Geothermal-Enabled Zero Energy Electric Community—An Integrated System Design Study

Preprint

Dane Christensen, William Becker, Andrew Speake, Kevin McCabe, Samantha Reese, Jeff Maguire, Dylan Cutler, and Caitlin Dorsey

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National Renewable Energy Laboratory
15013 Denver West Parkway
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Geothermal-Enabled Zero Energy Electric Community—An Integrated System Design Study

Dane Christensen, William Becker, Andrew Speake, Kevin McCabe, Samantha Reese, Jeff Maguire, Dylan Cutler, and Caitlin Dorsey

Keywords

Geothermal, Community, Renewable, Zero Energy, Design, Simulation, Analysis, Techno-Economic

ABSTRACT

Developing a zero energy community is a costly proposition in northern climates for many reasons, including higher building loads, lower solar incidence rendering solar photovoltaics (PV) less effective, and unbalanced energy needs (summer production, winter demands). We present a study on the novel application for geothermal energy production to support a zero energy community that functions as an integrated techno-economic package, combining appropriate energy efficiency (demand design), geothermal production (supply design), and asset dispatch. This paper describes the process used to explore this system integration challenge, presents initial results, and discusses some of the technical opportunities for increasing the community-scale adoption of geothermal as an electric generation resource.

Our results show that under certain conditions, community-scale geothermal electricity could be very competitive with today's grid tariffs and with PV; we show a levelized cost of electricity (LCOE) within $0.01/kilowatt-hour of each more-established generation technology. A combination of geothermal and PV could present a viable option that offers both lower costs than geothermal alone and greater resiliency than PV alone. Using optimistic geothermal cost assumptions, geothermal could be competitive with PV and utility supply. The data indicated a sensitivity of geothermal and PV LCOE with community size, and significant economies of scale were demonstrated for geothermal-based supply in communities of up to approximately 2,800 residential buildings. More modest economies of scale were shown for PV, because its cost is relatively flat in communities with sizes exceeding 1,500 residential buildings. Finally, when geothermal was made a significant part of the solution due to grid capacity constraints, it achieved an LCOE reduction of 9% compared to no-net-metered base case scenarios, and 12% compared to net-metered base case scenarios.

1. Introduction

The U.S. Department of Energy (DOE) defines a zero energy community as "an energy-efficient community where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE 2015). Current zero energy building and community design and construction practices focus on cost-effective packaging of energy-efficiency measures and solar photovoltaics (PV). Achieving zero energy in colder climates presents a greater economic challenge, though geothermal electricity generation can offer an opportunity to leverage greater on-site renewable energy without seasonal sensitivity.

This paper presents an initial examination of geothermal electricity generation's technical and economic feasibility in cold-climate zero energy communities. Battery storage is also considered and used where economically beneficial. This study supports and is part of a larger scope (Becker et al. 2019), which also incorporates direct-use thermal distribution and thermal energy storage for consideration. The goal of this research is to improve the cost-effectiveness of cold-climate zero energy communities, enhance asset utilization, and enable resiliency with distributed generation by informing the feasibility and value of geothermal resource integration with flexible, energy-efficient buildings, PV, and energy storage.

We used an iterative workflow to perform demand modeling and optimization, supply modeling and selection, energy storage modeling and selection, and optimized supply and storage dispatch within a techno-economic study. This analysis workflow, which used several existing software tools adapted to analyze a zero energy geothermal community, is discussed in Section 2. The community comprises both residential and commercial buildings, which are designed to achieve climate-appropriate levels of cost-effective efficiency using previously established methods, as discussed in Section 3. This work studied only all-electric communities. Electricity is supplied from the utility grid, PV panels, and geothermal electricity generation. These are dispatched as discussed in Section 4, and models and costs for the generation resources are presented in Section 5. Results from the scenario studies are presented in Section 6, and we provide conclusions and discuss technology opportunities for community-scale geothermal generation in Section 7.

2. Analysis Workflow

Several analysis tools were combined in a novel workflow to design and simulate an all-electric, geothermal-enabled zero energy community. Simulations were developed to evaluate costs associated with different technology packages, and thus examine how geothermal electricity generation might compete with PV to achieve community-scale zero energy targets. We initially developed a set of building models using ResStock™ (Wilson et al. 2017), BEopt™ (BEopt 2019), and EnergyPlus™ (Crawley et al. 2000; EnergyPlus 2019) analysis tools. These building models are discussed in Section 3. The baseline design for this project leveraged established cold-climate zero energy design practices, residential building energy optimization runs, and commercial designs from a suburban development in the Denver metro area (Pena 2019). In light of the relative cost-effectiveness of all-electric solutions, all-electric scenarios included different construction measures. These better reflected the business-as-usual cases in an on-grid suburban community that geothermal would likely compete with.

Baseline designs generated time-series electrical loads, which were then used to select, size, and dispatch electricity generation and storage to meet community demand using REopt, a techno-economic optimization model formulated as mixed-integer linear program that determines the optimal size and dispatch of distributed energy resources for a specific building or campus located behind the meter (Cutler et al. 2017). Supply-side resources considered included geothermal, solar, and grid energy, constrained such that the community would achieve zero energy on an annual basis. This techno-economic sizing and dispatch are detailed in Section 5.

