Presidio County Geothermal Assessment

Ken Wisian, Malcolm Ross, Shuvajit Bhattacharya, Mohamed Khaled
Bisset Young, David Chapman, Aysegul Turan

The Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Disclaimer: This report summarizes research conducted at the Bureau of Economic Geology at The University of Texas at Austin. As research, analyses contained in this report (including, but not limited to, estimates of resource in place and economic outlooks) are prepared using a specific set of assumptions and are subject to change.

Mark Shuster, Acting Director

May 2024

Executive Summary

Presidio County clearly has substantial, undeveloped geothermal resources. The geothermal resources of Presidio County could supply many times the county's electrical and direct-use needs if developed. Geothermal power would also increase power resiliency and incentivize businesses to settle and expand in the county. These resources could prove economically viable for development in a wide range of scenarios for electricity production, industrial/agricultural, and heating/cooling use. The economics of geothermal development are varied and (without considering any tax/credit/loan incentives, which can be substantial) range from poor to excellent.

The best quality resource (the Border region) is a strip approximately 16km (10 mi) wide along the border with Mexico running from Redford to the approximately the northwest corner of the county. The thermal gradients in the zone are high (on the order of 50°C/km), meaning the required drilling depths to reach a given temperature are relatively shallow (which in turn means lower project cost).

The bulk of the county, the inner 2/3 is in the Interior Region. Despite being cooler than the border region, this area is still a very good resource, with temperatures above the worldwide average. Although drilling depths needed to reach a given temperature are deeper than the Border Region, they are still within present technology, are potentially economic, and could easily support the population center of Marfa.

The county's southeast corner, the Big Bend Region, is a relative unknown. There is a severe lack of data other than surface geologic mapping; thus, not much can be said about the potential here, though it is likely to fall within the bounds of the Border and Interior regions and therefore have significant potential. Drilling new wells in this region would be needed to improve the assessment of this zone.

Further research is proposed that would “buy down” risk to all parties.

Table of Contents

List of Figures

1. Introduction

1.1 Purpose of this study

The Presidio Municipal Development District (PMDD) contracted with the Bureau of Economic Geology in 2023 to study the geothermal potential of Presidio County. Texas. ***The purpose of this study is to establish an up-to-date knowledge foundation that will enable the county government and citizens to promote the economic potential of geothermal power in the county as well as for prospective developers to understand the resource and appropriately evaluate and develop proposals.*** For this work, geothermal power is interpreted broadly to include electricity generation, heating and cooling, industrial and agricultural/aquaculture process heat, and energy storage. Besides the actual heat usage, the power infrastructure and project techno-economics are examined analyzing various use cases and engineering approaches for harvesting and utilizing heat.

1.2 Setting

Presidio County is located just west of Big Bend National Park and borders Mexico (the state of Chihuahua) (**Fig. 1**). It is a pie-shaped wedge with the apex on the second largest town and county seat of Marfa. The population is sparse (6,131 as of the 2020 census) and mostly located in the towns of Presidio, Marfa, and Shafter. With a total area of 9,990 km^2 (3,856 $miles^2$), this yields a population density of less than one person per square kilometer (~two people per square mile) (United States Census Bureau, 2020). The Big Bend Ranch State Park occupies much of the county's southeast corner.

Figure 1. Presidio County. (https://www.texasalmanac.com/places/presidio-county)

Presidio County is rural, has a median household income of $29,012, and has experienced a slow population decline of almost 1700 people between the 2010 and 2020 census. Approximately 1/3 of the population does not have health care. On the other hand, more than a 5th of the population has a college degree (United States Census Bureau, 2020), and the unemployment rate (currently around 6%) has seen consistent long-term improvement (Federal Reserve Bank of Saint Louis, 2023). The economy of Presidio County is focused on agriculture & construction (30% of workers) and tourism (~5%), though government workers of all levels make up 25% of the workforce (United States Census Bureau, 2020).

The economic development of Presidio County is an intense focus of the county leadership, the PMDD, the West Texas Economic Development District (WTEDD), and the Rio Grande Council of

Governments (RGCOG). All entities desire to turn the rural “brain drain” around and bring in good jobs/economic growth. The latest Comprehensive Economic Development Strategy (CEDS), authored by the WTEDDD and the RGCOG presents solid Strength Weakness Opportunities and Threats (SWOT) analysis and strategies going forward. The report covers six counties in Texas (including Presidio) and one in New Mexico. While it covers multiple areas, some key takeaways that bear on this report are (West Texas Economic Development District, 2021):

- Positives
  - Vast, inexpensive land
  - Good education infrastructure
  - Strong history of renewable energy projects, mostly solar and a notable molten salt energy storage project
  - Strong international trade and transportation infrastructure
  - Excellent federal and state-level incentives
  - The emergence of Marfa as a younger, artistic community
- Negatives
  - Very low population and power needs currently
  - Perception of the region (education, crime, infrastructure)
  - Little indigenous entrepreneurship
  - Limited water supply

- Strategies – investment/development areas
  - Energy – particularly renewable/energy transition/brownfield redevelopment
  - Infrastructure - Internal and cross-border
  - Agriculture
  - Food Processing
  - Manufacturing
  - Tourism

Developing the geothermal resources under Presidio County would amplify the positives, address the negatives, and lead or support the above-mentioned strategies. Resilient, reliable, and affordable energy is foundational to all economic activity. In the case of electricity, geothermal systems can supply baseload and/or dispatchable electricity at low-to-zero carbon production levels. While broadly already competitive cost-wise with most other energy sources, the available tax incentives and subsidized loans make development even more attractive. Although electricity generation gets the most attention, it is critical also to explore the direct uses of heat, which can utilize more resource more efficiently than electrical generation.

1.3 Key aspects of geothermal development

Geothermal power systems can be divided into two main types – **hydrothermal** (aka conventional) and **dry rock** (aka **Geothermal Anywhere (GA)**). Hydrothermal systems are a mature technology and are installed worldwide. They produce naturally occurring hot water or steam from the Earth and use that energy to drive a turbine/generator and produce electricity. The US is the world leader in geothermal electricity production, with all the currently producing systems being hydrothermal and located west of the Rockies.

Geothermal Anywhere[1], which uses an engineered (artificial) fluid system to extract heat from rock, has been a desire for decades. It is now becoming a reality thanks to multiple technological advances and the need to decarbonize electricity production coming together to make extracting heat directly from rock practical and economical. In Presidio County, indeed most of Texas, GA approaches are likely to be the most feasible versus hydrothermal. Geothermal Anywhere, as the name implies, is often available wherever needed, obviating the need for transmission and permits to connect to the grid (often a long-lead item).

While multiple approaches exist to create a heat extraction system deep underground, they generally divide into two broad categories – fracture flow and borehole conduction (**Fig. 2**). The geothermal systems discussed in this report are generally much deeper than common household ground return heat pumps -kilometers versus meters. The temperatures required for electricity production or direct use are typically found a kilometer or more below the surface for GA and sometimes much shallower for hydrothermal resources.

[1] The engineering naming of geothermal anywhere approaches is unsettled and imprecise. Advanced Geothermal Systems (AGS), Engineered (or Enhanced) Geothermal Systems (EGS) and Closed Loop Geothermal Systems (CLGS) are most frequently encountered. Whichever term is used or encountered needs to be clearly defined. This report will use the broad terms geothermal anywhere or dry rock interchangeably and more specific terms as needed.

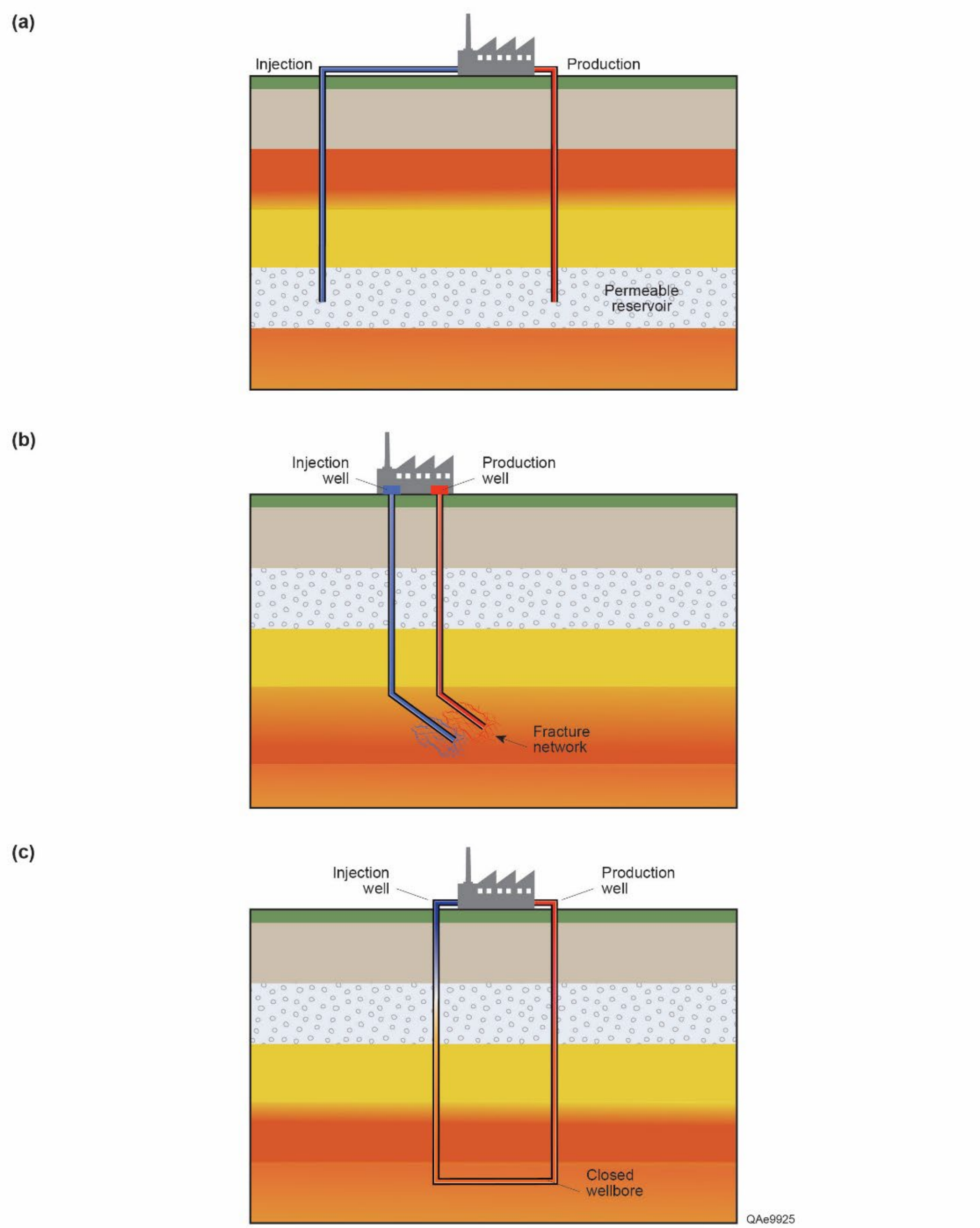


Figure 2. Generalized geothermal systems. (a) a "conventional" hydrothermal system produces formation fluids and reinjects as much as possible on the flanks of the system. (b) Fracture-based dry-rock, Enhanced Geothermal System (EGS) or Geothermal Anywhere system drills one or more wells and engineers a flow system to absorb heat from the rocks. No formation fluids are produced. (c) A closed-loop (conductive) dry-rock or Advanced Geothermal System (AGS) creates a long path in the ground to transfer heat from the rock into the wellbore and as with EGS, does not produce formation fluids, but instead continuously recirculates its own fluids.

Direct use of geothermal heat is much more efficient (generally >80% efficient) versus generating electricity (generally <20%). Further, the resources that are available at temperatures below the minimum required for electricity generation (around 150°C/300°F) are much larger. Direct heat can be used for heating and cooling, agriculture/aquaculture, and virtually any industrial process. In all these cases, replacing the electrical generation for heating and cooling does more to lessen the electrical load, and if fossil fuel is the current source of electricity, reduces the greenhouse gas (GHG) emissions more than generating the electricity geothermally. An adjunct technology is using the shallow subsurface as a bi-directional heat sink – known as a "ground source heat pump" - while implementation is relatively widespread in the US at the single-home and neighborhood scale (cf. Whisper Valley neighborhood near Austin, Texas), it is mostly used in northern regions of the USA, but is quite well suited to hotter regions. These direct-use technologies are relatively mature and quick to implement.

Finally, the use of the Earth as a battery for energy storage is a technology that is advancing rapidly. Energy stored in rock formations via pressure and or thermal change is much more environmentally friendly and flexible in extraction than lithium battery banks and appears to have an efficiency of around 75% or better in early trials. This technology is ready for prototype/early production implementation.

2. Findings

2.1 Geologic Setting

This report divides Presidio County into three parts based on the geology and thermal regimes, as delineated below (**Fig 3.**) This report will call them "Border," "Interior," and "Big Bend" Regions. The Border region is located along the US/Mexico border (Southwest Presidio County), and Interior region is in the inner majority of the pie-shaped county, whereas Big Bend is in the Southeast corner.

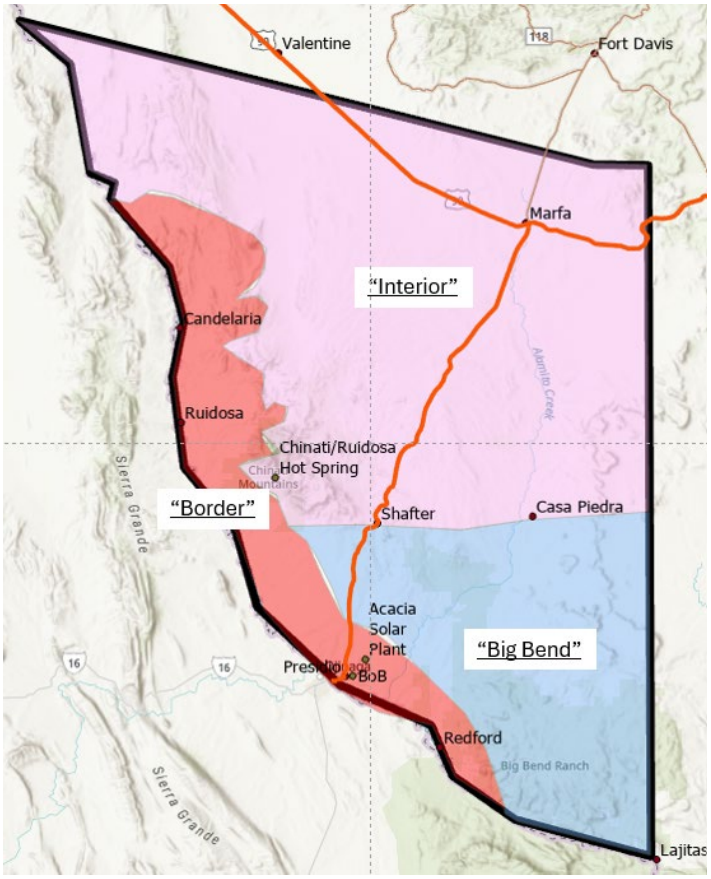


Figure 3. Border, Interior, and Big Bend zones delineating different thermal, data and geologic areas. The boundaries between regions should be taken as very "fuzzy" due to sparse data set available.

The subsurface geology of Presidio County, Texas, remains poorly constrained due to complex geology, the presence of multiple basins, thermal structures, and relatively few deep borehole penetrations. There have been limited geologic studies in Presidio County of the Trans-Pecos region of Texas (Lonsdale, 1940; Dietrich, 1965; Goldich, 1949; Kopp, 1977; Mraz, 1980; Parry, 1857). Some early studies were conducted by University of Texas at Austin students, supervised by DeFord in the 1950s. Unlike many parts of Texas, this area has not produced hydrocarbons after several drilling campaigns, thus the geology is far less extensively studied compared to the Permian Basin just to the north. Helios Energy recently drilled two vertical wells in the Cretaceous Austin Chalk-equivalent Ojinaga Shale (~4,800 ft) with unknown results.

In this study, we attempted to reduce the knowledge gap in geology by combining a swath of multi-scale geophysical data (gravity-magnetic), petrophysical logs, drilling mud logs from 14 deep boreholes, and surface geology maps (**Appendix 1**). Wells with geophysical logs are mostly distributed along the Border Region and Interior Region; none in the SE of Presidio County (Big Bend Region), thus adding to the uncertainties in characterization and resource evaluation.

Based on our interpretations of the limited data, we build two simplified litho-stratigraphic columns representing the SW border region (or Border Region) and the interior portion (Interior Region) (**Fig. 4**). As will be seen throughout this report, the third area, the Big Bend Region, has very little data other than surface mapping and cannot be modeled at any reasonable level at this time. Even in areas that have data, the information is limited in density; thus, only generalized models of the subsurface can be produced. The two simplified stratigraphic columns represent the overall geologic age and general rock composition present in the subsurface of Presidio County. The major differences between these stratigraphic columns are in the locations (Border and Interior regions), basement depth, structures, and geothermal gradient. The integrated and simplified stratigraphic column is primarily composed of three rock sequences: Precambrian granite, Paleozoic-Mesozoic carbonates with mixtures of shale and sandstone, and Tertiary volcanics. A large portion of the sedimentary rock is dominated by carbonates deposited during the Paleozoic-Mesozoic. Because of the small number of well penetrations and core samples, we decided not to subdivide these carbonates into different formations and correlate them across the basins in Presidio County. Note however that a more detailed site-specific analysis would be needed prior to launching a development project.

The Tertiary was a time of the Basin and Range extensional faulting and igneous activity in the Presidio area.

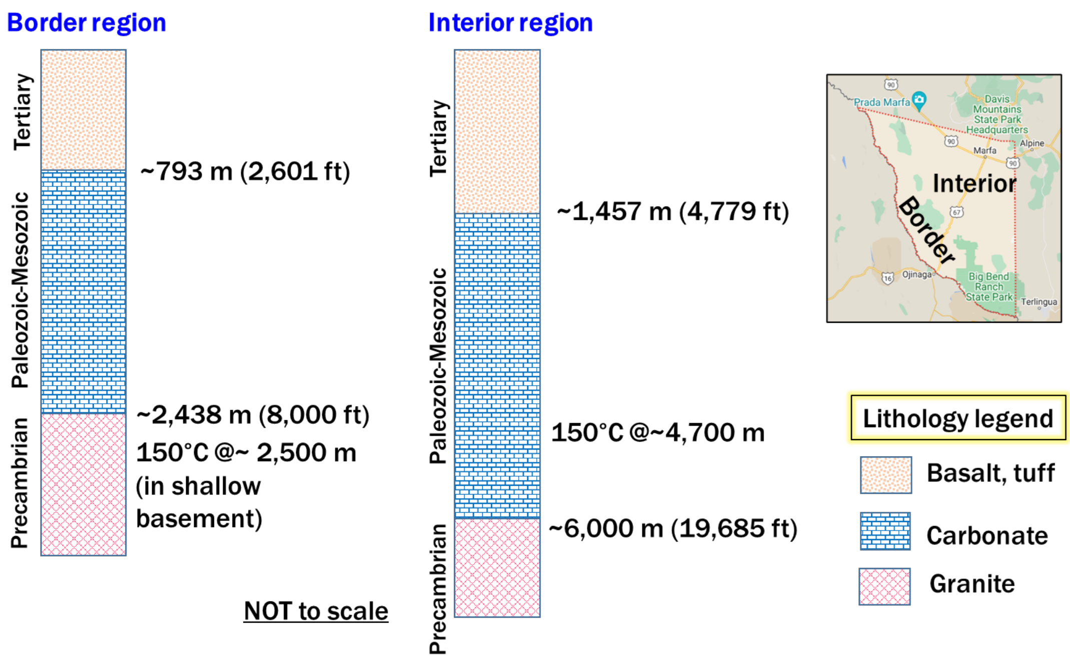


Figure 4. Simplified litho-stratigraphy of the Border and Interior regions, with the inset map of Presidio County.

Based on limited available geophysical interpretations, different rift structures (for example, uplifts and grabens) are present (**Figures 5, 6, and 7**). The Bolson graben in the border region has low gravity values and is surrounded by extensional faults. The basement is shallow towards the Border region, potentially contributing to high heat flow due to radiogenic heat production as well as thinner crust due to basin and range extension. The basement occurs at around 2,400 m (8,000 ft) in the Border region based on geophysical data corroborated by well drilling. The basement is deeper toward the Interior region, around > 5,800 m (19,000 ft).

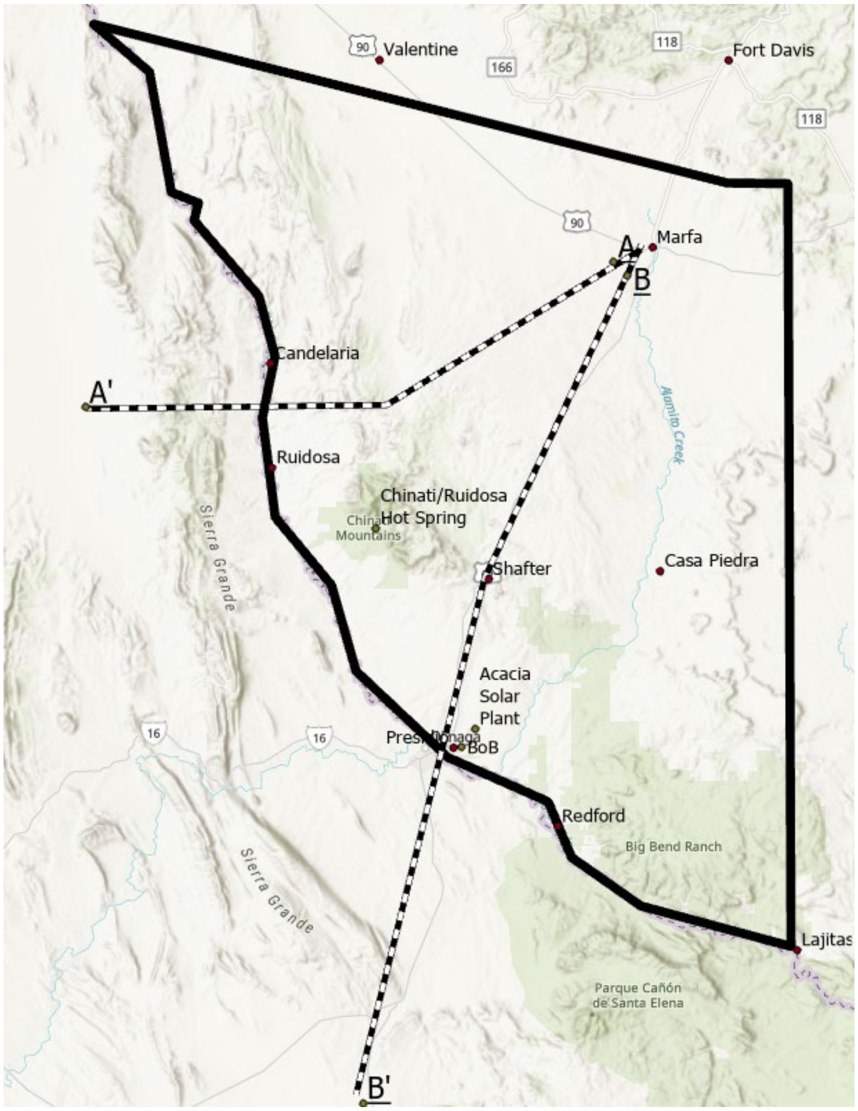


Figure 5. Locations of two cross-sections (AA' and BB') of gravity data (after Mraz, 1980).

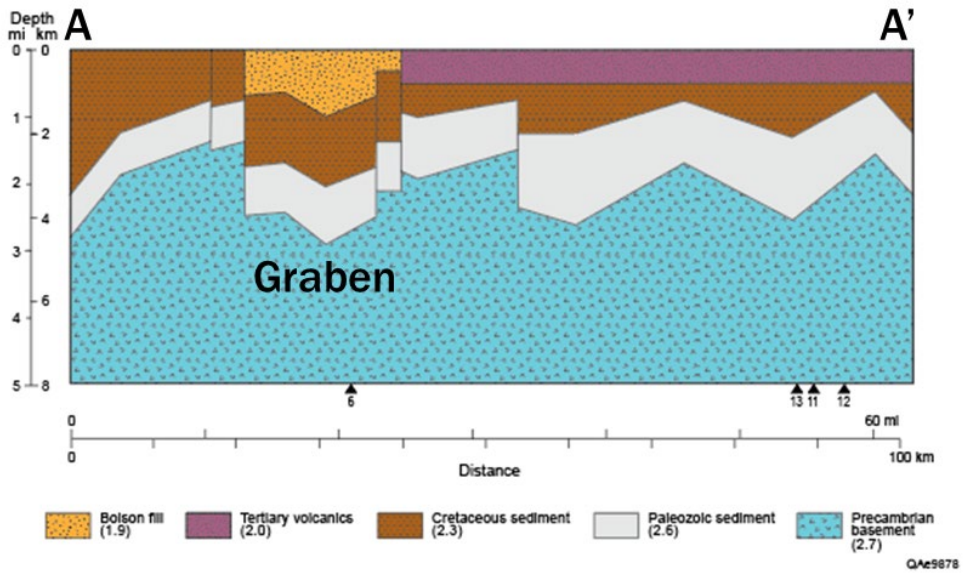


Figure 6. AA' cross-section indicating graben structures and shallow basement towards the border (after Mraz and Keller, 1980). The numerical values in the parentheses after formation names indicate density (in g/cc) of rock columns. Precambrian basement has high density value (2.7 g/cc).

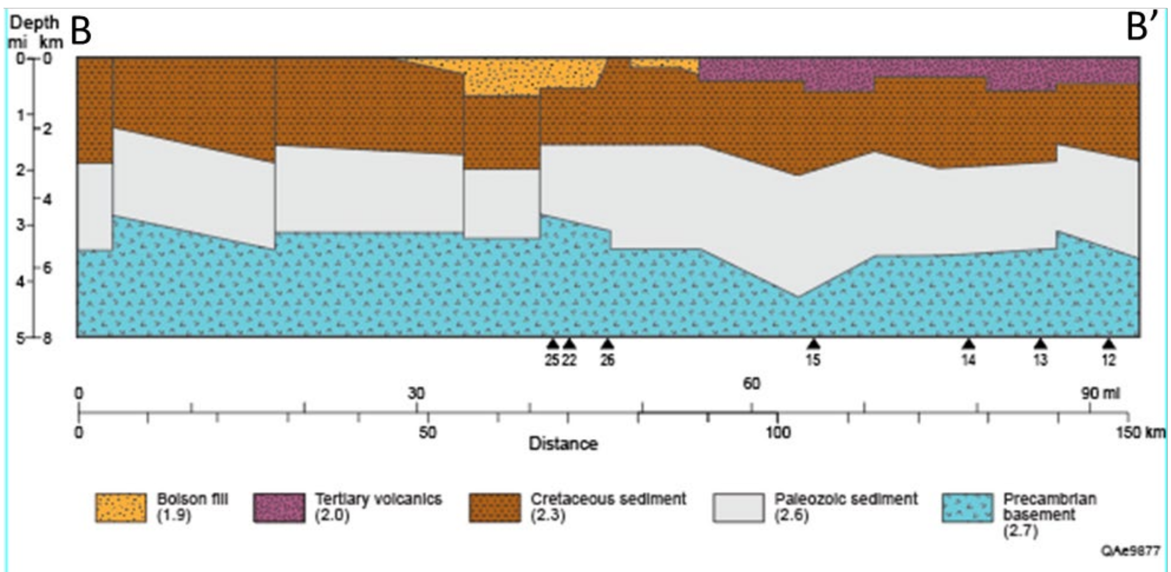


Figure 7. BB' cross-section showing deep structures in the interior region (after Mraz and Keller, 1980). The numerical values in the parentheses after formation names indicate density (in g/cc) of rock columns. Precambrian basement has high density value (2.7 g/cc).

We also analyzed available petrophysical logs and literature to estimate various rock properties. **Table 1** summarizes general lithology, depth, porosity, thermal conductivity estimates. Carbonate rocks have slightly higher porosity up to 9 p.u. (%). Tertiary rocks have a widely ranging porosity estimates due to intercalation with volcanics rocks with different pore characteristics. For formations with no direct measurements, we used analogs to estimate their thermal conductivity.

Table 1: Generalized deep subsurface rock properties in Presidio County, irrespective of border and interior regions. Yellow colors indicate high uncertainty estimates.

Age	Major rock type	Avg. Fm. top	Min. Fm. top	Max. Fm. top	Avg. thickness	Min. thickness	Max. thickness	Avg. porosity	Thermal conductivity	Avg. density
Units		ft	ft	ft	ft	ft	ft	p.u.	W/mK	g/cc
Tertiary	Basalt	30	0	60	4499	2571	4746	6	3.63	2.76
Mesozoic-Paleozoic	Carbonate	4091	2601	4779	4895	4393	14906	9	3	2.6
Precambrian	Granite	8585	7999	19685	n/a	n/a	n/a	n/a	3.3	2.75

2.2 Thermal Regime

The resource that this report is focused on is the heat in the ground (both the rock and any fluid in the rock). Temperature is the direct measurement of the resource (akin to measuring hydrocarbons in oil and gas exploration), and thus, significant effort is devoted to determining the subsurface temperatures. The temperature data for this study is derived from multiple sources:

1. The Southern Methodist University (SMU) node of the National Geothermal Data System (NGDS), using the Borehole Temperature in Content Model Formula and Heat Flow data files (http://geothermal.smu.edu/gtda/index.html)

2. The Bureau of Economic Geology (BEG) comprehensive well database (http://geothermal.smu.edu/gtda/index.html) and BEG log library

3. Standard and Poor's Enerdeq Browser managed by Information Handling Services (IHS), for data ranging January 2016 to May 2023 (https://energyportal.ci.spglobal.com/home)

The data points consist minimally of location (latitude and longitude), Bottom Hole Temperature (BHT), and depth of temperature measurement. We extracted 120 unique data points from 101 wells for Presidio County from the catalogs listed above. The data is moderately well-distributed across the county from West to East but significantly lacking in the southeastern part of the county (**Figures 8 and 9**). BHTs, while a very "noisy" data source, are generally the only source of temperature data, and while no single BHT should be relied upon, in the aggregate, they are a reasonable indicator of temperature.

