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Weighing Policy Incentives with Geothermal District Heat Planning Tools in Helena, Montana, USA

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ABSTRACT

This project explores how policymakers and designers may plan their way from geothermal district heating (DH) project assessment, through regulation, to implementation. A reservoir simulation with GEOPHIRES creates a 500m-deep stimulated well production test case using existing flow and temperature data. The system is a low-temperature fault-controlled geothermal area, common to the Western United States. Using a previous building heat demand map for a nearby municipality, Comsof Heat automatically generates the DH network, based on heat source matching and revenue optimization. Such design optimization highlights the cost savings for low-temperature geothermal production from a new generation of DH construction materials and control. This presents policymakers and designers with geothermal levelized costs of heat (LCOH) bordering price parity with individual building gas-burning systems.

After finding a low-cost geothermal LCOH from the design, this project explores utility regulation standing in the way of construction. Important barriers to overcome include the reclamation of proprietary customer data held by existing gas utilities, capital raises, revenue pressure, adoption incentive, and ownership. Using a combination of franchise agreements, tax credits, community ownership, municipal ordinance, and construction density incentives, policymakers can set conditions favoring network implementation. This will lead to permanent job growth in the development district. Helena, Montana serves as a demonstration site, proving design and policy are now ready for geothermal heat network deployment. In conclusion, if heat networks can meet the sustainability criteria set by State and local climate action plans across the United States while also delivering low-cost energy, they should be receiving broader attention.

1. INTRODUCTION

Rapid geothermal district heating assessments are possible using a combination of building heat demand mapping in Quantum Geographic Information Systems (QGIS), geothermal reservoir characterization in GEOthermal energy for the Production of Heat and Electricity (IR) Economically Simulated (GEOPHIRES), and district heating (DH) automation and optimization in Comsof Heat – a QGIS planning tool. These software and methods leverage modern DH materials and technology to minimize heat losses, reduce trenching, and decrease overall pipe diameters. The result is a minimization of the levelized costs of heat (LCOH) for geothermal DH systems (GDHS). This project finds LCOH values that near price parity with natural gas in what is considered a sparsely populated area for DH by previous design standards – Helena, Montana. With this increase in cost competitiveness in the USA, the question becomes:

How can policymakers and designers incentivize development?

Fourth generation district heating (4GDH) is the most recent development of advanced preinsulated direct-burial pipe materials, smart control, and network design that is improving the cost effectiveness of low temperature (<70°C) heat sources (Lund et al., 2014). As DH networks can accept lower temperature heat sources many more renewables are now capable of delivering heat to a network (Figure 1) that ultimately decarbonizes building heat consumption by reducing the use of fossil fuel combustion. Since there are so many geothermal resources of a low temperature value and these resources have a low marginal cost of heat generation (the cost to produce one additional unit of heat from the wells), geothermal is enjoying the greatest gains in cost effectiveness when the developer couples it with advanced DH components, in comparison to other renewable or nonrenewable heat sources (Averfalk & Werner, 2020).

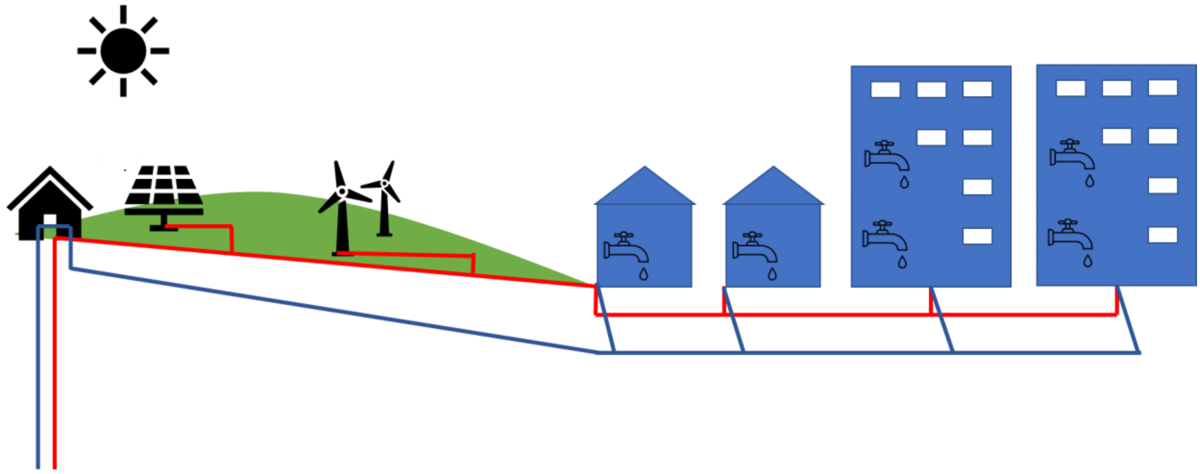

Figure 1 Fourth generation district heating (4GDH) leverages economies of scale and scope, meeting the needs of energy decarbonization by accepting multiple renewable heat source inputs across the network and reducing heat loss along the pipe with modern control systems and pre-insulated, direct-burial conduits.

2. BACKGROUND

2.1 GEOPHIRES Uses

Developing the LCOH for the entire GDHS is an iterative process that initially requires characterization of the geothermal reservoir in GEOPHIRES. The program originates from the MIT-Hot Dry Rock software of the 1990s and in version 2.0 allows users to input text files for acceptance into an advanced text editor using Python code (Beckers et al., 2013; Beckers & McCabe, 2019). The tool has several built-in models, including direct use only, that can provide outputs given little information on the subsurface, power plant, or financing options. A new version – 2.0 – became available in 2019, appearing in Figure 2. With the outputs a user can find proper insights on the sizing of a GDHS, compare different drawdown scenarios for management purposes, and project design efficiencies (Beckers & McCabe, 2019).