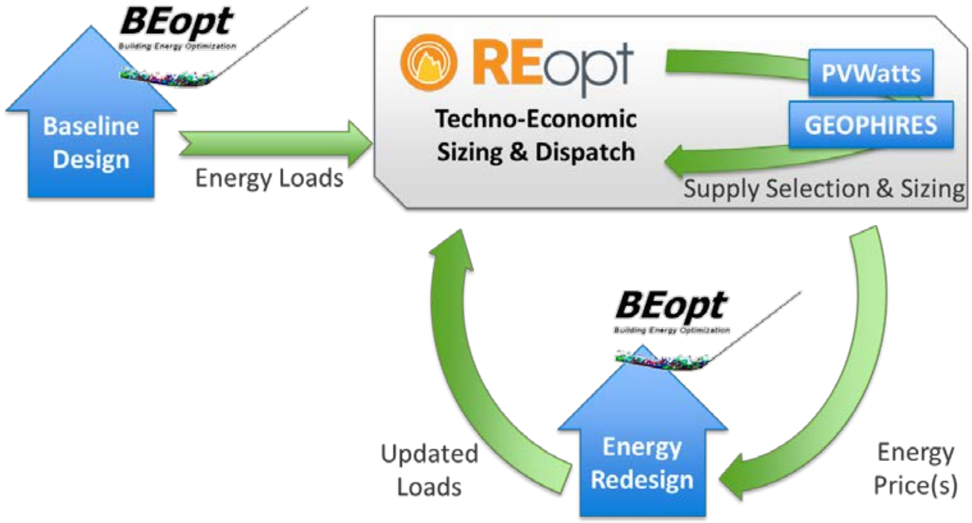


Figure 1: Analysis workflow, showing major tools used, objective for each, and data flows between tools

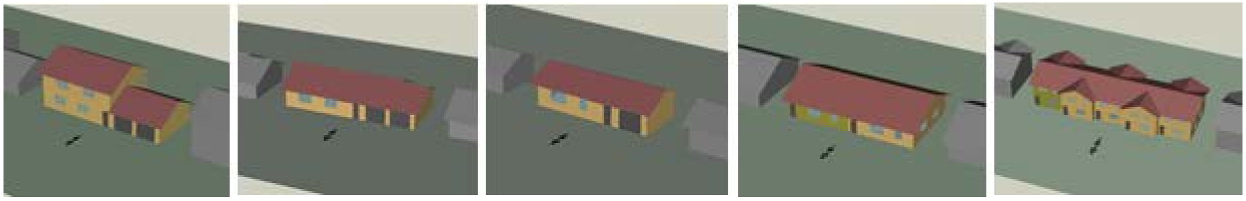
REopt generated the LCOE for selected and dispatched geothermal, solar, storage, and grid supplies. In early iterations, energy prices did not match the prices assumed for initial efficiency design, so the community and its buildings were redesigned, and updated loads were modeled. Techno-economic sizing and dispatch of generation were then performed again. This iterative process continued until it resulted in a consistent load and supply design. This process typically only required one or two iterations, because energy demand was found to be insensitive to small changes in supply costs.

3. Efficient Community Design (Demand)

Hourly community electric load was simulated with a mix of archetype models for residential detached, residential attached, and commercial buildings. Load profiles were scaled based on the size of the desired community and breakdown of building type. Table 1 details the relative mix by area and total electric load for each archetype.

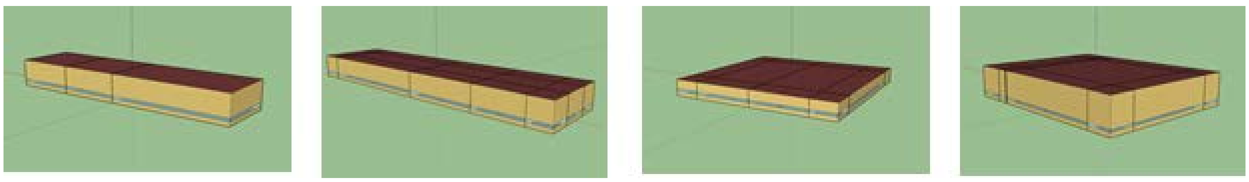
Residential building models consisted of large, midsized, and small detached homes, in addition to a duplex and a five-unit townhome. These home designs are shown in Figure 2. Models were generated with BEopt, a building optimization tool built on the EnergyPlus whole building energy simulation program. Initial home options were selected using an amended version of the 2012 International Energy Conservation Code adopted by Idaho, and the ResStock Analysis Tool (International Code Council 2013; DOE 2019; Wilson et al. 2017). To determine construction and operational characteristics not included within the International Energy Conservation Code, we used the sampling capabilities of ResStock. This analysis tool samples across distributions of home characteristics, generating models that account for diversity across the U.S. residential building stock. Highly representative sample homes for new constructions in Pocatello, Idaho, were located using ResStock.

We used BEopt to minimize annualized energy costs and optimize discrete efficiency and PV options in each building. This helped establish optimal efficiency options for zero energy community residences. All-electric loads were considered for this paper, so heating load was supplied by minisplit heat pumps and electric resistance heaters in the buildings. An example of the BEopt design result is shown in Figure 4 for the midsized home.



(a) Large (b) Midsized (c) Small (d) Duplex (e) Townhome

Figure 2. BEopt home designs for the five residential building models



(a) Retail strip mall 1 (b) Retail strip mall 2 (c) Retail and restaurant (d) Retail stand-alone

Figure 3. Commercial building designs

In selecting efficient construction measures, the zero energy design was determined to be the point at which PV became more cost-effective than additional energy efficient options. Energy efficiency options included insulation, air leakage, water heating, lighting, appliances, and windows. The average electricity rate in Idaho, $0.0952/kilowatt-hour (kWh), was used for the initial optimization, but was updated after each iteration of sizing and dispatch optimization, as discussed in Section 2.