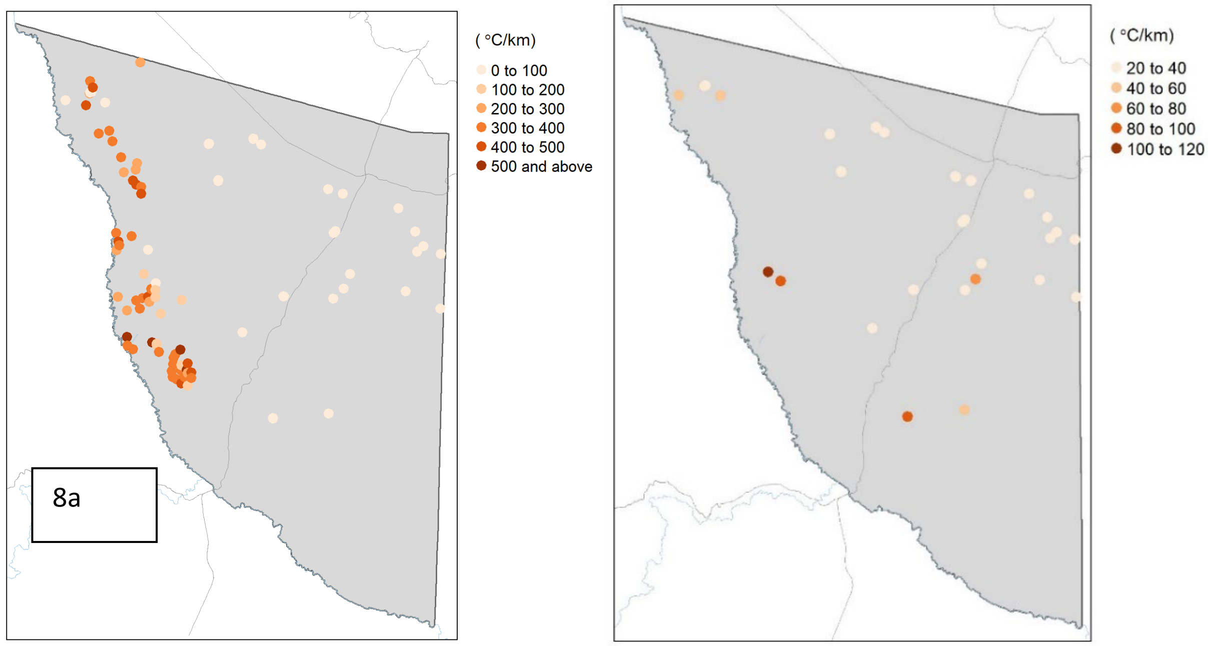


Figure 8 a&b. Presidio County, locations and approximate geothermal gradients for the wells used in this report. **8a** is all data points, **8b** has most of the shallow points that are disturbed by shallow groundwater movement removed. Notice the lack of data in the southeastern part of the county. The gradients are calculated with the formula $(T_c - T_0)/D$ where T_c is the Harrison corrected BHT, T_0 is the average surface temperature and D is the depth of the BHT reading. This is a rough cut of the data but clearly shows that the region divides into a Border zone along the Rio Grande in the northwest, an interior zone, and an undefined area in the southeast part of the county (Big Bend Region). Although difficult to distinguish on this scale, the county's interior, outside the Border zone, is still quite warm compared to other regions of North America and holds considerable resources.

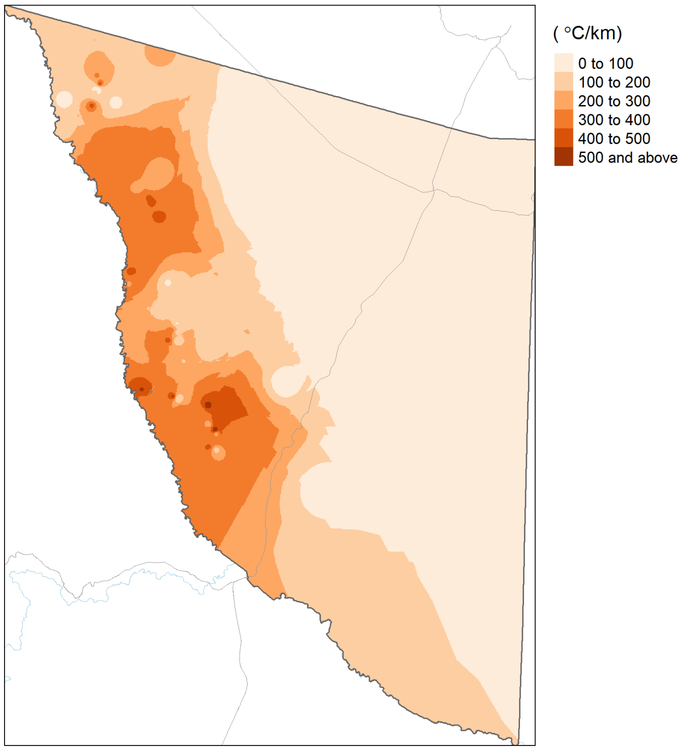


Figure 9. Disturbed BHT and thermal gradient contours. This contouring is only an approximation due to the heterogenous distribution of the data and significant groundwater disturbance, but the gross features are reasonable. The high temperatures along the Rio Grande River valley correspond to the Border Region in Figure 3. Note that the contours spread NE from the river and to the SE tip of the county more than is likely in reality – this is an artifact of the contouring and would be improved with more well data. Figure 8 is a better visual representation of the thermal picture.

A raw BHT is not equal to the true (equilibrium) temperature of the rock. BHT is normally measured, via probe down the well, immediately upon completion of drilling or a stage of drilling. While drilling a well "mud" is circulated through the wellbore. This fluid (mud) is usually at a lower temperature than the rock at the bottom of the well and thus it "disturbs" the temperatures. If allowed to lie inactive for months or more, the temperatures in the well would equalize with the rock temperatures (equilibrium), but allowing a well to idle while waiting for it to equilibrate is not economical and therefore rarely done; thus, a crude correction is applied to BHT to approximate the "true" background temperature.

Multiple BHT corrections methods exist, each created to calibrate BHT to equilibrium temperature for specific basins of interest and not necessarily reliable for general application. Nonetheless, some corrections have proven to have reasonable application in varied settings. Following previous geothermal studies for Texas, we apply a modified form of the Harrison correction (Batir & Richards, 2020; Blackwell, 2011; Harrison W. E., 1983). This correction is as close as one gets to an industry standard.

A Harrison corrected temperature (T_c), as defined by Southern Methodist Geothermal Laboratory, is given by the equation:

$$T_c(°C) = (T_m - T_s) - 16.512 + 0.0183x - 0.00000234x^2$$

where x is depth in meters, T_m is measured temperature, and T_s is average surface temperature for the area. The formula is applied to BHTs less than 3.8 km deep. For depths greater than 3.8 km, the temperature correction is a constant shift of +19.1°C.

<u>Temperatures in the Interior Region.</u>

Corrected BHT for the Interior Region are plotted in **Figure 10** and reach a maximum of 160°C at 4870m below the surface. Although there is moderate scatter in the data, they define a near-linear trend of increasing temperature at depth. A simple model was constructed using the lithology models discussed in section 2.1. In this case, the model values were:

Depth (m)	Thermal Conductivity (k) (W/m-K)
0-1457	3.63
1457-6001	3.0
6001-7850	3.3

The average surface temperature was set to 15°C, and then, assuming a constant heat flow, the temperatures were extrapolated downward sequentially according to the standard heat flow equation:

$\Delta T=(\Delta D*HF)/k$

Where ΔT is the change in temperature across the layer, ΔD is the thickness of the layer, k is the thermal conductivity of the layer, and HF is the crustal heat flow, assumed to be a constant (i.e., no in situ radiogenic production). The assumption of no radiogenic heat production is reasonable for the sedimentary layers but would need to be accounted for in future work if a geothermal system were drilled deep into the basement.

The ΔT is added to the bottom temperature of the layer above (or the average surface temperature for the top) to get the temperature at the bottom of the layer in question. This was repeated sequentially, adding the temperature change for each layer to the bottom temperature of the layer above to get the temperature at the bottom of the layer in question. The temperature change within each layer is assumed to be linear, and the resultant model temperature-depth plot for the Interior region is shown in orange in **Fig. 10**. The HF was adjusted in this model until the model temperatures best fit the observed BHT data. For the Interior Region, the calculated *HF* is 95mW/m^2. This number is lower than the Border region (as we will show shortly), but this is still higher than the world average continental HF of 71mW/m^2 (Davies, 2010) and thus represents an attractive target for development. This relatively high heat flow is probably due to crustal thinning as this area is on the edge of the southeastern extent of the basin and range extensional province. The basin and range heat flow is typically in the 60-100 mW/m^2 range, higher than the 35-60 mW/m^2 found in the stable craton of North America (Blackwell, 2011).

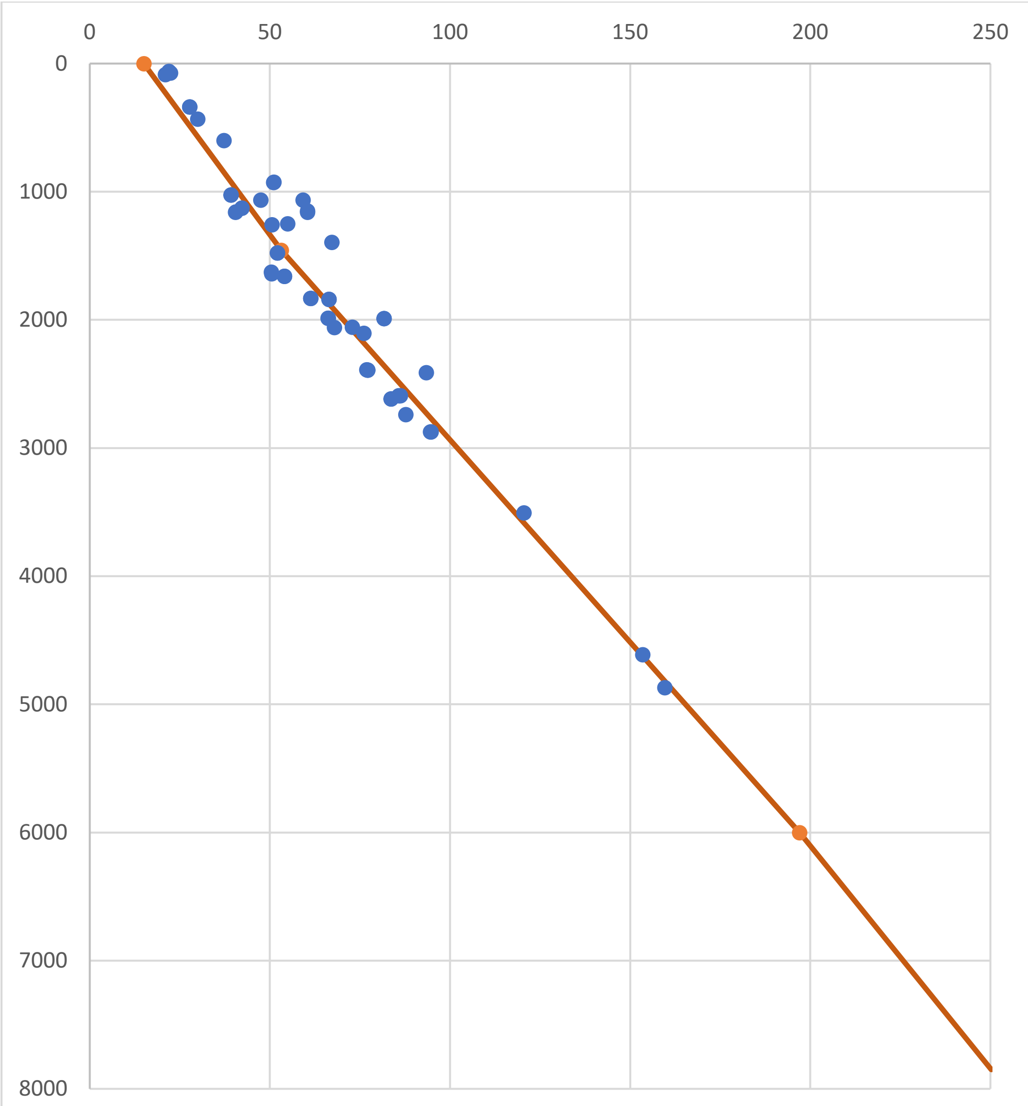


Figure 10. Temperature-depth data and models for the Interior region. Corrected BHT are shown in blue. Modeled temperatures are shown in orange.

The changes in thermal conductivity for the geologic sections are relatively small (from 3.0-3.63 W/m-K). Thus, the differences in gradient in the section are small, as seen in the slight changes in the slope of the orange line in **Fig 10**. Ideally, the temperature data would reflect the changes in *k*, but the scatter in BHT results in only a hint of (but also does not contradict) a correlation between *T* and *k*.

The main value of building such a thermal model is that it can then be used to predict temperatures at depths below where there is BHT data. For the Interior Region, the benchmark temperatures of 150°C, 200°C, and 250°C (~300°F, 390°F and 480°F) and occur at approximately 4,500, 6,100, and 7,800 meters (14,800, 20,000 and 25,600 feet), respectively. These temperature-depth pairs are within the range of economically viable projects proposed elsewhere in the midcontinent of North America. However, it must be kept in mind that the difficult-to-quantify uncertainties in the accuracy of BHT corrections and k measurements/estimates increase with depth and are likely around 10%. It will be important for any future development or proposed projects to acquire accurate equilibrium temperatures. Such data would calibrate the model and significantly reduce uncertainty/risk.

Temperatures in the Border Region.

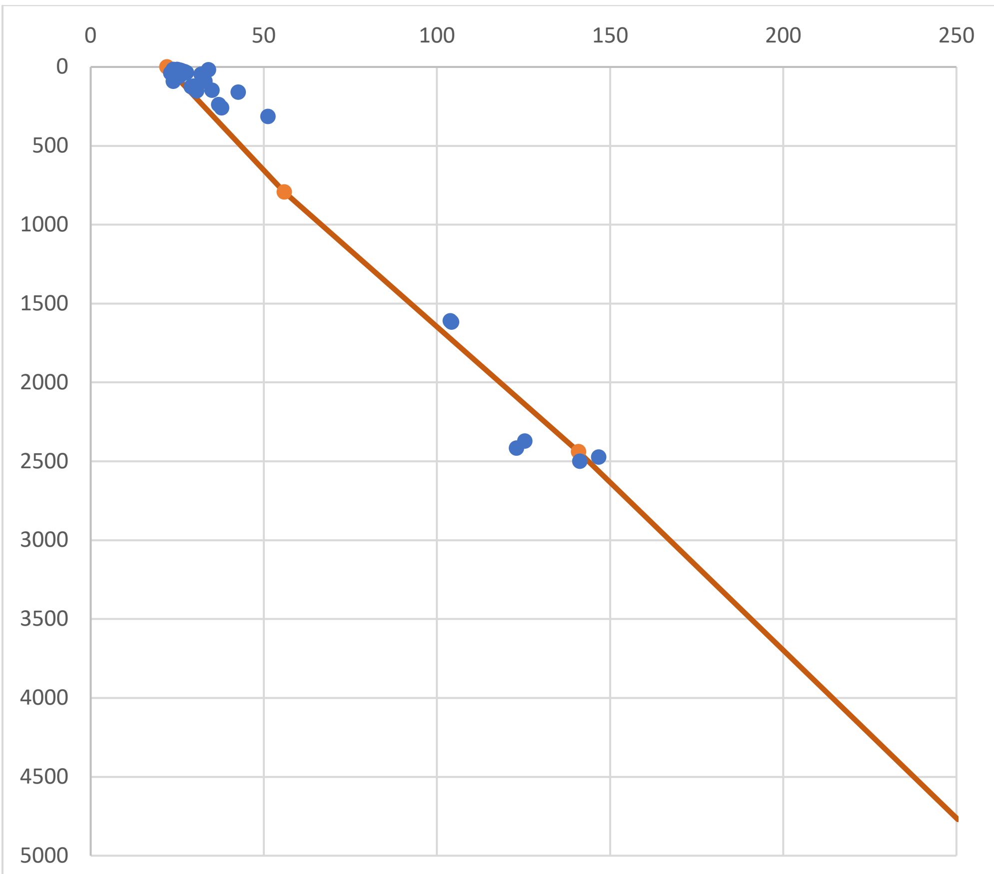


Figure 11. Temperature-depth data and models for the Border region. Note the cluster of temperatures above the model estimate in the shallow subsurface that are likely due to groundwater movement.

The Border Region has considerably higher temperatures than the adjacent Interior Region (**Fig. 11**). Following the same modeling and analysis process as for the Interior region, the calculated HF is 155 mW/m^2. This is at the upper end of Basin and Range values and indicates a high-quality resource. The benchmark depths for 150°C, 200°C, and 250°C (~300°F, 390°F and 480°F) occur at 2,600, 3,700, and 4,770 meters (8,500, 12,100 and 15,650 feet), respectively. These are easily reachable depths. The complicating factor, however, is that the basement in the Border region is quite shallow, at around 2,500 m, and thus, depending on the temperature target, drilling and building a geothermal system in a relatively hard basement will be required. The shallower depths to temperature (potentially offset by drilling in the basement) could result in up to a 20% greater CAPEX (up-front costs) for a project compared to the same project in the Interior region with its “softer” rocks.

The shallow (<300m, or 1,000 ft) temperatures in the Border Region (**Fig. 11**) show a consistent temperature greater than the model predicts. This could be due to several reasons: 1) simple noise in the data, 2) measurements taken systemically during the hotter months of the year, 3) a shallow thermal anomaly, or 4) upflow of groundwater from depth. A systemic noise error on the high side is unlikely. Ground heating due to annual temperature variation would only affect the uppermost ten meters or so. A shallow thermal anomaly (geologically recent magmatism) would likely be more observable with many techniques, but this is not seen. This leaves localized disturbance of temperatures due to water upflow as the most likely cause – a conclusion that warrants further investigation. While the shallow temperatures are not high enough for electricity generation, they do suggest a possibly economical source of direct-use heat and warrant further investigation.

3. Geothermal Development Scenarios

The location of drilling prospects for heat resources depends on the geology, infrastructure, as well as local demand. Therefore, we use our geologic analyses to define geothermal production targets, whose feasibility can later be analyzed via techno-economics. The Border Region seems to be the most prolific region with high heat flow and shallow Precambrian granitic basement. The concept of hot dry rock geothermal, involving stimulation of fractures in the granitic rocks, can be one of the options for heat extraction. The other GA approach is the AGS, conduction through the wellbore. In the Interior Region, we can potentially also utilize the hydrothermal (conventional) geothermal approach to utilize deep and porous carbonate rocks, which reach 150°C at around 4,500m (14,800 ft) and more.

3.1 Techno-economics

The above work in this report allows us to construct techno-economic models that synthesize technical information with economic estimates and data to construct models of the economic potential of deployment of geothermal energy systems in specific regions and particular scenarios. These models are very interesting to potential investors who can use them to compare and contrast projects within Presidio County and with projects in other areas.

This report offers estimates of economic potential with two different approaches that produce two different styles of results. The first approach is known as a “Heat In Place - Resource Assessment (HIP-RA)” (Muffler, 1978) (Garg, 2011). HIP-RA models an entire zone, measuring all the heat contained within one reservoir and reporting on the entire potential of the zone[2]. It calculates two key numbers – the amount of producible heat in that reservoir (if it were to be produced and used directly in “direct-heat” projects) and the amount of producible electricity in the reservoir (if the available heat were to be converted into electricity). Because the calculation is made for an entire zone, larger zones will report more resources than smaller zones unless the difference in area is accounted for. To correct for this area bias, the area of the zone normalizes the results and thus is reported on a per unit basis (in this case, per square kilometer). This makes the numbers

[2] Note that it is not possible to extract all heat from a large area; thus, they represent an upper limit. In reality, depending on the intensity of development, only a few percent of the energy will ever be extracted. This is analogous to Oil in Place calculations versus reserves calculations.

comparable between zones. The heat and producible electricity are also reported on a per unit volume (essentially, an "energy density").

The HIP-RA approach takes a very high-level view – it takes only about six easily determined input variables and makes reasonable assumptions to produce its results. The results must be considered to be of relatively low accuracy – probably no better than +/- 30% of the final result, but importantly, because the underlying assumptions are the same for every calculation, the results can be reasonably compared between reservoirs in one location, and for other reservoirs in other areas. In other words, if a HIP-RA model indicates one reservoir is 20% better than another reservoir, then that comparison will probably hold up in the long run – but the absolute estimate for a resource could be significantly different. To compensate for the lack of accuracy, HIP-RA analyses are often done using Monte Carlo (MC) simulations where thousands or tens of thousands of simulations are run where the input variables are randomly varied within specified reasonable ranges, producing a statistically significant probability distribution of results. For this report, MC runs of 2500 simulations were made (**fig. 12**).

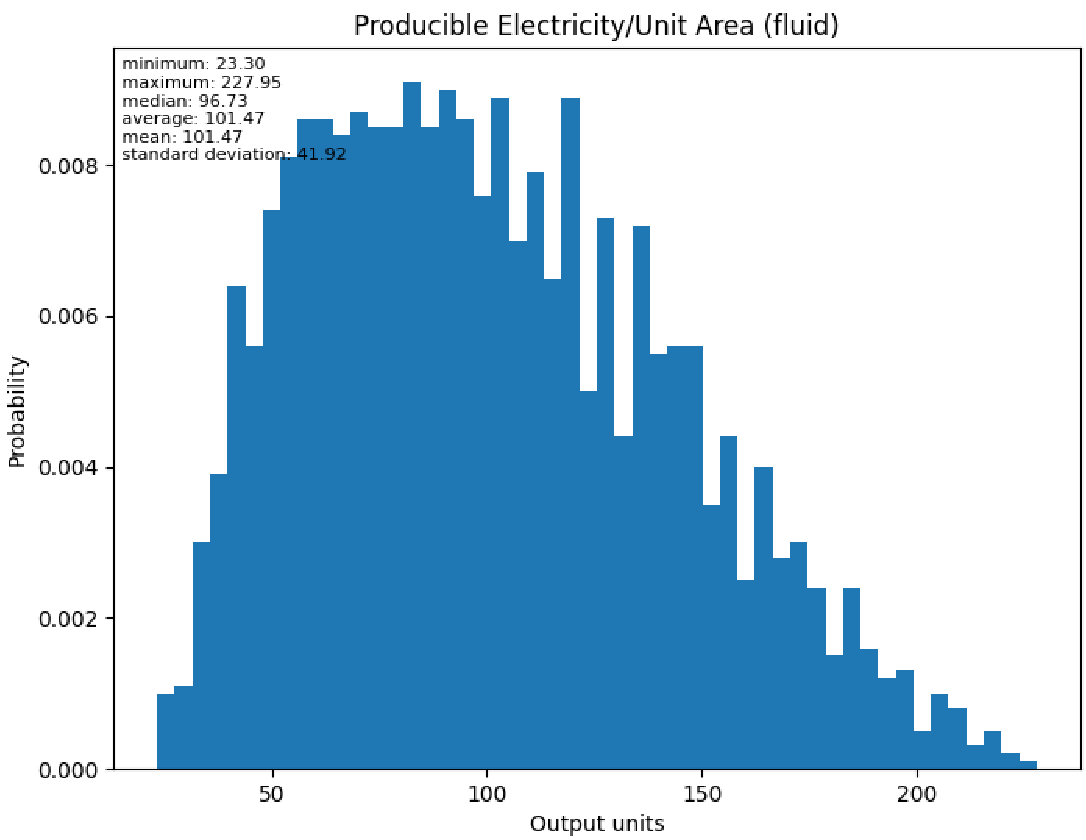


Figure 12. An example HIP-RA MC simulation for 2500 iterations: Interior Region, Basement Reservoir, Probability Density Function for Producible Electricity per Unit Area. The graph shows the probability of a certain amount of energy being produced, with the highest probability being about 96 "Output units" (where, in this case, the units are MW).

The second approach for techno-economic estimates used in this report is more computational and scientifically rigorous – real-world geothermal conditions are numerically simulated rather than lumped together in a single estimation, as is done with HIP-RA. This approach is called: “GEOthermal energy for Production of Heat and electricity (’IR’) Economically Simulated (GEOPHIRES)” (Beckers, 2019). GEOPHIRES models specific projects (also known herein as “scenarios”) rather than zones, as HIP-RA does. GEOPHIRES models have as many as 150 input variables, producing valuable and reasonably accurate results (+/-15%). Unlike HIP-RA, GEOPHIRES also includes a full economic analysis, including a sales price model, so that GEOPHIRES can calculate common project economic metrics, like “Net Present value (NPV),” “Value Investment Ratio (VIR),” and “Internal Rate of Return (IRR),” all of which are important to investors. GEOPHIRES can also calculate the most common metric used in valuing energy-related investments, “Levelized Cost of Electricity (or Heating, Cooling, or Carbon Sequestration), known as “LCOE” (LCOH, LCOC, or LCOCS), a metric familiar to energy investors (Lowry, 2019).

Note that the LCOE is not an entirely fair metric for evaluating renewable resources but is the de facto standard. The important consideration here is the concept of “capacity factor,” defined as plant “up-time” or “in-commission rates.” Electricity users need electricity when they need it, not when the generation resources can provide it (i.e., when it is sunny (solar photovoltaic) or windy (wind turbines). When comparing renewable energy sources, LCOE does not factor in the effect of the time when there is low wind and solar production due to a lack of sun and/or wind (thus giving those sources a low capacity factor). This effect is compounded when the grid demand at those times doesn’t diminish or is higher, thus creating price spikes because demand is exceeding supply, causing higher-cost generation capacity to be employed by the grid to keep the lights on. Geothermal plants have a very high capacity factor (**Fig. 13**), are even better than fossil fuel plants, and are almost as good as nuclear plants if you do not count refueling downtime. The fact that geothermal is reliable (e.g., high capacity factor) and able to operate as a baseload source makes the economics much better than the simple LCOE would indicate. Even better, some forms of geothermal are also dispatchable, meaning they can be ramped up and down as the demand changes, giving them the capability to fill in when the sun doesn’t shine, or the wind doesn’t blow, thus serving that need with a lower cost and lower carbon/environmental impact generation capacity than other dispatchable sources, like nuclear, coal, and natural gas plants.

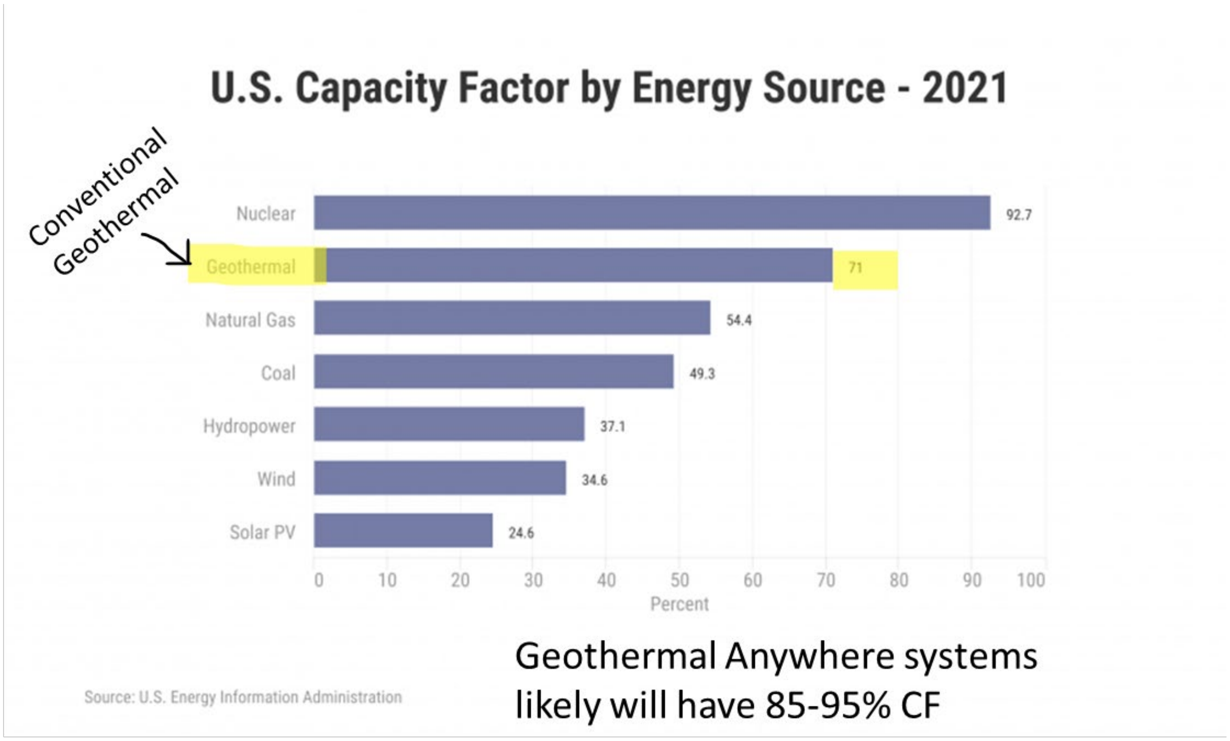


Figure 13. Capacity factors of various power types. Note, the geothermal in this figure is conventional hydrothermal power. Early indications are that GA will have a higher capacity factor than conventional geothermal (modified after U.S. EIA https://www.energy.gov/ne/articles/what-generation-capacity).

3.2 Regional Analysis

The HIP-RA analysis was divided into three geographical zones based on their different geological and geothermal characteristics (Border, Interior, and Big Bend, see above and **Fig. 3**). For each zone, three analyses were done that represent the three fundamentally different reservoirs observed in Presidio County (called “Tertiary” (the youngest, shallowest, and coolest), “Paleozoic-Mesozoic (PzMz)” (midrange in terms of age, depth, and temperature) and “Basement” (oldest, deepest, and hottest) see discussion above and **Figure 4**). Thus, nine simulations (three regions times three reservoirs in each region) were made. Bear in mind that the Big Bend calculations are highly subjective and based on very little data. Generally, hotter is better for geothermal electricity production, and the earth gets hotter at greater depths, so the best electricity and heat results are expected to be found within the Basement reservoir and the worst in the Tertiary reservoir. **Table 2** bears that out.

Table 2 Monte Carlo HIP-RA results for 2500 iterations

A) Results for 2500 iterations of Monte Carlo Simulations of heat output (in MW)

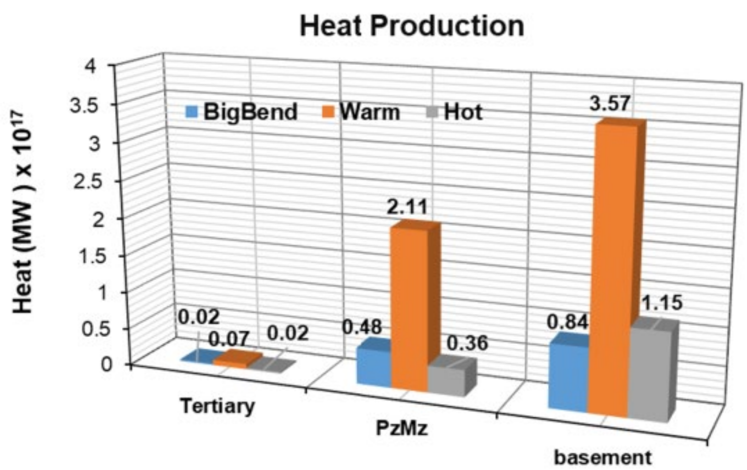
Zone	Region	Producible Heat × 10^{17} (MW)	Producible Heat/ Unit Area × 10^{13} (MW/km^2)	Producible Heat/ Unit Volume × 10^{13} (MW/km^3)
Basement	Big Bend	0.84	5.76	9.20
Basement	Warm	3.57	5.73	9.20
Basement	Hot	1.15	5.04	8.04
PzMz	Big Bend	0.48	3.27	5.30
PzMz	Warm	2.11	3.38	5.33
PzMz	Hot	0.36	1.59	2.52
Tertiary	Big Bend	0.02	0.11	0.18
Tertiary	Warm	0.07	0.11	0.17
Tertiary	Hot	0.02	0.11	0.17

QAe9951

B) Results for 2500 iterations of Monte Carlo Simulations of electricity output (in MW)

Zone	Region	Producible Electricity (MW)	Producible Electricity/ Unit Area (MW/km^2)	Producible Electricity/ Unit Volume (MW/km^3)
Basement	Big Bend	53,853.71	36.88	58.92
Basement	Warm	229,243.37	36.73	58.93
Basement	Hot	73,900.71	32.26	51.53
PzMz	Big Bend	28,714.16	19.66	31.91
PzMz	Warm	126,898.22	20.33	32.09
PzMz	Hot	18,057.57	7.88	12.51
Tertiary	Big Bend	304.97	0.21	0.34
Tertiary	Warm	1,304.36	0.21	0.33
Tertiary	Hot	470.95	0.21	0.32

QAe9951



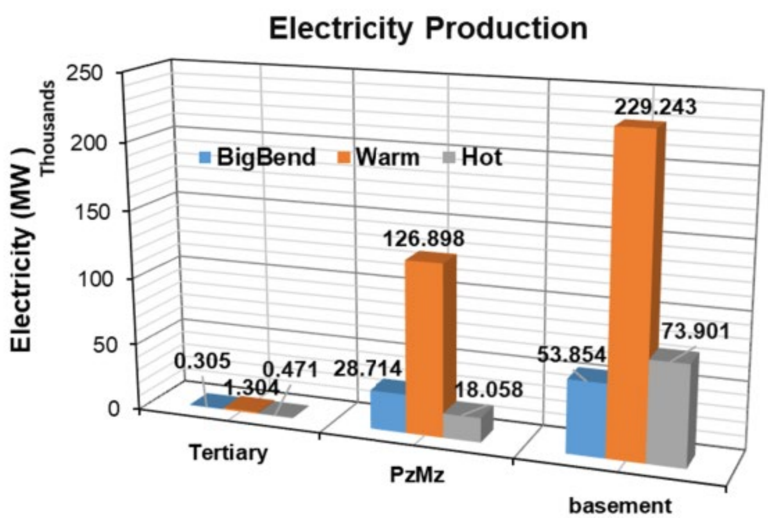


Figure 14. Monte Carlo HIP-RA results for 2500 iterations in graphical form: Estimated producible heat and electricity (units are MW) for the three zones - Big Bend, Warm (Interior), and Hot (Border) Regions.

