

**THE SPATIAL ECONOMICS OF GEOTHERMAL DISTRICT ENERGY
IN A SMALL, LOW-DENSITY TOWN:
A CASE STUDY OF MAMMOTH LAKES, CALIFORNIA**

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ABSTRACT

This research focuses on the spatial economics of geothermal district energy (DE) systems that distribute hot fluids through a pipeline network to multiple thermal customers. We argue here that DE is held back by uncertainty about its economic feasibility when implemented in real places. DE works best with high urban densities, but in the U.S. the best geothermal resources are in the less-populated west. Economic geography theory suggests that the optimal size of a DE firm's service area should depend on the tradeoff between the economies of scale inherent in a large service area and the greater network development costs and heat loss involved in serving a large area. The HEATMAP© software program developed by Washington State University was used to study the feasibility of numerous scenarios for a proposed DE system in Mammoth Lakes, California. Results indicate that the core area of the town is large enough, dense enough, and in close enough proximity to the resource for profitable DE development. Proposed ski village developments would increase the thermal load density and significantly enhance its ability to remain competitive with other fuels, even in pessimistic sensitivity analyses regarding geothermal heat input costs, public participation, and retrofitting costs.

Keywords: Geothermal, district energy, renewable energy, economic geography, network, HEATMAP.

1. INTRODUCTION

Despite the environmental benefits, geothermal energy accounted for only 0.45% of U.S. electricity generation and 0.32% of total energy consumption in 2000 (U.S. EIA, 2001). In contrast, leading geothermal countries like the Philippines and El Salvador rely on it for over 20% of their electricity, while in Iceland direct use of geothermal heat provides 86% of space-heating needs (Lund, 2000). One of the most efficient direct uses of geothermal energy is district energy (DE), in which the heated fluids are distributed through a pipeline network to multiple users. In the United States there are an estimated 18 working DE projects in seven western states with an annual energy capacity of 534.3 billion BTU per year (Oregon Institute of Technology, 2000). And yet the potential is far greater, with 271 cities and communities with a combined population of 7.4 million people located within 5 miles (8 km) of geothermal resources with a temperature above 122°F (50°C).

There are numerous reasons for geothermal DE's low penetration of the U.S. market. Like most renewables, geothermal DE must compete with low-cost fossil fuels that do not have to pay their full external costs. In addition, the cost of the DE delivery system requires that a significant share of a community's population agree to not only adopt it personally but pay for the construction of the delivery system through either revenue bonds or general obligation bonds.

Geothermal DE is also hampered by uncertainty about what it will cost when implemented in any given community with its unique geography of supply and demand. There is a body of theory in economic geography and regional science that is highly relevant to the spatial economics of DE. Research by Hoover (1937), Smith (1966) and Osleeb (1974) suggests that the optimal service area for an industry is determined by the tradeoff between economies of scale and transportation costs. There are substantial economies of scale in geothermal DE, which stem

from spreading the fixed costs of the well, heat exchanger, and trunk pipelines over more users, and from using larger-diameter pipes. These economies of scale can be attained, however, only by expanding the size of the service area to capture more customers. Increasing the service area increases the pipeline network development costs, and may also necessitate the construction and operation of remote reheating stations because of increased heat loss. These additional “transportation” costs, which are necessary to increase the service area to gain economies of scale, may offset the economies of scale at some point.

For these reasons, geothermal DE would be most economically feasible in urban areas with high population density. Urban densities would allow the capital costs to be spread over a large enough customer base without excessive pipeline or reheating costs. However, in the U.S., the best-quality resources are located in remote areas of the sparsely populated West. This paper analyzes a case study of a town typical of such conditions: Mammoth Lakes, California.

This is not the first feasibility study of geothermal DE in Mammoth Lakes. A previous study by the Ben Holt Co. (1977) did not lead to construction of a working system in Mammoth Lakes partly because it did not focus on the critical question, namely the unique geography of energy supply, demand, and delivery within the town. Our paper, on the other hand, uses the HEATMAP© analysis software to simulate how geothermal DE would perform on a digital map of Mammoth Lakes. Three different sizes of service areas are tested for each of two different resource locations. The largest service area tested includes the estimated heat load of the downtown, a condominium zone, and two proposed ski village developments that have been approved by the town planning office. In addition, three sensitivity analyses test the effects of key assumptions relating to participation rates, geothermal heat input costs, and retrofitting of existing buildings.