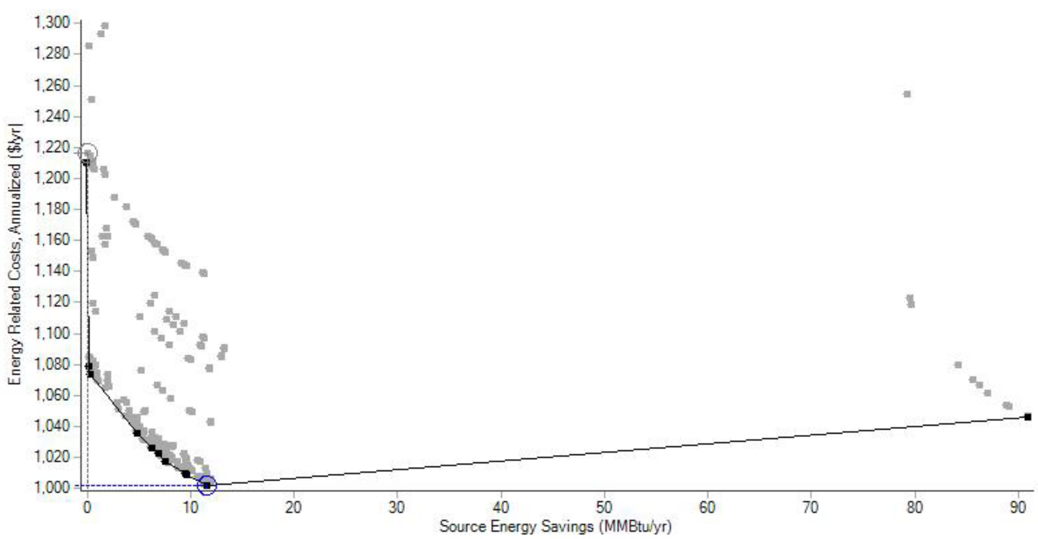


Figure 4. BEopt design solutions for the midsized home

The four commercial building designs used were patterned after existing building models from a Denver-area zero energy community currently under development (Pena 2019). These models are shown in Figure 3. These buildings were designed to meet zero energy in a climate similar to Pocatello, Idaho, when paired with renewables. These building models include a range of uses and schedules, providing a diverse load profile that might approximate that of a community center, grocery stores, restaurants, or retail shops.

Simulation of each building model was performed using EnergyPlus at 15-minute time steps as well as the typical meteorological year, version 3, weather file for Pocatello. EnergyPlus generated an hourly load profile for a full year, which was then used for the entire 30-year analysis. The community in this study is suburban by design, and comprises 90% residential buildings and 10% commercial buildings by area. By total electric load, it is 73% residential and 27% commercial. Half of the residential dwellings are attached homes (duplex or townhome), because of their higher potential for achieving zero energy through increased energy efficiency. The load profile from each residential model is scaled to establish the baseline community building mix, resulting in the area and load fractions shown in Table 1. With a baseline community defined, yearly load profiles can be further scaled based on power plant economics, as discussed in Section 5.2.

Table 1. Breakdown of Buildings Studied in the Net Zero Energy Community

<table>
<tr><th></th><th>Building</th><th>Building Area (ft²)</th><th>Floor Area Fraction</th><th>Electric Load Fraction</th><th>Total Floor Area Fraction</th><th>Total Electric Load Fraction</th></tr>
<tr><td rowspan="5">Residential</td><td>Large home</td><td>3,024</td><td>26%</td><td>15%</td><td rowspan="5">90%</td><td rowspan="5">72%</td></tr>
<tr><td>Midsized home</td><td>2,016</td><td>17%</td><td>13%</td></tr>
<tr><td>Small home</td><td>1,020</td><td>9%</td><td>10%</td></tr>
<tr><td>Duplex</td><td>2,040</td><td>12%</td><td>13%</td></tr>
<tr><td>Townhome</td><td>9,000</td><td>26%</td><td>20%</td></tr>
<tr><td rowspan="4">Commercial</td><td>Retail strip mall 1</td><td>5,000</td><td>1%</td><td>2%</td><td rowspan="4">10%</td><td rowspan="4">28%</td></tr>
<tr><td>Retail strip mall 2</td><td>10,000</td><td>3%</td><td>4%</td></tr>
<tr><td>Retail and restaurant</td><td>10,000</td><td>3%</td><td>19%</td></tr>
<tr><td>Retail stand-alone</td><td>10,000</td><td>3%</td><td>4%</td></tr>
</table>

4. Generation Design and Dispatch (Supply)

Geothermal and PV generation (supply) system sizes and dispatch were then modeled using REopt. The universe of technology options, objective functions, loads, and outputs used in REopt are shown in Figure 5. Minimizing the life cycle cost of energy is the most common objective function of the model. For complete detail on inputs, outputs, and problem formulation used within the model, please refer to Cutler et al. (2017). For the purposes of this analysis, the constraint of zero energy electric consumption was activated and electric exports offset electric imports from the grid on a one-to-one basis.

To evaluate geothermal-based electric and thermal supply, several new components were added to REopt. For the all-electric load scenario considered in this paper, a geothermal well-field and electric generating plant were added. For the direct-use thermal analysis (not included in this paper), models were also added for the thermal production plant, thermal storage, and district-heating distribution network—see Becker et al. (2019) for a description of this and related scenario study results.

Table 2 contains life cycle cost analysis parameters, with all cost values reported in 2019 dollars. We included an analysis period of 30 years with a 5% discount rate, with no tax credits or other subsidies. The local utility electricity rate, obtained from U.S. Energy Information Administration data, was used for average retail electricity prices in Idaho. The default value from REopt was used for electricity rate escalation. The electricity sell-back rate, or the credit provided for electricity exports to the grid under the no-net-metered scenario, was estimated at 30% of the base electricity rate (e.g., $0.03/kWh). If the community's system requires an import or export of greater than 10 megawatts electric (MWe), it is required to pay an interconnection fee of $33/kilowatt (kW), based on the maximum imported or exported electricity, in addition to a separate electric grid infrastructure upgrade charge (Fu et al. 2017). These fees are most relevant in the case of PV, which requires a much larger system-rated power than actual community loads to achieve zero energy.