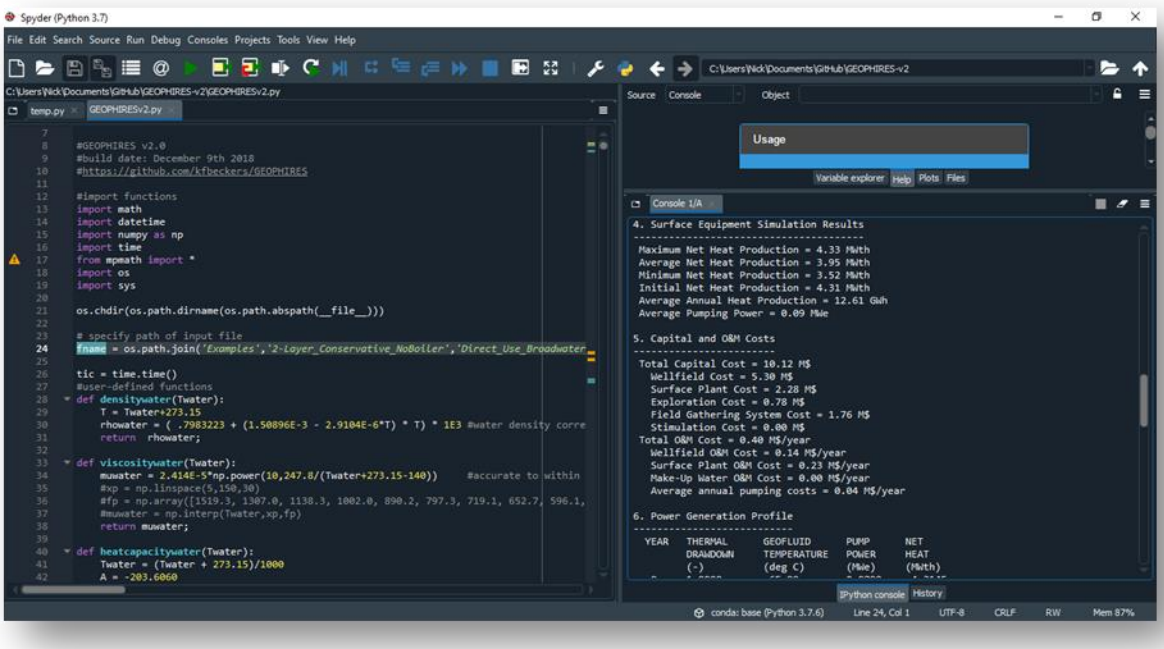

Figure 2 GEOPHIRES code operating in an advanced text editor, Spyder, running Python. The file inputs appear on the left with the outputs on the right.

GEOPHIRES, although capable of standalone reservoir simulation using various forms of drawdown equations, also can import reservoir models from several other simulators, such as TOUGH. TOUGH stands for the Transport of Unsaturated Groundwater and Heat. It is a popular external numerical modeling tool from Lawrence Berkley National Laboratory (Beckers & McCabe, 2019). A previous characterization of the geothermal reservoir conceptual model is a useful input for the software but is more commonly available from play fairways having been subject to heavy scientific or industrially commissioned research, such is the case in Lowry et al. (2020).

There are several built-in assumptions. The built-in fluid assumptions are for pure water. This can be modified to meet the chemical compositions of the production fluid if it is available to the user, though it is unnecessary for functionality. Six built-in reservoir models are available to provide calculations for production temperatures. These include multiple parallel fractures drawdown, 1-dimensional linear heat sweep, mass loading single fracture drawdown, percentage temperature drawdown, a user-defined temperature profile, or non-isothermal multiphase flow in fractured porous media from a TOUGH2 simulation. In wellbore simulations pumping can be specified for injection or production wells, or both. Allowable bore diameters are 1-30 inches, though the built-in cost correlations are only for a 0.16m inner diameter or 0.22m inner diameter. Wellbore simulation for the geofluid temperature change, over the user-defined time, relies on the Ramey Wellbore Heat Transmission model. This and further underlying organic equations for GEOPHIRES are available in Beckers & McCabe (2019).

The output of the simulation includes the thermal drawdown characteristics, production values in $MW_{thermal}$ and its economic traits, including the LCOH formula appearing in *Eq. 1*. This combination of parameters defines the tool as a techno-economic simulator, allowing the user to find the levelized costs.

$$LCOH = \frac{\sum_{t=1}^{n} \frac{C_t + OM_t - I_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{H_t}{(1+r)^t}} \tag{1}$$

Where:

C_t is the capital investment in year t
OM_t is the operating and maintenance costs in year t
I_t is the income from year t
H_t is the heat produced in year t
r is the discount rate
n is the lifetime of the plant

2.2 Building-level Heat Demand Mapping

In addition to the characterization of the geothermal reservoir production values, the designer must also complete building-level heat demand mapping in a GIS interface. During the summer of 2020, a building-level heat demand mapping method was found by collecting structure footprints from local GIS managers, attaching them to property tax parcel data, interpreting the building archetypes into load factors from previous Natural Resources Canada work (Dalla Rosa et al., 2012), then inferring the energy demand per area of floorspace from the Commercial Building Energy Consumption Survey (CBECS) and the Residential Energy Consumption Survey (RECS) (Energy Information Administration, 2012, 2015). Building-level heat demand mapping enables the designer to match the geothermal reservoir production value to the community needs using the heat source matching strategy in Comsof Heat software.

2.3 Comsof Heat Uses

While defining the resource and the building-level demand are important components of the DH feasibility analysis, another major hurdle is the network design. Designers of DH networks have long relied on manual CAD drawings and spreadsheet analysis to plan their fluid networks across a community. These methods are not only time consuming but also susceptible to frequent human error. Comsof Heat is a unique GIS-integrated software plugin that provides rapid automation of a DH network layout (Jebamalai et al., 2019). Full integration of the plug-in to the Quantum Geographic Information System (QGIS) platform allows designers to calculate the pipe sizes, pressure levels, and construction materials list from pipe manufacturer catalogs. Multi-stage roll-out forecasting allows designers, investors, and planners to quickly determine the potential outcomes for a variety of scenarios. Such scenarios could include the manipulation of the heat source size itself, targeting specific buildings at different phases of heat network construction, or understanding of temperature boost requirements to meet community demands (Comsof Heat, 2020).