Because renewable resources must compete with fossil fuels and energy conservation for capital investment and the end-user market, it is important to rigorously model the economic viability of geothermal DE as it would perform in the specific geography of the location in question (Wyman and Kuby, 1995). This case study shows the viability of geothermal DE in a small community with moderate thermal load densities, which is especially relevant given the energy crisis in California in 2001. The methodology developed here can be applied to other areas with geothermal resources.

2. PRIOR RESEARCH

Lunis (1985) highlighted three primary determinants of the economic feasibility of renewable energy sources: thermodynamic gradients, diffuseness, and site specificity. A low-temperature resource provides a smaller temperature gradient compared with ambient temperatures, and is therefore less capable of performing work—a major problem for solar thermal energy, and a lesser but still significant one for geothermal fluids. Diffuseness refers to the geographic “density” of the resource; this is a major drawback of solar, wind, and hydropower, but not for geothermal because a large underground heated reservoir can be tapped at a single point. Site specificity, i.e., the lack of mobility of the energy from its source location, is the greatest hurdle faced by geothermal energy. Heated fluids can be moved—but only several kilometers without losing too much heat. Because of the capital requirements for constructing a distribution network for geothermal DE, and because of its low temperature, Agioutantis and Bekas (2000) and Bloomquist (1987) focused on the spatial concentration of users as the primary determinant of the viability of site-specific renewables generally and DE in particular.

Bloomquist et al. (1999) refer to this concentration as “thermal load density.” They developed a software program called HEATMAP[®] to rigorously examine how DE would

perform financially under various thermal load densities. HEATMAP[®] was developed by the Washington State University (WSU) Energy Program in conjunction with the U.S. Departments of Defense and Energy, at a cost of over \$1 million. Given inputs of building uses and sizes, a supply source, a pipeline configuration to connect them, and other assumptions, HeatMap will calculate the thermal load density for the community, customize the diameters of the various pipes to serve the demand, cost out the entire project, estimate revenues and costs over the project's lifetime, and determine its economic viability. HEATMAP[®] automates a painstaking and time-consuming process and allows for changes to be made easily to any of the parameters.

HEATMAP[®] has been applied to proposed DE systems in Chicago, Atlantic City, Houston, and Portland, but not for geothermal energy sources. Prior to this paper, geothermal DE applications have been restricted to large single users such as army bases. This paper marks the first time HEATMAP[®] has been applied to a proposed geothermal DE project.

Prior geothermal research in Mammoth Lakes consists of a single study by the Ben Holt Co. (1977) that found that geothermal DE could be competitive with natural gas. Completed prior to the availability of automated cartography in general and HEATMAP[®] in particular, their data came from surveys and historical energy use rather than being calculated from a town plan. The method we develop in the following section is better able to change assumptions, test different spatial configurations, and deal with all aspects of DE simultaneously.

3. RESEARCH METHOD

Overall Framework

The process flow chart in Figure 1 outlines the method of analyzing the feasibility of geothermal DE in Mammoth Lakes. In Step 1, field visits are conducted to collect data on end use types (e.g., school, hotel, restaurant, office) and building square footages. Step 2 involves

loading all spatial data such as the location and floor space of each building into AutoCAD© and all nonspatial data and assumptions into HEATMAP©. In Step 3 the analyst designs a distribution pipeline network to connect all of the users in a specific service area. Step 4 specifies a scenario in which all engineering, climatological, behavioral, and financial assumptions are input into the program. In Step 5, the distribution network is transferred from AutoCAD© into HEATMAP©.

Step 6 is feasibility analysis based on the distribution network and other data.

HEATMAP© automatically determines the energy demand of each potential customer based on building usage and climate data. It then optimizes the pipe sizes based on engineering and physics principles and the 3-dimensional topography of the area. Next, it estimates the development costs of the network based on its data library plus other user-supplied factors such as inflation. Gross revenues from the sale of geothermal energy to potential users are based on current regional energy prices. HEATMAP© creates a cash flow table by projecting all costs and revenues over time and discounting them to present value. Its final output consists of financial results such as price to the consumer and return on investment. Consumer price equivalents are calculated on a unit of plant output (per MBTU) based upon both the escalated carrying costs (such as repayment of debt and property taxes that apply regardless of how the plant operates) and the escalated variable expenses (such as fuel, electricity, labor, and maintenance).

The resource location, service area covered, and layout of the pipeline network are all input by the analyst. After solving the base case scenario, these assumptions can be varied in different scenarios in Step 7, which returns one to Steps 3 or 4. Finally, in Step 8, a final design is recommended.