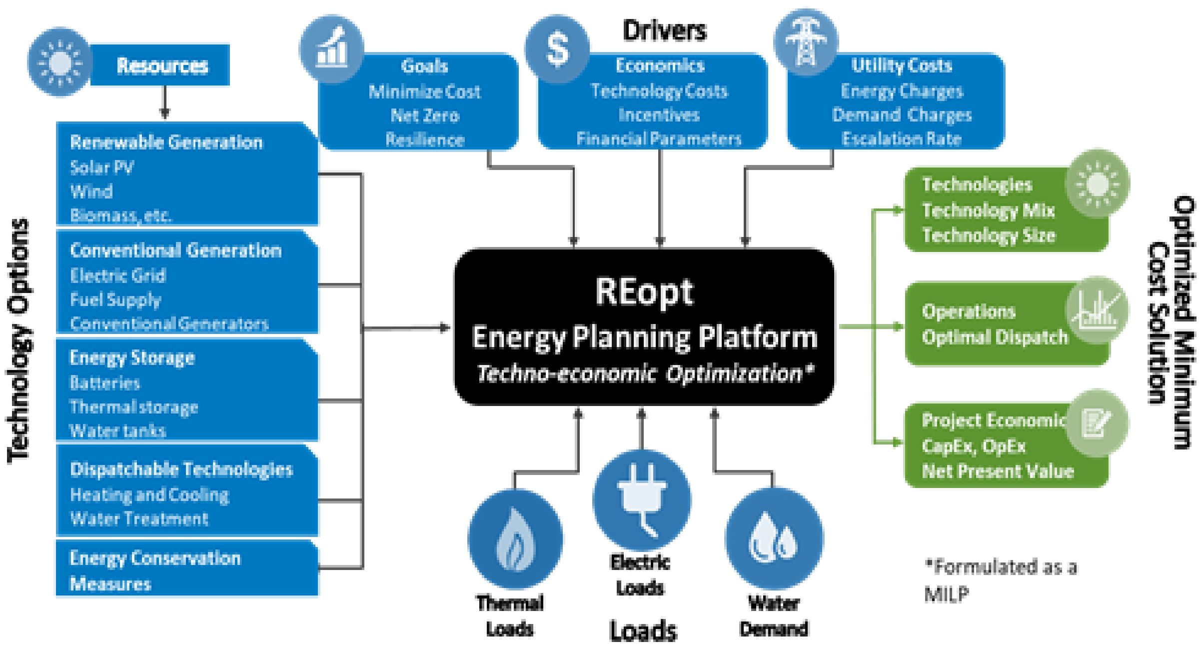


Figure 5. REopt techno-economic optimization tool. Source: Cutler et al. (2017)

Table 2. Parameters for Economic Analysis

Parameter	Value	Unit
Year-basis for cost	2019	
Lifetime period	30	yrs
Discount rate	5%	%
General inflation	2.5%	%/yr
Utility electricity rate	0.10	$/kWh
Utility electricity rate escalation	2.6%	%/yr
Electricity sell-back rate as percentage of utility rate	30%	%
Electric infrastructure upgrade cost, if above 10 MW	33	$/kW

5. Generation Resources

5.1 Geothermal Resource Modeling

A full-scale resource assessment would typically be necessary at the techno-economic modeling stage to understand the local geothermal resource in Pocatello. For the purposes of this preliminary study, a literature search replaced a more detailed assessment to determine relevant subsurface parameters such as depth of resource, flow rate, and temperature. Several sources enabled sufficient understanding of the local resource for this stage of the analysis. These include a report within the "Geothermal Investigations in Idaho" series conducted by the Idaho Department of Water Resources (Corbett et al. 1976), a technical and economic feasibility assessment of using geothermal heat in a barley malting facility (Christensen et al. 1981), and a study of shallow, low-temperature geothermal resources in the United States (Mullane et al. 2016).

Corbett et al. (1976) examined the Tyhee area of Idaho, located directly north of Pocatello. The area had been the subject of many resident reports of warm to hot waters, and is also located on the margin of the Snake River Plain, an area known for favorable geothermal conditions. The authors conducted gravity, magnetic, and limited geochemical surveys to investigate water quality and fluid temperature at depth. From shallow well observations, it was determined that the upper sections of several wells exhibited lower temperature gradients, and a gradient of greater magnitude was found in the deeper parts of those wells. The authors stated that these various subsurface measurements indicated a geothermal gradient of 60°C/km.

Christensen et al. (1981) investigated the viability of geothermal heat as an alternative to continued use of natural gas for heating purposes at a barley processing plant in northwest Pocatello. Data indicated the existence of a geothermal reservoir in the 150°F to 250°F range in the Tyhee area, 5 miles northwest of the processing plant. From these measurements and other data gathered from geophysical surveys and previous studies of the area, the authors estimated both an 8.0°F/100 feet (146°C/km) as well as a 9.25°F/100 feet (169°C/km) at depths below 110 feet and 400 feet, respectively. The study concluded that a 230°F resource could be expected at a depth between 2,000 and 2,500 feet.

Mullane et al. (2016) provided a summary and analysis of shallow (≤ 3 km), low-temperature (30°C–150°C) geothermal resources in the United States. The authors performed a geostatistical analysis to estimate temperature at depth for the entirety of the United States at depths from 500–3,000 meters (m) in intervals of 500 m, using data from known hydrothermal resources and bottom hole temperature measurements from oil, gas, and water wells. Their data from various locations in Pocatello indicated a mean resource temperature of approximately 120°C at 3,000 m deep, with a standard deviation of approximately 9°C.

While the reports by Corbett et al. (1976) and Christensen et al. (1981) indicate geothermal gradient estimates that appear extremely favorable, it would be prohibitively uncertain to project these same gradients to depths greater than 1,000 m. Nonetheless, using these optimistic reports in tandem with the geostatistical estimates of temperature at depth by Mullane et al. (2016), the analysis presented here considers a "base case" geothermal resource of 130°C at 3,000 m deep. This "base case" reflects one standard deviation above the mean resource temperature. Additionally, given the favorable nature of the cited resource assessments, this analysis also considers an "optimistic" case in which the geothermal resource is assumed to be 150°C at 2,500 m deep, reflecting the 60°C/km geothermal gradient estimated by Corbett et al. (1976), and capped at the upper bound of the temperature range for binary power plants found in the analysis by Verkis Consulting Engineers (2014).