Comsof has been in the business of fiber optic network planning for more than 2 decades. Using this network software expertise in cooperation with the University of Ghent, Comsof Heat became the DH software spin-off of the company in 2018. The software also enables researchers, such is the case in this work, to quickly configure different network sizes and parameters. The automated optimization of the network provides a more complete depiction of possible outcomes for a given thermal resource (Jebamalai et al., 2019). This all takes place on a graphical user interface, as shown in Figure 3.

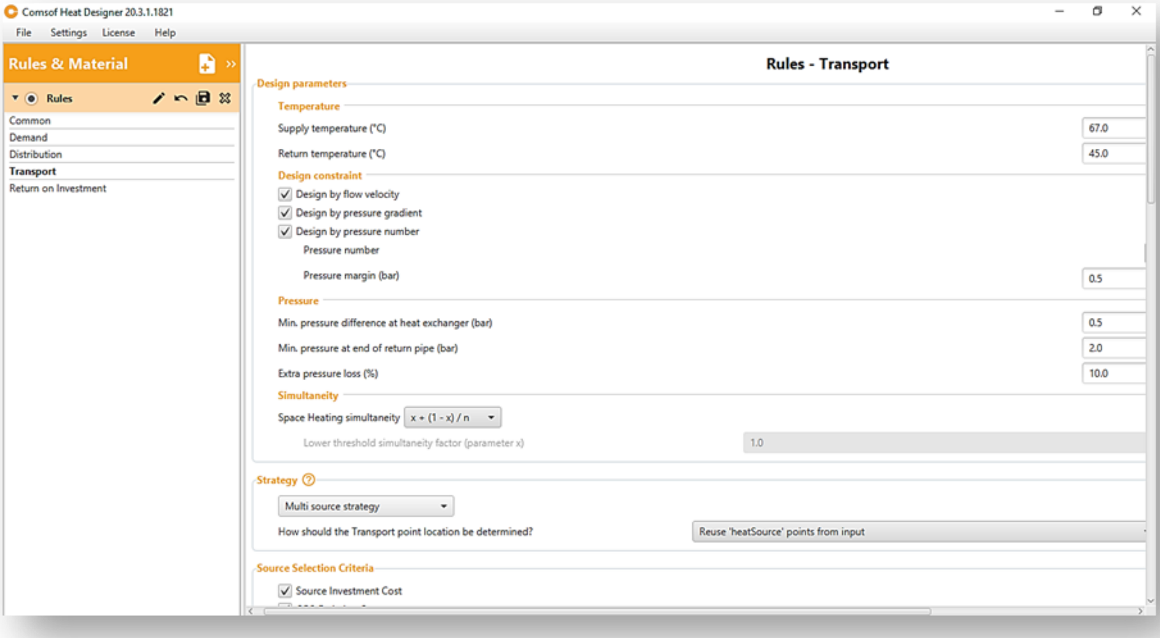

Figure 3 Comsof Heat graphical user interface for DH designers. Changing sets of rules enables a developer to run many scenarios in pursuit of cost optimal solutions for the heat network.

There are three primary strategies for simulation of a DH transportation and distribution circuit in Comsof Heat. Clustering strategy places substations at optimal locations throughout a community based on the parameter inputs from the heat source, known as "rules," on the interface. The rules include parameters such as the pressure input and flow velocity maximums, specific to each pipe manufacturer and product type. Building these distribution clusters before connecting the heat source in a centralized scheme is a bottom-up approach to design. The manufacturer specifications of maximum flow velocities increase the overall network pipe diameter, so Comsof Heat also allows for simulation of manual manipulations of a pressure increase from the source. Another design strategy organic to Comsof Heat is heat source matching. This will allow the DH designer to find a maximum number of buildings that a given heat source can supply, whether that be for space heating, space heating and DHW, or both with priority switching (Jebamalai et al., 2019). A third strategy, multi-heat source matching, became available after the proposal of this work. It further allows for heat source matching from different locations, cost optimizing for CO_2 emissions, source investment costs, and heat production costs (Jebamalai et al., 2020).

The clustering algorithms are an in-house development that avoids the data analysis techniques associated with k-means, hierarchical clustering, and hierarchical k-clustering as these largely rely on the uniform data inputs. Demands across a DH network are anything but uniform (Jebamalai et al., 2019). The algorithms behind the network automation are the intellectual property of Comsof Heat and are not the subject of this writing. Comsof Heat, however, rapidly enables feasibility studies of DH networks with a minimum input of building data and road centerlines. The backbone of the transportation and distribution circuits follow these road centerlines during the network generation process. Of course, the more specifics that the planner is able to provide the software, through either rules, specific demand information, most desirable network pathways, etcetera, the more accurate a picture Comsof Heat will provide (Comsof Heat, 2020a).

2.4 Diversity of Heat Demands Across a Network

Peak demand across the heat network does not require simultaneous delivery. In the heat demand density mapping for the development area, DHW demand is drawn from an empirical formula and 80% of the building peak demand is assigned to space heating demand. Comsof Heat identifies these attributes in the building polygon attribute table. Space heating and DHW each have a unique simultaneity formula across the software (Comsof Heat, 2020).

The simultaneity formula for DHW is:

$$\frac{1}{\sqrt{number\ of\ homes}} \qquad (2)$$

The simultaneity formula for space heating is:

$$X + \frac{(1 - X)}{number\ of\ homes} \qquad (3)$$

where:

X is the selected simultaneity factor, also known as the diversity factor.