The HIP-RA results are comparable between zones, so there is an observable and justifiable variation in the zones – the Border Region has the shallowest and hottest reservoirs geologically speaking, and thus should yield the best results for electricity generation predictions), while Interior and Big Bend regions have lower and similar results. But in these models, the basement reservoir of each zone is at a similar temperature, so the estimated producible heat and electricity are similar for all zones. This happened because the depth to the reservoir in the Interior & Big Bend regions is deeper (8.4 kilometers) than the depth to the same temperature reservoir in the Border region (4.7 kilometers). Given that the drilling costs make up as much as half of the cost of a project, shallower reservoirs will be cheaper to produce; thus, the economics for the Border region basement reservoir are better than the same reservoir in the Big Bend and Interior regions (but note the economics is not a part of HIP-RA, so this is not discernable from the HIP-RA model results in table 2 – see the GEOPHIRES results below to see the effect of depth on the economics).

Note also that the observation above focuses on electricity generation, but electricity generation is not the only way to use geothermal. Hotter is not always better for the direct use scenarios in geothermal energy – for direct use, the temperature you get out of the ground should be no more than the temperature required for that use case – for example, in greenhouses, there is an optimal temperature for the plants – too hot will kill them, *so direct use projects are about finding the right temperature, not always the hottest temperature*. Thus, for direct-use projects, the Tertiary reservoir may be better than the Basement reservoir because it is shallower (easier/cheaper to drill) while producing fluids with a more moderate but useful temperature. See **Appendices 2 & 3** for a HIP-RA example output.

3.3 Scenario studies

As previously discussed, GEOPHIRES results are focused on specific project scenarios, not regional analyses (as in HIP-RA). In this report, we chose to model various potential scenarios, with both electricity production (four models) and direct-use/hybrid (four models) use cases. Note there are no models for the Big Bend region due to the lack of reliable data for this zone. Also note that an obvious scenario to construct is one for the Border Region, Basement Reservoir, in the hydrothermal/conventional style, to take advantage of the known hot water resource at Chinati Hot Springs. We chose not to model that scenario without further detailed research on the nature of the springs due to the concern that such a project could negatively interfere with the current ongoing operations at the springs. We want to ensure that those interactions won't happen before we model it.

It is worth noting that in all cases, the calculations do not include local or state subsidies or incentives – inclusion of these is beyond the scope of the project – but as noted, the subsidies could be substantial. One subsidy that is included in the calculations is the federal "Inflation Reduction Act (IRA)" which includes both Investment Tax Credits[3] (ITC) and Production Tax Credits[4] (PTC). An IRA Investment Tax Credit of 50% was included in all scenarios since the IRA ITC & PTC are becoming commonplace, and any project in Presidio County would likely include one. A first-order understanding of the impact of these styles of subsidy is easy to understand and applies to all the scenarios below. An ITC is a one-time tax credit awarded once a project is completed – the amount is a percentage of the total invested amount. In the case of the IRA, up to 60% of the amount invested can be returned to the investor based on meeting certain criteria. The impact of this award is very direct – a 50% ITC credit has the effect of lowering the leveled cost of energy by about that amount – thus if the Levelized Cost of Electricity (LCOE) for a project is 15 cents/kWh, the adjusted LCOE will be about 7.5 cents/kWh (changing a marginally economically viable project into an entirely viable one; see scenario 3 as an example). If the agency to which the tax credit was awarded is a non-taxable entity (like an electric co-op), the credit can be sold on an open market and some percentage of the value of the tax credit can applied to offset the cost of the project (100% in this case). The effect of a PTC is even more direct – if the IRA awards a 5 cent/kWh PTC, then the LCOE is reduced by that amount (a 15 cent/kWh LCOE becomes 10 cents/kWh) – a substantial and robust lever to make a project viable.

Several of the scenarios involve creating a fracture-based system. It is vital to understand that fracture creation in geothermal systems is of a very different nature than "fracking" in the oil and

[3] https://www.thehartford.com/business-insurance/strategy/business-tax-credits/investment-tax-credits
[4] https://www.carboncollective.co/sustainable-investing/production-tax-credit-ptc

gas industry. Geothermal fracture creation is generally much less than oil and gas fracking in terms of intensity, extent and duration, and thus likely results in a much smaller risk of induced seismicity.

Electricity-generation-only scenarios:

1) Border Region, Basement Reservoir, Enhanced Geothermal System (EGS/induced fracturing) style, maximum initial reservoir temperature of 240°C (aspirational) – Fully comparable to scenario 2.
2) Border Region, Basement Reservoir, Enhanced Geothermal System (EGS/induced fracturing) style – maximum initial reservoir temperature of 200°C - Fully comparable to scenario 1 (for the impact of temperature differences) and scenarios 3 & 4 (for comparison of the impact of various geothermal styles).
3) Border Region, Basement Reservoir, Advanced Geothermal System (AGS/Closed Loop) style – the setup is the same as (2) but completed with a different/competing style of heat production. Fully comparable to scenarios 2 & 4.
4) Interior Region, Basement reservoir, Advanced Geothermal System (AGS/Closed Loop) style - this is the same style as (3) but in a different zone, where the depth is greater to access the same level of heat. Fully comparable to scenarios 2 & 3.

Direct-use or hybrid scenarios:

5) Border Region, PzMz Reservoir, Agri-food processing (drying) plant, targeting a heat production temperature of 100°C.
6) Interior Region, PzMz Reservoir, Combined Heat and Power (CHP) for a greenhouse complex for food/high-value crop production
7) Interior Region, Basement Reservoir, geothermally powered Direct Air Capture of CO_2 using a solid sorbent method (S-DAC-GT)
8) Interior Region, PzMz Reservoir, Absorption Chiller (makes cool-water stream from the heat) for commercial or industrial cooling (data center, factory, campuses, etc.)

Note that these analyses are conservative in that only one of them (scenario 7) accounts for carbon pricing, state tax incentives, and/or other similar programs that can substantially improve the economic picture. This is a fast-changing area; these factors should be incorporated into actual project planning when appropriate. Another factor beyond the techno-economic scope of this study is combining revenue streams into the models. Extracting minerals from the hot fluids, connecting a greenhouse after the powerplant, and/or other uses of the “waste” heat from the first power production stage are examples of cascading scenarios that produce an additional possible cumulative revenue stream that would improve the economic picture. This could be a productive direction for future study.

3.4 Summary and discussion of the GEOPHIRES results

<u>Electricity production models:</u>

Note: for all electricity-producing scenarios, the financial model assumes a sale of the electricity at a price starting at $0.15/kWh and rising with 2% inflation after plant completion.

1) Border Region, basement reservoir, Enhanced Geothermal System (EGS/induced fracturing) style maximum initial reservoir temperature of 240°C (aspirational) – For all of Presidio County, this scenario would traditionally be believed to produce the most electricity at the lowest cost; thus, every effort was made to maximize electricity production at the lowest cost, to show what the best possible scenario might achieve. To achieve the aspiration goal of drilling to a reservoir temperature of 240°C, some new techniques and technologies may need to be developed or refined, thus the "aspirational" label. This scenario assumes a plant location near the town of Presidio drilled into the basement reservoir in the Border zone, close to the available transmission. The location could be close to and perhaps integrated with NAS Battery[5] and the Acacia Solar Plant[6]. The scenario calls for four wells to be drilled (two producers, two injectors) to a total depth of 4.7 kilometers and for an energy production plant with a 30-year lifetime to be constructed for a total system cost of $57.08 MM (after ITC; an annualized capital cost of $2.85MM and an operating cost of $3.2MM). The plant is predicted to produce 20.83 MW (average) from an initial reservoir temperature of 241.7 C (average). The LCOE of the project is $0.0371/kWh; the project NPV[7] is $316.75 MM with an IRR of 40.98%, and a MOIC of 5.5. See **Appendix 4** for the complete results.

2) Border Region, basement reservoir, Enhanced Geothermal System (EGS/induced fracturing) style – maximum initial reservoir temperature of 200°C. For all of Presidio County, this scenario would traditionally be believed to produce the most electricity at the lowest cost in a project that is achievable today with no new technologies required; thus, every effort was made to maximize electricity production at the lowest cost to show what this achievable scenario might produce. It is, in every way, the same as scenario #1, except for the changes that are required to change the modeled reservoir to be at ~200°C instead of ~240°C (~40°C lower than in scenario 1). Just like in scenario #1, the plant location is envisioned to be near the town of Presidio. The wells will be drilled 3.7 km into the Basement reservoir in the Border zone, close to the available transmission, near to and perhaps integrated with NAS Battery and the Acacia Solar Plant. The plan calls for four wells to be drilled (two producers, two injectors) and for an energy production plant with a 30-year lifetime to be constructed for a total system cost of $39.98 MM (after ITC; less than scenario #1 because the wells are shallower), with an annualized capital cost of $2 MM and an operating cost of $2.43 MM. The plant is predicted to produce 12.25 MW from an initial reservoir temperature of 196.7 C. The LCOE of the project is $0.0461/kWh; the project NPV is $173.43 MM with an IRR of 33.92%, VIR of 5.34, and a MOIC of 4.18. See **Appendix 5** for complete results.

---

[5] NAS Battery is a 4MW/24MWh molten sodium battery installed in 2010
[6] A 12MW solar phot-voltaic system was commissioned in 2013.
[7] See http://www.investopedia.com for complete definitions of these terms.

3) Border Region, basement reservoir, Advanced Geothermal System (AGS/Closed Loop (Yuan, 2021)) style – This scenario demonstrates a different style of geothermal – AGS/Closed Loop. All the inputs other than the style of the geothermal are the same as Scenario 2. See **Appendix 6** for the complete results. Note however that AGS projects still have relatively large uncertainty in drilling costs.

4) Interior Region, basement reservoir, Advanced Geothermal System (AGS/Closed Loop) style – This scenario imagines a powerplant located close to transmission in the Marfa area, or directly tied to the Permian Basin to support oil & gas production. This scenario mimics the style of Scenario 3, except the target temperature is lower by 25 C. See **Appendix 7** for the complete results.

Table 3 below summarizes the electricity scenarios, Hot (Border) and Warm (Interior) zones. EGS (250) is actually the 240°C scenario:

Scenario	Style	Region	Zone	Electricity (MW)	LCOE (cents/kWh)	NPV (M$)	IRR (%)	VIR=PI=PIR	Temperature (degC)	CAPEX (M$)	OPEX (M$)
1	EGS (250)	Border	Basement	20.83	3.71	316.75	40.98	6.55	241.7	57.08	3.2
2	EGS (200)	Border	Basement	12.25	4.61	173.43	33.92	5.34	196.7	39.98	2.43
3	AGS (200)	Border	Basement	5.54	13.53	7.32	7.07	1.1	173	71.24	2.3
4	AGS (175)	Interior	Basement	5.46	15.28	-6.35	5.6	0.92	172	80.78	2.48

<u>Direct-use/hybrid models:</u>

Note: for all electricity-producing scenarios, the financial model assumes a sale of the electricity at a price starting at \$0.15/kWh and rising with 2% inflation after plant completion. For all heat-producing scenarios, the financial model assumes a sale of the heat at a price starting at \$0.12/kWh and rising with 2% inflation after plant completion. If the scenario involves cooling, the pricing model is the same as the electricity model, assuming that the user would create the cooling otherwise with electricity. When the scenario involves taking a carbon credit for using zero-emission geothermal energy for heating and electricity generation, it is modeled as a single fixed credit of \$0.039/pound of CO_2 saved.

5) Border Region, PzMz reservoir, Agri-food processing plant – targeted heat production temperature of 240°C. See the discussion below entitled: “Creation of a Geothermal Agri-food Processing Hub near the Texas-Pacifico South Orient Rail Line.” This scenario is very similar to Scenario 6 (below), except it envisions a food processing plant in Presidio City operating for 30 years near the rail line, where all the heat is used in food processing activities that require only heat (e.g., drying of fruits). The simple 2-well fractured system is drilled to 4.7 km and produces a flow of 238.4 C water at 55 kg/sec. Over the project's lifetime, that system produced an average of 37.45 MW of heat for US\$2.72/MMBTU. CAPEX for the geothermal system would be about US\$23.3 MM; OPEX would be about US\$1.56 MM and would have an NPV of US\$558.91 MM (IRR: 147.29%, VIR=PI=PIR: 24.97, and MOIC: 20.54). See **Appendix 8** for the complete results.

6) Interior Region, PzMz reservoir, Combined Heat and Power (CHP) for a greenhouse complex for food/high-value crop production – This 30-year scenario imagines a minimal 2-well fractured geothermal system coupled to a greenhouse in the Marfa region that produces a high-value crop that is difficult/expensive/illegal to produce elsewhere. It is very similar to scenario #5, except this system provides both heat and electricity – the heat goes into the greenhouse for optimal plant growth (the heat may also be converted to cooling via an absorption chiller if the optimal environment needs to be cooler than ambient), while the electricity goes towards running pumps, fans, and other equipment required to keep the greenhouse running at maximum efficiency. The wells are drilled into the PzMz reservoir to a depth of 3.1 km. This produces water at about 100 C; this water is split evenly between being used to generate electricity via a subcritical Organic Rankine Cycle (ORC) generator' the remaining heat is sent directly into the greenhouse for heating (or cooling). The electricity system generates about 0.069 MW; the heat/cooling system carries about 2.8 MW of heat. That heat costs US$4.30/MMBTU to produce. The all-in CAPEX for the geothermal part of this project (not including the greenhouse itself) is about US$8.93 MM; the OPEX is about US$0.42MM/year. The financial summary suggests an NPV of US$32.9 MM, an IRR of 29.89%, a VIR=PI=PIR of 4.68, and a MOIC of 4.3. See **Appendix 9** for the complete results.

7) Interior Region, basement reservoir, geothermally powered Direct Air Capture of CO_2 using a solid sorbent method (S-DAC-GT, (Kuru, 2023)) – In this scenario, a geothermal system is paired with a newly constructed plant capable of capturing CO_2 from the air using a solid sorbent process and delivers it to the greenhouse in scenario 6 to improve agricultural productivity and/or the CO_2 is sold into the Permian Basin for CO_2-flood Enhance Oil Recovery processes. This plant could be given federal credits for carbon capture and use (but not sequestration; estimates of those credits are beyond this project's scope). The GEOPHIRES model assumes an EGS-style (induced fracturing) reservoir at a depth of 7 kilometers, which puts it within the basement regime. At that depth, given the depth/temperature modeling above, the model predicts an initial reservoir temperature of 222°C, which, along with the total percentage of heat mined from the site of ~49%, suggests that the 20-year lifetime of the project may be an under-estimate of the potential longevity of the project. The heat reservoir is produced geothermally, and that heat is split into generating electricity of 12.1 MW and 4.82 MW of heat. The capital cost for the construction of the geothermal portion of this project is predicted to be $39.82 MM, with an annual operating cost of $2.27 MM. The LCOE for the surplus electricity would be $0.0611/kWh so the project would never be profitable for electricity sale (but that is not the intent of the project). The model calculates that the cost of the carbon extraction would be $310.96/tonne[8] (1000kg/2205 lbs) and that over the 20-year lifetime of the project, about 203,863,767 tonnes of $C0_2$ would be captured at a price of about $237.98/tonne. For the project to be successful, the buyer of that CO_2 must be willing to pay more than $237.98/tonne for the CO_2 (exclusive of any offsets for carbon capture and use,

[8] A tonne is a metric unit of weight equal to 1,000 kilograms, or about 2,204.6 pounds.

which are beyond the scope of this report). See **Appendix 10** for the complete results.

8) Interior Region, PzMz Reservoir, Absorption Chiller for commercial or industrial cooling – This scenario imagines a customer interested in only environmental cooling (provided by an absorption chiller). It could be a large office building or a data center, for example. Its input parameters are similar to Scenario 7 (depth, number of wells, etc.) but 100% of the energy is used for chilling, with a conversion efficiency of >75%. One of the main reasons that Scenarios 6 & 7 have low economic performance is that a significant portion of the heat is going to make electricity, and the conversion process from heat to electricity has a low efficiency – <15% of the energy becomes electricity, and that lack of efficiency makes the economic picture significantly challenging. See **Appendix 11** for the complete results.

Table 4 summarizes the direct-use and combined-use scenarios:

Scenario	Type of Direct Use	NPV (M$)	IRR (%)	VIR=PI=PIR	Payback (years)	Lifetime (years)	Depth (km)	Temperature (degC)	Heat (MW)	CAPEX (M$)	OPEX (M$)
5	Agri-processing	558.61	147.29	24.97	1.69	30	4.7	238.4	37.45	23.3	1.56
6	Greenhouses	32.9	29.89	4.68	4.54	30	3.1	100.2	2.8	8.93	0.42
7	Geothermally driven Direct Air Capture of CO2	29.42	13.81	1.74	8.05	20	7	222	4.82	39.82	2.27
8	Absorption Chiller	241.05	90.3	11.71	2.13	20	6	209	27.31	22.51	1.26

Note that NPV for two of these scenarios (Greenhouse and CO_2 capture) is low or negative and would thus the scenarios would normally be considered to be marginally economic, but in both cases, the sale of the heat and/or the electricity is not the main revenue generator. In both cases, they provide resources for operations that are the revenue generators (greenhouses produce food for sale, and CO_2 capture generates revenue from awards for sequestration). The net cost is just part of the cost of doing the business and generating the revenue.

An additional consideration not directly addressed in the models is the potential CO_2 savings from displacing fossil fuel power with geothermal anywhere systems. See **Appendix 12** for a brief discussion of the topic.

These scenarios are a small subset of potential studies that could be of interest. They are intended to illustrate the range of developments possible in Presidio County. Some look very promising financially while others, not so much. However, even the worst cases should still be considered as merely a starting point. As we have noted, the government incentives can have a huge impact on project economics and projects can combine revenue streams and stages of heat use. Further, the technology is advancing steadily and what might be too difficult or expensive now, might look more favorable in a few years. What is evident in broad terms is that the Border Region is a prime target and likely first development area but that some development in the Interior Region is also viable in the near-term.

3.5 Potential creation of a geothermal agri-food processing hub

Other than geothermal electricity generation, there is an opportunity to increase the system's sustainability by utilizing the concept of the use of residual (aka “waste”) heat. After a geothermal resource has been used to generate electricity, the effluent output will still contain usable heat, which can be used for a secondary application requiring a lower temperature. The heat pattern can be continued in an efficiently designed system, with the effluent of one process cascading through lower and lower temperature applications. See **Fig. 14** for various direct-use applications and their associated temperature needs.

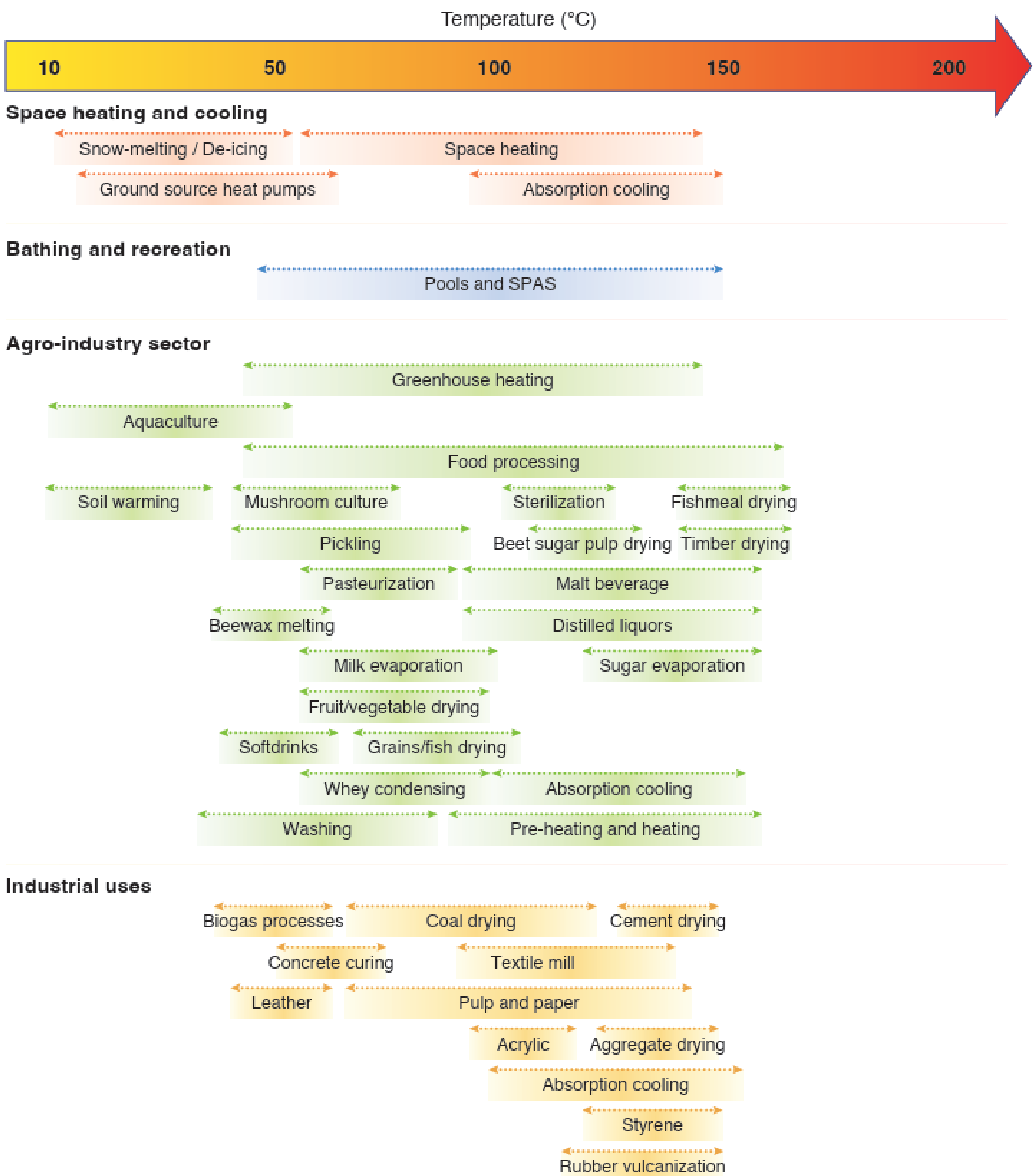


Figure 15. Examples of direct use temperature needs of geothermal energy (Pinnington, Rai, Hallgrimsdottir, & Pedersen, 2024)

One of the most prevalent direct-use applications worldwide falls within the agri-food sector. Nations across the globe that benefit from readily available and abundant geothermal heat have altered trends of economic stagnation and food insecurity through the development of geothermal agri-processing operations. Many of these have been constructed in climates where such an industry would have been impossible to realize just decades ago.

Iceland**,** a country known for its harsh climate, has created a successful agriculture industry by constructing climate-controlled greenhouses that utilize geothermal heat. This practice has extended the growing season to operate year-round while simultaneously reducing water demand in the greenhouses. The total surface area of greenhouses in Iceland is 200,000 m^2; of this area, 50% is used for growing vegetables (tomatoes, cucumbers, paprika, etc.), and have reached a total annual production of 18,000 metric tons of vegetables (Ragnarsson, Steingrímsson, & Thorhallsson, 2023). While the climates of Presidio County and Iceland are at different extremes, the ability of geothermal energy to control growing conditions inside greenhouses to increase efficiency and crop production is equal.

Beyond agriculture, Iceland is heavily engaged in the aquaculture sector. Of the 60 fish farms in Iceland, 15 to 20 of them utilize geothermal water (Ragnarsson, Steingrímsson, & Thorhallsson, 2023). The main use of geothermal energy in the fish farming sector in Iceland is for raising juveniles so they can grow to a marketable size year-round. Research and development around increasing the value of previously discarded fish products has created a side revenue stream from such products, valued at $121MM in 2018 (Finger, Saevarsdottir, & Svavarsson, 2021). Similar research on resources and goods within Presidio County, which could see an increase in value through geothermal processing, might identify a currently unknown revenue stream.

In Mexico, the National Autonomous University of Mexico's Grupo iiDEA has recently installed Latin America's first industrial-grade geothermal food dehydrator in the coastal State of Nayarit (Richter, 2020). Food dehydration is a preservation technique that requires temperatures above 45 C, and when it is conducted with geothermal heat, it emits zero or near-zero GreenHouse Gas (GHG) (Pérez-González, Severiano-Pérez, Aviña-Jiménez, & Del C Velázquez-Madrazo, 2023). The facility prioritized social integration early in development, created 50 local direct jobs, 80% of which are women, and created roughly 60 more indirect employment opportunities within the immediate region (Richter, 2020). The operation runs in a cascading system, using only the residual geothermal heat in a cascading system from the nearby Domo de San Pedro power plant, and processes 9,000 kg/day of food (Richter, 2020). The plant processes locally grown pineapple, mango, tomato, and jackfruit, but it has been constructed to dehydrate food and products beyond simply growing the fruit. A study on the health benefits and overall analysis of the geothermally dehydrated pineapple at the Nayarit revealed that Vitamin C, carbohydrates, and dietary fiber were all increased in the final product, which has encouraged the Mexican government and private sector to consider replicating and scaling this technology throughout other regions of Mexico (Pérez-González, Severiano-Pérez, Aviña-Jiménez, & Del C Velázquez-Madrazo, 2023).

Kenya is leading the way in geothermal development in East Africa, and while producing electricity is its primary role, the nation has simultaneously developed a leading global fresh-cut flower farming sector using its geothermal resources. Kenya is the 4th largest exporter of flowers to Europe and

Russia and controls 6.5% of the global market share, equating to a $500MM industry in 2018 (Ngethe & Jalilinasrabady, 2021). Fresh-cut flower farming involves using greenhouses to limit evapotranspiration, disease, and pest control. Since these activities are labor-intensive, flower farming employs a significant number of farmhands and can greatly increase employment opportunities in the agricultural sector. In Kenya, 10% of the agricultural workforce is employed by the greenhouse fresh-cut flower industry (Ngethe & Jalilinasrabady, 2021).

Flower farms are known to use large quantities of chemical pesticides, fungicides, and herbicides and are water intensive. However, in Kenya, the Oserian Development Company (ODC), situated near the Olkaria geothermal field, uses brine in a cascading system to heat its greenhouses, thus saving on chemical fungicides by raising dew-point temperatures, and the warming caused by the greenhouse structure reduces humidity levels thus limiting the growth of fungi. The ODC flower farm reduced heating fuel costs by 70% and overall operational costs by 5-10% by adopting geothermal heating in greenhouses (O'Lakes & Winrock, 2013). The study also showed that greenhouse heating maximized production to meet peak market periods, shortened crop production cycles, and created a consistent quality of flowers, thus improving overall production per hectare by 15-20% (O'Lakes & Winrock, 2013). Additionally, the fertilized water used in ODC's hydroponic irrigation systems is sterilized using geothermal steam to allow for recycling, helping save water and fertilizer usage. The ODC's Olkaria Park functions as an effective cascading system whose current purchasers of residual heat for direct use include a fish farm, a factory producing animal feed, a company raising insects for biological pest control, and several others (Pinnington, Rai, Hallgrimsdottir, & Pedersen, 2024).

When looking at potential futures for Presidio County, a unique opportunity is on the horizon. With the new investment and interest in geothermal technologies and the large resources in the Border Region along the border, Presidio County could become an international hub for geothermal agri-food processing.

With the Texas-Pacifico South Orient Rail Line (TP-SORL) International Inspection Station set to be completed and operating in the Fall of 2024, international freight will once again cross through Presidio County (Karas, 2022). If cheap geothermal heat was made available near the TP-SORL, agricultural suppliers could use this heat to process their food and greatly improve the value of their products. Once fruit, vegetables, or animal products have undergone geothermal processing, their shelf life greatly increases, and thus, the product can be shipped into larger international markets. This relocating of industry closer to consumers is a type of nearshoring. See the Cross-border Possibilities Section of this report for more detail.

At the beginning of such a project, the focus of the processing hub would be agri-food, but over time, it could expand to include the production of textiles and any other market good that requires industrial-scale heat during the manufacturing process. **Table 5** shows the total tons of commodities that have crossed through the Texas Pacifico Rail System since 2014. A secondary study should be undertaken to understand what percentage of these commodities could benefit from geothermal processing to increase product value.

Table 5: Commodities shipped by the Texas Pacifico Rail Company since 2014; Amount in Tons (TxDOT Rail Divison, 2022)

Commodities	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Minerals	6,506	15,269	22,906	22,104	25,212	40,006	32,367	7,821	1,962	3,631	7,142	164,370
Energy	2,214	5,787	1,422	416	1,040	0	897	2,775	302	187	147	11,776
Metals	326	404	333	342	303	361	303	497	1,881	592	623	2,372
Agriculture	874	927	196	953	1,369	749	691	1,160	958	621	370	5,759
Industrials	0	0	0	1,362	1,406	959	2,545	3,724	1,662	327	40	6,272
Misc/cement	729	1,171	503	726	1,185	1,125	1,286	2,686	244	282	614	6,725
Chemicals	0	0	0	0	0	557	360	292	321	310	352	917
Totals	10,649	25,571	25,360	25,903	30,515	43,757	38,449	18,955	7,330	5,950	9,288	202,216

3.6 Grid, Utility Factors, State Subsidies, and Local Generation

Presidio County currently has no electric generation facilities in the county and only a single transmission line runs to Presidio City from Marfa **(Fig 15)**. Upgrading electric service capacity and reliability will be necessary for economic growth in the county. An upgraded transmission line between Marfa and Ft. Davis has been in discussion for years, as some want the line buried, but the cost to do so and concerns over grassland impact are creating delays (Cantrell, 2023). The years over which this upgraded line has been discussed demonstrate that approving new transmission lines for remote generation could be a bottleneck for future development. Creating local county generation capacity as well as consumption will enable economic development to proceed faster as it will require fewer transmission lines to be approved and constructed. In addition, shorter transmission lines or buried transmission lines reduce the risk of wildfire, and local transmission improves access to power during severe weather events. Presidio City has a solar facility (which sells to Bryan Texas Utilities) and a 4MW battery installation. We assert that adding geothermal could create a more robust electrical supply in times of increasing drought and severe weather events.