The cost basis for much of this study follows the analysis of Verkis Consulting Engineers (Verkis 2014). This analysis was funded by the Icelandic International Development Agency and explored the feasibility of electricity production from binary power plants in low-temperature geothermal areas, along with those factors that influence feasibility. The primary objective of the study was to evaluate the economics of producing electricity with fluid temperatures below 150°C, in particular, determining how binary power plant technology could enable the production of electricity from such low-temperature resources. Given the estimates of temperature at depth discussed earlier, this study assumes that the only technology feasible to implement from a techno-economic perspective would be binary cycle technologies (e.g., organic Rankine cycle [ORC], Kalina Cycle).

A detailed cost analysis for determining the techno-economic details of generating electricity from low-temperature geothermal resources was included in the Verkis report. Of greatest interest for the purposes of this study was the construction of supply curves (i.e., system size [kW] vs. total normalized installed cost [$/kW]), which are essential to the REopt optimization routine. The Verkis report divided the full cost into two categories: 1) power plant costs, including electrical and controls equipment, mechanical equipment, and civil work; and 2) geothermal field costs, including pumps, wells, and gathering and reinjection systems.

Power plant costs used in the Verkis report are based on purchasing prices, quotations, and the authors' experience from other geothermal projects. Costs for both single-stage ORC and two-stage ORC cycles and for a range of plant sizes and temperatures are tabulated in Table 6-4 (Verkis 2014). This table also contains estimated geothermal steam field costs, often a large proportion of any geothermal project's total investment cost. To estimate field costs, Verkis first obtained estimates of flow rates required for the various combinations of fluid temperatures and plant sizes by conducting a heat and mass balance calculation for the single-stage and two-stage ORC cycles given the design parameters listed in Table 5-1. After estimating the total cost of geothermal field infrastructure, they arrived at an estimate of 100,500 USD/(liters per second). The estimate was based on the assumption that the field would contain two production wells and one injection well, all drilled to a depth of 1,400 m and capable of producing 40 liters per second.

To reflect the depths identified for both the "base" and "optimistic" cases described earlier, the normalized cost of the geothermal steam field was scaled appropriately, of particular importance in the case of the cost contribution of a single well. Without further detail in Verkis (2014) regarding the calculation of the well cost, cost correlations developed for the U.S. Department of Energy's GeoVision study (GeoVision 2019) were used to determine the well cost. These include drilling cost curves that account for the various costs associated with developing geothermal wells, including costs related to drilling time, flat time, trouble time, and any other additional time, developed by the study's Reservoir Maintenance and Development Task Force (Lowry et al. 2017).

These drilling cost curves have been used within other recent techno-economic models including GEOPHIRES (Beckers and McCabe 2018; Beckers and McCabe 2019). Additionally, the correlation for a small-diameter, vertical open-hole well was used in calculating well costs for the "base case" depth of 3,000 m as well as in the "optimistic" case well depth of 2,500 m. These new cost estimates for the wells were then used to recalculate the normalized steam field cost, using the same assumed costs for the gathering system and reinjection system.

The Verkis report also accounted for the power required by the line shaft pump in the production well(s) as well as parasitic losses. Both are assumed to be covered by the plant itself. The pumping power requirement is a function of the depth of the water table. Estimates for the pumping power demand are given for each combination of temperature and power plant size in Table C-5. Corbett et al. (1976) stated that water levels in the Tyhee area are found to range from 60–90 m below land surface, and water levels in the Snake River Plain are usually no more than 15 m below land surface. As a result, this study assumes the given pumping power values for a pumping depth of 100 m (Table C-5, Verkis 2014).

5.2 Geothermal Costs

Capital and operation and maintenance (O&M) cost estimates for geothermal electric generating plants are taken from Verkis, 2014, while this study leveraged the concurrent GeoVision study (GeoVision 2019) to extract the 130°C resource temperature from the Pocatello, Idaho, location to determine the well-field cost to drill to a depth of 3,000 m. Base and optimistic case geothermal resource capital cost estimates are included in Figure 6. Costs include well pumping power requirements and plant parasitic loads and are reported on a net power production basis. The lower efficiency of smaller plants is the main driver for increased cost at these plants, which require more parasitic and pumping power relative to the electric power production.

The fixed O&M cost is modeled as a function of system size (see Figure 7). The high fixed costs for plants less than 1,000 kW reflect the salary required for the minimum number of operators; no additional operators are needed until the size of the plant grows beyond the 1,000-kilowatt-electric (kWe) range. The variable O&M cost is assumed to be constant in relation to system size with a value of $0.027/kWh.