Study Area

Located on the eastern side of the Sierra Nevada Mountains, Mammoth Lakes, CA was chosen from a list of 271 western U.S. towns identified by the OIT Geo-Heat Center as having known geothermal resources available for development. Mammoth Lakes was chosen because, as small town with significant heat demand, it is representative of the other candidate communities, and because it has been previously studied. Located at 8,000 feet in elevation, it typically does not require any space cooling, but does require year-round space heating.

Data

The primary data inputs to HEATMAP© consist of end use and building size of each property in the study area. These data were used to estimate demand. Location and square footage were acquired for each building in the core development area from the Mammoth Lakes Town Planners Office. Existing condominium buildings for which data were unavailable were surveyed by telephone. Approximately 5-10% of commercial and condominium buildings were excluded due to lack of data. For the proposed ski villages, Intrawest Co. provided estimates of the square footage going on-line over a ten-year period.

Much of the other required data was cross-referenced through HEATMAP©'s data library, including construction costs, local ambient temperatures, and geothermal heat input costs. The Public Works Department of Mammoth Lakes confirmed cost data on trenching, piping, and alternative energy sources such as propane and electricity.

Assumptions

Technologically, this analysis assumed a supply-return system in which a heat exchanger located at the well-head transfers heat to a working fluid, which is transmitted to the users and then returned to the heat exchanger for reheating. The working fluid limits corrosion of the pipeline distribution network, thereby protecting the investment of the community. We estimate

that the temperature difference from the first to last customers would be small (less than 3–5°F, or 1.5–3°C), and so we did not include any reheating stations.

HEATMAP© requires the user to assume either public or private ownership. The former was assumed because the historically low profit margins of DE systems typically have not attracted private developers. HEATMAP© incorporates this assumption as a zero profit margin.

Community acceptance of DE is an intangible that is difficult to measure and forecast. High participation rates require education of the citizens as to the benefits of renewable resources such as geothermal energy. For the base case, 100% participation was assumed, but additional scenarios were analyzed based on lower participation rates of 50% and 33%.

Economic assumptions used in this report were based on consultations with WSU's Energy Program and OIT's GeoHeat Center. A discount rate of 5% is HEATMAP©'s default setting for economic analysis. Given the inherent political, social, and engineering uncertainties, a conservative discount rate such as this was considered reasonable. A 4% inflation rate was assumed given the fiscal policies of the Federal Reserve Board: recent inflation has averaged 3-4%. Representatives of Mammoth Community Water District, which is authorized to float municipal bonds, estimated a real interest rate of 6% for this analysis.

Meteorologists and local weather observers, climatology experts, geothermal specialists, and the HEATMAP© weather library were consulted for local weather information. The heating degree-days for a specific location were assumed to be the total accumulated degrees below a 65°F (18°C) heating base. Using an annual average daily estimate of 25°F (14°C), total heating degree-days were estimated at 9125. A ground temperature of 38° F (3.3°C) was used to estimate heat loss within the distribution network.

Scenario Analysis

The “base case” analysis consisted of three possible service areas for each of two geothermal source locations for a total of six scenarios. One potential source is located three miles east of town at the Casa Diablo Hot Springs power plant (Figure 2). The site is owned by Mammoth Energy Co., which has identified three potential wells there that are available for the project. The second source is located near the Shady Rest Campground on the north side of town.

Geothermal resource costs for each location were estimated from consultations with geothermal experts and town officials. Market rates for wholesale geothermal energy generally average \$5.00 per MBTU of thermal energy consumed. This price was assumed to apply to the Shady Rest resource location. For that price, it was assumed that the owner-developer would be responsible for the maintenance and operation of all wells, pumps, etc. Geothermal heat input costs for Casa Diablo, however, were assumed to be lower than for Shady Rest. The owner of the Casa Diablo power plant has agreed to sell geothermal energy to the community at the below-market rate of \$1 per MBTU.

For each source location, three successively larger service areas were analyzed (Figure 2). The first consisted of the central business district (CBD) by itself, which has the highest thermal load density in the town. The second service area consisted of the CBD plus the existing condominiums. Although it is less common for DE systems to serve residential areas, it may be feasible to serve the condominiums because of their greater density. Also the developer would not have to deal with each individual owner but only with the homeowners association. The largest service area analyzed consisted of the CBD, the condos, and the two planned ski villages.