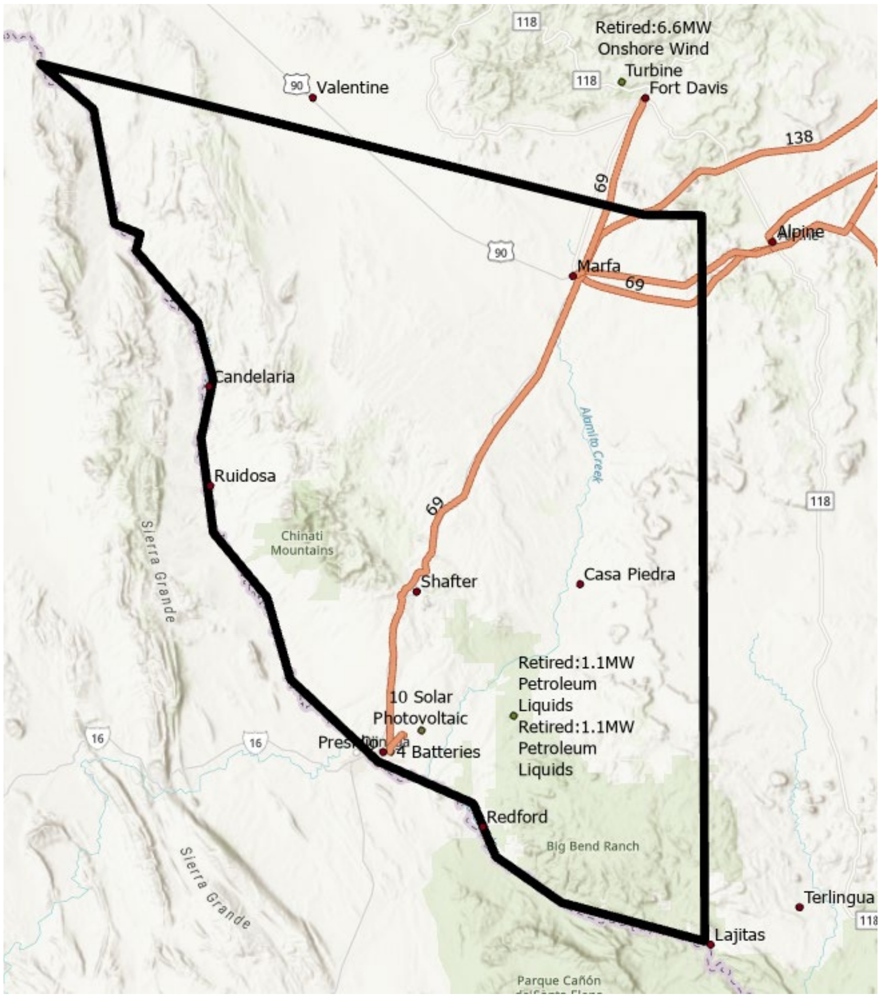


Figure 16. Current electrical infrastructure in Presidio County. There is one main line which connects the Texas/ERCOT grid to the largest population centers in the county. Also relevant, the molten salt energy storage project (~4 MW Batteries) and the 12 MW Presidio-Acacia Solar PV Park.

In March 2010, the city of Presidio became an early adopter of low carbon energy storage by installing a 4MW molten sodium-sulfur battery system (NAS Battery) to improve electric service reliability, which was frequently interrupted by thunderstorms, typically during the summer and at night. In addition, the battery installation allowed the city to upgrade its single 60-mile-long powerline that had supplied the city for 60 years (Electric Transmission Texas, n.d.). In 2020, the battery system was estimated to be able to power the city for 8 hours continuously. In 2020, the battery discharged and recharged 36 times in 12 months (Electric Transmission Texas, 2020). As much as 734MW of storage was listed in ERCOT's fuel mix for Texas on Jan 30th, 2024, partially to balance the intermittency of wind and solar and be an on-demand resource for demand peaks when needed (Electric Reliability Council of Texas, 2024). An advantage of locating geothermally based electricity production in Presidio County is that it provides local baseload (24/7) generation for real-time economic development use, as well as for keeping storage systems such as the one in Presidio or an expanded storage system fully charged and online. One battery system could constantly charge from geothermal, with the second in ready-to-supply mode to offset the decline from wind or solar when the wind isn't blowing and/or the sun has set or is occluded. The geothermal system can also be ramped up to provide local power if the battery system gets depleted by a long-duration energy production reduction event (e.g., Winter Storm Yuri). In addition, well-managed geothermal systems will not experience the strong annual decline curve expected from aging solar panels or batteries and can be operated far beyond the lifetime of batteries, therefore picking up the slack as these resources systematically decline.

A significant and important part of Presidio County is included in a state Economic Development Zone (EDZ, see **Figure 16**). EDZ's provide for capital gains tax abatement, for those who invest eligible capital into zone assets.

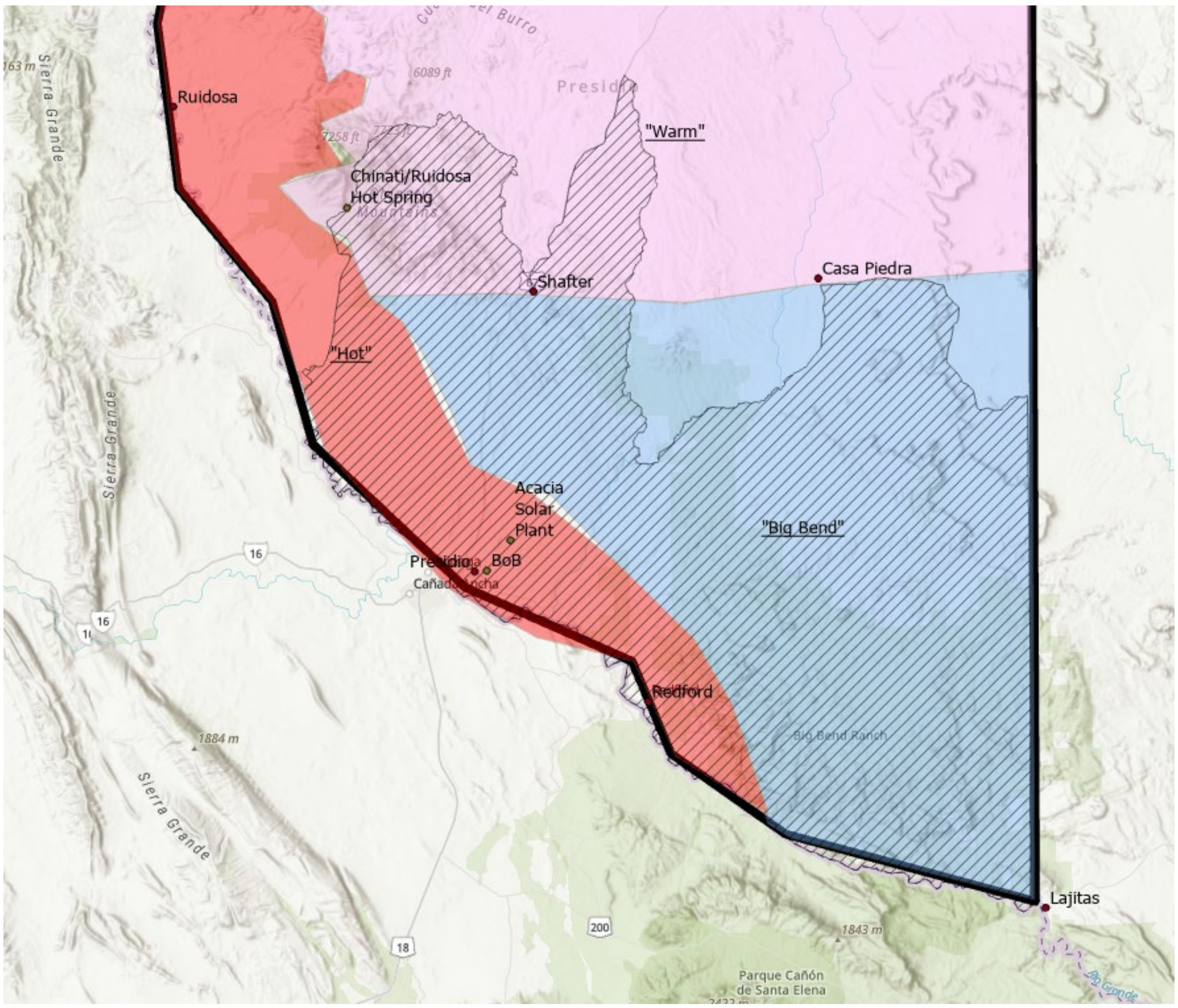


Figure 17. The Economic Development Zone (EDZ, cross-hatched area) in southern Presidio County compared to the temperature regions of this report.

Constructing a substantial infrastructure project like a geothermal development in the EDZ would likely be rewarded with substantial sate supported subsidies (as well as federal subsidies from the Build-Back-Better and Inflation Reduction Act), but the calculation of the actual amounts involved is beyond the scope of this project. The EDZ covers much of the Big Bend region (light blue on **Figure**

16), for which there is a great deal of uncertainty about the geothermal opportunities, but the EDZ also includes about half of the Border region, for which there is much more clarity about the opportunity. The EDZ also includes the entire city of Presidio, where many of the citizens live, and the demand exists, as well as the existing renewable energy systems, like the Sulphur battery (here referred to as "BoB" or Big 'ol Battery) and the Acacia Solar Plant, suggesting that a geothermal project that pairs with and enhances the existing renewable energy infrastructure could be valuable and receive substantial subsidies. The impact of the EDZ on geothermal development is not evaluated in this report but is a priority for future techno-economic model enhancement.

An example of such a hypothetical county-run (or at least county-permitted) geothermal project that would receive such subsidies is shown in **Fig. 17** (taken from Scenario 3, above). It imagines a closed-loop/AGS style plant constructed on a 1-hectare site in the southwest corner of the land parcel where "BoB" is located.

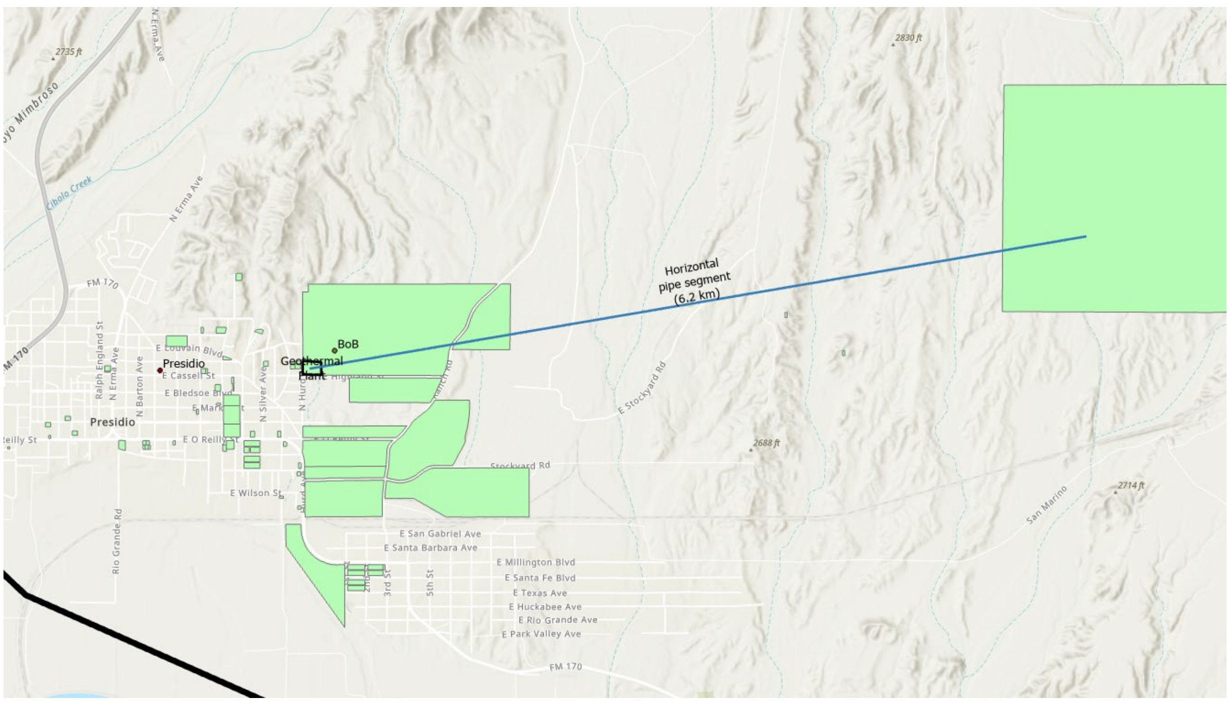


Figure 18. The extent of a hypothetical geothermal plant constructed near the site of "BoB." The green boxes represent county-owned land.

The plan envisages a long (6.2 km) horizontal section of multilateral pipes which stretch to the northeast. This is designed to maximize the amount of county-owned land under which these pipes lie. The Texas legislature recently passed laws that say that the surface rights owner owns the heat in the subsurface, so from a permitting point of view, such a project would only have to obtain/pay for the right to extract heat from the areas above not covered by green boxes.

3.7 Cross-border Possibilities

While the possibility of a grid connection across the international border is beyond the scope of the paper and a political topic, the possibility of selling excess heat might be significant. Recent shifts in global supply chains and trade dynamics are causing an ever-increasing demand for industrial spaces along the US-Mexico border in a concept known as "nearshoring" (essentially the transfer of a company's manufacturing operations closer to their markets and with similar time zones, to minimize the effects of disruption). This practice has gained momentum in recent years, with significant foreign investment and job creation taking place in the Mexican states of Nuevo León and Chihuahua. Data shows that total trade between Texas and Mexico reached a value of US$515 billion in 2021, a 28% increase from the US$401 billion USD in 2019 (Triolet, 2023). Creating a geothermal heat processing operation is an exciting possibility and could be envisioned as a type of nearshoring. The Border Trade Alliance is interested in general trade expansion throughout the region, even going as far as suggesting the creation of a new Foreign Trade Region to stimulate further development (Triolet, 2023).

4. Next Steps/Recommendations

This report is a foundational step in bringing clean, baseload geothermal energy to Presidio County, Texas. It is robust and offers sub-county scale resolution clearly identifying significant geothermal potential both in electricity generation and direct-use heat. Citizens and local government officials can use this study to attract development and to understand the situation sufficiently to assess development proposals. This study is, however, not fine enough in resolution to determine the site for a particular project. Depending on the specificity of an RFI/RFP/FOA [9]or proposal, there will need to be site-specific studies conducted.

Additional work is recommended that will improve the picture (further buy down risk/uncertainty):

- Thermal well(s) drilled and/or logged
    - A set of shallow gradient holes can improve their thermal picture of an area.
    - Any wells in the Big Bend region will possibly tell whether or not the Border region continues along the river valley or not
    - A single deep well with a research grade thermal log obtained would significantly help correct the BHT data
        - Owners/operators of wells in the county should be queried for static (non-producing) wells that could be logged – again significantly helping the BHT corrections which in turn are the best, but noisy, direct measure of the resource
- A small number of warm (often called hot) springs or artesian wells have been reported in the county
    - Detailed assessment of the local hydrology and chemical assays might reveal shallow, moderate temperature resources
- Updating the techno-economic models will be important as the technology of and experience with geothermal anywhere deployment is advancing rapidly and will provide better price points in the future.
    - Determine basement radiogenic heat production to refine deeper production techno-economic models

[9] RFI – Request for Information, RFP – Request for Proposals, FOA – Funding Opportunity Announcement

  - Possible to do as an academic research project, but perhaps better left to industry, will be a complete accounting of incentives into project cost estimates – again, this is a dynamic area with rapid change
- Further analysis of well cores from the county and thermal conductivity measurements on core plugs will refine the thermal and geologic picture – this is a relatively low-cost option
- Continued research into the feasibility of a geothermal agri-food processing hub should begin with an analysis of the commodities that travel through the Texas Pacifico Rail Company and how geothermal heat could improve the value of the various products and materials.

5. Summary

Presidio county clearly has substantial, undeveloped geothermal resources. These resources could prove economically viable to develop in a wide range of scenarios for electricity production, and for industrial/agricultural and heating/cooling use.

The best quality resource (the Border region) is a strip approximately 16km (10mi) wide along the border with Mexico running from Redford to the NW corner of the County. The thermal gradients in the zone are quite high (on the order of 200-300°C/km), meaning required drilling depths to reach a given temperature are relatively shallow (which in turn means lower project cost). This zone corresponds to a large percentage of the relatively low population and thus energy demand of all types - a very good synergy.

The bulk of the county, the inner 2/3 of the “pie,” is in the Interior Region. Though cooler than the Border Region, this zone is still an excellent resource, with temperatures above the worldwide average. Although drilling depths needed to reach a given temperature are greater than in the Border Region, they are still within present technology, are potentially economic, and could easily support the main population center of Marfa.

The county's southeast corner, the Big Bend Region, is a relative unknown. There is a severe lack of data other than surface geologic mapping; thus, not much can be said about the potential here, though it is likely to fall within the bounds of the Border and Interior regions and, therefore, have significant potential. Drilling new wells in this region would be needed to improve the assessment of this zone.

This report has provided an up-to-date assessment of the geothermal potential of Presidio County and provides a foundation for further development. Although further steps are outlined in section 4, The county could solicit proposals based on this report. At relatively low investment costs, developers could perform site-specific studies to determine the economic viability of projects and make proposals.

Acknowledgements

This research was funded by a grant from the Presidio Municipal Development District and with support from the State of Texas Advanced Resource Recovery program. The authors thank Trey Gerfers, General Manager, Presidio County Underground Water Conservation District for his work in making this report possible.

References

Batir, J., & Richards, M. (2020). *Analysis of Geothermal Resources in Three Texas Counties.* Dallas.

Beckers, K. F. (2019). GEOPHIRES v2. 0: updated geothermal techno-economic simulation tool. *Geothermal Energy*, 1-28.

Blackwell, D. M. (2011). *Heat flow map of the continental U.S in 2011*. Retrieved 1 28, 2024, from SMU Geothermal Lab: https://www.smu.edu/-/media/Site/Dedman/Academics/Programs/Geothermal-Lab/Graphics/SMUHeatFlowMap2011_CopyrightVA0001377160_jpg.jpg

Cantrell, M. (2023, July 5). *AEP delays Marfa to Fort Davis transmission line upgrade*. Retrieved from The Big Bend Sentinel: https://bigbendsentinel.com/2023/07/05/aep-delays-marfa-to-fort-davis-transmission-line-upgrade/

Davies, J. D. (2010). Earth's surface heat flux. *Solid Earth, 1*(1), 5-24.

Dietrich, J. W. (1965). *Geology of Presidio Area, Presidio County, Texas.* The University of Texas at Austin.

Electric Reliability Council of Texas. (2024, Jan 30). *Fuel Mix*. Retrieved from ercot: https://www.ercot.com/gridmktinfo/dashboards/fuelmix

Electric Transmission Texas. (2020). *Summary of Presidio Battery Operations for 2020*. Retrieved from ETT: http://ettexas.com/Content/documents/2020SummaryofPresidioBattery.pdf

Electric Transmission Texas. (n.d.). *Presidio NaS Battery Project*. Retrieved from Project & Plans: http://www.ettexas.com/Projects/Presidio

Federal Reserve Bank of Saint Louis. (2023). *Unemployment Rate in Presidio County, TX*. Retrieved 01 02, 2024, from FRED Economic Data: https://fred.stlouisfed.org/series/LAUCN483770000000003A

Finger, D. C., Saevarsdottir, G., & Svavarsson, H. G. (2021). Improved Value Generation from Residual Resources in Iceland: the First Step Towards a Circular Economy. *Circular Economy and Sustainability, 1*, 525-543. doi:10.1007/s43615-021-00010-7

Garg, S. K. (2011). A reexamination of USGS volumetric “Heat in Place” method. *Proceedings*.

Goldich, S. &. (1949). Stratigraphy and petrology of the Buck Hill quadrangle, Texas. *Geological Society of America Bulletin*, 1133-1182.

Harrison W. E., L. K. (1983). *Geothermal resource assessment of Oklahoma.* Oklahoma Geologic Survey.

Karas, S. (2022, December 7). *TxDOT projects December 2024 completion date for Presidio rail inspection facility*. Retrieved from The Big Bend Sentinel: https://bigbendsentinel.com/2022/12/07/txdot-projects-december-2024-completion-date-for-presidio-rail-inspection-facility/

Kopp, R. A. (1977). *Geothermal exploration of Presidio County, Texas.* The University of Texas at El Paso.

Kuru, T. K. (2023). Solid sorbent direct air capture using geothermal energy resources (S-DAC-GT)–Region specific analysis. *Geoenergy Science and Engineering*, 211645.

Lonsdale, J. T. (1940). Igneous rocks of the Terlingua-Solitario region, Texas. *Bulletin of the Geological Society of America*, 1539-1626.

Lowry, T. F. (2019). GeoVision Analysis Supporting Task Force Report: Reservoir Maintenance and Development. *Lowry, T., Finger, J., Carrigan, C., Foris, A., Kennedy, M., Corbet, T., ... & Sonnenthal, E. (2017). GeoVision Analysis Supporting Task ForcSAND2017-9977. Albuquerque, NM: Sandia National Laboratories*.

Mahoney, N. (2020, December 6). *Borderlands: Trade official wants new free-trade zone on Texas-Mexico border*. Retrieved from Freight Waves: https://www.freightwaves.com/news/officials-want-new-ftz-along-texas-mexico-border

Mraz, J. a. (1980). *Structure of the Presidio bolson area, Texas, interpreted from gravity data.* Bureau of Economic Geology, Univ. of Texas at Austin.

Muffler, P. &. (1978). Methods for regional assessment of geothermal resources. *Geothermics*, 53-89.

Ngethe, J., & Jalilinasrabady, S. (2021). Optimization of Geothermal Greenhouses Design for Kenyan Fresh-cut Flowers. *Stanford Workshop on Geothermal Reservoir Engineering. 46th Proceeding.* Stanford University. Retrieved from . https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2021/Ngethe.pdf

O'Lakes, L., & Winrock. (2013). *Priority Geothermal Direct-Use Applications for Kenya: A Pre-feasibility Study for Crop Drying.* United States Agency for International Development. Retrieved from https://www.academia.edu/12986558/Priority_Geothermal_Direct_Use_Applications_for_Kenya_A_Pre_feasibility_Study_for_Crop_Drying

Parry, C. (1857). *Report on the United States and Mexican boundary survey, Part 2, Paleontology and Geology of the Boundary.* Dept. of Interior.

Pérez-González, E., Severiano-Pérez, P., Aviña-Jiménez, H. M., & Del C Velázquez-Madrazo, O. (2023). Geothermal food dehydrator system, operation and sesnory analysis, and dehydrated pineapple quality. *Food Science and Nutrition, 11*(11), 6711 - 6727. doi:10.1002/fsn3.3249

Pinnington, S., Rai, K., Hallgrimsdottir, E., & Pedersen, A. (2024). *Geothermal Energy: Unveiling the Socioeconomic Benefits.* Energy Sector Management Assistance Program. Washington D.C.: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/099122823090547278/P1744881ab11080191a03411d191385e065

Ragnarsson, Á., Steingrímsson, B., & Thorhallsson, S. (2023). Geothermal Development in Iceland 2020-2022. *World Geothermal Congress, Beijing.* International Geothermal Association. Retrieved from https://www.geothermal-energy.org/cpdb/record_detail.php?id=35816

Richter, A. (2020, September 5). *First industrial-grade geothermal food dehydrator of Latin America installed in Nayarit, Mexico*. Retrieved from Think GeoEnergy: https://www.thinkgeoenergy.com/first-industrial-grade-geothermal-food-dehydrator-of-latin-america-installed-in-nayarit-mexico/

Triolet, S. (2023, October 25). *The Booming Texas-Mexico Trade Corridor and its Impact on Industrial Demand.* Retrieved from Partners Real Estate: https://partnersrealestate.com/research/the-booming-texas-mexico-trade-corridor/

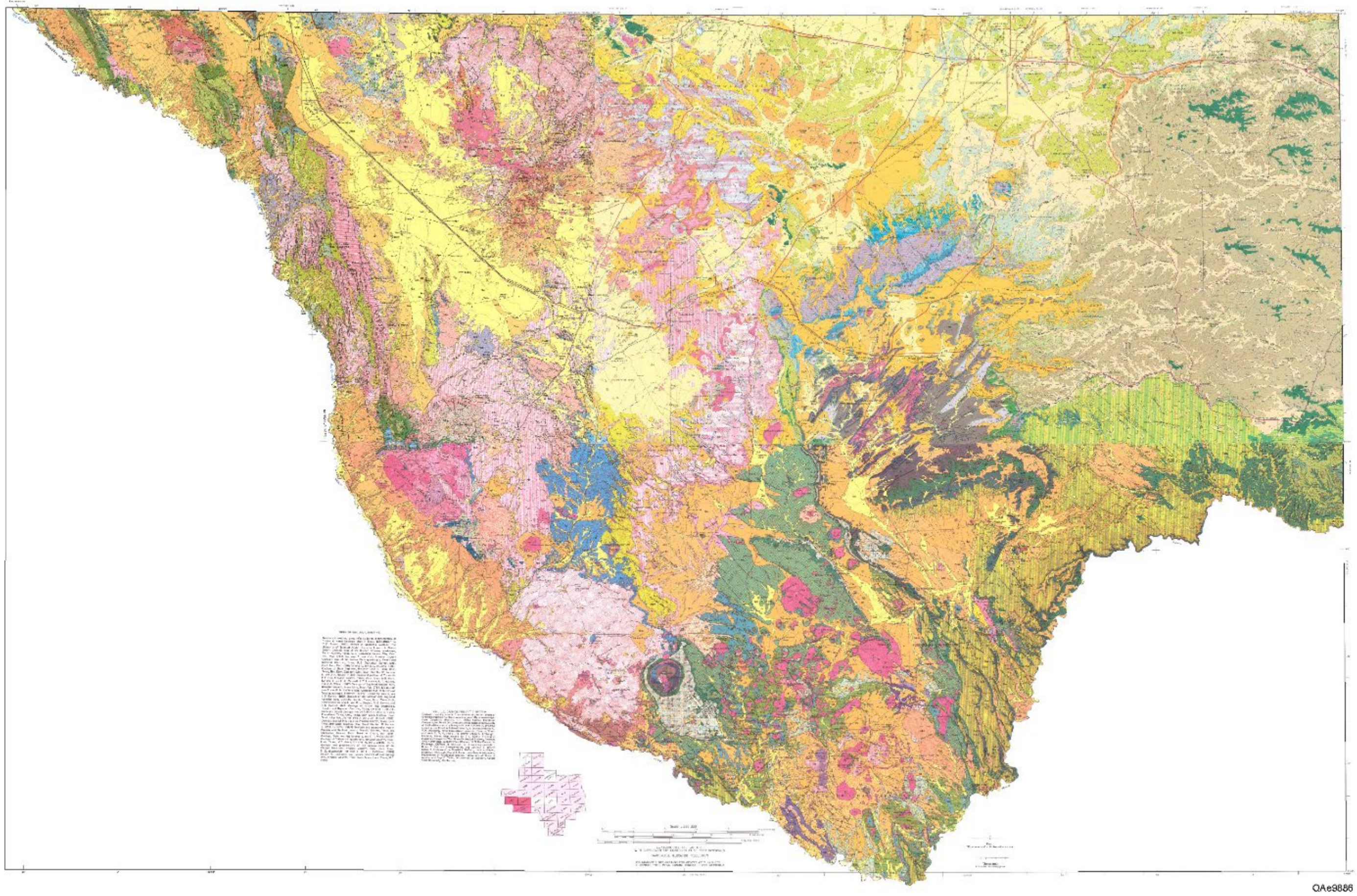
TxDOT Rail Divison. (2022). *2022 South Orient Rail Line Annual Report.* Texas Department of Transportation. Retrieved from https://ftp.txdot.gov/pub/txdot/move-texas-freight/2022-south-orient-rail-annual-report.pdf

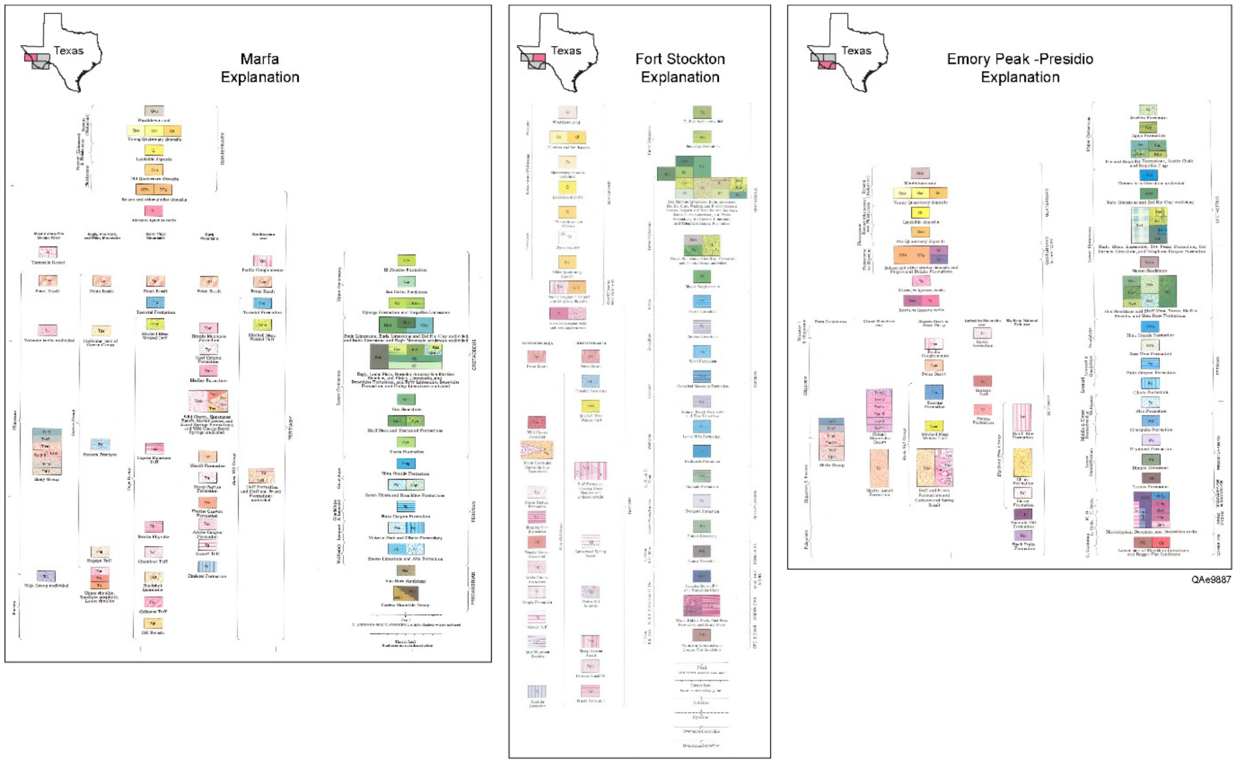
United States Census Bureau. (2020). *Presidio County, Texas*. Retrieved 01 02, 2024, from data.census.gov: https://data.census.gov/profile?g=050XX00US48377

West Texas Economic Development District. (2021). *Economic Development*. Retrieved 01 02, 2024, from Rio Grande Council of Governments: http://www.riocog.org/wp-content/uploads/2022/09/2021thru2025.WTEDD_.CEDS_.pdf

Yuan, W. C. (2021). Closed-loop geothermal energy recovery from deep high enthalpy systems. *Renewable Energy*, 976-991.