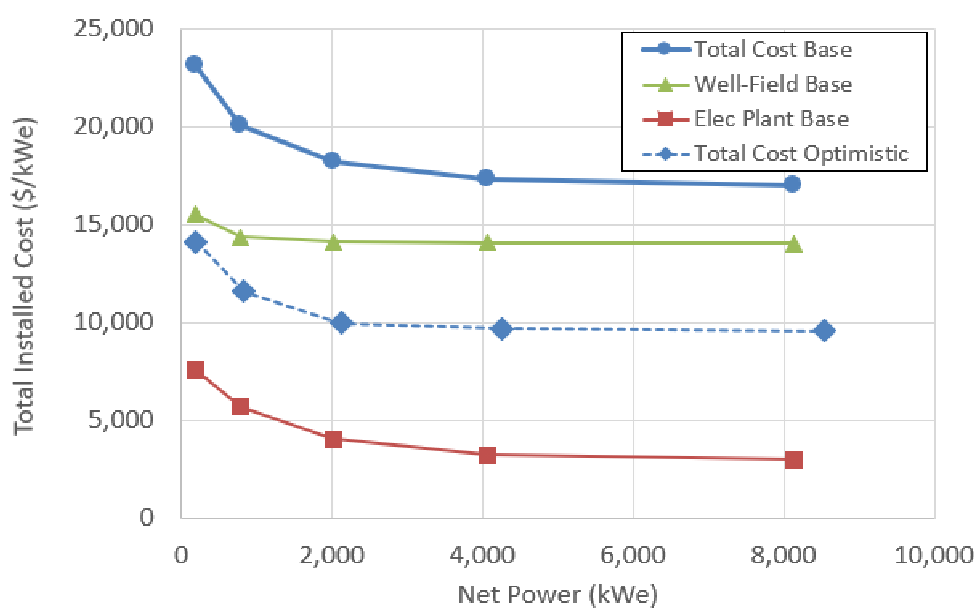


Figure 6. Geothermal well-field and electric plant cost

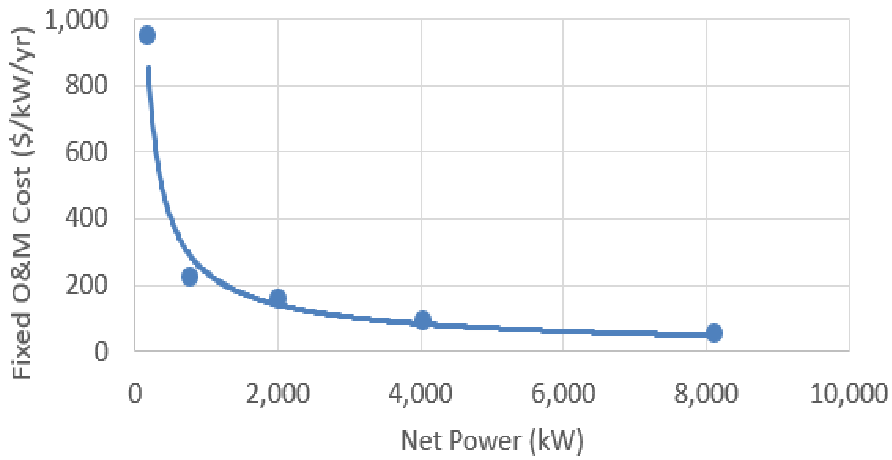


Figure 7. Fixed O&M cost for combined well and plant

5.3 PV Resource Modeling

All PV modeling was performed by calling PVWatts (PVWatts 2019) directly from REopt.

5.4 PV Costs

2018 community-scale PV array projections from the Annual Technology Baseline (Annual Technology Baseline 2018) were used to determine PV capital and O&M cost estimates. The capital cost sensitivity to system size is shown in Figure 8, and the fixed O&M is assumed to be constant with respect to system size with a value of $18.1/kW/yr.

Fixed and variable electricity costs for both the comparison and baseline case were sourced from Idaho Power (Idaho Power 2019). These were further confirmed using U.S. Utility Rate Database (U.S. Utility Rate Database 2019). Calculations of savings realized from reducing the infrastructure upgrades necessary to connect the community were based on the model developed by Fu et al. (2017).

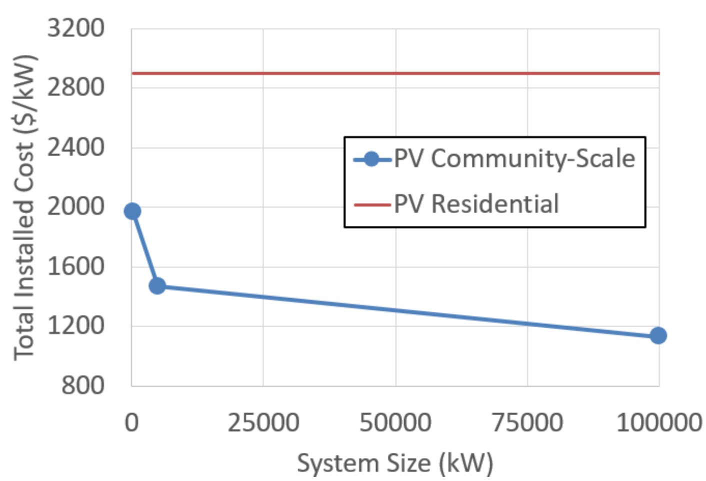


Figure 8. PV-installed capital cost

5.5 Grid Electricity Costs

The scenarios analyzed consider geothermal and PV electric supply with and without net-metering contracts, as well as a scenario where there is a constraint of 5 MWe on the maximum import and export of electricity to the grid. These scenarios are shown in Table 3. For the net-metering scenarios, electric generation sold back to the grid is credited at the retail electricity rate. For the no-net-metering scenarios, all electric generation sold back to the grid is credited at 30% of the retail electricity rate. The max import/export scenario is meant to investigate a situation where the grid may be constrained for congestion purposes and there is not an option to upgrade. A flat electricity rate was assumed for the community.

Table 3. Scenarios Studied, Grid-Connected, Pocatello, Idaho, All Electric

	Base Electricity Rate for Building Design	**Adjusted Electricity Rate Building Design, If Different**
Net metering	1) 1,200x dwelling community: 1a) PV supply 1b) Geothermal supply	1) 1,200x dwelling community: 1a) PV supply 1b) Geothermal supply
No net metering: sell-back credit at 30% retail rate	1) 1,200x dwelling community: 1a) PV supply 1b) Geothermal supply 1c) Optimistic geothermal supply 2) Scale community size and supply	1) 1,200x dwelling community: 1a) PV supply 1b) Geothermal supply 1c) Optimistic geothermal supply 2) Scale community size and supply
Max import/export of 5 MW	1) 1,200x dwelling community: Optimal mix of PV and geothermal supply	

6. Techno-Economic Results

The resulting system size, annualized cost breakdown, LCOE, and life cycle cost are shown for the no-net-metered scenario in Table 4 and for the net-metered scenario in Table 5. The iteration on zero energy building design from the base electricity rate of $0.10/kWh to the LCOE of geothermal supply of $0.14/kWh resulted in insignificant additional investments in efficiency measures. As a result, there are no separate results with building efficiency upgrades. The incremental improvement from net metering for PV is much greater than for geothermal. PV exports much more of its energy production back to the grid—about 50% compared to 15% for geothermal. Additionally, the lower sell-back credit in the no-net-metered scenario degrades the value of its energy. If the community imports or exports more than 10 MW, electric infrastructure upgrade costs are accounted for—the interconnection cost of $33/kW is applied to supply system size (worst-case scenario). However, this is not a significant cost (about 1%) relative to the total life cycle cost.