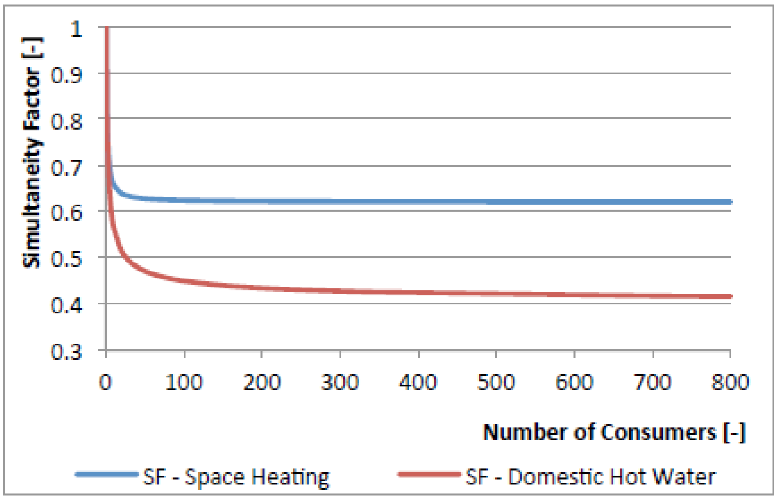

Figure 4 The non-linear decline curve of simultaneous demand. As the number of consumers on the DH network increases, so too does the simultaneity factor (Tol & Svendsen, 2020).

Simultaneity factor is 0.62 in this case and follows from the same methods of Jebamalai et al. (2019) and H. Tol & Svendsen (2020), known as a Danish standard for residential structures, with a non-linear decline curve appearing in Figure 4. No differentiation between a commercial consumer and residential consumer is made in this case for the simultaneity factor. This decline curve, significant if there are less than about 100 consumers, is uniform across the entire Helena demonstration site where 1050 demand structures appear with still more apartments in each. Of these 1050 structures, 499 are connected by simulations.

2.5 Advantages of Rural and Suburban GDHS

Previous work from the Geo-Heat Center informs this project of the advantages of DH across sparsely populated areas. The rural and suburban areas of the Western United States frequently are without paving across the road surfaces that serve as utility corridors. In addition, these utility corridors have fewer additional utility installations to cross. For each additional utility crossing, the price of the DH network would grow because of labor increases to safeguard DH installation. Repaving is an obvious additional cost to the developer (Rafferty, 1996). There is also a large quantity of individual forced-air systems (Northwest Energy Efficiency Alliance, 2014) that require heating terminal units (HTU) retrofit (Rafferty, 2003). The HTU could accept the space heating fluids directly from neighborhood substations. If that is the case, the heat interface unit (HIU) would not require a brazed heat exchanger for space heating preparation, eliminating some components found in Figure 5 (Rafferty, 1996). The designer must weigh these energetic and economic advantages from the perspective of the utility and the customer that takes the geothermal heat.

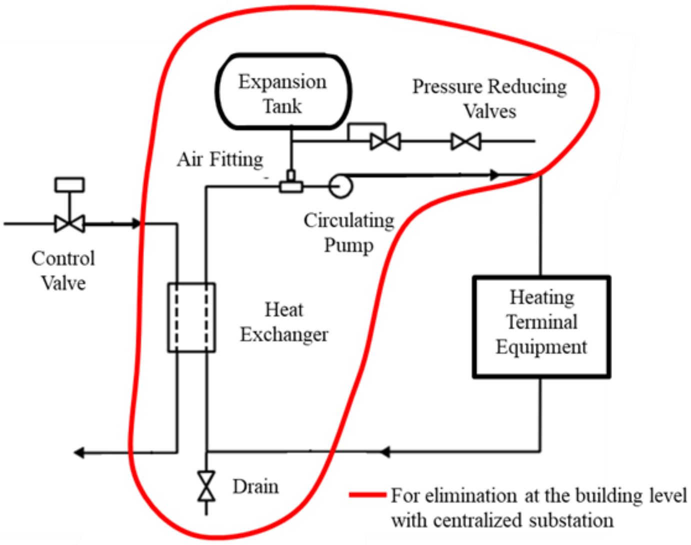

Figure 5 The building side heating solution for forced air to DH retrofits. The elements in red may be eliminated with the installation of a centralized substation, possibly saving the structure owner money (modified from: K Rafferty, 1996).

2.6 Energy Policies Available to the Policymaker and Geothermal Developer in Montana

GDHS utilities, unlike electricity generating utilities, are subject to market competition in Montana. To overcome the problem of gas utility protectionism, a community may petition the county board for a Rural Improvement District (RID) or similarly the Special Improvement District (SID) within a municipal limit to raise money for a GDHS. Petitioners supporting the project could simultaneously disclose their specific heating needs, energy bills, to the would-be DH operator. Disclosing this information to a potential geothermal developer would improve the building-level heat demand mapping and planning. This results in a municipal or community cooperative ownership scheme. A RID/SID in Montana requires that 60% of those residents throughout the service area become signatories on the petition. The RID/SID allows the district to sell bonds which can in turn fund the DH improvement (Perlmutter & Birkby, 1980). Community buy-in through a RID/SID levee, therefore, could increase the financial sustainability of the GDHS in Montana by socially incentivizing low-emission heating delivery.

In addition, a municipality is free to make franchise agreements outside of the confines of state elected energy regulatory bodies, such as the Public Service Commission (PSC) in Montana. Franchise agreements enable the city to gain access to proprietary utility data such as heat consumption patterns and engineering information in exchange for access to public roadways (Montana State Legislature, 2015). This is one mechanism by which cities across the United States are implementing clean energy plans outside of gas utility monopoly control (Platt & Cilimburg, 2018). From the perspective of the competitive geothermal developer, this should encourage cooperative arrangements by working directly with local governments, such as city councils. The city councils may favor building-stock decarbonization in their community while the geothermal developer wishes to deliver their expertise and heat to a new range of customers.