1. **Appendix 1: Surface geology map of Presidio County (compiled from previous BEG map publications on Marfa, Fort Stockton, and Emory Peak quadrants)**




Texas
Marfa
Explanation
Texas
Fort Stockton
Explanation
Texas
Emory Peak -Presidio
Explanation
QAe9887

2. Appendix 2: HIP-RA Example Output: "Border" region, Basement Reservoir

****
HIP CASE REPORT
****

SUMMARY OF INPUTS
Reservoir Temperature: 250.39 degC
Rejection Temperature: 39.00 degC
Reservoir Porosity: 15.00 %
Reservoir Area: 2290.66 km**2
Reservoir Thickness: 0.50 kilometer
Reservoir Life Cycle: 30.00 yr
Rock Heat Capacity: 2.84e+12 kJ/km**3C
Fluid Specific Heat Capacity: 4.34 kJ/kgC
Density Of Reservoir Fluid: 8.62e+11 kg/km**3
Density Of Reservoir Rock: 2.76e+12 kg/km**3
Recoverable Fluid Factor: 0.50
Recoverable Heat from Rock: 0.75

SUMMARY OF RESULTS
Reservoir Pressure: 76.95 mPa
Reservoir Depth: 7.85 kilometer
Reservoir Volume (reservoir): 1145.33 km**3
Reservoir Volume (rock): 973.53 km**3
Recoverable Volume (recoverable fluid): 85.90 km**3
Stored Heat (reservoir): 5.03e+17 kJ
Stored Heat (rock): 4.38e+17 kJ
Stored Heat (fluid): 6.47e+16 kJ
Mass of Reservoir (rock): 2.69e+15 kilogram
Mass of Reservoir (fluid): 5.75e+14 kilogram
Specific Enthalpy (reservoir): 426.13 kJ/kg
Specific Enthalpy (rock): 217.52 kJ/kg
Specific Enthalpy (fluid): 208.61 kJ/kg
Recovery Factor (reservoir): 15.74 %
Available Heat (reservoir): 1.20e+17 kJ
Producible Heat (reservoir): 7.92e+16 kJ
Producible Heat/Unit Area (reservoir): 3.46e+13 kJ/km**2
Producible Heat/Unit Volume (reservoir): 6.91e+13 kJ/km**3
Producible Electricity (reservoir): 50735.39 MW
Producible Electricity/Unit Area (reservoir): 22.15 MW/km**2
Producible Electricity/Unit Volume (reservoir): 44.30 MW/km**3

3. Appendix 3: Monte Carlo HIP-RA result: "Hot" Region, PzMz Reservoir

Producible Heat/Unit Area (fluid), Producible Electricity/Unit Area (fluid), Reservoir Porosity, Reservoir Thickness, Reservoir Temperature, Rejection Temperature
1.50e+12, 47.67, (Reservoir Porosity:6.3134858648770145;Reservoir Thickness:0.8669094079641646;Reservoir Temperature:139.07076143087843;Rejection Temperature:8.602173563155008;)
1.26e+12, 39.87, (Reservoir Porosity:7.852626818548783;Reservoir Thickness:0.5904759888353608;Reservoir Temperature:142.0089769648559;Rejection Temperature:21.913870082364483;)
2.65e+12, 84.01, (Reservoir Porosity:10.452596624302199;Reservoir Thickness:0.9389641292934333;Reservoir Temperature:141.28348911352424;Rejection Temperature:20.567611338632503;)
[….2500 rows like this…]
1.39e+12, 44.06, (Reservoir Porosity:8.58290958843623;Reservoir Thickness:0.7041415027247104;Reservoir Temperature:130.34575070236835;Rejection Temperature:18.8088460919759;)
7.11e+11, 22.54, (Reservoir Porosity:6.189784124302546;Reservoir Thickness:0.4652868952804792;Reservoir Temperature:133.89600949242873;Rejection Temperature:15.703657511083973;)

2483 iterations finished successfully and were used to calculate the statistics

Producible Heat/Unit Area (fluid):
- minimum: 273,000,000,000.00
- maximum: 3,460,000,000,000.00
- median: 1,230,000,000,000.00
- average: 1,318,081,353,201.77
- mean: 1,318,081,353,201.77
- standard deviation: 600,216,032,918.68

Producible Electricity/Unit Area (fluid):
- minimum: 8.64
- maximum: 109.65
- median: 39.09
- average: 41.81
- mean: 41.81
- standard deviation: 19.02

4. Appendix 4: "Border" region, Basement Reservoir, Enhanced Geothermal System (EGS/induced fracturing) style

Hot_EGS_250C_Electricity_4wells_Input.txt

```
Investment Tax Credit Rate, 0.5
Reservoir Model,1,                                  ---Multiple, Fractures, reservoir, model
Reservoir Depth,4.7,                                ---[km]
Number of Segments,3,                               ---[-]
Gradient 1,42.69972,                                ---[deg.C/km]
Gradient 2,51.66667,                                ---[deg.C/km]
Thickness 1,0.793,                                  ---[km]
Gradient 3,46.9697,                                 ---[deg.C/km]
Thickness 2,1.646,                                  ---[km]
Maximum Temperature,400,                            ---[deg.C]
Number of Production Wells,2,                       ---[-]
Number of Injection Wells,2,                        ---[-]
Production Well Diameter,7,                         ---[inch]
Injection Well Diameter,7,                          ---[inch]
Ramey Production Wellbore Model,1,                  ---
Production Wellbore Temperature Drop,.5,            ---[deg.C]
Injection Wellbore Temperature Gain,0,              ---[deg.C]
Production Flow Rate per Well,90,                   ---[kg/s]
Fracture Shape,3,                                   ---[-]
Fracture Height,700,                                ---[m]
Reservoir Volume Option,3,                          ---[-]
Reservoir Volume,1000000000000,                     ---[m^3]
Number of Fractures,20,                             ---[-]
Water Loss Fraction,.02,                            ---[-]
Productivity Index,5,                               ---[kg/s/bar]
Injectivity Index,5,                                ---[kg/s/bar]
Injection Temperature,40,                           ---[deg.C]
Maximum Drawdown,0.3,                               ---[-] no redrilling considered
Reservoir Heat Capacity,975,                        ---[J/kg/K]
Reservoir Density,2600,                             ---[kg/m^3]
Reservoir Thermal Conductivity,3.3,                 ---[W/m/K]

***SURFACE TECHNICAL PARAMETERS***
**********************************
End-Use Option,1,                                   ---[-] Electricity
Economic Model,1,                                   ---[-] Fixed Charge Rate Model
Power Plant Type,2,                                 ---[-] Supercritcal ORC
Circulation Pump Efficiency,.8,                     ---[-] between .1 and 1
Utilization Factor,.9,                              ---[-] between .1 and 1
Surface Temperature,22,                             ---[deg.C]
Ambient Temperature,22,                             ---[deg.C]

***FINANCIAL PARAMETERS***
**************************
Plant Lifetime,30,                                  ---[years]
Fixed Charge Rate,.05,                              ---[-] between 0 and 1
Inflation Rate During Construction,0,               ---[-]
Starting Electricity Sale Price,0.15
Ending Electricity Sale Price,1.00
Electricity Escalation Start Year,1
Electricity Escalation Rate Per Year, 0.004053223
```

Simulation Parameters
****

Print Output to Console,1, ---[-] Should be 0 (don't print results) or 1 (print results)
Time steps per year,6, ---[1/year]

Hot_EGS_250C_Electricity_4wells_Result.txt
****
CASE REPORT
****

Simulation Metadata

GEOPHIRES Version: 3.4.25
GEOPHIRES Build Date: 2024-03-05
Simulation Date: 2024-05-06
Simulation Time: 09:35
Calculation Time: 1.368 sec

SUMMARY OF RESULTS

End-Use Option: Electricity
Average Net Electricity Production: 20.83 MW
Electricity breakeven price: 3.71 cents/kWh
Number of production wells: 2
Number of injection wells: 2
Flowrate per production well: 90.0 kg/sec
Well depth (or total length, if not vertical): 4.7 kilometer
Segment 1 Geothermal gradient: 0.0427 degC/m
Segment 1 Thickness: 793 meter
Segment 2 Geothermal gradient: 0.0517 degC/m
Segment 2 Thickness: 1646 meter
Segment 3 Geothermal gradient: 0.0470 degC/m

ECONOMIC PARAMETERS

Economic Model = Fixed Charge Rate (FCR)
Fixed Charge Rate (FCR): 5.00
Accrued financing during construction: 0.00
Project lifetime: 30 yr
Capacity factor: 90.0 %
Project NPV: 316.75 MUSD
Project IRR: 40.98 %
Project VIR=PI=PIR: 6.55
Project MOIC: 5.50
Project Payback Period: 3.56 yr

ENGINEERING PARAMETERS

Number of Production Wells: 2
Number of Injection Wells: 2
Well depth (or total length, if not vertical): 4.7 kilometer
Water loss rate: 2.0
Pump efficiency: 80.0
Injection temperature: 40.0 degC
Production Wellbore heat transmission calculated with Ramey's model

Average production well temperature drop: 5.1 degC
Flowrate per production well: 90.0 kg/sec
Injection well casing ID: 7.000 in
Production well casing ID: 7.000 in
Number of times redrilling: 0
Power plant type: Supercritical ORC

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 3
Segment 1 Geothermal gradient: 0.0427 degC/m
Segment 1 Thickness: 793 meter
Segment 2 Geothermal gradient: 0.0517 degC/m
Segment 2 Thickness: 1646 meter
Segment 3 Geothermal gradient: 0.0470 degC/m

RESERVOIR PARAMETERS

Reservoir Model = Multiple Parallel Fractures Model
Bottom-hole temperature: 247.10 degC
Fracture model = Square
Well separation: fracture height: 700.00 meter
Fracture area: 490000.00 m**2
Reservoir volume: 1000000000000 m**3
Reservoir hydrostatic pressure: 45387.66 kPa
Plant outlet pressure: 4061.01 kPa
Production wellhead pressure: 4129.96 kPa
Productivity Index: 5.00 kg/sec/bar
Injectivity Index: 5.00 kg/sec/bar
Reservoir density: 2600.00 kg/m**3
Reservoir thermal conductivity: 3.30 W/m/K
Reservoir heat capacity: 975.00 J/kg/K

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 241.7 degC
Average Production Temperature: 237.7 degC
Minimum Production Temperature: 227.9 degC
Initial Production Temperature: 239.0 degC
Average Reservoir Heat Extraction: 143.55 MW
Production Wellbore Heat Transmission Model = Ramey Model
Average Production Well Temperature Drop: 5.1 degC
Average Injection Well Pump Pressure Drop: -1674.6 kPa
Average Production Well Pump Pressure Drop: 5203.8 kPa

CAPITAL COSTS (M$)

Drilling and completion costs: 28.92 MUSD
Drilling and completion costs per well: 7.23 MUSD
Stimulation costs: 3.02 MUSD
Surface power plant costs: 72.74 MUSD
Field gathering system costs: 2.87 MUSD
Total surface equipment costs: 75.61 MUSD

Exploration costs: 6.61 MUSD
Investment Tax Credit: -57.08 MUSD
Total capital costs: 57.08 MUSD
Annualized capital costs: 2.85 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 0.74 MUSD/yr
Power plant maintenance costs: 2.36 MUSD/yr
Water costs: 0.09 MUSD/yr
Total operating and maintenance costs: 3.20 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Initial geofluid availability: 0.24 MW/(kg/s)
Maximum Total Electricity Generation: 22.92 MW
Average Total Electricity Generation: 22.13 MW
Minimum Total Electricity Generation: 20.15 MW
Initial Total Electricity Generation: 22.39 MW
Maximum Net Electricity Generation: 21.65 MW
Average Net Electricity Generation: 20.83 MW
Minimum Net Electricity Generation: 18.76 MW
Initial Net Electricity Generation: 21.11 MW
Average Annual Total Electricity Generation: 173.55 GWh
Average Annual Net Electricity Generation: 163.31 GWh
Initial pumping power/net installed power: 6.04 %
Average Pumping Power: 1.31 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (degC)	PUMP POWER (MW)	NET POWER (MW)	FIRST LAW EFFICIENCY (%)
1	1.0000	239.00	1.2760	21.1113	14.6132
2	1.0066	240.57	1.2726	21.4297	14.7176
3	1.0085	241.03	1.2716	21.5219	14.7474
4	1.0095	241.26	1.2711	21.5701	14.7630
5	1.0101	241.42	1.2707	21.6021	14.7733
6	1.0106	241.54	1.2705	21.6253	14.7807
7	1.0109	241.62	1.2704	21.6417	14.7860
8	1.0111	241.66	1.2705	21.6509	14.7888
9	1.0111	241.66	1.2709	21.6507	14.7886
10	1.0109	241.61	1.2718	21.6389	14.7845
11	1.0104	241.49	1.2732	21.6135	14.7760
12	1.0096	241.30	1.2752	21.5732	14.7624
13	1.0085	241.03	1.2779	21.5175	14.7437
14	1.0071	240.69	1.2812	21.4462	14.7197
15	1.0054	240.28	1.2851	21.3597	14.6905
16	1.0034	239.80	1.2896	21.2588	14.6563
17	1.0011	239.26	1.2946	21.1446	14.6173
18	0.9986	238.66	1.3002	21.0179	14.5738
19	0.9958	238.00	1.3062	20.8801	14.5262
20	0.9929	237.30	1.3126	20.7323	14.4747
21	0.9898	236.55	1.3193	20.5756	14.4197
22	0.9865	235.77	1.3263	20.4110	14.3615

23	0.9831	234.96	1.3336	20.2397	14.3004
24	0.9796	234.12	1.3410	20.0625	14.2366
25	0.9760	233.25	1.3487	19.8803	14.1704
26	0.9723	232.37	1.3565	19.6939	14.1021
27	0.9685	231.47	1.3643	19.5041	14.0318
28	0.9647	230.55	1.3723	19.3115	13.9599
29	0.9608	229.63	1.3803	19.1167	13.8864
30	0.9569	228.70	1.3884	18.9202	13.8116

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	ELECTRICITY PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	167.8	1144.0	525001.25	0.00
2	169.4	1149.4	524997.11	0.00
3	169.9	1151.3	524992.97	0.00
4	170.2	1152.4	524988.82	0.00
5	170.4	1153.2	524984.66	0.00
6	170.6	1153.7	524980.51	0.00
7	170.7	1154.1	524976.36	0.01
8	170.7	1154.2	524972.20	0.01
9	170.7	1154.1	524968.05	0.01
10	170.5	1153.6	524963.89	0.01
11	170.3	1152.7	524959.74	0.01
12	169.9	1151.4	524955.60	0.01
13	169.4	1149.7	524951.46	0.01
14	168.8	1147.5	524947.33	0.01
15	168.0	1145.0	524943.21	0.01
16	167.2	1142.0	524939.10	0.01
17	166.2	1138.8	524935.00	0.01
18	165.2	1135.2	524930.91	0.01
19	164.0	1131.3	524926.84	0.01
20	162.8	1127.1	524922.78	0.02
21	161.6	1122.8	524918.74	0.02
22	160.2	1118.2	524914.71	0.02
23	158.9	1113.4	524910.70	0.02
24	157.5	1108.6	524906.71	0.02
25	156.0	1103.6	524902.74	0.02
26	154.5	1098.5	524898.79	0.02
27	153.0	1093.3	524894.85	0.02
28	151.5	1088.0	524890.93	0.02
29	149.9	1082.7	524887.04	0.02
30	123.8	898.1	524883.80	0.02

****
* REVENUE & CASHFLOW PROFILE *
****

Year Electricity | Heat | Cooling | Carbon | Project
Since Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | OPEX Net Rev. Net Cashflow
Start (cents/kWh)(MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(USD/tonne) (MUSD/yr) (MUSD) |(MUSD/yr) (MUSD/yr) (MUSD)

```
 1    0.00       -57.08  0.00   |  0.00   0.00     0.00  |  0.00   0.00     0.00  |  0.00   0.00     0.00  | 0.00   -
57.08   -57.08
 2   15.00       21.98 25.18   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
21.98   -35.11
 3   15.00       22.21 50.58   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
22.21   -12.90
 4   15.41       22.97 76.75   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
22.97   10.07
 5   15.81       23.71 103.66   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
23.71   33.78
 6   16.22       24.43 131.29   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
24.43   58.22
 7   16.62       25.15 159.64   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
25.15   83.37
 8   17.03       25.86 188.70   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
25.86   109.23
 9   17.43       26.56 218.46   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
26.56   135.79
 10   17.84       27.24 248.90   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
27.24   163.03
 11   18.24       27.91 280.00   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
27.91   190.94
 12   18.65       28.55 311.75   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
28.55   219.49
 13   19.05       29.17 344.12   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
29.17   248.65
 14   19.46       29.76 377.07   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
29.76   278.41
 15   19.86       30.32 410.60   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
30.32   308.73
 16   20.27       30.86 444.65   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
30.86   339.59
 17   20.67       31.36 479.21   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
31.36   370.95
 18   21.08       31.84 514.25   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
31.84   402.79
 19   21.49       32.29 549.73   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
32.29   435.08
 20   21.89       32.71 585.64   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
32.71   467.79
 21   22.30       33.11 621.95   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
33.11   500.90
 22   22.70       33.48 658.63   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
33.48   534.38
 23   23.11       33.83 695.66   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
33.83   568.21
 24   23.51       34.16 733.01   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
34.16   602.36
 25   23.92       34.46 770.67   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
34.46   636.83
 26   24.32       34.75 808.61   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
34.75   671.57
 27   24.73       35.01 846.82   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
35.01   706.58
 28   25.13       35.26 885.28   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
35.26   741.84
 29   25.54       35.49 923.97   |  2.50   0.00     0.00  |  2.50   0.00     0.00  |  0.00   0.00     0.00  | 3.20
35.49   777.33
```

30 25.94 35.70 962.87 | 2.50 0.00 0.00 | 2.50 0.00 0.00 | 0.00 0.00 0.00 | 3.20
35.70 813.03

5. Appendix 5: "Border" region, Basement Reservoir, Enhanced Geothermal System (EGS/induced fracturing) style – maximum initial reservoir temperature of 200 C

Hot_EGS_200C_Electricity_4wells_Result.txt

Investment Tax Credit Rate, 0.5
Reservoir Model,1, ---Multiple, Fractures, reservoir, model
Reservoir Depth,3.7, ---[km]
Number of Segments,3, ---[-]
Gradient 1,42.69972, ---[deg.C/km]
Gradient 2,51.66667, ---[deg.C/km]
Thickness 1,0.793, ---[km]
Gradient 3,46.9697, ---[deg.C/km]
Thickness 2,1.646, ---[km]
Maximum Temperature,400, ---[deg.C]
Number of Production Wells,2, ---[-]
Number of Injection Wells,2, ---[-]
Production Well Diameter,7, ---[inch]
Injection Well Diameter,7, ---[inch]
Ramey Production Wellbore Model,1, ---
Production Wellbore Temperature Drop,.5, ---[deg.C]
Injection Wellbore Temperature Gain,0, ---[deg.C]
Production Flow Rate per Well,90, ---[kg/s]
Fracture Shape,3, ---[-]
Fracture Height,700, ---[m]
Reservoir Volume Option,3, ---[-]
Reservoir Volume,1000000000000, ---[m^3]
Number of Fractures,20, ---[-]
Water Loss Fraction,.02, ---[-]
Productivity Index,5, ---[kg/s/bar]
Injectivity Index,5, ---[kg/s/bar]
Injection Temperature,40, ---[deg.C]
Maximum Drawdown,0.3, ---[-] no redrilling considered
Reservoir Heat Capacity,975, ---[J/kg/K]
Reservoir Density,2600, ---[kg/m^3]
Reservoir Thermal Conductivity,3.3, ---[W/m/K]

SURFACE TECHNICAL PARAMETERS
****
End-Use Option,1, ---[-] Electricity
Economic Model,1, ---[-] Fixed Charge Rate Model
Power Plant Type,2, ---[-] Supercritcal ORC
Circulation Pump Efficiency,.8, ---[-] between .1 and 1
Utilization Factor,.9, ---[-] between .1 and 1
Surface Temperature,22, ---[deg.C]
Ambient Temperature,22, ---[deg.C]

FINANCIAL PARAMETERS
****
Plant Lifetime,30, ---[years]
Fixed Charge Rate,.05, ---[-] between 0 and 1
Inflation Rate During Construction,0, ---[-]
Starting Electricity Sale Price,0.15
Ending Electricity Sale Price,1.00
Electricity Escalation Start Year,1
Electricity Escalation Rate Per Year, 0.004053223

Simulation Parameters

****

Print Output to Console,1, ---[-] Should be 0 (don't print results) or 1 (print results)
Time steps per year,6, ---[1/year]

Hot_EGS_200C_Electricity_4wells_Result.txt

****

CASE REPORT

****

Simulation Metadata

GEOPHIRES Version: 3.4.25

GEOPHIRES Build Date: 2024-03-05

Simulation Date: 2024-05-06

Simulation Time: 09:38

Calculation Time: 1.390 sec

SUMMARY OF RESULTS

End-Use Option: Electricity

Average Net Electricity Production: 12.25 MW

Electricity breakeven price: 4.61 cents/kWh

Number of production wells: 2

Number of injection wells: 2

Flowrate per production well: 90.0 kg/sec

Well depth (or total length, if not vertical): 3.7 kilometer

Segment 1 Geothermal gradient: 0.0427 degC/m

Segment 1 Thickness: 793 meter

Segment 2 Geothermal gradient: 0.0517 degC/m

Segment 2 Thickness: 1646 meter

Segment 3 Geothermal gradient: 0.0470 degC/m

ECONOMIC PARAMETERS

Economic Model = Fixed Charge Rate (FCR)

Fixed Charge Rate (FCR): 5.00

Accrued financing during construction: 0.00

Project lifetime: 30 yr

Capacity factor: 90.0 %

Project NPV: 173.43 MUSD

Project IRR: 33.92 %

Project VIR=PI=PIR: 5.34

Project MOIC: 4.18

Project Payback Period: 4.12 yr

ENGINEERING PARAMETERS

Number of Production Wells: 2

Number of Injection Wells: 2

Well depth (or total length, if not vertical): 3.7 kilometer

Water loss rate: 2.0

Pump efficiency: 80.0

Injection temperature: 40.0 degC

Production Wellbore heat transmission calculated with Ramey's model

Average production well temperature drop: 3.1 degC

Flowrate per production well: 90.0 kg/sec

Injection well casing ID: 7.000 in

Production well casing ID: 7.000 in

Number of times redrilling: 0

Power plant type: Supercritical ORC

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC

Number of segments: 3

Segment 1 Geothermal gradient: 0.0427 degC/m

Segment 1 Thickness: 793 meter

Segment 2 Geothermal gradient: 0.0517 degC/m

Segment 2 Thickness: 1646 meter

Segment 3 Geothermal gradient: 0.0470 degC/m

RESERVOIR PARAMETERS

Reservoir Model = Multiple Parallel Fractures Model

Bottom-hole temperature: 200.13 degC

Fracture model = Square

Well separation: fracture height: 700.00 meter

Fracture area: 490000.00 m**2

Reservoir volume: 1000000000000 m**3

Reservoir hydrostatic pressure: 36106.99 kPa

Plant outlet pressure: 1835.01 kPa

Production wellhead pressure: 1903.96 kPa

Productivity Index: 5.00 kg/sec/bar

Injectivity Index: 5.00 kg/sec/bar

Reservoir density: 2600.00 kg/m**3

Reservoir thermal conductivity: 3.30 W/m/K

Reservoir heat capacity: 975.00 J/kg/K

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 196.7 degC

Average Production Temperature: 193.6 degC

Minimum Production Temperature: 185.7 degC

Initial Production Temperature: 195.1 degC

Average Reservoir Heat Extraction: 112.07 MW

Production Wellbore Heat Transmission Model = Ramey Model

Average Production Well Temperature Drop: 3.1 degC

Average Injection Well Pump Pressure Drop: 1161.3 kPa

Average Production Well Pump Pressure Drop: 3708.7 kPa

CAPITAL COSTS (M$)

Drilling and completion costs: 21.01 MUSD

Drilling and completion costs per well: 5.25 MUSD

Stimulation costs: 3.02 MUSD

Surface power plant costs: 47.77 MUSD

Field gathering system costs: 2.99 MUSD

Total surface equipment costs: 50.77 MUSD

Exploration costs: 5.15 MUSD

Investment Tax Credit: -39.98 MUSD

Total capital costs: 39.98 MUSD

Annualized capital costs: 2.00 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 0.58 MUSD/yr

Power plant maintenance costs: 1.75 MUSD/yr

Water costs: 0.09 MUSD/yr

Total operating and maintenance costs: 2.43 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Initial geofluid availability: 0.16 MW/(kg/s)

Maximum Total Electricity Generation: 14.00 MW

Average Total Electricity Generation: 13.41 MW

Minimum Total Electricity Generation: 11.97 MW

Initial Total Electricity Generation: 13.69 MW

Maximum Net Electricity Generation: 12.86 MW

Average Net Electricity Generation: 12.25 MW

Minimum Net Electricity Generation: 10.75 MW

Initial Net Electricity Generation: 12.55 MW

Average Annual Total Electricity Generation: 105.17 GWh

Average Annual Net Electricity Generation: 96.07 GWh

Initial pumping power/net installed power: 9.11 %

Average Pumping Power: 1.16 MW

****

* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *

****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (degC)	PUMP POWER (MW)	NET POWER (MW)	FIRST LAW EFFICIENCY (%)
1	1.0000	195.09	1.1426	12.5474	11.0867
2	1.0050	196.07	1.1410	12.7334	11.1803
3	1.0065	196.35	1.1406	12.7875	11.2073
4	1.0073	196.50	1.1403	12.8157	11.2214
5	1.0078	196.60	1.1402	12.8344	11.2307
6	1.0081	196.67	1.1401	12.8480	11.2375
7	1.0084	196.72	1.1400	12.8572	11.2420
8	1.0085	196.74	1.1401	12.8614	11.2441
9	1.0084	196.73	1.1404	12.8588	11.2427
10	1.0081	196.67	1.1409	12.8477	11.2370
11	1.0076	196.57	1.1418	12.8265	11.2262
12	1.0067	196.40	1.1430	12.7945	11.2098
13	1.0056	196.18	1.1446	12.7510	11.1877
14	1.0042	195.90	1.1466	12.6962	11.1596
15	1.0024	195.56	1.1489	12.6304	11.1259
16	1.0004	195.17	1.1516	12.5543	11.0868

17	0.9982	194.73	1.1545	12.4687	11.0425
18	0.9957	194.24	1.1578	12.3744	10.9936
19	0.9930	193.71	1.1613	12.2724	10.9405
20	0.9901	193.15	1.1651	12.1636	10.8835
21	0.9870	192.55	1.1690	12.0489	10.8230
22	0.9838	191.93	1.1731	11.9291	10.7594
23	0.9805	191.28	1.1774	11.8049	10.6932
24	0.9770	190.61	1.1817	11.6772	10.6245
25	0.9735	189.92	1.1862	11.5464	10.5538
26	0.9699	189.22	1.1908	11.4134	10.4813
27	0.9662	188.50	1.1954	11.2785	10.4073
28	0.9625	187.78	1.2000	11.1422	10.3321
29	0.9588	187.04	1.2047	11.0050	10.2557
30	0.9550	186.30	1.2094	10.8673	10.1785

****

* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *

****

YEAR	ELECTRICITY PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	99.7	895.4	405933.95	0.00
2	100.6	898.9	405930.72	0.00
3	100.9	900.0	405927.48	0.00
4	101.1	900.7	405924.23	0.00
5	101.2	901.2	405920.99	0.00
6	101.3	901.5	405917.74	0.00
7	101.4	901.7	405914.50	0.01
8	101.4	901.8	405911.25	0.01
9	101.3	901.6	405908.01	0.01
10	101.2	901.1	405904.76	0.01
11	101.0	900.3	405901.52	0.01

12	100.7	899.2	405898.28	0.01
13	100.3	897.8	405895.05	0.01
14	99.8	896.0	405891.83	0.01
15	99.3	893.9	405888.61	0.01
16	98.6	891.5	405885.40	0.01
17	97.9	888.8	405882.20	0.01
18	97.2	885.9	405879.01	0.01
19	96.3	882.8	405875.83	0.02
20	95.4	879.4	405872.67	0.02
21	94.5	875.9	405869.51	0.02
22	93.6	872.2	405866.37	0.02
23	92.6	868.4	405863.25	0.02
24	91.5	864.5	405860.13	0.02
25	90.5	860.5	405857.04	0.02
26	89.5	856.5	405853.95	0.02
27	88.4	852.3	405850.88	0.02
28	87.3	848.1	405847.83	0.02
29	86.2	843.9	405844.79	0.02
30	71.0	700.0	405842.27	0.02

****

* REVENUE & CASHFLOW PROFILE *

****

Year Electricity | Heat | Cooling | Carbon | Project

Since Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | OPEX Net Rev. Net Cashflow

Start (cents/kWh)(MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(USD/tonne) (MUSD/yr) (MUSD) |(MUSD/yr) (MUSD/yr) (MUSD)

____

1 0.00 -39.98 0.00 | 0.00 0.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 0.00 | 0.00 -39.98 -39.98

2 15.00 12.53 14.96 | 2.50 0.00 0.00 | 2.50 0.00 0.00 | 0.00 0.00 0.00 | 2.43 12.53 -27.44

3	15.00	12.67	30.06	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	12.67	-14.78
4	15.41	13.12	45.60	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	13.12	-1.65
5	15.81	13.56	61.59	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	13.56	11.91
6	16.22	13.99	78.01	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	13.99	25.90
7	16.62	14.42	94.85	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	14.42	40.31
8	17.03	14.84	112.12	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	14.84	55.15
9	17.43	15.25	129.79	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	15.25	70.40
10	17.84	15.65	147.87	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	15.65	86.05
11	18.24	16.04	166.33	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	16.04	102.09
12	18.65	16.41	185.17	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	16.41	118.49
13	19.05	16.76	204.35	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	16.76	135.26
14	19.46	17.09	223.87	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	17.09	152.35
15	19.86	17.41	243.71	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	17.41	169.76
16	20.27	17.70	263.83	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	17.70	187.45
17	20.67	17.97	284.23	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	17.97	205.42
18	21.08	18.22	304.87	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	18.22	223.64
19	21.49	18.45	325.75	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	18.45	242.09
20	21.89	18.66	346.83	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	18.66	260.75
21	22.30	18.85	368.12	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	18.85	279.60
22	22.70	19.03	389.57	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.43	19.03	298.64

```
 23    23.11        19.19  411.19    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.19    317.83

 24    23.51        19.34  432.96    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.34    337.16

 25    23.92        19.47  454.85    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.47    356.63

 26    24.32        19.59  476.87    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.59    376.22

 27    24.73        19.69  498.99    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.69    395.91

 28    25.13        19.79  521.20    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.79    415.70

 29    25.54        19.87  543.50    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.87    435.57

 30    25.94        19.94  565.86    |   2.50    0.00       0.00   |   2.50    0.00       0.00   |   0.00    0.00       0.00    | 2.43
19.94    455.51
```