The first column in Table 4 shows the life cycle cost if all energy is purchased from the grid. Two results for geothermal are displayed, which show the LCOE is reduced by about 30% compared to the base assumptions. This indicates the value of achieving a good geothermal resource. Even in the no-net-metered scenario, the LCOE for PV is below the cost of grid-purchased electricity, and in the net-metered scenario the LCOE is 40% below the grid electricity rate. Each table's final column illustrates the results of the addition of a maximum import/export constraint of 5 MW.

This is a somewhat arbitrary quantity, but congestion or other limitations at certain locations on the grid may cap the amount of power able to be injected or extracted from the local grid. The constraint forces geothermal to be a significant part of the solution, and it achieves an LCOE reduction of 9% for the no-net-metered scenario and 12% for the net-metered scenario compared to the geothermal base case.

A sensitivity of geothermal and PV LCOE to community size is shown in Figure 9. Geothermal results in a significant cost reduction as the community size increases from 120 residential buildings to 1,200 buildings. PV cost reduction for the same increase in community size is significantly less, but PV achieves lower LCOE than the grid above about 1,000 buildings.

Table 4. Economic Results for the 1,200-Home Community No-Net-Metered Scenarios

	Utility/Grid Purchases Only	**Geothermal Base**	**Geothermal Optimistic**	**PV**	**Capped Import/ Export**	**Units**
System size	-	2,968	2,968	18,109	Geo/PV 1,985/9,586	kWe
Capital cost supply	-	2,500,111	1,416,733	1,040,935	2,306,902	$/yr
Fixed O&M cost supply	-	279,889	279,889	327,733	425,951	$/yr
Variable O&M cost supply	-	674,255	674,255	-	317,335	$/yr
Utility electricity purchases	2,496,114	346,480	346,480	1,396,394	455,434	$/yr
Sell-back electricity credits	-	(104,011)	(104,011)	(419,189)	(136,718)	$/yr
Capital cost grid upgrade	-	-	-	28,319	-	$/yr
Total annualized cost	2,496,114	3,696,724	2,613,346	2,374,193	3,368,905	$/yr
Total electric production	24,961,100	24,961,100	24,961,100	24,961,100	24,961,100	kWh/yr
Levelized cost of electricity	**0.100**	**0.148**	**0.105**	**0.095**	**0.135**	**$/kWh**
Life cycle cost	**53,382,400**	**78,006,430**	**55,145,530**	**50,099,034**	**71,088,940**	**$**

Table 5. Economic Results for the 1,200-Home Community Net-Metered Scenarios

	Geothermal	**PV**	**Capped Import/Export**	**Units**
System size	2,968	18,109	Geo/PV 1985/9586	kWe
Capital cost supply	2,500,111	1,040,935	2,306,902	$/yr
Fixed O&M cost supply	279,889	327,733	425,951	$/yr
Variable O&M cost supply	674,255	-	317,335	$/yr
Utility electricity purchases	346,480	1,396,394	455,434	$/yr
Sell-back electricity credits	(346,055)	(1,394,683)	(454,876)	$/yr
Capital cost grid upgrade	-	28,319	-	$/yr
Total annualized cost	3,454,680	1,398,699	3,050,747	$/yr
Total electric production	24,961,100	24,961,100	24,961,100	kWh/yr
Levelized cost of electricity	**0.138**	**0.056**	**0.122**	**$/kWh**
Life cycle cost	**72,898,930**	**29,514,644**	**64,375,330**	**$**

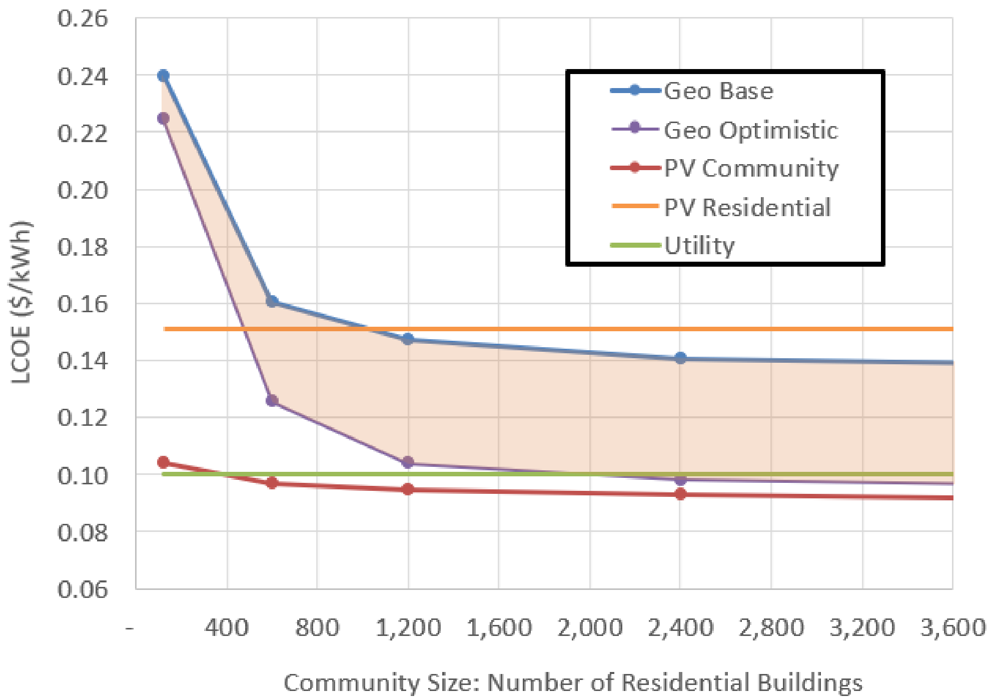


Figure 9. Levelized cost of electricity vs. community size, for different generation technologies (no-net-metered, all-electric scenario)

We also identify grid benefits from using geothermal as a zero energy community generation source, which are not accounted for other than through the tariff structures, as discussed earlier. The better alignment of geothermal generation with community energy demand provides additional benefits, which could provide further offsets of capital cost through infrastructure upgrade avoidance or other incentives. This is evident in hourly electric import data, as shown in Figure 10.