Analyzing the three service areas with both geothermal sources provided an initial assessment of the optimal spatial configuration of DE in Mammoth Lakes. Sensitivity analysis

then explored the financial effects of key assumptions regarding geothermal heat input costs, public participation rates, and the costs of retrofitting existing buildings.

4. RESULTS

The first six scenarios analyzed the most economical combination of service area and resource location. At first glance, the Shady Rest resource would seem to provide the most viable DE development option for the community due to its proximity. The Casa Diablo resource would require 3 miles (5 km) of trenching to reach the CBD and an additional 6 miles (10 km) of pipe. However, the beneficial geothermal heat input purchase agreement makes the Casa Diablo resource an attractive possibility for development.

Table 1 summarizes the key outputs of the model, including the average price to the consumer per MBTU and per kWh, which are the most relevant measures for comparing scenarios with each other and with real-world competition. The least-cost scenario in this analysis utilizes the Casa Diablo resource and serves the largest service area, including the CBD, condos, and ski villages, at an average price of \$4.20 per MBTU. This translates to an electricity equivalent rate of approximately \$0.014 per kWh. Current rates for propane in Mammoth Lakes average \$17-\$22 per MBTU, while electricity rates range between \$0.10 and \$0.12 per kWh. In fact, the most costly of the scenarios utilized in this analysis would still be 2-3 times cheaper than current electric rates. All of these scenarios are based on a 100%-market-capture rate, as previously stated.

As indicated by Table 1, the average consumer price decreases with the size of the service area. The optimal size of the service area may well be even larger than the ski villages scenario, but because thermal load density would drop sharply with any further extensions of the network, it is also possible that the ski villages scenario could be optimal. Without additional

suitable service area in Mammoth Lakes, however, it is difficult to test how much lower the average consumer price would go before diseconomies of scale and distance set in. It appears, however, that the network could be expanded somewhat into the surrounding low-density residential areas before the zero-profit, maximum-size service area would be surpassed. If service were expanded into the residential areas, delivered costs would turn upwards and rise above electric-heat costs, but even so, if the savings in the central areas were used to subsidize the low-density residential areas, it would be possible to serve some single-family residential areas. This analysis, however, is beyond the scope of this study.

Total development costs increase with the size of the service area (Figures 3 and 4), but each new service area adds more consumers to the system. The economies of scale offered by the larger service area more than outweigh the higher development costs and result in a lower average cost per unit to the consumer. The transmission pipe costs for Casa Diablo are much higher, but they are offset by lower geothermal heat input costs. Additionally, per unit development costs do not decrease as rapidly as they do in the Shady Rest scenarios because of the fixed cost of the three-mile pipeline to reach the CBD and the limited number of users along the way. Assuming that the below-market geothermal input cost agreement between Mammoth Lakes and the owner of Casa Diablo is a legally enforceable and binding contract, the Casa Diablo resource serving the CBD plus condo plus ski villages is the most financially attractive option available to the community.

A significant change in any of the financial and economic parameters may have a substantial impact on the feasibility of the base scenarios. Sensitivity to participation rates, geothermal heat input costs, and financing arrangements are explored in the following analyses.

Participation Rate Sensitivity

HEATMAP© assumes that all potential users are connected to the system. However, it is unlikely that a prospective system will realize a 100% participation rate. Therefore, three different levels of market capture were tested to reflect optimistic (100%), best-guess (50%), and pessimistic (33%) levels of consumer acceptance. In the absence of an exhaustive survey of landowners, it is impossible to know which particular building owners will connect to the system. Because HEATMAP© requires a determinate set of demands, the 50% and 33% capture-rate scenarios systematically included every second and every third potential user in the DE system, respectively.

Even with the most pessimistic market-capture rate, the medium and large service areas for both resource locations were competitive with prevailing electricity rates (Table 2). The Casa Diablo scenarios, however, resulted in a more feasible DE system because of the lower geothermal heat input costs as compared to the Shady Rest scenarios.

An interesting aspect of the economics of geothermal DE is illustrated by a reversal of the pattern from the base case. In the base case, the larger market size was always more economical than the smaller ones, but with the lower market-capture assumption, their positions are reversed for Shady Rest. With fewer customers over which to spread the additional network costs, the bottom point of the U-shaped cost curve shifts to the left, and the ski villages scenario is now on the upwards-sloping part of the average cost curve because transportation costs are outweighing economies of scale (Figure 5). Yet this is not the case for the Casa Diablo scenario, where the ski villages scenario is cheaper than the condo scenario. This is the result of the ski villages network making up a smaller percentage of the overall network costs because of the added 3-mile pipeline from Casa Diablo, and because of the lower heat input cost.