6. Appendix 6: "Border" region, Basement Reservoir, Advanced Geothermal System (AGS/Closed Loop) style

```
Hot_AGS_200C_Electricity_input.txt
-----------------------------------------------------------------------------------------
GEOPHIRES v3.0 Input File
Geothermal Electricity Example Problem using Percentage Thermal Drawdown Model (Example X) and closed loops
Oringinally created by NREL on 3/26/2018 as Example 4
Last modified on 2/26/2023
-----------------------------------------------------------------------------------------
*** closed loop parameters ***
****************************************
Is AGS, True
Well Geometry Configuration, 1
Has Nonvertical Section, True
Multilaterals Cased, False
Reservoir Stimulation Capital Cost, 0.0
Exploration Capital Cost, 0.0
Plant Lifetime, 30, ---Years
Water Thermal Conductivity, 0.7
Total Nonvertical Length, 6200
Nonvertical Wellbore Diameter, 8.5, -----inch
Cylindrical Reservoir Radius of Effect Factor, 1.0
Closed Loop Calculation Start Year, 0.1
Number of Multilateral Sections, 10
Well Drilling Cost Correlation,3,                    --- [-] Use built-in well drilling cost correlation #3 =
vertical open-hole, large diameter
Horizontal Well Drilling Cost Correlation,1,                    --- [-] Use built-in well drilling cost
correlation #3 = vertical open-hole, large diameter
Reservoir Impedance, 1E-4, ----assume a very low reservoir impedance since the working fluid is never in contact with the
reservoir
Production Flow Rate per Well, 90,     -----kg/sec
Injection Temperature, 40,      -----C
Number of Segments,3,                    ---[-]
Gradient 1,42.69972,                ---[deg.C/km]
Gradient 2,51.66667,                ---[deg.C/km]
Thickness 1,0.793,                  ---[km]
Gradient 3,46.9697,                 ---[deg.C/km]
Thickness 2,1.2,                    ---[km]
Reservoir Depth, 3.7,     ----km
Cylindrical Reservoir Input Depth, 3.7, -----km
Cylindrical Reservoir Output Depth, 3.7, ------km
Cylindrical Reservoir Length, 6.2,     ----km
Reservoir Model,0,                  ---simople cylinder reservoir model
Number of Production Wells,1,       ---[-]
Number of Injection Wells,1,        ---[-]
Reservoir Thermal Conductivity,3.3,          ---[W/m/K]

*** Subsurface technical parameters ***
****************************************
Ramey Production Wellbore Model,0,   --- Should be 0 (disable) or 1 (enable)
Production Wellbore Temperature Drop,0,      --- [deg.C]
Production Flow Rate per Well,90,      --- [kg/s]
Maximum Temperature,400,               --- [deg.C]
Reservoir Volume Option,4,             --- Should be 1 2 3 or 4. See manual for details.
Reservoir Volume,1e9,                  --- [m3] (required for reservoir volume option 3 and 4
Reservoir Heat Capacity,975,           --- [J/kg/K]
```

```
*** Surface technical parameters ***
************************************
End-Use Option,1,                --- [-] Electricity
Power Plant Type,2,                       --- [1] Subcritical ORC
Circulation Pump Efficiency,0.8,   --- [-]
Plant Outlet Pressure, 68.95

*** Economic/Financial Parameters ***
*************************************
Economic Model,1,                --- Should be 1 (FCR model) 2 (Standard LCOE/LCOH model) or 3 (Bicycle model).
Plant Lifetime,30,                                   ---[years]
Fixed Charge Rate,.05,                                       ---[-] between 0 and 1
Inflation Rate During Construction,0,           ---[-]
Starting Electricity Sale Price,0.15
Ending Electricity Sale Price,1.00
Electricity Escalation Start Year,1
Electricity Escalation Rate Per Year, 0.004053223
Investment Tax Credit Rate, 0.5

*** Simulation Parameters ***
Print Output to Console,1,       --- [-] Should be 0 (don't print results to console) or 1 (print results to console)


                 *****************
                 ***CASE REPORT***
                 *****************

Simulation Metadata
----------------------
 GEOPHIRES Version: 3.4.25
 GEOPHIRES Build Date: 2024-03-05
 Simulation Date: 2024-05-06
 Simulation Time:  09:45
 Calculation Time:      2.635 sec

                  ***SUMMARY OF RESULTS***

      End-Use Option: Electricity
      Average Net Electricity Production:               5.54 MW
      Electricity breakeven price:                   13.53 cents/kWh
      Number of production wells:                        1
      Number of injection wells:                       1
      Flowrate per production well:                  90.0 kg/sec
      Well depth (or total length, if not vertical):       3.7 kilometer
      Geothermal gradient:                          0.0427 degC/m


                  ***ECONOMIC PARAMETERS***

      Economic Model = Fixed Charge Rate (FCR)
      Fixed Charge Rate (FCR):                    5.00
      Accrued financing during construction:             0.00
      Project lifetime:                      30 yr
      Capacity factor:                      90.0 %
      Project NPV:                         7.32 MUSD
      Project IRR:                        7.07 %
      Project VIR=PI=PIR:                    1.10
```

Project MOIC: 0.89
Project Payback Period: 14.66 yr

ENGINEERING PARAMETERS

Number of Production Wells: 1
Number of Injection Wells: 1
Well depth (or total length, if not vertical): 3.7 kilometer
Water loss rate: 0.0
Pump efficiency: 80.0
Injection temperature: 40.0 degC
User-provided production well temperature drop
Constant production well temperature drop: 0.0 degC
Flowrate per production well: 90.0 kg/sec
Injection well casing ID: 8.000 in
Production well casing ID: 8.000 in
Number of times redrilling: 0
Power plant type: Supercritical ORC

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 1
Geothermal gradient: 0.0427 degC/m

RESERVOIR PARAMETERS

The AGS models contain an intrinsic reservoir model that doesn't expose values that can be used in extensive reporting.

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 173.0 degC
Average Production Temperature: 173.0 degC
Minimum Production Temperature: 172.9 degC
Initial Production Temperature: 173.0 degC
The AGS models contain an intrinsic reservoir model that doesn't expose values that can be used in extensive reporting.

CAPITAL COSTS (M$)

Drilling and completion costs: 121.05 MUSD
Drilling and completion costs per vertical production well: 9.21 MUSD
Drilling and completion costs per vertical injection well: 9.21 MUSD
Drilling and completion costs per non-vertical sections: 96.86 MUSD
Stimulation costs: 0.00 MUSD
Surface power plant costs: 20.46 MUSD
Field gathering system costs: 0.98 MUSD
Total surface equipment costs: 21.43 MUSD
Exploration costs: 0.00 MUSD
Investment Tax Credit: -71.24 MUSD
Total capital costs: 71.24 MUSD
Annualized capital costs: 3.56 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 1.41 MUSD/yr
Power plant maintenance costs: 0.89 MUSD/yr
Water costs: 0.00 MUSD/yr
Total operating and maintenance costs: 2.30 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Initial geofluid availability: 0.13 MW/(kg/s)
Maximum Total Electricity Generation: 5.55 MW
Average Total Electricity Generation: 5.55 MW
Minimum Total Electricity Generation: 5.54 MW
Initial Total Electricity Generation: 5.55 MW
Maximum Net Electricity Generation: 5.55 MW
Average Net Electricity Generation: 5.54 MW
Minimum Net Electricity Generation: 5.54 MW
Initial Net Electricity Generation: 5.55 MW
Average Annual Total Electricity Generation: 43.36 GWh
Average Annual Net Electricity Generation: 43.35 GWh
Initial pumping power/net installed power: 0.02 %
Average Pumping Power: 0.00 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (degC)	PUMP POWER (MW)	NET POWER (MW)	FIRST LAW EFFICIENCY (%)
1	1.0000	172.99	0.0010	5.5466	11.2775
2	1.0000	172.99	0.0010	5.5465	11.2775
3	1.0000	172.99	0.0010	5.5464	11.2773
4	1.0000	172.98	0.0010	5.5462	11.2772
5	1.0000	172.98	0.0010	5.5460	11.2770
6	1.0000	172.98	0.0010	5.5459	11.2768
7	0.9999	172.98	0.0010	5.5458	11.2767
8	0.9999	172.98	0.0010	5.5456	11.2765
9	0.9999	172.98	0.0010	5.5455	11.2763
10	0.9999	172.98	0.0010	5.5453	11.2762
11	0.9999	172.97	0.0010	5.5452	11.2761
12	0.9999	172.97	0.0010	5.5451	11.2759
13	0.9999	172.97	0.0010	5.5450	11.2758
14	0.9999	172.97	0.0010	5.5448	11.2757
15	0.9999	172.97	0.0010	5.5447	11.2755
16	0.9999	172.97	0.0010	5.5446	11.2754
17	0.9999	172.97	0.0010	5.5445	11.2753
18	0.9999	172.96	0.0010	5.5444	11.2752
19	0.9999	172.96	0.0010	5.5443	11.2750
20	0.9998	172.96	0.0010	5.5442	11.2749
21	0.9998	172.96	0.0010	5.5441	11.2748
22	0.9998	172.96	0.0010	5.5440	11.2747
23	0.9998	172.96	0.0010	5.5439	11.2746
24	0.9998	172.96	0.0010	5.5438	11.2745
25	0.9998	172.96	0.0010	5.5437	11.2744
26	0.9998	172.96	0.0010	5.5436	11.2743
27	0.9998	172.95	0.0010	5.5435	11.2742
28	0.9998	172.95	0.0010	5.5434	11.2741
29	0.9998	172.95	0.0010	5.5433	11.2740

30	0.9998	172.95	0.0010	5.5432	11.2739

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	ELECTRICITY PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	43.7	387.8	55.61	2.45
2	43.7	387.7	54.22	4.90
3	43.7	387.7	52.82	7.35
4	43.7	387.7	51.42	9.79
5	43.7	387.7	50.03	12.24
6	43.7	387.7	48.63	14.69
7	43.7	387.7	47.24	17.14
8	43.7	387.7	45.84	19.59
9	43.7	387.7	44.44	22.04
10	43.7	387.7	43.05	24.49
11	43.7	387.7	41.65	26.93
12	43.7	387.7	40.26	29.38
13	43.7	387.7	38.86	31.83
14	43.7	387.7	37.47	34.28
15	43.7	387.7	36.07	36.73
16	43.7	387.7	34.67	39.17
17	43.7	387.7	33.28	41.62
18	43.7	387.7	31.88	44.07
19	43.7	387.7	30.49	46.52
20	43.7	387.7	29.09	48.97
21	43.7	387.7	27.70	51.42
22	43.7	387.7	26.30	53.86
23	43.7	387.7	24.91	56.31
24	43.7	387.7	23.51	58.76
25	43.7	387.7	22.11	61.21
26	43.7	387.7	20.72	63.66
27	43.7	387.7	19.32	66.10
28	43.7	387.7	17.93	68.55
29	43.7	387.6	16.53	71.00
30	32.8	290.8	15.49	72.84

****
* REVENUE & CASHFLOW PROFILE *
****

Year Electricity | Heat | Cooling | Carbon | Project
Since Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | OPEX Net Rev. Net Cashflow
Start (cents/kWh)(MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(USD/tonne) (MUSD/yr) (MUSD) |(MUSD/yr) (MUSD/yr) (MUSD)

____

1 0.00 -71.24 0.00 | 0.00 0.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 0.00 | 0.00 -71.24 -71.24
2 15.00 4.26 6.56 | 2.50 0.00 0.00 | 2.50 0.00 0.00 | 0.00 0.00 0.00 | 2.30 4.26 -66.98
3 15.00 4.26 13.12 | 2.50 0.00 0.00 | 2.50 0.00 0.00 | 0.00 0.00 0.00 | 2.30 4.26 -62.73

```
 4   15.41      4.43  19.86   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
4.43   -58.29
 5   15.81      4.61  26.77   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
4.61   -53.68
 6   16.22      4.79  33.86   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
4.79   -48.90
 7   16.62      4.96  41.13   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
4.96   -43.93
 8   17.03      5.14  48.57   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
5.14   -38.79
 9   17.43      5.32  56.19   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
5.32   -33.47
 10   17.84      5.50  63.99   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
5.50   -27.98
 11   18.24      5.67  71.97   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
5.67   -22.30
 12   18.65      5.85  80.12   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
5.85   -16.45
 13   19.05      6.03  88.45   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
6.03   -10.43
 14   19.46      6.20  96.95   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
6.20   -4.22
 15   19.86      6.38  105.64   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
6.38    2.16
 16   20.27      6.56  114.50   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
6.56    8.71
 17   20.67      6.73  123.54   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
6.73   15.45
 18   21.08      6.91  132.75   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
6.91   22.36
 19   21.49      7.09  142.14   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
7.09   29.45
 20   21.89      7.27  151.71   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
7.27   36.72
 21   22.30      7.44  161.46   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
7.44   44.16
 22   22.70      7.62  171.38   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
7.62   51.78
 23   23.11      7.80  181.48   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
7.80   59.57
 24   23.51      7.97  191.75   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
7.97   67.55
 25   23.92      8.15  202.21   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
8.15   75.70
 26   24.32      8.33  212.84   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
8.33   84.03
 27   24.73      8.50  223.65   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
8.50   92.53
 28   25.13      8.68  234.63   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
8.68   101.21
 29   25.54      8.86  245.79   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
8.86   110.07
 30   25.94      9.03  257.13   |  2.50   0.00    0.00  |  2.50   0.00    0.00  |  0.00   0.00    0.00  | 2.30
9.03   119.11
```

7. Appendix 7: "Interior" region, Advanced Geothermal System (AGS/Closed Loop) style

GEOPHIRES_Presidio_warm_basement_AGS_electricity.txt

```
-----------------------------------------------------------------------------------------
GEOPHIRES v3.0 Input File
Geothermal Electricity Example Problem using Percentage Thermal Drawdown Model (Example X) and closed loops
Oringinally created by NREL on 3/26/2018 as Example 4
Last modified on 2/26/2023

-----------------------------------------------------------------------------------------
*** closed loop parameters ***
****************************************
Exploration Capital Cost, 0.0
Reservoir Stimulation Capital Cost, 0.0
Is AGS, True
Well Geometry Configuration, 1
Has Nonvertical Section, True
Multilaterals Cased, False
Plant Lifetime, 30, ---Years
Water Thermal Conductivity, 0.7
Total Nonvertical Length, 6200.0
Nonvertical Wellbore Diameter, 8.5, -----inch
Cylindrical Reservoir Radius of Effect Factor, 1.0
Closed Loop Calculation Start Year, 0.1
Number of Multilateral Sections, 10
Well Drilling Cost Correlation,3,                 --- [-] Use built-in well drilling cost correlation #3 =
vertical open-hole, large diameter
Horizontal Well Drilling Cost Correlation,1,                 --- [-] Use built-in well drilling cost
correlation #3 = vertical open-hole, large diameter
Reservoir Impedance, 1E-4, ----assume a very low reservoir impedance since the working fluid is never in contact with the
reservoir
Production Flow Rate per Well, 90,     -----kg/sec
Injection Temperature, 40,     -----C
Number of Segments,3,                 ---[-]
Gradient 1,26.17,                 ---[deg.C/km]
Gradient 2,31.66,                 ---[deg.C/km]
Thickness 1,1.457,                 ---[km]
Gradient 3,28.78,                 ---[deg.C/km]
Thickness 2,6.001,                 ---[km]
Reservoir Depth, 6.0,     ----km
Cylindrical Reservoir Input Depth, 6.0, -----km
Cylindrical Reservoir Output Depth, 6.0, ------km
Cylindrical Reservoir Length, 6.2,     ----km
Reservoir Model,0,                 ---simople cylinder reservoir model
Number of Production Wells,1,                 ---[-]
Number of Injection Wells,1,                 ---[-]
Reservoir Thermal Conductivity,3.3,                 ---[W/m/K]

*** Subsurface technical parameters ***
****************************************
Ramey Production Wellbore Model,0,   --- Should be 0 (disable) or 1 (enable)
Production Wellbore Temperature Drop,0,          --- [deg.C]
Production Flow Rate per Well,90,        --- [kg/s]
Maximum Temperature,400,         --- [deg.C]
Reservoir Volume Option,4,         --- Should be 1 2 3 or 4. See manual for details.
Reservoir Volume,1e9,                 --- [m3] (required for reservoir volume option 3 and 4
Reservoir Heat Capacity,975,         --- [J/kg/K]
```

```
*** Surface technical parameters ***
************************************
End-Use Option,1,                      --- [-] Electricity
Power Plant Type,2,                            --- [1] Subcritical ORC
Circulation Pump Efficiency,0.8,       --- [-]
Plant Outlet Pressure, 68.95

*** Economic/Financial Parameters ***
*************************************
Economic Model,1,                      --- Should be 1 (FCR model) 2 (Standard LCOE/LCOH model) or 3 (Bicycle model).
Plant Lifetime,30,                                         ---[years]
Fixed Charge Rate,.05,                                             ---[-] between 0 and 1
Inflation Rate During Construction,0,                  ---[-]
Starting Electricity Sale Price,0.15
Ending Electricity Sale Price,1.00
Electricity Escalation Start Year,1
Electricity Escalation Rate Per Year, 0.004053223
Investment Tax Credit Rate, 0.5

*** Simulation Parameters ***
Print Output to Console,1,             --- [-] Should be 0 (don't print results to console) or 1 (print results to console)

GEOPHIRES_Presidio_warm_basement_AGS_electricity_Result.txt
                 *****************
                 ***CASE REPORT***
                 *****************

Simulation Metadata
----------------------
 GEOPHIRES Version: 3.4.25
 GEOPHIRES Build Date: 2024-03-05
 Simulation Date: 2024-05-06
 Simulation Time:  09:02
 Calculation Time:    102.577 sec

               ***SUMMARY OF RESULTS***

   End-Use Option: Electricity
   Average Net Electricity Production:                5.46 MW
   Electricity breakeven price:                   15.28 cents/kWh
   Number of production wells:                      1
   Number of injection wells:                      1
   Flowrate per production well:                  90.0 kg/sec
   Well depth (or total length, if not vertical):        6.0 kilometer
   Geothermal gradient:                          0.0262 degC/m


               ***ECONOMIC PARAMETERS***

   Economic Model = Fixed Charge Rate (FCR)
   Fixed Charge Rate (FCR):                      5.00
   Accrued financing during construction:              0.00
   Project lifetime:                        30 yr
   Capacity factor:                        90.0 %
   Project NPV:                           -6.35 MUSD
   Project IRR:                           5.60 %
   Project VIR=PI=PIR:                       0.92
```

Project MOIC: 0.68
Project Payback Period: 16.83 yr

ENGINEERING PARAMETERS

Number of Production Wells: 1
Number of Injection Wells: 1
Well depth (or total length, if not vertical): 6.0 kilometer
Water loss rate: 0.0
Pump efficiency: 80.0
Injection temperature: 40.0 degC
User-provided production well temperature drop
Constant production well temperature drop: 0.0 degC
Flowrate per production well: 90.0 kg/sec
Injection well casing ID: 8.000 in
Production well casing ID: 8.000 in
Number of times redrilling: 0
Power plant type: Supercritical ORC

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 1
Geothermal gradient: 0.0262 degC/m

RESERVOIR PARAMETERS

The AGS models contain an intrinsic reservoir model that doesn't expose values that can be used in extensive reporting.

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 172.0 degC
Average Production Temperature: 172.0 degC
Minimum Production Temperature: 172.0 degC
Initial Production Temperature: 172.0 degC
The AGS models contain an intrinsic reservoir model that doesn't expose values that can be used in extensive reporting.

CAPITAL COSTS (M$)

Drilling and completion costs: 140.41 MUSD
Drilling and completion costs per vertical production well: 18.43 MUSD
Drilling and completion costs per vertical injection well: 18.43 MUSD
Drilling and completion costs per non-vertical sections: 96.86 MUSD
Stimulation costs: 0.00 MUSD
Surface power plant costs: 20.17 MUSD
Field gathering system costs: 0.98 MUSD
Total surface equipment costs: 21.15 MUSD
Exploration costs: 0.00 MUSD
Investment Tax Credit: -80.78 MUSD
Total capital costs: 80.78 MUSD
Annualized capital costs: 4.04 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 1.61 MUSD/yr
Power plant maintenance costs: 0.88 MUSD/yr
Water costs: 0.00 MUSD/yr
Total operating and maintenance costs: 2.48 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Initial geofluid availability: 0.13 MW/(kg/s)
Maximum Total Electricity Generation: 5.46 MW
Average Total Electricity Generation: 5.46 MW
Minimum Total Electricity Generation: 5.46 MW
Initial Total Electricity Generation: 5.46 MW
Maximum Net Electricity Generation: 5.46 MW
Average Net Electricity Generation: 5.46 MW
Minimum Net Electricity Generation: 5.46 MW
Initial Net Electricity Generation: 5.46 MW
Average Annual Total Electricity Generation: 42.68 GWh
Average Annual Net Electricity Generation: 42.66 GWh
Initial pumping power/net installed power: 0.03 %
Average Pumping Power: 0.00 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (degC)	PUMP POWER (MW)	NET POWER (MW)	FIRST LAW EFFICIENCY (%)
1	1.0000	172.02	0.0014	5.4589	11.4580
2	1.0000	172.02	0.0014	5.4588	11.4579
3	1.0000	172.02	0.0014	5.4587	11.4578
4	1.0000	172.02	0.0014	5.4585	11.4576
5	1.0000	172.01	0.0014	5.4584	11.4574
6	1.0000	172.01	0.0014	5.4582	11.4572
7	0.9999	172.01	0.0014	5.4581	11.4571
8	0.9999	172.01	0.0014	5.4579	11.4569
9	0.9999	172.01	0.0014	5.4578	11.4568
10	0.9999	172.01	0.0014	5.4576	11.4566
11	0.9999	172.00	0.0014	5.4575	11.4565
12	0.9999	172.00	0.0014	5.4574	11.4563
13	0.9999	172.00	0.0014	5.4573	11.4562
14	0.9999	172.00	0.0014	5.4571	11.4560
15	0.9999	172.00	0.0014	5.4570	11.4559
16	0.9999	172.00	0.0014	5.4569	11.4558
17	0.9999	172.00	0.0014	5.4568	11.4556
18	0.9999	172.00	0.0014	5.4567	11.4555
19	0.9999	171.99	0.0014	5.4566	11.4554
20	0.9998	171.99	0.0014	5.4565	11.4553
21	0.9998	171.99	0.0014	5.4564	11.4552
22	0.9998	171.99	0.0014	5.4563	11.4550
23	0.9998	171.99	0.0014	5.4562	11.4549
24	0.9998	171.99	0.0014	5.4561	11.4548
25	0.9998	171.99	0.0014	5.4560	11.4547
26	0.9998	171.99	0.0014	5.4559	11.4546
27	0.9998	171.99	0.0014	5.4558	11.4545
28	0.9998	171.98	0.0014	5.4557	11.4544
29	0.9998	171.98	0.0014	5.4556	11.4543

30	0.9998	171.98	0.0014	5.4555	11.4542

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	ELECTRICITY PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	43.0	375.6	55.24	2.39
2	43.0	375.6	53.89	4.78
3	43.0	375.6	52.54	7.17
4	43.0	375.6	51.18	9.56
5	43.0	375.6	49.83	11.95
6	43.0	375.6	48.48	14.34
7	43.0	375.6	47.13	16.73
8	43.0	375.6	45.77	19.11
9	43.0	375.6	44.42	21.50
10	43.0	375.6	43.07	23.89
11	43.0	375.6	41.72	26.28
12	43.0	375.6	40.37	28.67
13	43.0	375.6	39.01	31.06
14	43.0	375.6	37.66	33.45
15	43.0	375.6	36.31	35.84
16	43.0	375.5	34.96	38.23
17	43.0	375.5	33.61	40.62
18	43.0	375.5	32.25	43.00
19	43.0	375.5	30.90	45.39
20	43.0	375.5	29.55	47.78
21	43.0	375.5	28.20	50.17
22	43.0	375.5	26.85	52.56
23	43.0	375.5	25.50	54.95
24	43.0	375.5	24.14	57.34
25	43.0	375.5	22.79	59.73
26	43.0	375.5	21.44	62.12
27	43.0	375.5	20.09	64.50
28	43.0	375.5	18.74	66.89
29	43.0	375.5	17.38	69.28
30	32.3	281.7	16.37	71.07

****
* REVENUE & CASHFLOW PROFILE *
****

Year Since Start	Electricity Price (cents/kWh)	Electricity Ann. Rev. (MUSD/yr)	Electricity Cumm. Rev. (MUSD)	Heat Price (cents/kWh)	Heat Ann. Rev. (MUSD/yr)	Heat Cumm. Rev. (MUSD)	Cooling Price (cents/kWh)	Cooling Ann. Rev. (MUSD/yr)	Cooling Cumm. Rev. (MUSD)	Carbon Price (USD/tonne)	Carbon Ann. Rev. (MUSD/yr)	Carbon Cumm. Rev. (MUSD)	Project OPEX (MUSD/yr)	Project Net Rev. (MUSD/yr)	Project Net Cashflow (MUSD)
1	0.00	-80.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-80.78	-80.78
2	15.00	3.97	6.46	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	3.97	-76.81
3	15.00	3.97	12.91	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	3.97	-72.83

4	15.41	4.15	19.54	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	4.15	-68.69
5	15.81	4.32	26.35	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	4.32	-64.36
6	16.22	4.50	33.32	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	4.50	-59.87
7	16.62	4.67	40.48	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	4.67	-55.20
8	17.03	4.84	47.80	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	4.84	-50.35
9	17.43	5.02	55.30	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	5.02	-45.33
10	17.84	5.19	62.98	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	5.19	-40.14
11	18.24	5.37	70.83	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	5.37	-34.77
12	18.65	5.54	78.85	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	5.54	-29.23
13	19.05	5.72	87.05	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	5.72	-23.52
14	19.46	5.89	95.42	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	5.89	-17.63
15	19.86	6.06	103.97	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	6.06	-11.56
16	20.27	6.24	112.69	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	6.24	-5.32
17	20.67	6.41	121.58	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	6.41	1.09
18	21.08	6.59	130.65	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	6.59	7.68
19	21.49	6.76	139.89	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	6.76	14.44
20	21.89	6.94	149.31	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	6.94	21.37
21	22.30	7.11	158.90	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	7.11	28.48
22	22.70	7.28	168.67	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	7.28	35.77
23	23.11	7.46	178.61	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	7.46	43.22
24	23.51	7.63	188.72	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	7.63	50.85
25	23.92	7.81	199.01	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	7.81	58.66
26	24.32	7.98	209.47	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	7.98	66.64
27	24.73	8.15	220.11	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	8.15	74.80
28	25.13	8.33	230.92	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	8.33	83.12
29	25.54	8.50	241.90	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	8.50	91.63
30	25.94	8.68	253.06	2.50	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.48	8.68	100.30

8. Appendix 8: "Border" region, PzMz Reservoir, Agri-food processing plant – targeted heat production temperature of 240C.

GEOPHIRES_Presidio_hot_DU_Agriprocessing.txt

```
***Subsurface technical parameters***
****************************************
Reservoir Model,1,                                  ---Multiple Fractures reservoir model
Reservoir Depth,4.7,                                        ---[km]
Number of Segments,3,                                       ---[-]
Gradient 1,42.69972,                                ---[deg.C/km]
Gradient 2,51.66667,                                ---[deg.C/km]
Thickness 1,0.793,                                  ---[km]
Gradient 3,46.9697,                                 ---[deg.C/km]
Thickness 2,1.646,                                  ---[km]
Maximum Temperature,400,                            ---[deg.C]
Number of Production Wells,1,                       ---[-]
Number of Injection Wells,1,                        ---[-]
Production Well Diameter,8.5,                                       ---[inch]
Injection Well Diameter,8.5,                                ---[inch]
Ramey Production Wellbore Model,1,                          ---0 if disabled  1 if enabled
Production Wellbore Temperature Drop,.5,                    ---[deg.C]
Injection Wellbore Temperature Gain,0,                      ---[deg.C]
Production Flow Rate per Well,55,                   ---[kg/s]
Fracture Shape,3,                                   ---[-] Should be 1 2 3 or 4. See manual for details
Fracture Height,900,                                                ---[m]
Reservoir Volume Option,3,                          ---[-] Should be 1 2 3 or 4. See manual for details
Number of Fractures,20,                                             ---[-]
Reservoir Volume,1000000000,                                        ---[m^3]
Water Loss Fraction,.02,                                    ---[-]
Productivity Index,5,                                               ---[kg/s/bar]
Injectivity Index,5,                                        ---[kg/s/bar]
Injection Temperature,50,                                   ---[deg.C]
Maximum Drawdown,1,                                                 ---[-] no redrilling considered
Reservoir Heat Capacity,1000,                                       ---[J/kg/K]
Reservoir Density,2700,                                             ---[kg/m^3]
Reservoir Thermal Conductivity,2.7,                         ---[W/m/K]

***Surface Technical Parameters***
*************************************
End-Use Option,2,                                           ---Direct Use Heat
Circulation Pump Efficiency,.8,                                     ---[-]
Utilization Factor,.9,                                              ---[-]
End-Use Efficiency Factor,.9,                               ---[-]
Surface Temperature,20,                                             ---[deg.C]
Ambient Temperature,20,                                             ---[deg.C]

***FINANCIAL PARAMETERS***
***************************
Plant Lifetime,30,                                          ---[years]
Economic Model,1,                                           ---[-] Fixed Charge Rate Model
Fixed Charge Rate,.05,                                              ---[-] between 0 and 1
Inflation Rate During Construction,0,               ---[-]
Starting Electricity Sale Price,0.15
Ending Electricity Sale Price,1.00
Electricity Escalation Start Year,1
```

Electricity Escalation Rate Per Year, 0.004053223
Starting Heat Sale Price, 0.12192
Ending Heat Sale Price, 10.0
Heat Escalation Start Year, 1
Heat Escalation Rate Per Year, 0.003327033
Investment Tax Credit Rate, 0.5

CAPITAL AND O&M COST PARAMETERS
****
Well Drilling and Completion Capital Cost Adjustment Factor,1, ---[-] Use built-in correlations
Well Drilling Cost Correlation,1, ---[-] Use built-in correlations
Reservoir Stimulation Capital Cost Adjustment Factor,1, ---[-] Use built-in correlations
Surface Plant Capital Cost Adjustment Factor,1, ---[-] Use built-in correlations
Field Gathering System Capital Cost Adjustment Factor,1, ---[-] Use built-in correlations
Exploration Capital Cost Adjustment Factor,1, ---[-] Use built-in correlations
Wellfield O&M Cost Adjustment Factor,1, ---[-] Use built-in correlations
Surface Plant O&M Cost Adjustment Factor,1, ---[-] Use built-in correlations
Water Cost Adjustment Factor,1, ---[-] Use built-in correlations

Simulation Parameters
****

Print Output to Console,1, ---[-] Should be 0 (don't print results) or 1 (print results)
Time steps per year,6, ---[1/year]

GEOPHIRES_Presidio_hot_DU_Agriprocessing_Result.txt

****
CASE REPORT
****

Simulation Metadata

GEOPHIRES Version: 3.4.25
GEOPHIRES Build Date: 2024-03-05
Simulation Date: 2024-05-06
Simulation Time: 10:08
Calculation Time: 1.361 sec

SUMMARY OF RESULTS

End-Use Option: Direct-Use Heat
Average Direct-Use Heat Production: 37.45 MW
Direct-Use heat breakeven price (LCOH): 2.72 USD/MMBTU
Number of production wells: 1
Number of injection wells: 1
Flowrate per production well: 55.0 kg/sec
Well depth (or total length, if not vertical): 4.7 kilometer
Segment 1 Geothermal gradient: 0.0427 degC/m
Segment 1 Thickness: 793 meter
Segment 2 Geothermal gradient: 0.0517 degC/m
Segment 2 Thickness: 1646 meter
Segment 3 Geothermal gradient: 0.0470 degC/m

ECONOMIC PARAMETERS

Economic Model = Fixed Charge Rate (FCR)
Fixed Charge Rate (FCR): 5.00
Accrued financing during construction: 0.00
Project lifetime: 30 yr
Capacity factor: 90.0 %
Project NPV: 558.61 MUSD
Project IRR: 147.29 %
Project VIR=PI=PIR: 24.97
Project MOIC: 20.54
Project Payback Period: 1.69 yr