For the individual building owner in Montana, there is a geothermal systems income tax credit (GSITC). The GSITC offers participants $1500 for the connection, installation, or purchase of a geothermal heating system. This GSITC can offset building connection fees, the purchase of a HIU, or retrofits (Birkby, 2012; Montana Department of Revenue, n.d.). Depending on the contracts made with the geothermal developer, this could be fed directly to the heat operator for bulk purchases of components that ultimately save on costs.

Early in the planning stage, the developer of geothermal DH should encourage a stability of demand by improving the building insulation efficiencies of their service area. This ensures that long-term heat network operation is consistent across all structures. If the GDHS operator connects to high-demand structures with low-efficiency insulation, they risk a revenue loss when the building owner decides to upgrade the insulation values of their structure (Persson & Werner, 2011). Though the DH operator can counter this phenomena by improving the overall system efficiency (Figure 6), all efforts should be made to start with a high building insulation efficiency baseline.

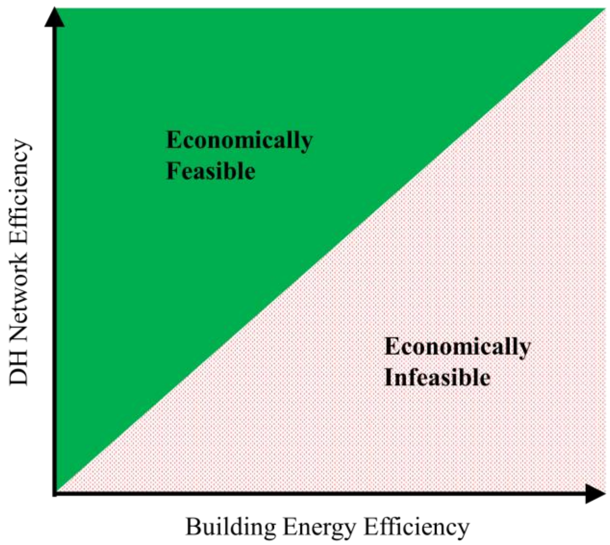

Figure 6 The relationship between DH network efficiency and building energy efficiency. A system can remain economically feasible by increasing network efficiency in the face of increasing building energy efficiency.

Potential GDHS ratepayers in Montana can take advantage of the Energy Conservation Tax Credit (ECTC). The ECTC will pay up to 25% of a building owner's insulation upgrade costs (Birkby, 2012; Montana Energy Office, 2019). Upgrading insulation could be another standard in the GDHS contract. Improving insulation, however, provides a built-in incentive of energy bill decreases for the customers, regardless of the arrangements made between the community geothermal heat utility and the building owner.

3. METHODS

This project simulates a geothermal production scenario using GEOPHIRES from a surface manifestation, Broadwater Hot Springs, about 2km from Helena, Montana municipal boundaries. After determining the production values, along with the wellfield, gathering system, surface plant, stimulation, and exploration costs, a previously made building-level heat demand map is connected to the geothermal resource using Comsof Heat (Fry, 2020). The output from Comsof Heat balances the LCOH formula in GEOPHIRES by determining the overall end-use efficiency factor (EUEF) during operation and the utilization rate of the system across a year. Several policy incentives are weighed against the initial production values and costs. Weighing these policy incentives results in either direct cost reductions to the operation in place or an extension of the service area by improving individual building insulation values.

3.1 Reservoir Production Characterization

The current maximum temperature values at the wellhead from Broadwater Hot Springs is 67°C with flow rates of 31.5 liters per second (l/s) from existing 4.5” wells. In this project, a deeper drilling simulation with stimulation extends 2 wells of 8.5” outer diameter, increases flow 15%, and produces from a depth of 500m. Reservoir size estimation is made by using the areal extent of map overlays from water well log reporting at the Montana Groundwater Information Center (Gruber & Lindsay Drilling, 1976), geologic formation mapping (Green, 2004), and resistivity survey (Galloway, 1977). The cost correlation in GEOPHIRES is for small diameter wells using US market averages built into the software (Beckers & McCabe, 2019). The model in use estimates linear thermal drawdown, with a production to reinjection well separation of 1km. A project lifetime is set for 40 years to define the LCOH output and the final wellhead production values ($6.31MW_{thermal}$).

3.2 District Heating Demonstration Site

A community near Broadwater Hot Springs serves as the demonstration site (Figure 7). Across the demonstration site, the building-level heat demand map includes 1050 structures. These are mostly single-family homes with some commercial and multi-family structures. The average year of construction is 1963. Living units within the structures are each given a DHW peak demand of 32.29kW and the space heating values are taken from CBECS and RECS estimations by year of construction and building typology. This technique is a modification of those methods found in Jebamalai et al. (2019), with an adaptation to US market data. Building load factors in use for the peak demand are found in Natural Resources Canada building simulations from Dalla Rosa et al. (2012).

Figure 7 Looking south across the DH demonstration site from Spring Meadow Lake in Helena, Montana (Helena Convention and Visitors Bureau, 2020).

3.3 Component Cost Estimations

Each component cost will vary with the extent of the DH network and the pressures and temperatures of the fluid delivery. For example, the size and cost of a forced air conversion unit – an HTU – will increase with lower delivery temperatures (Rafferty, 2003). This project solicits all prices from vendors. HTU costs come from Vemco Inc. of Montana (Mueller, 2020). Control modules, control consoles, and central control management system costs come from Ouman of Finland (Mertala, 2020). Substation and building-level HIU costs come from Gebwell of Finland (Ozolins, 2020) in combination with estimations from Danish Energy public information releases (Danish Energy Agency, 2018). Preinsulated series 2, direct-burial, continuously produced, DH twin and single-pipe with leak alarm, plus joint costs, come from Logstor A/S of Denmark (Lorenzen, 2020).