Geothermal Heat Input Cost Sensitivity

Sensitivity analyses were run to determine the level at which geothermal heat input costs would make DE development cost prohibitive in Mammoth Lakes. This is a relevant question on many levels, given the dynamic nature of the power industry, the perceived high cost of renewable energy generally, and the uncertainty surrounding the cost of heated fluids at Shady Rest. Therefore, the input costs were adjusted from the original assumption of \$5 per MBTU to \$10, \$15 and \$20.

Table 3 reveals that \$15 per MBTU is the maximum limit of heat input costs for a DE system using the Shady Rest resource. Beyond \$15, the geothermal price begins to surpass the average rates for electricity (\$.10-.12 per kWh). This test shows that the financial feasibility of geothermal DE in Mammoth could withstand a tripling of the heat input price and remain competitive.

Retrofitting Sensitivity

Another significant factor for the feasibility of the DE system is retrofitting costs. Many existing buildings would require retrofitting with hot water radiators. HEATMAP© allows the user to input a per-building connection fee into a scenario, which can serve as a proxy for retrofitting costs. Retrofitting costs can vary substantially depending on the type of heating system used in each building, from a low of \$1,000 to over \$10,000 per building.

Initial testing showed that a \$1,000 per building retrofitting cost was not significant in this analysis. Therefore, retrofitting costs of \$5,000, \$10,000 and \$15,000 per building were tested for the Casa Diablo/ski villages scenario. These assumptions are conservative with respect to both the dollar cost and the fact that they are applied to every building. The results indicate that retrofitting costs could go significantly higher than the maximum \$15,000 tested here before the average price for DE becomes noncompetitive (Table 4). The flexibility in handling the

retrofitting costs again reflects the favorable geothermal heat input cost arrangement between the community and the owner of the Casa Diablo site, which allows for more leeway in absorbing expenses.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the available data, the six geographic scenarios analyzed in this report are all feasible assuming a 100% market-capture rate. The most cost-effective scenario is to utilize the Casa Diablo resource to serve the Mammoth Lakes CBD, plus the existing condominium complexes and the planned ski villages. The converted average price per MBTU for the six scenarios ranged from \$4.20 per MBTU for the Casa Diablo/ski villages scenario to \$11.96 per MBTU for the Shady Rest/CBD scenario. In Mammoth Lakes, most space heating is by propane, which therefore constitutes the main competition for geothermal DE. According to Amerigas of Mammoth Lakes and the Mammoth Lakes Water Department, commercial propane prices currently range from \$1.50 to \$1.80 per gallon, which equates to a price of \$17-\$22 per MBTU—substantially higher than the DE consumer price. Geothermal DE compares even more favorably with the prevailing price of electricity in Mammoth Lakes. The six base case scenarios price out at \$0.014-\$0.040 per kWh, compared with electric rates of \$0.10-\$0.12 per kWh.

However, given that some consumers will likely refuse to participate, the 50% market-capture rate may be a more realistic assessment of a DE system in Mammoth Lakes. This level of market capture would still yield a more-than-competitive average consumer price of \$4.52-\$6.20 per MBTU for both the medium (CBD + condo) and large (CBD + condo + ski villages) market areas for the Casa Diablo resource. For the Shady Rest resource, however, these medium and large market areas with 50% market capture would yield a consumer price of \$27-28 per MBTU, which is \$5-\$10 higher than propane.

One of the primary questions investigated in this paper is whether the heat load of the Mammoth Lakes CBD by itself is sufficient to justify development of a geothermal DE system. Under the most realistic scenario, the core area of the Mammoth Lakes CBD is sufficient in heat load to support a geothermal DE system at an average price of \$0.018 per kWh. The addition of the ski villages will enhance the feasibility because it will constitute approximately 50% of the total potential heat load with only a moderate increase in development cost, and it will serve as the anchor customer at the end of the distribution pipeline.

It would be interesting and useful to determine the service-area size at which average costs bottom out, at which profit is maximized, and at which the service area is maximized. As demonstrated by Hoover (1937) and Osleeb (1974), the size of the service area depends on the tradeoff between economies of scale and distribution costs and on whether the provider is maximizing profit or market share. Unfortunately, existing lands uses beyond the areas tested are primarily single-family residential, which are inherently less feasible for a DE system. This study was designed to test the feasibility of the existing land use configuration, and was limited to areas of suitable heat load density. If there were more infill or redevelopment, it would be more realistic to look for the expected diseconomies of scale and trace the entire U-shaped average cost curve.