ENGINEERING PARAMETERS

Number of Production Wells: 1
Number of Injection Wells: 1
Well depth (or total length, if not vertical): 4.7 kilometer
Water loss rate: 2.0
Pump efficiency: 80.0
Injection temperature: 50.0 degC
Production Wellbore heat transmission calculated with Ramey's model
Average production well temperature drop: 7.4 degC
Flowrate per production well: 55.0 kg/sec
Injection well casing ID: 8.500 in
Production well casing ID: 8.500 in
Number of times redrilling: 0

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 3
Segment 1 Geothermal gradient: 0.0427 degC/m
Segment 1 Thickness: 793 meter
Segment 2 Geothermal gradient: 0.0517 degC/m
Segment 2 Thickness: 1646 meter
Segment 3 Geothermal gradient: 0.0470 degC/m

RESERVOIR PARAMETERS

Reservoir Model = Multiple Parallel Fractures Model
Bottom-hole temperature: 245.10 degC
Fracture model = Square
Well separation: fracture height: 900.00 meter
Fracture area: 810000.00 m**2
Reservoir volume: 1000000000 m**3
Reservoir hydrostatic pressure: 45507.63 kPa
Plant outlet pressure: 3933.38 kPa
Production wellhead pressure: 4002.33 kPa
Productivity Index: 5.00 kg/sec/bar
Injectivity Index: 5.00 kg/sec/bar
Reservoir density: 2700.00 kg/m**3
Reservoir thermal conductivity: 2.70 W/m/K
Reservoir heat capacity: 1000.00 J/kg/K

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 238.4 degC
Average Production Temperature: 237.7 degC
Minimum Production Temperature: 233.3 degC
Initial Production Temperature: 233.3 degC
Average Reservoir Heat Extraction: 41.61 MW
Production Wellbore Heat Transmission Model = Ramey Model
Average Production Well Temperature Drop: 7.4 degC
Average Injection Well Pump Pressure Drop: -4643.1 kPa
Average Production Well Pump Pressure Drop: 1409.6 kPa

CAPITAL COSTS (M$)

Drilling and completion costs: 21.37 MUSD
Drilling and completion costs per well: 10.68 MUSD
Stimulation costs: 1.51 MUSD
Surface power plant costs: 13.45 MUSD
Field gathering system costs: 1.13 MUSD
Total surface equipment costs: 14.57 MUSD
Exploration costs: 9.15 MUSD
Investment Tax Credit: -23.30 MUSD
Total capital costs: 23.30 MUSD
Annualized capital costs: 1.16 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 0.49 MUSD/yr
Power plant maintenance costs: 0.98 MUSD/yr
Water costs: 0.03 MUSD/yr
Average Reservoir Pumping Cost: 0.06 MUSD/yr
Total operating and maintenance costs: 1.56 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Maximum Net Heat Production: 37.58 MW
Average Net Heat Production: 37.45 MW
Minimum Net Heat Production: 36.57 MW
Initial Net Heat Production: 36.57 MW
Average Annual Heat Production: 293.59 GWh
Average Pumping Power: 0.11 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (deg C)	PUMP POWER (MW)	NET HEAT (MW)
0	1.0000	233.32	0.1115	36.5698
1	1.0104	235.75	0.1096	37.0562
2	1.0134	236.45	0.1090	37.1944
3	1.0150	236.81	0.1087	37.2661
4	1.0160	237.04	0.1086	37.3135
5	1.0167	237.22	0.1084	37.3484
6	1.0173	237.36	0.1083	37.3759
7	1.0178	237.47	0.1082	37.3983

8	1.0182	237.56	0.1081	37.4173
9	1.0186	237.64	0.1081	37.4336
10	1.0189	237.72	0.1080	37.4479
11	1.0191	237.78	0.1080	37.4606
12	1.0194	237.84	0.1079	37.4720
13	1.0196	237.89	0.1079	37.4823
14	1.0198	237.94	0.1079	37.4917
15	1.0200	237.98	0.1078	37.5004
16	1.0202	238.02	0.1078	37.5084
17	1.0203	238.06	0.1078	37.5159
18	1.0205	238.09	0.1077	37.5228
19	1.0206	238.13	0.1077	37.5294
20	1.0207	238.16	0.1077	37.5355
21	1.0209	238.18	0.1077	37.5413
22	1.0210	238.21	0.1076	37.5467
23	1.0211	238.24	0.1076	37.5519
24	1.0212	238.26	0.1076	37.5568
25	1.0213	238.29	0.1076	37.5615
26	1.0214	238.31	0.1076	37.5660
27	1.0215	238.33	0.1075	37.5703
28	1.0216	238.35	0.1075	37.5744
29	1.0217	238.37	0.1075	37.5783

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	HEAT PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	290.5	322.7	525.62	0.22
2	292.8	325.3	524.44	0.44
3	293.5	326.2	523.27	0.67
4	294.0	326.7	522.09	0.89
5	294.3	327.0	520.92	1.11
6	294.6	327.3	519.74	1.34
7	294.8	327.5	518.56	1.56
8	294.9	327.7	517.38	1.78
9	295.1	327.8	516.20	2.01
10	295.2	328.0	515.02	2.23
11	295.3	328.1	513.84	2.46
12	295.4	328.2	512.66	2.68
13	295.5	328.3	511.47	2.91
14	295.5	328.4	510.29	3.13
15	295.6	328.5	509.11	3.35
16	295.7	328.5	507.93	3.58
17	295.7	328.6	506.74	3.80
18	295.8	328.7	505.56	4.03
19	295.9	328.7	504.38	4.25
20	295.9	328.8	503.19	4.48
21	296.0	328.8	502.01	4.70
22	296.0	328.9	500.83	4.93
23	296.0	328.9	499.64	5.15
24	296.1	329.0	498.46	5.38
25	296.1	329.0	497.27	5.60
26	296.2	329.1	496.09	5.83
27	296.2	329.1	494.90	6.05
28	296.2	329.1	493.72	6.28

29	296.3	329.2	492.53	6.50
30	246.9	274.3	491.55	6.69

****
* REVENUE & CASHFLOW PROFILE *
****

Year Since Start	Electricity Price (cents/kWh)	Electricity Ann. Rev. (MUSD/yr)	Electricity Cumm. Rev. (MUSD)	Heat Price (cents/kWh)	Heat Ann. Rev. (MUSD/yr)	Heat Cumm. Rev. (MUSD)	Cooling Price (cents/kWh)	Cooling Ann. Rev. (MUSD/yr)	Cooling Cumm. Rev. (MUSD)	Carbon Price (USD/tonne)	Carbon Ann. Rev. (MUSD/yr)	Carbon Cumm. Rev. (MUSD)	Project OPEX (MUSD/yr)	Project Net Rev. (MUSD/yr)	Project Net Cashflow (MUSD)
1	0.00	0.00	0.00	0.00	-23.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-23.30	-23.30
2	15.00	0.00	0.00	2.50	33.92	35.41	2.50	0.00	0.00	0.00	0.00	0.00	1.50	33.92	10.62
3	15.00	0.00	0.00	2.50	34.20	71.11	2.50	0.00	0.00	0.00	0.00	0.00	1.50	34.20	44.81
4	15.41	0.00	0.00	2.50	35.27	107.87	2.50	0.00	0.00	0.00	0.00	0.00	1.50	35.27	80.08
5	15.81	0.00	0.00	2.50	36.30	145.67	2.50	0.00	0.00	0.00	0.00	0.00	1.50	36.30	116.39
6	16.22	0.00	0.00	2.50	37.33	184.49	2.50	0.00	0.00	0.00	0.00	0.00	1.50	37.33	153.71
7	16.62	0.00	0.00	2.50	38.34	224.33	2.50	0.00	0.00	0.00	0.00	0.00	1.50	38.34	192.05
8	17.03	0.00	0.00	2.50	39.34	265.17	2.50	0.00	0.00	0.00	0.00	0.00	1.50	39.34	231.40
9	17.43	0.00	0.00	2.50	40.35	307.01	2.50	0.00	0.00	0.00	0.00	0.00	1.50	40.35	271.74
10	17.84	0.00	0.00	2.50	41.35	349.86	2.50	0.00	0.00	0.00	0.00	0.00	1.50	41.35	313.09
11	18.24	0.00	0.00	2.50	42.35	393.71	2.50	0.00	0.00	0.00	0.00	0.00	1.50	42.35	355.44
12	18.65	0.00	0.00	2.50	43.35	438.55	2.50	0.00	0.00	0.00	0.00	0.00	1.50	43.35	398.79
13	19.05	0.00	0.00	2.50	44.34	484.39	2.50	0.00	0.00	0.00	0.00	0.00	1.50	44.34	443.14
14	19.46	0.00	0.00	2.50	45.34	531.23	2.50	0.00	0.00	0.00	0.00	0.00	1.50	45.34	488.48
15	19.86	0.00	0.00	2.50	46.34	579.06	2.50	0.00	0.00	0.00	0.00	0.00	1.50	46.34	534.81
16	20.27	0.00	0.00	2.50	47.33	627.89	2.50	0.00	0.00	0.00	0.00	0.00	1.50	47.33	582.14
17	20.67	0.00	0.00	2.50	48.33	677.71	2.50	0.00	0.00	0.00	0.00	0.00	1.50	48.33	630.47
18	21.08	0.00	0.00	2.50	49.32	728.53	2.50	0.00	0.00	0.00	0.00	0.00	1.50	49.32	679.79
19	21.49	0.00	0.00	2.50	50.31	780.34	2.50	0.00	0.00	0.00	0.00	0.00	1.50	50.31	730.11
20	21.89	0.00	0.00	2.50	51.31	833.14	2.50	0.00	0.00	0.00	0.00	0.00	1.50	51.31	781.41
21	22.30	0.00	0.00	2.50	52.30	886.94	2.50	0.00	0.00	0.00	0.00	0.00	1.50	52.30	833.72
22	22.70	0.00	0.00	2.50	53.29	941.73	2.50	0.00	0.00	0.00	0.00	0.00	1.50	53.29	887.01

```
 23   23.11      0.00  0.00   |  2.50   54.29    997.51  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
54.29   941.30
 24   23.51      0.00  0.00   |  2.50   55.28    1054.29  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
55.28   996.58
 25   23.92      0.00  0.00   |  2.50   56.27    1112.06  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
56.27   1052.85
 26   24.32      0.00  0.00   |  2.50   57.27    1170.82  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
57.27   1110.12
 27   24.73      0.00  0.00   |  2.50   58.26    1230.58  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
58.26   1168.37
 28   25.13      0.00  0.00   |  2.50   59.25    1291.32  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
59.25   1227.63
 29   25.54      0.00  0.00   |  2.50   60.24    1353.06  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
60.24   1287.87
 30   25.94      0.00  0.00   |  2.50   61.24    1415.79  |  2.50   0.00     0.00   |  0.00   0.00     0.00  | 1.50
61.24   1349.10
```

9. Appendix 9: "Interior" region, PzMz reservoir, Combined Heat and Power (CHP) for a greenhouse complex for food/high-value crop production

GEOPHIRES_Presidio_Warm_PzMz_AGS_greenhouse.txt

```
***Subsurface technical parameters***
*************************************
Reservoir Model,3,                              ---m/A Single Fracture Thermal Drawdown
Drawdown Parameter,.00002,                      ---[kg/s/m2]
Reservoir Depth,3.1,                            ---[km]
Number of Segments,1,                           ---[-]
Maximum Temperature,400,                        ---[deg.C]
Number of Production Wells,1,                   ---[-]
Number of Injection Wells,1,                    ---[-]
Production Well Diameter,8.5,                   ---[inch]
Injection Well Diameter,8.5,                    ---[inch]
Ramey Production Wellbore Model,0,              ---Should be 0 (disabled) or 1 (enabled)
Production Wellbore Temperature Drop,5,         ---[deg.C]
Injection Wellbore Temperature Gain,3,          ---[deg.C]
Production Flow Rate per Well,55,               ---[kg/s]
Reservoir Volume Option,1,                      ---Should be 1 2 3 or 4. See manual for details.
Fracture Shape,1,                               ---Should be 1 2 3 or 4
Fracture Area,200000,                           ---[m2]
Number of Fractures,12,                         ---[-]
Fracture Separation,80,                         ---[m]
Injectivity Index,5,                            ---[kg/s/bar]
Injection Temperature,70,                       ---[deg.C]
Maximum Drawdown,1,                             ---[-] no redrilling considered
Reservoir Heat Capacity,1000,                   ---[J/kg/K]
Reservoir Density,3000,                         ---[kg/m3]
Reservoir Thermal Conductivity,3,               ---[W/m/K]
Water Loss Fraction,0.02,                       ---[-]
Number of Segments,3,                           ---[-]
Gradient 1,26.17079,                            ---[deg.C/km]
Gradient 2,31.6666,                             ---[deg.C/km]
Thickness 1,1.457,                              ---[km]
Gradient 3,28.787878,                           ---[deg.C/km]
Thickness 2,6.001,                              ---[km]


***Surface Technical Parameters***
**********************************

End-Use Option,52,                              ---CHP Parallel Cycle: The geothermal fluid flow splits
in two parts two serve an electricity generation cycle in parallel with direct-use heat, both at the same temperature.
Power Plant Type,1,                             ---subCrit ORC
Circulation Pump Efficiency,.80,                ---[-]
Utilization Factor,.9,                          ---[-]
End-Use Efficiency Factor,.9,                   ---[-]
Surface Temperature,15,                         ---[deg.C]
Ambient Temperature,15,                         ---[deg.C]

***Financial Parameters***
**************************

Plant Lifetime,30,                              ---[years]
Economic Model,3,                               ---BICYCLE Levelized Cost Model
Fraction of Investment in Bonds,.5,             ---[-] Required for BICYCLE model
```

```
Inflated Bond Interest Rate,.05,                        ---[-] Required for BICYCLE model
Inflated Equity Interest Rate,.08,                      ---[-] Required for BICYCLE model
Inflation Rate,.02,                                     ---[-] Required for BICYCLE model
Combined Income Tax Rate,.3,                                  ---[-] Required for BICYCLE model
Gross Revenue Tax Rate,0,                               ---[-] Required for BICYCLE model
Investment Tax Credit Rate,0,                                 ---[-] Required for BICYCLE model
Property Tax Rate,0,                                          ---[-] Required for BICYCLE model
Inflation Rate During Construction,0.05,                      ---[-]
Starting Electricity Sale Price,0.15
Ending Electricity Sale Price,1.00
Electricity Escalation Start Year,1
Electricity Escalation Rate Per Year, 0.004053223
Starting Heat Sale Price, 0.12192
Ending Heat Sale Price, 10.0
Heat Escalation Start Year, 1
Heat Escalation Rate Per Year, 0.003327033
Investment Tax Credit Rate, 0.5


***Capital and O&M Cost Parameters***
*************************************
Heat Rate,.02,                                                ---[$/kWh]

***Simulation Parameters***
***************************

Print Output to Console,1,                              ---Should be 1 (to print) or 0 (to not print)
Time steps per year,10,                                       ---[-]

GEOPHIRES_Presidio_Warm_PzMz_AGS_greenhouse_Result.txt

                    *****************
                    ***CASE REPORT***
                    *****************

Simulation Metadata
----------------------
 GEOPHIRES Version: 3.4.25
 GEOPHIRES Build Date: 2024-03-05
 Simulation Date: 2024-05-06
 Simulation Time:  10:11
 Calculation Time:      0.275 sec

                  ***SUMMARY OF RESULTS***

    End-Use Option: Cogeneration Parallel Cycle, Electricity sales considered as extra income
    Average Net Electricity Production:                  0.09 MW
    Average Direct-Use Heat Production:                  2.80 MW
    Electricity breakeven price:                  49.50 cents/kWh
    Direct-Use heat breakeven price (LCOH):              4.30 USD/MMBTU
    Number of production wells:                     1
    Number of injection wells:                      1
    Flowrate per production well:                   55.0 kg/sec
    Well depth (or total length, if not vertical):        3.1 kilometer
    Segment 1   Geothermal gradient:                 0.0262 degC/m
    Segment 1   Thickness:                    1457 meter
    Segment 2   Geothermal gradient:                 0.0317 degC/m
    Segment 2   Thickness:                    6001 meter
```

Segment 3 Geothermal gradient: 0.0288 degC/m

ECONOMIC PARAMETERS

Economic Model = BICYCLE
Accrued financing during construction: 5.00
Project lifetime: 30 yr
Capacity factor: 90.0 %
Project NPV: 32.90 MUSD
Project IRR: 29.89 %
Project VIR=PI=PIR: 4.68
Project MOIC: 4.30
Project Payback Period: 4.54 yr
CHP: Percent cost allocation for electrical plant: 52.72%

ENGINEERING PARAMETERS

Number of Production Wells: 1
Number of Injection Wells: 1
Well depth (or total length, if not vertical): 3.1 kilometer
Water loss rate: 2.0
Pump efficiency: 80.0
Injection temperature: 71.3 degC
User-provided production well temperature drop
Constant production well temperature drop: 5.0 degC
Flowrate per production well: 55.0 kg/sec
Injection well casing ID: 8.500 in
Production well casing ID: 8.500 in
Number of times redrilling: 0
Power plant type: Subcritical ORC

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 3
Segment 1 Geothermal gradient: 0.0262 degC/m
Segment 1 Thickness: 1457 meter
Segment 2 Geothermal gradient: 0.0317 degC/m
Segment 2 Thickness: 6001 meter
Segment 3 Geothermal gradient: 0.0288 degC/m

RESERVOIR PARAMETERS

Reservoir Model = Single Fracture m/A Thermal Drawdown Model
m/A Drawdown Parameter: 0.00002 1/year
Bottom-hole temperature: 105.16 degC
Reservoir volume calculated with fracture separation and number of fractures as input
Number of fractures: 12.00
Fracture separation: 80.00 meter
Reservoir volume: 176000000 m**3
Reservoir hydrostatic pressure: 31243.93 kPa
Plant outlet pressure: 397.32 kPa
Production wellhead pressure: 466.27 kPa
Productivity Index: 10.00 kg/sec/bar
Injectivity Index: 5.00 kg/sec/bar

Reservoir density: 3000.00 kg/m**3
Reservoir thermal conductivity: 3.00 W/m/K
Reservoir heat capacity: 1000.00 J/kg/K

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 100.2 degC
Average Production Temperature: 99.3 degC
Minimum Production Temperature: 97.3 degC
Initial Production Temperature: 100.2 degC
Average Reservoir Heat Extraction: 6.23 MW
Wellbore Heat Transmission Model = Constant Temperature Drop: 5.0 degC
Average Injection Well Pump Pressure Drop: 1460.7 kPa
Average Production Well Pump Pressure Drop: 292.2 kPa

CAPITAL COSTS (M$)

Drilling and completion costs: 8.52 MUSD
Drilling and completion costs per well: 4.26 MUSD
Stimulation costs: 1.51 MUSD
Surface power plant costs: 2.18 MUSD
Field gathering system costs: 1.23 MUSD
Total surface equipment costs: 3.41 MUSD
Exploration costs: 4.42 MUSD
Investment Tax Credit: -8.93 MUSD
Total capital costs: 8.93 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 0.16 MUSD/yr
Power plant maintenance costs: 0.23 MUSD/yr
Water costs: 0.03 MUSD/yr
Total operating and maintenance costs: 0.42 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Initial geofluid availability: 0.04 MW/(kg/s)
Maximum Total Electricity Generation: 0.22 MW
Average Total Electricity Generation: 0.21 MW
Minimum Total Electricity Generation: 0.20 MW
Initial Total Electricity Generation: 0.22 MW
Maximum Net Electricity Generation: 0.10 MW
Average Net Electricity Generation: 0.09 MW
Minimum Net Electricity Generation: 0.07 MW
Initial Net Electricity Generation: 0.10 MW
Average Annual Total Electricity Generation: 1.67 GWh
Average Annual Net Electricity Generation: 0.72 GWh
Initial pumping power/net installed power: 121.42 %
Maximum Net Heat Production: 2.89 MW
Average Net Heat Production: 2.80 MW
Minimum Net Heat Production: 2.60 MW
Initial Net Heat Production: 2.89 MW
Average Annual Heat Production: 22.02 GWh
Average Pumping Power: 0.12 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (deg C)	PUMP POWER (MW)	NET POWER (MW)	NET HEAT (MW)	FIRST LAW EFFICIENCY (%)
0	1.0000	100.16	0.1202	0.0990	2.8871	3.0868
1	1.0000	100.16	0.1202	0.0990	2.8871	3.0868
2	1.0000	100.16	0.1202	0.0990	2.8871	3.0868
3	1.0000	100.16	0.1202	0.0990	2.8871	3.0868
4	1.0000	100.16	0.1202	0.0990	2.8871	3.0868
5	1.0000	100.16	0.1202	0.0990	2.8870	3.0866
6	1.0000	100.15	0.1202	0.0990	2.8866	3.0860
7	0.9999	100.15	0.1202	0.0989	2.8857	3.0843
8	0.9997	100.13	0.1203	0.0987	2.8840	3.0811
9	0.9994	100.10	0.1203	0.0985	2.8811	3.0757
10	0.9990	100.06	0.1204	0.0981	2.8769	3.0680
11	0.9984	100.00	0.1204	0.0976	2.8713	3.0577
12	0.9977	99.93	0.1205	0.0969	2.8643	3.0448
13	0.9969	99.85	0.1206	0.0961	2.8560	3.0293
14	0.9959	99.75	0.1208	0.0952	2.8464	3.0114
15	0.9949	99.64	0.1209	0.0942	2.8356	2.9912
16	0.9937	99.53	0.1211	0.0932	2.8238	2.9690
17	0.9924	99.40	0.1212	0.0920	2.8110	2.9449
18	0.9910	99.26	0.1214	0.0907	2.7974	2.9191
19	0.9896	99.12	0.1216	0.0894	2.7831	2.8918
20	0.9881	98.97	0.1218	0.0881	2.7682	2.8631
21	0.9866	98.82	0.1220	0.0867	2.7527	2.8333
22	0.9850	98.66	0.1222	0.0852	2.7368	2.8025
23	0.9834	98.50	0.1225	0.0838	2.7206	2.7708
24	0.9817	98.33	0.1227	0.0823	2.7041	2.7383
25	0.9801	98.16	0.1229	0.0808	2.6874	2.7052
26	0.9784	97.99	0.1231	0.0793	2.6706	2.6714
27	0.9767	97.82	0.1233	0.0778	2.6536	2.6373
28	0.9750	97.65	0.1236	0.0762	2.6365	2.6027
29	0.9733	97.48	0.1238	0.0747	2.6194	2.5678

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	HEAT PROVIDED (GWh/year)	ELECTRICITY PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	22.8	0.8	50.58	16.80	1.07
2	22.8	0.8	50.58	16.62	2.14
3	22.8	0.8	50.58	16.43	3.22
4	22.8	0.8	50.58	16.25	4.29
5	22.8	0.8	50.58	16.07	5.36
6	22.8	0.8	50.58	15.89	6.43
7	22.8	0.8	50.57	15.71	7.51
8	22.7	0.8	50.54	15.52	8.58
9	22.7	0.8	50.50	15.34	9.65
10	22.7	0.8	50.44	15.16	10.72
11	22.7	0.8	50.36	14.98	11.79
12	22.6	0.8	50.25	14.80	12.85
13	22.6	0.8	50.11	14.62	13.91

14	22.5	0.8	49.95	14.44	14.97
15	22.4	0.7	49.78	14.26	16.03
16	22.3	0.7	49.58	14.08	17.08
17	22.2	0.7	49.36	13.90	18.13
18	22.1	0.7	49.13	13.73	19.17
19	22.0	0.7	48.89	13.55	20.20
20	21.9	0.7	48.63	13.37	21.23
21	21.8	0.7	48.36	13.20	22.26
22	21.6	0.7	48.09	13.03	23.28
23	21.5	0.7	47.81	12.85	24.29
24	21.4	0.7	47.52	12.68	25.30
25	21.3	0.6	47.23	12.51	26.30
26	21.1	0.6	46.94	12.34	27.30
27	21.0	0.6	46.64	12.18	28.29
28	20.9	0.6	46.34	12.01	29.27
29	20.7	0.6	46.04	11.84	30.24
30	18.5	0.5	41.18	11.70	31.12

****
* REVENUE & CASHFLOW PROFILE *
****

Year Electricity | Heat | Cooling | Carbon | Project
Since Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | OPEX Net Rev. Net Cashflow
Start (cents/kWh)(MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(USD/tonne) (MUSD/yr) (MUSD) |(MUSD/yr) (MUSD/yr) (MUSD)

1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-8.93	-8.93
2	15.00	0.12	0.12	2.50	2.78	2.78	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.47	-6.46
3	15.00	0.12	0.23	2.50	2.78	5.55	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.47	-3.98
4	15.41	0.12	0.35	2.50	2.85	8.40	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.55	-1.43
5	15.81	0.12	0.48	2.50	2.93	11.33	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.63	1.20
6	16.22	0.13	0.60	2.50	3.00	14.33	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.71	3.91
7	16.62	0.13	0.73	2.50	3.08	17.41	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.79	6.70
8	17.03	0.13	0.87	2.50	3.15	20.56	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.87	9.57
9	17.43	0.14	1.00	2.50	3.23	23.79	2.50	0.00	0.00	0.00	0.00	0.00	0.42	2.94	12.51
10	17.84	0.14	1.14	2.50	3.30	27.09	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.02	15.53
11	18.24	0.14	1.28	2.50	3.37	30.46	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.09	18.63
12	18.65	0.14	1.43	2.50	3.44	33.90	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.17	21.79
13	19.05	0.15	1.57	2.50	3.51	37.41	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.24	25.03
14	19.46	0.15	1.72	2.50	3.57	40.98	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.30	28.33

15	19.86	0.15	1.87	2.50	3.64	44.62	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.37	31.70
16	20.27	0.15	2.02	2.50	3.70	48.32	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.43	35.13
17	20.67	0.15	2.17	2.50	3.76	52.08	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.49	38.63
18	21.08	0.15	2.33	2.50	3.82	55.90	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.55	42.18
19	21.49	0.15	2.48	2.50	3.87	59.77	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.61	45.79
20	21.89	0.16	2.64	2.50	3.93	63.70	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.66	49.45
21	22.30	0.16	2.79	2.50	3.98	67.68	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.72	53.17
22	22.70	0.16	2.95	2.50	4.03	71.70	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.77	56.93
23	23.11	0.16	3.11	2.50	4.08	75.78	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.82	60.75
24	23.51	0.16	3.26	2.50	4.13	79.91	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.86	64.61
25	23.92	0.16	3.42	2.50	4.17	84.08	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.91	68.52
26	24.32	0.16	3.58	2.50	4.22	88.30	2.50	0.00	0.00	0.00	0.00	0.00	0.42	3.96	72.48
27	24.73	0.16	3.73	2.50	4.26	92.56	2.50	0.00	0.00	0.00	0.00	0.00	0.42	4.00	76.48
28	25.13	0.16	3.89	2.50	4.30	96.86	2.50	0.00	0.00	0.00	0.00	0.00	0.42	4.04	80.52
29	25.54	0.16	4.04	2.50	4.35	101.21	2.50	0.00	0.00	0.00	0.00	0.00	0.42	4.08	84.60
30	25.94	0.15	4.20	2.50	4.39	105.60	2.50	0.00	0.00	0.00	0.00	0.00	0.42	4.12	88.72

10. Appendix 10: "Interior" region, Basement Reservoir, geothermally powered Direct Air Capture of CO_2 using a solid sorbent method (S-DAC-GT).