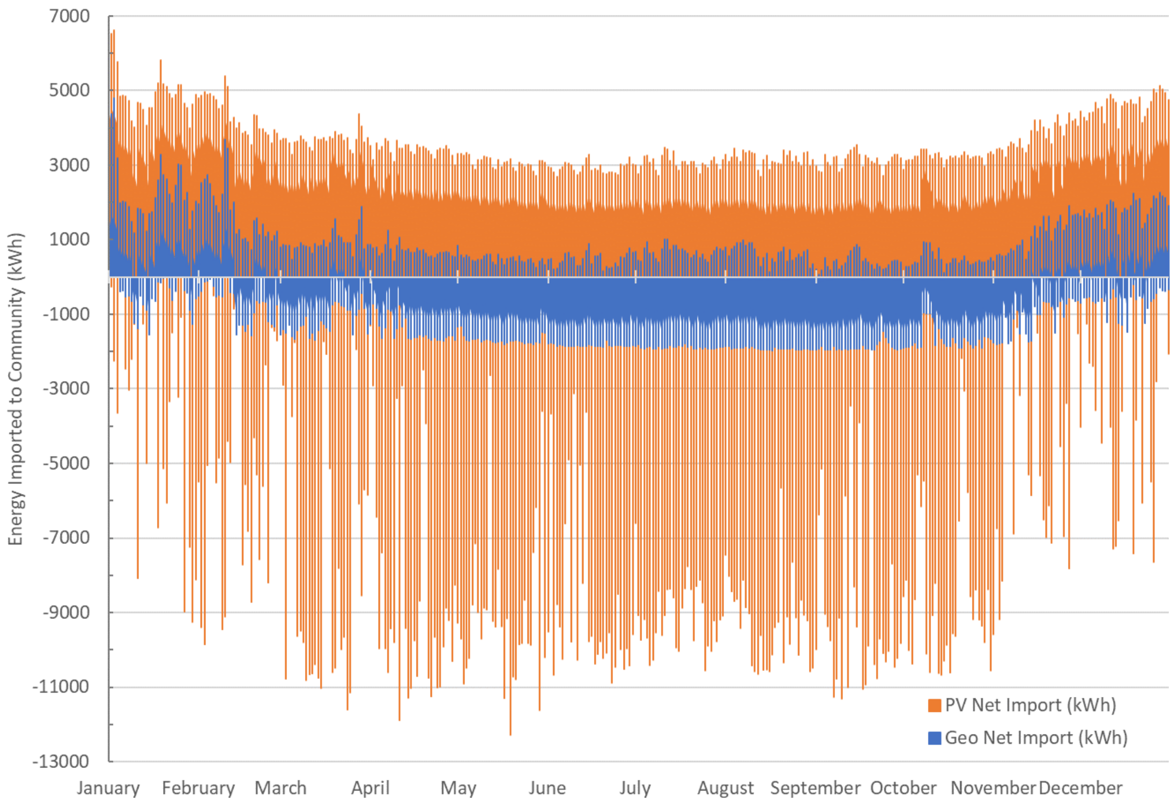


Figure 10. Chart showing the hourly net import (and export) of energy from the zero energy community, for the PV and geothermal electric generation cases

7. Conclusions

An iteration on building design optimization was conducted after the cost of energy delivered to an all-electric community was evaluated based on a geothermal electric generating plant supply. However, the 40% higher cost of energy of geothermal relative to the local utility-purchased electricity did not warrant significant additional investment in building energy efficiency measures above that which was already included in the zero energy building designs. This means that builder construction practices and home offerings are transferrable from business-as-usual zero energy community designs.

A comparison of geothermal to PV electricity supply for the community was shown for various scenarios of net metering, geothermal resource estimates, and capped import/export constraints. Although the PV supply competes with the utility purchased grid and is lower cost than geothermal, the competitive advantage of PV to geothermal depends heavily on the net metering and sell-back contract in place with the utility. With conservative estimates for geothermal costs, large zero energy communities will see approximately $0.02/kWh increased utility pricing when using geothermal vs. PV in cold climates.

The capped import/export scenario showed how a mix of geothermal and PV could be a viable option, with the combination of lower cost than geothermal alone and increased resiliency than PV alone. Using optimistic geothermal cost assumptions, this cost gaps narrows to less than $0.01/kWh. The optimistic estimates of geothermal resource indicate that geothermal could be competitive with PV and the local utility if more favorable conditions are found around Pocatello, Idaho. A sensitivity of geothermal and PV LCOE with community size was shown, and geothermal-based supply achieves significant economies of scale for community sizes up to about 2,800 residential buildings. PV has much more modest economies of scale and is relatively flat above 1,500 residential buildings. Additional research and development underway is focusing on reducing geothermal drilling and production costs (DOE 2009), which are expected to result in geothermal electricity costs below that of PV- and grid-supplied electricity for additional cases.

We conclude that there are viable cases where distributed power generation from low-temperature geothermal resources is worth considering at community scale, as part of a zero energy cold climate strategy. Site-specific techno-economic analysis can be used by developers, utilities, and cities to understand the economic viability of geothermal for future developments.

The techno-economic analysis identified several key barriers to market adoption of community-scale geothermal technology:

1. Well costs, including resource assessment, drilling, and completion, are too high;
2. Geothermal power/thermal generators could be more efficient and should be proven under a broader range of operating conditions;
3. Utility tariffs and incentives could be developed to better value the difference between renewable generation resources; and
4. The regulatory environment raises significant questions about adoption of community-scale resources, yet this can be a more cost-effective scale of distributed generation deployment.

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