Sensitivity testing on the effects of market-capture rates, geothermal heat input costs, and retrofitting costs showed the results to be fairly robust. As assumptions were made more pessimistic, the project did not immediately become infeasible. Generally speaking, the lower heat input costs of the Casa Diablo scenarios and the higher demand of the ski villages scenarios were better able to cushion the negative effects of the more pessimistic sensitivity analyses. The one exception was the lower market-penetration rate, which impacted the ski villages scenarios

the hardest. It is also important to note that many other towns would face higher up-front costs of the well fields than Mammoth Lakes.

This paper has shown the value of analyzing the economics of geothermal DE based on the actual characteristics of an actual community. Geothermal DE, with its especially high cost for fixed network development, is highly sensitive to the location and density of demand relative to the location, quality, and cost of the resource. More than any other kind of renewable or nonrenewable energy, geothermal DE requires that each locale be analyzed individually. We have demonstrated here that programs like HEATMAP© are ideally suited to conducting this analysis. Considering the significant amount of energy cost savings a community can achieve with geothermal DE, a small investment in place-specific network feasibility analysis using HEATMAP© is worthwhile.¹ Perhaps this type of place-specific feasibility research would more readily illuminate the advantages of geothermal energy, and thereby create a greater interest on the part of those communities with known geothermal energy resources.

Wider and easier usage of HEATMAP© could be greatly enhanced through integration of HEATMAP© with a true geographic information system (GIS) platform, as compared with the computer-aided design (CAD) capabilities of the current AutoCAD platform. A true GIS has greater analytical capabilities. This study was limited by the inability of the HEATMAP©-AutoCAD© interface to easily manipulate the scenarios on a smaller incremental basis at the scale of individual properties. Greater flexibility to experiment with different service areas and pipeline configurations would enhance the program's ability to develop an optimal network.

¹ The cost of a study like this would depend on the skill and experience of the researcher, the availability of a digital map of the town, the complexity of the analysis, and the number of scenarios. This research was completed as a Master's thesis (at negligible cost to Mammoth Lakes) in 7-8 person-months, which included learning AutoCAD© and HEATMAP©, collecting data, and writing the thesis. For an experienced researcher with a digital map available, the study should not take more than two months, or three if a lot of basic data gathering is required. This would equate to approximately \$20K-30K per study. Without HEATMAP©, similar studies cost about \$75K in the 1980s.

Several avenues for further research on Mammoth Lakes are indicated by the results of this study. First among these is a market survey of the local residents and business owners of Mammoth Lakes to ascertain the level of knowledge and receptiveness to geothermal DE. Community support is the primary determinant in the success or failure of many geothermal DE systems. Quite often the lack of a leading agency or champion promoting the development of DE is a significant factor in the failure of a DE system. Unlike European communities where property owners are often required by local governments to connect to DE systems, the success of a DE system in the US depends on how many consumers participate. Related to the market study is the need for an engineering study to ascertain the cost of retrofitting required.

Further research on the externalities of geothermal DE on the local and regional community is also warranted. These include external economic benefits such as additional employment, attraction of green industries, and street de-icing. External environmental benefits include reduced local air pollution, less salt on the roads (with street de-icing), and, globally, reduced CO₂ emissions.

The most significant aspect of these additional avenues of research is that they are all interdependent. Local sentiments toward DE are directly related to the cost effectiveness and external benefits of the system, and the cost effectiveness and benefits of the system are directly related to how many consumers are willing to participate. Local government agencies play a direct role in the marketing and selling of geothermal DE by educating the citizens on the benefits of DE. As such the cohesiveness of a community is an instrumental factor in developing a successful geothermal DE system. Use of a tool such as HEATMAP© that can customize the analysis to the local area may significantly increase the saleability of geothermal DE to the community and to investors.

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List of Figure Captions

1. Flowchart of analysis steps.
2. Map of Mammoth Lakes, CA showing proposed pipeline distribution network and three market area sizes.
3. Financial results for Shady Rest base case showing downwards-sloping average price with increasing market area size.
4. Financial results for Casa Diablo base case showing downwards-sloping average price with increasing market area size.
5. Average price declines with market area size for 100% participation but increases with area for 50% and 33% participation rates.