GEOPHIRES_Presidio_warm_S-DAC-GT.txt

```
GEOPHIRES v3.0 Input File
Geothermal Combined Heat and Power Problem using a Thermal Drawdown Reservoir Model and BICYCLE Economic
Model and
Solid Sorbent Direct Air Capture powered by geothermal as the direct use. generation is done with a subcritical ORC
The is for the BEG HotRock Presidio County Project.
The assumption is that this project will be situated very close to the northeastern corner of Presidio County
because that is close to Marfa and is the area closest to the oil fields of West Texas (which could consume the
captured CO2 for CO2 flood EOR).

That makes it in the "Laurentia" region. It is an EGS project that needs as high a temperature as possible which
means "basement" is the reservoir.

***Subsurface technical parameters***
*************************************
Do S-DAC-GT Calculations, True
Reservoir Model,3,                          ---m/A Single Fracture Thermal Drawdown
Drawdown Parameter,.00002,                  ---[kg/s/m2]
Number of Segments,3,                       ---[-]
Gradient 1,26.17,                           ---[deg.C/km]
Gradient 2,31.66,                           ---[deg.C/km]
Thickness 1,1.457,                          ---[km]
Gradient 3,28.78,                           ---[deg.C/km]
Thickness 2,6.001,                          ---[km]
Reservoir Depth, 7,                         ---[km]
Number of Production Wells,1,               ---[-]
Number of Injection Wells,1,                ---[-]
Production Well Diameter,12,                ---[inch]
Injection Well Diameter,12,                 ---[inch]
Ramey Production Wellbore Model,1,          ---Should be 0 (disabled) or 1 (enabled)
Production Flow Rate per Well,110,          ---[kg/s]
Reservoir Volume Option,1,                  ---Should be 1 2 3 or 4. See manual for details.
Fracture Shape,1,                           ---Should be 1 2 3 or 4
Fracture Area,200000,                       ---[m2]
Number of Fractures,12,                     ---[-]
Fracture Separation,80,                     ---[m]
Injectivity Index,5,                        ---[kg/s/bar]
Water Loss Fraction,0.02,                   ---[-]

***Surface Technical Parameters***
**********************************

End-Use Option,31,                          ---CHP Topping Cycle with electricity as the main
product
Power Plant Type,1,                         ---subcritical ORC
Circulation Pump Efficiency,.80,            ---[-]

***Financial Parameters***
**************************
Do Carbon Price Calculations, True
Starting Electricity Sale Price, 0.15
Ending Electricity Sale Price, 1.00
Electricity Escalation Start Year, 1
Electricity Escalation Rate Per Year, 0.004053223
```

Starting Heat Sale Price, 0.12192
Ending Heat Sale Price, 10.0
Heat Escalation Start Year, 1
Heat Escalation Rate Per Year, 0.003327033
Starting Carbon Credit Value, 0.039
Ending Carbon Credit Value, 0.039
Carbon Escalation Start Year, 1
Carbon Escalation Rate Per Year, 0.0
Investment Tax Credit Rate, 0.5

Economic Model,3, ---BICYCLE Levelized Cost Model
Inflated Equity Interest Rate,.08, ---[-] Required for BICYCLE model
Combined Income Tax Rate,.3, ---[-] Required for BICYCLE model
Gross Revenue Tax Rate,0, ---[-] Required for BICYCLE model

Simulation Parameters
****

Plant Lifetime, 20
Print Output to Console,1, ---Should be 1 (to print) or 0 (to not print)
Time steps per year,10, ---[-]

GEOPHIRES_Presidio_warm_S-DAC-GT_Result.txt

****
CASE REPORT
****

Simulation Metadata

GEOPHIRES Version: 3.4.25
GEOPHIRES Build Date: 2024-03-05
Simulation Date: 2024-05-06
Simulation Time: 10:13
Calculation Time: 0.235 sec

SUMMARY OF RESULTS

End-Use Option: Cogeneration Topping Cycle, Heat sales considered as extra income
Average Net Electricity Production: 12.10 MW
Average Direct-Use Heat Production: 4.82 MW
Electricity breakeven price: 6.11 cents/kWh
Direct-Use heat breakeven price (LCOH): -1.92 USD/MMBTU
Number of production wells: 1
Number of injection wells: 1
Flowrate per production well: 110.0 kg/sec
Well depth (or total length, if not vertical): 7.0 kilometer
Segment 1 Geothermal gradient: 0.0262 degC/m
Segment 1 Thickness: 1457 meter
Segment 2 Geothermal gradient: 0.0317 degC/m
Segment 2 Thickness: 6001 meter
Segment 3 Geothermal gradient: 0.0288 degC/m
Total Avoided Carbon Emissions: 459544.42 metric tonnes

ECONOMIC PARAMETERS

Economic Model = BICYCLE
Accrued financing during construction: 0.00
Project lifetime: 20 yr
Capacity factor: 90.0 %
Project NPV: 29.42 MUSD
Project IRR: 13.81 %
Project VIR=PI=PIR: 1.74
Project MOIC: 1.02
Project Payback Period: 8.05 yr
CHP: Percent cost allocation for electrical plant: 95.58%

ENGINEERING PARAMETERS

Number of Production Wells: 1
Number of Injection Wells: 1
Well depth (or total length, if not vertical): 7.0 kilometer
Water loss rate: 2.0
Pump efficiency: 80.0
Injection temperature: 70.0 degC
Production Wellbore heat transmission calculated with Ramey's model
Average production well temperature drop: 6.4 degC
Flowrate per production well: 110.0 kg/sec
Injection well casing ID: 12.000 in
Production well casing ID: 12.000 in
Number of times redrilling: 0
Power plant type: Subcritical ORC

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 3
Segment 1 Geothermal gradient: 0.0262 degC/m
Segment 1 Thickness: 1457 meter
Segment 2 Geothermal gradient: 0.0317 degC/m
Segment 2 Thickness: 6001 meter
Segment 3 Geothermal gradient: 0.0288 degC/m

RESERVOIR PARAMETERS

Reservoir Model = Single Fracture m/A Thermal Drawdown Model
m/A Drawdown Parameter: 0.00002 1/year
Bottom-hole temperature: 228.62 degC
Reservoir volume calculated with fracture separation and number of fractures as input
Number of fractures: 12.00
Fracture separation: 80.00 meter
Reservoir volume: 176000000 m**3
Reservoir hydrostatic pressure: 70081.95 kPa
Plant outlet pressure: 3002.85 kPa
Production wellhead pressure: 3071.80 kPa
Productivity Index: 10.00 kg/sec/bar
Injectivity Index: 5.00 kg/sec/bar
Reservoir density: 2700.00 kg/m**3
Reservoir thermal conductivity: 3.00 W/m/K
Reservoir heat capacity: 1000.00 J/kg/K

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 222.0 degC
Average Production Temperature: 220.5 degC
Minimum Production Temperature: 216.3 degC
Initial Production Temperature: 217.3 degC
Average Reservoir Heat Extraction: 65.50 MW
Production Wellbore Heat Transmission Model = Ramey Model
Average Production Well Temperature Drop: 6.4 degC
Average Injection Well Pump Pressure Drop: -2076.6 kPa
Average Production Well Pump Pressure Drop: -860.9 kPa

CAPITAL COSTS (M$)

Drilling and completion costs: 26.58 MUSD
Drilling and completion costs per well: 13.29 MUSD
Stimulation costs: 1.51 MUSD
Surface power plant costs: 39.51 MUSD
Field gathering system costs: 0.99 MUSD
Total surface equipment costs: 40.49 MUSD
Exploration costs: 11.07 MUSD
Investment Tax Credit: -39.82 MUSD
Total capital costs: 39.82 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 0.61 MUSD/yr
Power plant maintenance costs: 1.60 MUSD/yr
Water costs: 0.06 MUSD/yr
Total operating and maintenance costs: 2.27 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Initial geofluid availability: 0.21 MW/(kg/s)
Maximum Total Electricity Generation: 12.38 MW
Average Total Electricity Generation: 12.10 MW
Minimum Total Electricity Generation: 11.40 MW
Initial Total Electricity Generation: 11.57 MW
Maximum Net Electricity Generation: 12.38 MW
Average Net Electricity Generation: 12.10 MW
Minimum Net Electricity Generation: 11.40 MW
Initial Net Electricity Generation: 11.57 MW
Average Annual Total Electricity Generation: 55.74 GWh
Average Annual Net Electricity Generation: 55.74 GWh
Maximum Net Heat Production: 4.88 MW
Average Net Heat Production: 4.82 MW
Minimum Net Heat Production: 4.68 MW
Initial Net Heat Production: 4.71 MW
Average Annual Heat Production: -24.14 GWh
Average Pumping Power: 0.00 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR THERMAL GEOFLUID PUMP NET NET FIRST LAW

	DRAWDOWN	TEMPERATURE (deg C)	POWER (MW)	POWER (MW)	HEAT (MW)	EFFICIENCY (%)
0	1.0000	217.33	0.0000	11.5677	4.7132	19.6391
1	1.0149	220.57	0.0000	12.1195	4.8264	20.1377
2	1.0178	221.21	0.0000	12.2307	4.8488	20.2372
3	1.0193	221.53	0.0000	12.2882	4.8603	20.2885
4	1.0203	221.75	0.0000	12.3259	4.8679	20.3221
5	1.0210	221.90	0.0000	12.3526	4.8732	20.3459
6	1.0215	222.00	0.0000	12.3699	4.8766	20.3613
7	1.0217	222.04	0.0000	12.3769	4.8780	20.3676
8	1.0215	222.01	0.0000	12.3719	4.8770	20.3631
9	1.0210	221.91	0.0000	12.3533	4.8733	20.3466
10	1.0202	221.72	0.0000	12.3206	4.8668	20.3174
11	1.0189	221.45	0.0000	12.2736	4.8574	20.2754
12	1.0174	221.10	0.0000	12.2130	4.8452	20.2213
13	1.0154	220.68	0.0000	12.1398	4.8305	20.1559
14	1.0132	220.19	0.0000	12.0553	4.8134	20.0801
15	1.0106	219.65	0.0000	11.9609	4.7942	19.9952
16	1.0079	219.05	0.0000	11.8579	4.7731	19.9023
17	1.0049	218.40	0.0000	11.7477	4.7505	19.8025
18	1.0017	217.71	0.0000	11.6314	4.7264	19.6970
19	0.9984	216.99	0.0000	11.5103	4.7012	19.5867

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	HEAT PROVIDED (GWh/year)	ELECTRICITY PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	-24.1	54.9	512.87	73.53	2.45
2	-24.3	56.5	518.02	71.67	4.92
3	-24.4	57.0	519.57	69.80	7.41
4	-24.4	57.3	520.48	67.92	9.89
5	-24.4	57.5	521.10	66.05	12.38
6	-24.5	57.6	521.53	64.17	14.87
7	-24.5	57.7	521.77	62.29	17.36
8	-24.5	57.7	521.80	60.41	19.85
9	-24.5	57.7	521.57	58.53	22.35
10	-24.4	57.5	521.07	56.66	24.83
11	-24.4	57.2	520.29	54.78	27.32
12	-24.4	56.9	519.23	52.92	29.80
13	-24.3	56.5	517.91	51.05	32.27
14	-24.3	56.0	516.35	49.19	34.74
15	-24.2	55.4	514.57	47.34	37.20
16	-24.1	54.8	512.59	45.49	39.64
17	-24.0	54.1	510.45	43.66	42.08
18	-23.9	53.4	508.16	41.83	44.51
19	-23.8	52.6	505.74	40.01	46.92
20	-21.4	46.7	453.01	38.38	49.09

****
* REVENUE & CASHFLOW PROFILE *
****

Year Electricity | Heat | Cooling | Carbon | Project
Since Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann.
Rev. Cumm. Rev. | OPEX Net Rev. Net Cashflow

Start	(cents/kWh)	(MUSD/yr)	(MUSD)	(cents/kWh)	(MUSD/yr)	(MUSD)	(cents/kWh)	(MUSD/yr)	(MUSD)	(USD/tonne)	(MUSD/yr)	(MUSD)	(MUSD/yr)	(MUSD/yr)	(MUSD)
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-39.82	-39.82
2	15.00	8.23	8.23	2.50	-2.94	-2.94	2.50	0.00	0.00	0.04	1.94	1.94	2.27	4.97	-34.85
3	15.00	8.48	16.70	2.50	-2.97	-5.91	2.50	0.00	0.00	0.04	2.00	3.95	2.27	5.25	-29.61
4	15.41	8.78	25.49	2.50	-3.05	-8.96	2.50	0.00	0.00	0.04	2.02	5.97	2.27	5.48	-24.12
5	15.81	9.06	34.55	2.50	-3.14	-12.10	2.50	0.00	0.00	0.04	2.03	8.00	2.27	5.69	-18.44
6	16.22	9.32	43.87	2.50	-3.22	-15.32	2.50	0.00	0.00	0.04	2.04	10.04	2.27	5.87	-12.56
7	16.62	9.58	53.45	2.50	-3.31	-18.63	2.50	0.00	0.00	0.04	2.04	12.08	2.27	6.05	-6.51
8	17.03	9.83	63.28	2.50	-3.39	-22.02	2.50	0.00	0.00	0.04	2.05	14.13	2.27	6.22	-0.29
9	17.43	10.06	73.34	2.50	-3.47	-25.50	2.50	0.00	0.00	0.04	2.05	16.18	2.27	6.37	6.08
10	17.84	10.28	83.63	2.50	-3.55	-29.05	2.50	0.00	0.00	0.04	2.04	18.22	2.27	6.51	12.59
11	18.24	10.49	94.12	2.50	-3.63	-32.68	2.50	0.00	0.00	0.04	2.04	20.26	2.27	6.63	19.22
12	18.65	10.67	104.79	2.50	-3.71	-36.39	2.50	0.00	0.00	0.04	2.03	22.29	2.27	6.73	25.95
13	19.05	10.84	115.63	2.50	-3.78	-40.17	2.50	0.00	0.00	0.04	2.02	24.31	2.27	6.81	32.76
14	19.46	10.99	126.62	2.50	-3.85	-44.02	2.50	0.00	0.00	0.04	2.00	26.31	2.27	6.87	39.63
15	19.86	11.12	137.73	2.50	-3.93	-47.95	2.50	0.00	0.00	0.04	1.98	28.29	2.27	6.91	46.54
16	20.27	11.23	148.96	2.50	-3.99	-51.94	2.50	0.00	0.00	0.04	1.96	30.25	2.27	6.93	53.47
17	20.67	11.32	160.28	2.50	-4.06	-56.01	2.50	0.00	0.00	0.04	1.94	32.19	2.27	6.94	60.41
18	21.08	11.40	171.68	2.50	-4.13	-60.13	2.50	0.00	0.00	0.04	1.92	34.11	2.27	6.92	67.33
19	21.49	11.47	183.15	2.50	-4.19	-64.32	2.50	0.00	0.00	0.04	1.89	36.00	2.27	6.90	74.23
20	21.89	11.52	194.67	2.50	-4.25	-68.58	2.50	0.00	0.00	0.04	1.86	37.86	2.27	6.86	81.09

S_DAC_GT ECONOMICS

S-DAC-GT Report: Levelized Cost of Direct Air Capture (LCOD)
Using grid-based electricity only: 403.39 USD/tonne
Using natural gas only: 327.70 USD/tonne
Using geothermal energy only: 310.96 USD/tonne

S-DAC-GT Report: CO2 Intensity of process (percent of CO2 mitigated that is emitted by S-DAC process)
Using grid-based electricity only: 94.52%
Using natural gas only: 64.85%

Using geothermal energy only: 37.81%

Geothermal LCOH: 0.0061 USD/kWh
Geothermal Ratio (electricity vs heat): 24.1208%
Percent Energy Devoted To Process: 50.0000%

Total Tonnes of CO2 Captured: 856,653.88 tonne
Total Cost of Capture: 203,863,767.40 USD

****
* S_DAC_GT PROFILE *
****

Year Since Start	Carbon Captured (tonne/yr)	Cumm. Carbon Captured (tonne)	S_DAC_GT Annual Cost (USD/yr)	S_DAC_GT Cumm. Cash Flow (USD)	Cumm. Cost Cost Per Tonne (USD/tonne)
1	42,746.82	42,746.82	10,172,752.89	10,172,752.89	237.98
2	43,175.48	85,922.31	10,274,764.60	20,447,517.49	237.98
3	43,305.02	129,227.32	10,305,590.24	30,753,107.73	237.98
4	43,380.88	172,608.21	10,323,644.82	41,076,752.55	237.98
5	43,432.86	216,041.06	10,336,012.86	51,412,765.41	237.98
6	43,468.71	259,509.77	10,344,544.64	61,757,310.05	237.98
7	43,488.76	302,998.53	10,349,318.08	72,106,628.13	237.98
8	43,490.61	346,489.14	10,349,756.64	82,456,384.77	237.98
9	43,471.55	389,960.69	10,345,220.24	92,801,605.01	237.98
10	43,429.76	433,390.45	10,335,276.76	103,136,881.77	237.98
11	43,364.61	476,755.06	10,319,771.49	113,456,653.26	237.98
12	43,276.47	520,031.53	10,298,797.15	123,755,450.41	237.98
13	43,166.51	563,198.04	10,272,629.84	134,028,080.25	237.98
14	43,036.39	606,234.43	10,241,663.78	144,269,744.02	237.98
15	42,888.03	649,122.46	10,206,357.43	154,476,101.45	237.98
16	42,723.46	691,845.93	10,167,193.59	164,643,295.04	237.98
17	42,544.70	734,390.62	10,124,652.15	174,767,947.19	237.98
18	42,353.67	776,744.30	10,079,192.61	184,847,139.80	237.98
19	42,152.19	818,896.49	10,031,243.93	194,878,383.73	237.98
20	37,757.39	856,653.88	8,985,383.66	203,863,767.40	237.98

11. Appendix 11: "Interior" region, PzMz Reservoir, Absorption Chiller for commercial or industrial cooling

GEOPHIRES_Presidio_warm_PzMz_AC.txt

```
***Subsurface technical parameters***
*************************************
Reservoir Model,3,                                  ---m/A Single Fracture Thermal Drawdown
Drawdown Parameter,.00002,                          ---[kg/s/m2]
Reservoir Depth, 6.001,                             ---[km]
Number of Segments,3,                               ---[-]
Gradient 1,26.17,                       ---[deg.C/km]
Gradient 2,31.66,                       ---[deg.C/km]
Thickness 1,1.457,                      ---[km]
Gradient 3,28.78,                       ---[deg.C/km]
Thickness 2,6.001,                      ---[km]
Number of Production Wells,1,                       ---[-]
Number of Injection Wells,1,                        ---[-]
Production Well Diameter,8.5,                       ---[inch]
Injection Well Diameter,8.5,                        ---[inch]
Ramey Production Wellbore Model,0,                  ---Should be 0 (disabled) or 1 (enabled)
Injection Wellbore Temperature Gain,3,              ---[deg.C]
Production Flow Rate per Well,55,                   ---[kg/s]
Reservoir Volume Option,1,                          ---Should be 1,2,3 or 4. See manual for details.
Fracture Shape,1,                                   ---Should be 1,2,3 or 4
Fracture Area,200000,                               ---[m2]
Number of Fractures,12,                             ---[-]
Fracture Separation,80,                             ---[m]
Injectivity Index,5,                                ---[kg/s/bar]
Injection Temperature,80,                           ---[deg.C]
Reservoir Density,2600,                             ---[kg/m3]
Water Loss Fraction,0.02,                           ---[-]

***Surface Technical Parameters***
**********************************
End-Use Option,2, --- Direct use
Power Plant Type, 5,                    ---[-] Absorption Chiller
Circulation Pump Efficiency,.80,                    ---[-]
Surface Temperature,32,                             ---[deg.C]
Ambient Temperature,32,                             ---[deg.C]
Plant Outlet Pressure, 11
Absorption Chiller COP, 0.72,       --- [-]

***Financial Parameters***
**************************
Plant Lifetime,20,                                  ---[years]
Economic Model,2,                                   ---BICYCLE Levelized Cost Model
Discount Rate, 0.05,                    --- [-] Required if Standard LCOE/LCOH model is selected. See manual for
details.
Inflation Rate During Construction,0.05,            ---[-]
Starting Cooling Sale Price,0.15
Ending Cooling Sale Price,1.00
Cooling Escalation Start Year,1
Cooling Escalation Rate Per Year, 0.004053223
Investment Tax Credit Rate, 0.5

***Capital and O&M Cost Parameters***
```

```
*************************************
Electricity Rate,.1,                                            ---[$/kWh]
Absorption Chiller Capital Cost,3.74,        --- [$M]
Absorption Chiller O&M Cost,0.065,          --- [$M/year]

***Simulation Parameters***
***************************

Print Output to Console,1,                              ---Should be 1 (to print) or 0 (to not print)
Time steps per year,10,                                          ---[-]

GEOPHIRES_Presidio_warm_PzMz_AC_Result.txt

                  *****************
                  ***CASE REPORT***
                  *****************

Simulation Metadata
----------------------
 GEOPHIRES Version: 3.4.25
 GEOPHIRES Build Date: 2024-03-05
 Simulation Date: 2024-05-06
 Simulation Time:  10:16
 Calculation Time:      0.214 sec

                  ***SUMMARY OF RESULTS***

     End-Use Option: Direct-Use Heat
     Surface Application: Absorption Chiller
     Average Direct-Use Heat Production:              27.31 MW
     Average Cooling Production:                 17.70 MW
     Direct-Use Cooling Breakeven Price (LCOC):           6.44 USD/MMBTU
     Number of production wells:                   1
     Number of injection wells:                  1
     Flowrate per production well:               55.0 kg/sec
     Well depth (or total length, if not vertical):        6.0 kilometer
     Segment 1   Geothermal gradient:                 0.0262 degC/m
     Segment 1   Thickness:                    1457 meter
     Segment 2   Geothermal gradient:                 0.0317 degC/m
     Segment 2   Thickness:                    6001 meter
     Segment 3   Geothermal gradient:                 0.0288 degC/m


                  ***ECONOMIC PARAMETERS***

     Economic Model = Standard Levelized Cost
     Interest Rate:                          5.00
     Accrued financing during construction:              5.00
     Project lifetime:                        20 yr
     Capacity factor:                         90.0 %
     Project NPV:                          241.05 MUSD
     Project IRR:                          90.30 %
     Project VIR=PI=PIR:                      11.71
     Project MOIC:                          9.90
     Project Payback Period:                    2.13 yr

                  ***ENGINEERING PARAMETERS***
```

Number of Production Wells: 1
Number of Injection Wells: 1
Well depth (or total length, if not vertical): 6.0 kilometer
Water loss rate: 2.0
Pump efficiency: 80.0
Injection temperature: 83.0 degC
User-provided production well temperature drop
Constant production well temperature drop: 5.0 degC
Flowrate per production well: 55.0 kg/sec
Injection well casing ID: 8.500 in
Production well casing ID: 8.500 in
Number of times redrilling: 0

RESOURCE CHARACTERISTICS

Maximum reservoir temperature: 400.0 degC
Number of segments: 3
Segment 1 Geothermal gradient: 0.0262 degC/m
Segment 1 Thickness: 1457 meter
Segment 2 Geothermal gradient: 0.0317 degC/m
Segment 2 Thickness: 6001 meter
Segment 3 Geothermal gradient: 0.0288 degC/m

RESERVOIR PARAMETERS

Reservoir Model = Single Fracture m/A Thermal Drawdown Model
m/A Drawdown Parameter: 0.00002 1/year
Bottom-hole temperature: 213.99 degC
Reservoir volume calculated with fracture separation and number of fractures as input
Number of fractures: 12.00
Fracture separation: 80.00 meter
Reservoir volume: 176000000 m**3
Reservoir hydrostatic pressure: 59652.86 kPa
Plant outlet pressure: 11.00 kPa
Production wellhead pressure: 2409.39 kPa
Productivity Index: 10.00 kg/sec/bar
Injectivity Index: 5.00 kg/sec/bar
Reservoir density: 2600.00 kg/m**3
Reservoir thermal conductivity: 3.00 W/m/K
Reservoir heat capacity: 1000.00 J/kg/K

RESERVOIR SIMULATION RESULTS

Maximum Production Temperature: 209.0 degC
Average Production Temperature: 207.3 degC
Minimum Production Temperature: 202.6 degC
Initial Production Temperature: 209.0 degC
Average Reservoir Heat Extraction: 27.31 MW
Wellbore Heat Transmission Model = Constant Temperature Drop: 5.0 degC
Average Injection Well Pump Pressure Drop: 766.5 kPa
Average Production Well Pump Pressure Drop: -871.9 kPa

CAPITAL COSTS (M$)

Drilling and completion costs: 20.80 MUSD
Drilling and completion costs per well: 10.40 MUSD
Stimulation costs: 1.51 MUSD
Surface power plant costs: 12.65 MUSD
of which Absorption Chiller Cost: 3.74 MUSD
Field gathering system costs: 1.11 MUSD
Total surface equipment costs: 13.76 MUSD
Exploration costs: 8.94 MUSD
Investment Tax Credit: -22.51 MUSD
Total capital costs: 22.51 MUSD

OPERATING AND MAINTENANCE COSTS (M$/yr)

Wellfield maintenance costs: 0.41 MUSD/yr
Power plant maintenance costs: 0.71 MUSD/yr
Water costs: 0.03 MUSD/yr
Average Reservoir Pumping Cost: 0.04 MUSD/yr
Absorption Chiller O&M Cost: 0.07 MUSD/yr
Total operating and maintenance costs: 1.26 MUSD/yr

SURFACE EQUIPMENT SIMULATION RESULTS

Maximum Net Heat Production: 27.68 MW
Average Net Heat Production: 27.31 MW
Minimum Net Heat Production: 26.27 MW
Initial Net Heat Production: 27.68 MW
Average Annual Heat Production: 214.28 GWh
Maximum Cooling Production: 17.94 MW
Average Cooling Production: 17.70 MW
Minimum Cooling Production: 17.02 MW
Initial Cooling Production: 17.94 MW
Average Annual Cooling Production: 138.85 GWh/year
Average Pumping Power: 0.05 MW

****
* HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	THERMAL DRAWDOWN	GEOFLUID TEMPERATURE (deg C)	PUMP POWER (MWe)	NET HEAT (MWt)	NET COOLING (MWt)
0	1.0000	208.99	0.0523	27.6795	17.9363
1	1.0000	208.99	0.0523	27.6795	17.9363
2	1.0000	208.99	0.0523	27.6795	17.9363
3	1.0000	208.99	0.0523	27.6795	17.9363
4	1.0000	208.99	0.0523	27.6792	17.9361
5	0.9999	208.98	0.0523	27.6771	17.9347
6	0.9998	208.95	0.0523	27.6699	17.9301
7	0.9994	208.87	0.0523	27.6536	17.9195
8	0.9988	208.74	0.0523	27.6248	17.9008
9	0.9979	208.54	0.0523	27.5812	17.8726
10	0.9966	208.27	0.0523	27.5217	17.8341
11	0.9949	207.93	0.0523	27.4464	17.7853
12	0.9930	207.52	0.0523	27.3561	17.7267
13	0.9907	207.05	0.0523	27.2518	17.6592
14	0.9881	206.51	0.0523	27.1350	17.5835
15	0.9854	205.93	0.0523	27.0073	17.5007

16	0.9824	205.31	0.0523	26.8700	17.4118
17	0.9792	204.65	0.0523	26.7248	17.3176
18	0.9759	203.95	0.0523	26.5727	17.2191
19	0.9725	203.24	0.0523	26.4152	17.1170

****
* ANNUAL HEATING, COOLING AND/OR ELECTRICITY PRODUCTION PROFILE *
****

YEAR	COOLING PROVIDED (GWh/year)	HEAT EXTRACTED (GWh/year)	RESERVOIR HEAT CONTENT (10^15 J)	PERCENTAGE OF TOTAL HEAT MINED (%)
1	141.4	218.2	59.16	1.31
2	141.4	218.2	58.37	2.62
3	141.4	218.2	57.59	3.93
4	141.4	218.2	56.80	5.24
5	141.4	218.2	56.01	6.55
6	141.4	218.2	55.23	7.86
7	141.3	218.1	54.44	9.17
8	141.2	217.9	53.66	10.48
9	141.0	217.6	52.88	11.79
10	140.8	217.2	52.09	13.09
11	140.4	216.7	51.31	14.40
12	140.0	216.0	50.54	15.69
13	139.5	215.3	49.76	16.99
14	138.9	214.4	48.99	18.27
15	138.3	213.4	48.22	19.55
16	137.6	212.4	47.46	20.83
17	136.9	211.3	46.70	22.10
18	136.1	210.1	45.94	23.36
19	135.4	208.9	45.19	24.62
20	121.1	186.9	44.51	25.74

****
* REVENUE & CASHFLOW PROFILE *
****

Year Electricity | Heat | Cooling | Carbon | Project
Since Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | Price Ann. Rev. Cumm. Rev. | OPEX Net Rev. Net Cashflow
Start (cents/kWh)(MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(cents/kWh) (MUSD/yr) (MUSD) |(USD/tonne) (MUSD/yr) (MUSD) |(MUSD/yr) (MUSD/yr) (MUSD)

---

1 0.00 0.00 0.00 | 0.00 0.00 0.00 | 0.00 -22.51 0.00 | 0.00 0.00 0.00 | 0.00 -22.51 -22.51
2 5.50 0.00 0.00 | 15.00 0.00 0.00 | 15.00 19.99 21.21 | 0.00 0.00 0.00 | 1.22 19.99 -2.51
3 5.50 0.00 0.00 | 15.00 0.00 0.00 | 15.00 19.99 42.42 | 0.00 0.00 0.00 | 1.22 19.99 17.48
4 5.50 0.00 0.00 | 15.41 0.00 0.00 | 15.41 20.56 64.21 | 0.00 0.00 0.00 | 1.22 20.56 38.04
5 5.50 0.00 0.00 | 15.81 0.00 0.00 | 15.81 21.14 86.57 | 0.00 0.00 0.00 | 1.22 21.14 59.18
6 5.50 0.00 0.00 | 16.22 0.00 0.00 | 16.22 21.71 109.50 | 0.00 0.00 0.00 | 1.22 21.71 80.89
7 5.50 0.00 0.00 | 16.62 0.00 0.00 | 16.62 22.28 133.00 | 0.00 0.00 0.00 | 1.22 22.28 103.16

8	5.50	0.00	0.00	17.03	0.00	0.00	17.03	22.84	157.06	0.00	0.00	0.00	1.22	22.84	126.01
9	5.50	0.00	0.00	17.43	0.00	0.00	17.43	23.39	181.67	0.00	0.00	0.00	1.22	23.39	149.40
10	5.50	0.00	0.00	17.84	0.00	0.00	17.84	23.93	206.83	0.00	0.00	0.00	1.22	23.93	173.33
11	5.50	0.00	0.00	18.24	0.00	0.00	18.24	24.46	232.51	0.00	0.00	0.00	1.22	24.46	197.79
12	5.50	0.00	0.00	18.65	0.00	0.00	18.65	24.96	258.69	0.00	0.00	0.00	1.22	24.96	222.76
13	5.50	0.00	0.00	19.05	0.00	0.00	19.05	25.45	285.37	0.00	0.00	0.00	1.22	25.45	248.21
14	5.50	0.00	0.00	19.46	0.00	0.00	19.46	25.92	312.51	0.00	0.00	0.00	1.22	25.92	274.13
15	5.50	0.00	0.00	19.86	0.00	0.00	19.86	26.38	340.11	0.00	0.00	0.00	1.22	26.38	300.51
16	5.50	0.00	0.00	20.27	0.00	0.00	20.27	26.81	368.14	0.00	0.00	0.00	1.22	26.81	327.32
17	5.50	0.00	0.00	20.67	0.00	0.00	20.67	27.23	396.59	0.00	0.00	0.00	1.22	27.23	354.55
18	5.50	0.00	0.00	21.08	0.00	0.00	21.08	27.64	425.45	0.00	0.00	0.00	1.22	27.64	382.19
19	5.50	0.00	0.00	21.49	0.00	0.00	21.49	28.03	454.71	0.00	0.00	0.00	1.22	28.03	410.22
20	5.50	0.00	0.00	21.89	0.00	0.00	21.89	28.41	484.34	0.00	0.00	0.00	1.22	28.41	438.63

12. Appendix 12: A brief discourse on carbon savings

In the United States, electricity generation is responsible for around 25% of the total greenhouse gas emissions and in 2019, natural gas accounted for 34% of the electricity generation (U.S. Environmental Protection Agency, 2021).

In this section, the impact of producing heat or electricity from geothermal resources is examined in terms of annual amount of saved CO_2 emissions by exploiting the geothermal system in Presidio, rather than natural gas.

The following assumptions were made: i) complete combustion is assumed to occur, ii) natural gas is 100 % composed of methane (CH_4), iii) 1 joule= 0.239 cal. Combustion of 1 m^3 natural gas yields 8,250 kcal energy (Çengel, 2020; Meşin and Karakaya, 2023), iv) density of natural gas is equal to 0.68 kg/m^3 (Eswara et al. 2013), v) all the CO_2 would be released directly into the atmosphere without any capture, vi) natural gas' combustion reaction with oxygen is as follows: $CH_4+2O_2 \rightarrow CO_2+2H_2O$, and vii) the efficiency of the natural gas cycle power plant, described by the thermal efficiency (η_{th}), is 50%, indicating that 50% of the heat input is converted into useful work output. The governing equation for thermal efficiency in the context of a power plant is:

$$\eta th = \frac{Useful\ work\ Output}{Heat\ Input} \quad (1)$$

For a natural gas cycle power plant, the thermal efficiency can be further expressed in terms of the key temperatures in the cycle, such as the high-temperature T_{hot} and low-temperature T_{cold}:

$$\eta th = 1 - \frac{Tcold}{Thot} \quad (2)$$

This formula is obtained from the Carnot efficiency, which signifies the highest possible efficiency that a heat engine can achieve when functioning between two temperature reservoirs. The sustainability attribute of the discussed system is examined in terms of saved annual CO_2 amount by employing geothermal energy rather than fossil fuels, such as natural gas. Results are presented in Table 1, highlighting significant increases in carbon savings with increasing energy outputs.

Table 1. Results of saved CO_2 amount calculated for minimum (Tertiary zone - Border Region) and maximum (Basement zone - Interior Region) values of producible electricity per unit volume derived from Table 2 A and B.

Parameter		
	minimum case	maximum case
Producible Electricity per unit volume (MW)	0.32	58.93
Carbon Saving (kg)	1,093,000	201,353,000

The table demonstrates the substantial environmental benefits of transitioning to geothermal energy for electricity generation. Utilizing geothermal resources to produce 0.32 MW in the Tertiary zone at the Border region can annually save 1,093,000 kg of CO_2 compared to natural gas. Similarly, the maximum scenario in the Basement zone at the Interior region, generating 58.93 MW, results in an annual carbon saving of 201,353,000 kg. This emphasizes the potential for significant reductions in greenhouse gas emissions by embracing geothermal energy, underscoring its role in fostering a more sustainable and environmentally friendly energy landscape.

References

U.S. Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2019 , 2021. EPA430-R-21-005. https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf (accessed February 28, 2024).

Çengel YA. Power generation potential of liquified natural gas regasification terminals. Int J Energy Res. 2020; 44: 3241–3252. https://doi.org/10.1002/er.5116

Meşin V., and Karakaya A., “Contribution of Geothermal Resources that Could Be Used in District Heating System to Türkiye Economy and Analysis in terms of Carbon Emissions”, Journal of Polytechnic, 26(1): 345-355, (2023).

Eswara, A.K.; Misra, S.C.; Ramesh, U.S. Introduction to natural gas: A comparative study of its storage, fuel costs and emissions for a harbor tug. In Proceedings of the Annual Meeting of Society of Naval Architects & Marine Engineers (SNAME), Bellevue, WA, USA