3.4 Comsof Heat DH Simulations

Using the component cost estimations and the well production values, Comsof Heat incorporates a heat source matching strategy to automate the connection from wellhead to home, providing a technical report output and bill of materials. A portion of the production, 410kW, is withheld to sustain ongoing operations at a nearby geothermal resort. This project implements a 2-layer design scheme that creates $1MW_{thermal}$ substation clusters across the demonstration site to decrease overall pipe diameters across the network (Figure 8). A 2-layer design scheme also allows the operator to run a higher pressure backbone on a transportation line that leads up to a neighborhood substation for additional heat exchange, then onto a low pressure delivery at the point of building connection. These constraints create lower cost outcomes (Jebamalai et al., 2019). Water volumes serve as working fluids from the wellhead and substations, recirculating to the heat source after delivery, to save the operator from make-up water costs.

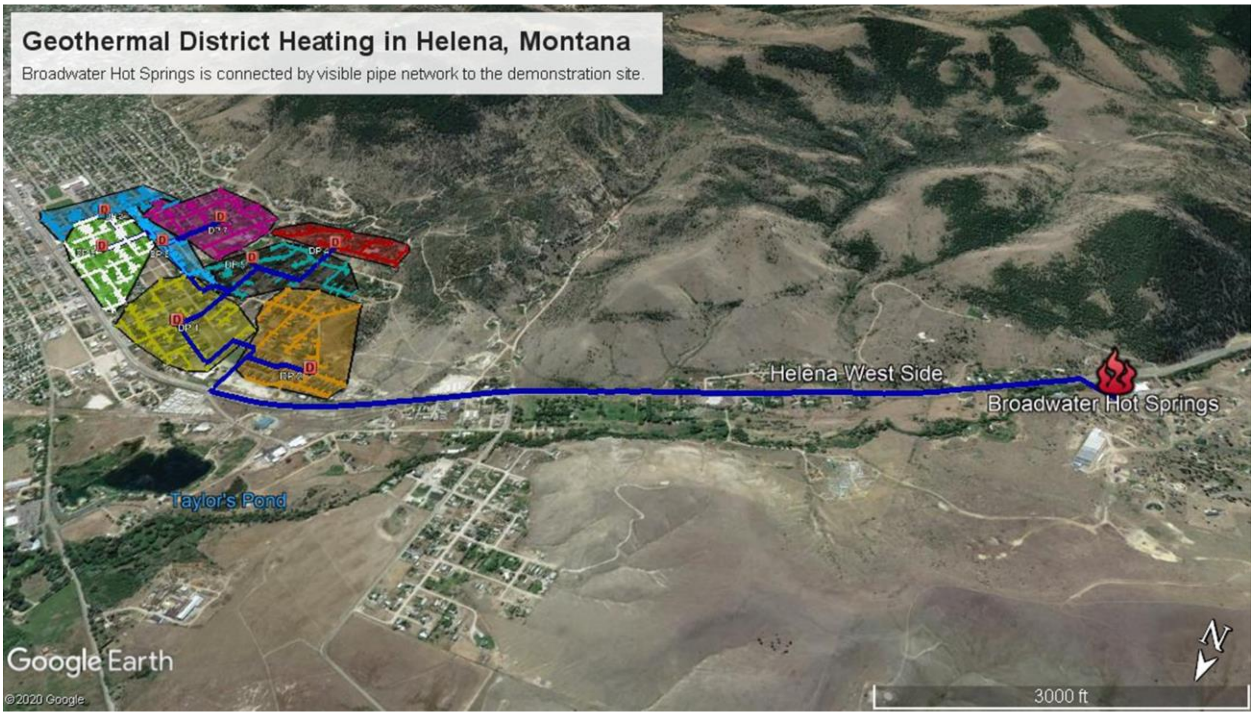

Figure 8 Looking south across the demonstration site at the simulated Comsof Heat network using Google Earth. A transportation circuit travels from the geothermal area to substation clusters, constrained to 1MW$_{thermal}$ sizes.

3.5 Simplified Whole System Cost of Natural Gas

To compare the GDHS option to the incumbent heating source, a simple formulation of the building owner costs over the same project lifetime appears in *Eq. 4*.

$$WSC_{NG} = \frac{\left((AD_{CH,TR} * .8) * 1000 * \left(\frac{NGC}{EF_{SH}}\right) * PL\right) + \left((AD_{CH,TR} * .2) * 1000 * \left(\frac{NGC}{EF_{DHW}}\right) * PL\right) + (EC * DP_{BP} * X)}{AD_{CH,TR} * 1000 * PL} \quad (4)$$

where:

WSC_{NG} is the whole system cost of heating with natural gas in $/kWh
$AD_{CH,TR}$ is the annual demand in MWh found in the Comsof Heat technical report
NGC is the natural gas cost in $/kWh
EF_{SH} is an annual efficiency factor of natural gas for space heating using a condensing furnace
EF_{DHW} is an annual efficiency factor of natural gas for DHW using a power vent water heater
PL is the project life, in this case 40 years
EC is the equipment cost for 1 SFR condensing furnace ($CFC_{SH,DP}$) and 1 SFR power vent water heater ($HWHC_{DHW,DP}$)
DP_{BP} is the number of active demand points per scenario, attached to building polygons
X is the number of service life periods for the furnace and water heater, over the project life*
*The service life of a furnace and water heater in this project is assumed to be 20 years

The equipment cost, *EC*, per demand point is scaled from individual building demands in the maximum production case, per design scheme, per kW peak demand for DHW and space heating following the formula:

$$HWHC_{DHW,DP} = \frac{\sum_{i=1}^{n} HWHC_{kW_i} * \sum_{i=1}^{n} PD_{DHW_i}}{DP_n} \quad (5)$$

where:

