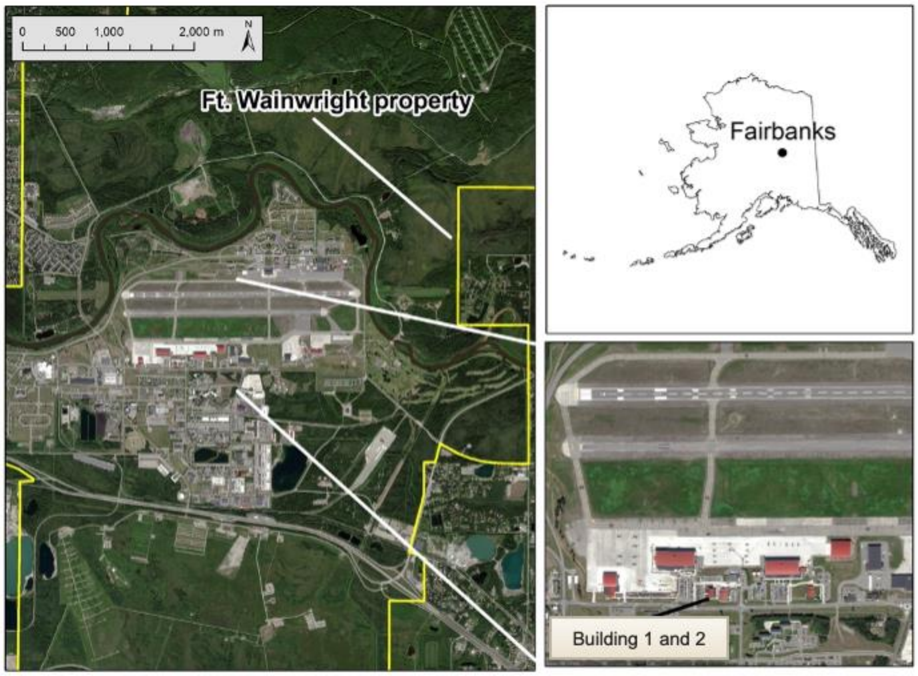

Figure 6: Aerial view of the proposed project site.

The primary source of subsurface data available are recorded water levels from historical bore logs (a U.S. Army Corps of Engineers depository). There are limitations to the accuracy and reliability of the recorded data, notably in what recorded water table levels say about the hydraulic gradient since times of recording can span many decades and different seasons. The bore logs do provide useful information, such as geologic material and range of water table depths. In the immediate project site, there are 26 known bore logs, 16 of which recorded groundwater encounters. The bore logs show a consistent pattern of sands and gravels in the project site down to 30 to 50 feet depth with a minimal variation in water depths. None of the bore logs recorded intersecting any frozen ground or formations beyond the near surface. Figure 7 shows the locations of the wellbores identified in the bore logs relative to geolocated building features and recorded water table depths. Significant information on thermal gradients and properties in the area are not available, and the water temperatures at the drilling are not available.

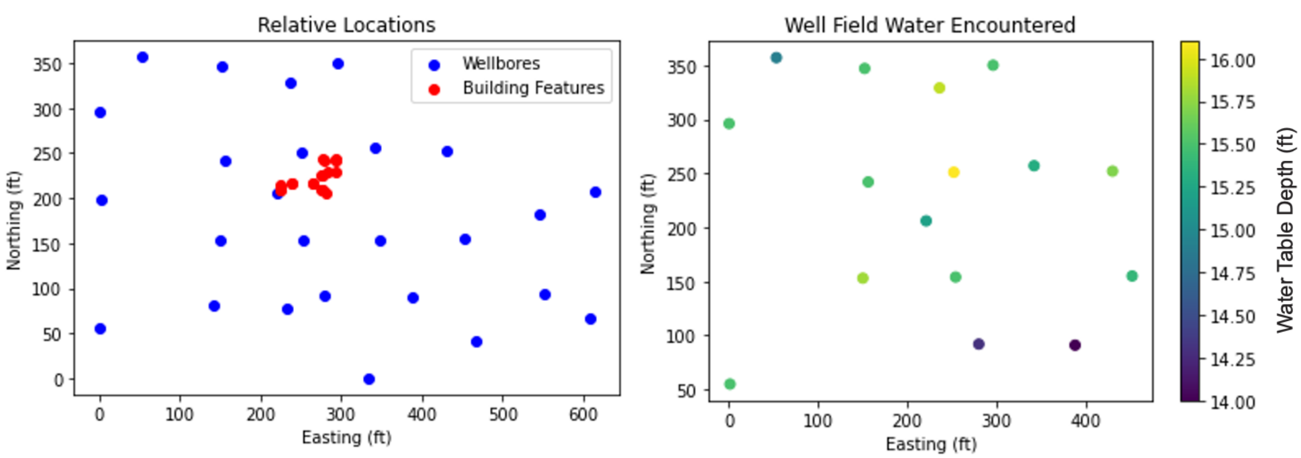

Figure 7: Wellbore locations within the study area.

For the optimization of the large-scale GDHC system with UTES system it is desirable to consider the impact of geologic coupling at Fort Wainwright. To enhance system efficiency while managing the unbalanced heating load the rate of thermal drawdown in the surrounding ground of GHP components is of prime importance. For BTES systems groundwater advection can convert over 50% of stored heat seasonally into the formation (Skarphagen et al. 2019). Such considerations can be used to enhance performance of the system as well as to avoid downstream heat pollution in the subsurface, as to prevent damage by thermal degradation in neighboring infrastructure with underlying permafrost. Well testing to better quantify the magnitudes and rates of these effects is necessary to fully understand how the local geology and hydrology alter system performance. This demonstration may provide a baseline for quantifying these transport properties in this particular geologic setting. Further data and modeling are required to fully understand the local subsurface regime and coupling between the building systems. Model results are outside the scope of this paper.

System design and field campaign for the case study are ongoing. A combination of different models is being utilized to inform the understanding of coupling between the building systems, BTES array, and subsurface. These include GLHEPro for heat pump and ground loop sizing, EnergyPlus for whole-building energy simulation, COMSOL Multiphysics for simulation of complex subsurface interactions, and various other tools for geologic modeling and characterization. Our goal is to demonstrate that deploying the system would:

1) reduce use of primary energy for heating and cooling,
2) show that the system could operate without use of other energy sources, and
3) determine what the economics of deployment would be.

If all these metrics are successful the objective is, with installation support, to move to deployment phase.

5. CONCLUSIONS

Advancing geothermal energy in cold environments and Interior Alaska would increase energy resilience at installations and in local communities. Direct heat and/or power production is shown to be viable in Interior Alaska under the right circumstances. However, significant progress still needs to be made on several fronts to establish systematic practices, enhance data availability, and reduce risk. Shallow geothermal energy systems with underground thermal energy storage have been piloted but demonstrations in a wider variety of environments would provide valuable data and knowledge to de-risk the technology for future deployment. Particularly in extreme cold environments where the opportunities and the challenges are unique. Geothermal is shown to be viable in the region under the right circumstances. However, scalability can only come through further advancement of methodology for deep resource location and demonstration of shallow technology for risk retirement.

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