$HWHC_{DHW,DP}$ is the hot water heater cost for domestic hot water supply, per demand point
$HWHC_{kW,i}$ is the hot water heater cost per kW demand, per building
$PD_{DHW,i}$ is the peak demand for domestic hot water at each building
DP_n is the number of demand points met per maximum production scenario

$$CFC_{SH,DP} = \frac{\sum_{i=1}^{n} CFC_{kW_i} * \sum_{i=1}^{n} PD_{SH_i}}{DP_n} \quad (6)$$

where:

$CFC_{SH,DP}$ is the hot water heater cost for domestic hot water supply, per demand point
$CFC_{kW,i}$ is the condensing furnace cost per kW demand, per building
$PD_{SH,i}$ is the peak demand for space heating at each building

Therefore,

$$EC = CFC_{SH,DP} + HWHC_{DHW,DP} \tag{7}$$

In each circumstance the efficiency factors and component costs for the natural gas system are drawn from Schoenbauer et al. (2017). This report includes the prices found in residential units, surveyed in Minnesota. The open market price for the average condensing furnace is $4250. Assuming this is equivalent to meet the needs of a 10kW peak space heating demand, based on Danish Energy Agency (2018) averages for SFRs, the per kW price (CFC_{kW}) is $425. The efficiency factor for a condensing furnace (EF_{SH}) used in *Eq. 4* is 90%. The open market price for the average power vent water heater is $2100. Assuming from 3.2 that the typical residential peak load for DHW is 32kW, then the per kW price ($HWHC_{kW}$) is $65.60. The efficiency factor for a power vent hot water heater (EF_{DHW}) used in *Eq. 4* is 60%, largely the result of standby heat losses.

Average *EC* values are $7137 for equal building coverage of the 2-layer design. Natural gas costs (*NGC*) in use for this project are drawn from July 2020 residential consumer rates (NorthWestern Energy, 2020).

3.6 Weighing Potential Policy Actions

Persistent barriers to GDHS implementation include mandates to deliver the lowest cost energy solution to customers, and a lack of available public information describing heat demand (Gils et al., 2013; Nowakowski, 2018). These lowest cost mandates neglect the long-term costs to the consumer for components, fuel losses, and maintenance. Lack of heat demand information available to the public is typically the monopolistic approach of gas utilities. After projecting the unsubsidized LCOH values by combining Comsof Heat and GEOPHIRES, this project prescribes several policy initiatives that could change the outcomes for the LCOH by overcoming persistent barriers. These policies include ordinance, the GSITC, SID, and separately the ECTC. Each of the policies has either a direct price affect for the 499 buildings that are heat customers across the network, or it extends the network while also changing LCOH values.

Improving the energy efficiency of the heat network is possible by improving the target market, or service area. Improving the target market would likely require the municipality to create an ordinance or franchise agreement with the existing gas utility to release the current annual consumption patterns. While this is not a perfect proxy because of flue gas losses, oversizing of furnaces and boilers, and leakage (Bennett & Elwell, 2020; Schweitzer, 2017), this project assumes a 2% system efficiency increase is possible for the GDHS by selecting ideal heat customers.

In addition to the efficiency improvement, GEOPHIRES LCOH values decrease by subtracting the value of the SID and applying the GSITC. A 20-year 0.31% SID is created across all 499 structures in the service area clusters, taking their property value from Department of Revenue assessments (Montana Department of Revenue, 2020) and assuming a 1% annual appreciation. This is equivalent to $9,541,199. Across the same service area, the GSITC is equivalent to $748,500. The total is taken from the surface plant and DH network cost parameter in the LCOH outputs of GEOPHIRES.

Separately, this project weighs the potential outcomes from use of the ECTC. If a 15% decrease in building heat demands takes place across the service area, the GDHS operator would have to extend the network. If the insulation values occur at the beginning of the network development, the operator would need to reexamine the maximum potential of the heat network. This 15% building heat demand decrease is rerun in Comsof Heat to determine the system effects. Insulation improvements in this second policy condition are the only changing parameter.

4. RESULTS

The baseline outputs from the unsubsidized GEOPHIRES and Comsof Heat simulations come to a LCOH of $0.128/kWh. Well utilization rates are 33.5%. The simplified equivalent whole system cost of individual gas heating is $0.212/kWh. An upfront capital cost average per building owner is $24,122 for the GDHS solution or $7,137 for natural gas heating equipment. Total capital costs for the GDHS come to $24,770,000.

Applying the GSITC and SID cost defrayments, in conjunction with a 2% system efficiency increase, reduces the LCOH to $0.078/kWh. The remaining capital costs are $14,480,000, (Figure 9). This is equivalent to $7,130 per building owner – less than the gas equivalent.

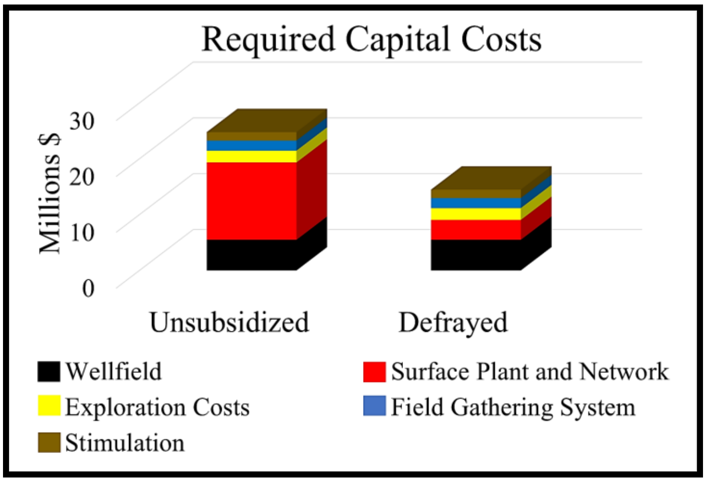

Figure 9 Capital cost without subsidy or with a defrayed cost using a Special Improvement District levy, tax credit, and efficiency gain.

The second policy incentive outcome weighs the effects of a 15% building heat demand decrease from insulation improvements, on the GDHS. This decrease could result from residents taking advantage of the ECTC to decrease the financial burden of building insulation improvements. With 15% insulation improvements to the structures in the service area, it is possible to deliver heat to 123 more structures. This represents a 24% increase in the number of customer hookups (Figure 10). There is also a 5% increase in annual demand met per year using the extended network, offsetting a total of 12,944MWh of fossil fuel heating. Network extension decreases the LCOH by $0.006/kWh, to $0.122/kWh, and decreases the average capital cost per structure by 13.5%.

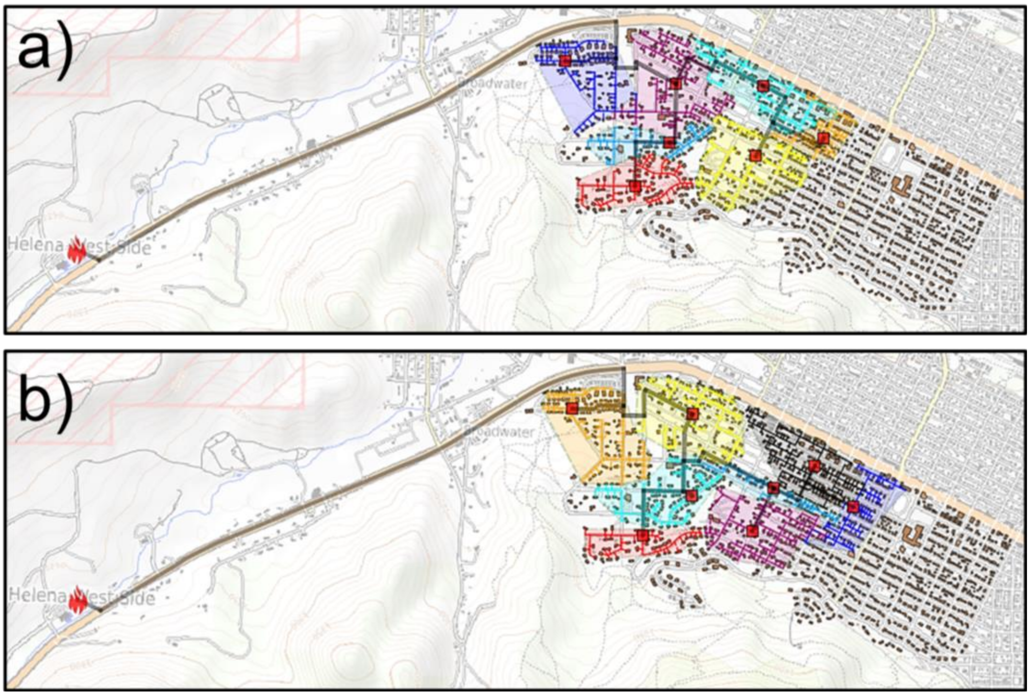

Figure 10 a) Production test case with optimized DH network from Comsof Heat. b) Extension of DH network with building insulation; The red flame on the left is the location of the geothermal wells. Each of the different color clusters are fed by a unique substation.

5. DISCUSSION

It is evident through the application of these policy mechanisms and incentives that geothermal DH should find its way to the policymaker's toolbox. Additional ways to create functional DH business models and sustainable building heat demand profiles for a community do exist. A nearby example includes the Lulu Island Energy Company in Richmond, Canada. The DH utility works with the municipal government to mandate DH-ready building standards. In addition, the DH utility offers building density bonuses. Gains in heat demand density improve the efficiency of the GDHS (*IDEA Expert Panel Discussion*, 2020) and drive the LCOH down. Replicating this success in the United States can be done through municipal zoning code. A community building inward and upward, rather than outward, will continue to be a powerful cost savings and emissions reduction policy standard.

Geothermal experts, planners, and business practitioners may now quickly explore the potential of the lowest-temperature resources. Manipulation of these outcomes is easy in the GEOPHIRES, Comsof Heat, and GIS software packages. Early results are possible with minimal amounts of upfront fieldwork, empowering the investment intelligence of communities and utilities alike. Inputs can range from the distinct detail found in the most complete TOUGH2 numerical model for the geothermal reservoir, to minimum information found in state water, geology, and mining repositories.

Summarizing these policy outcomes with visualizations relevant to even the building owner makes bridging the communications gap between all stakeholders easier. A utility, its engineers, geologists, business experts, the municipality, its policymakers, civil works staff, and the community members can quickly understand potential long-term cost savings, risk or reward, and local effects that a geothermal DH network can bring to them. This allows the designer and the community to understand exactly the extent of development, the possible advantages, and the effects of revenue collection (Fry, 2020). Using previous work as a proxy, a GDHS of this size should provide approximately 4 permanent jobs and 10 construction jobs in Helena (Jones & Luke, 2019; Smith, 2015).

6. CONCLUSION

Using new techniques to improve DH cost effectiveness in suburban and rural communities, there should be no reason that a rapid expansion of GDHS in the United States cannot take place. High temperature economic thresholds from previous GDHS development (>70°C) are no longer a significant limitation to implementation. Low temperature GDHS is economic, now more than ever. Business models should shift with this information and a new era of exploration and feasibility assessments should take place.

Municipal franchise agreements with gas companies that include the release of building heat demand data can improve heat network planning and efficiency. GDHS assemblies with a larger supporting bond levy, in conjunction with automated network cost optimizations, and community cooperative ownership, will alleviate revenue pressure on the operation. GDHSs create several permanent jobs and, in this case, can deliver at a price that beats natural gas. With assessment of GDHS now possible at the local level, across even sparse housing zones, heat networks should be receiving broader attention in the United States.

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