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Case Study of Geothermal Power Plant in Metropolitan Paris Using NREL SAM

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ABSTRACT

This paper presents the results of a simulation case study of the performance and financial analysis of a geothermal power plant located in Paris, France. The National Renewable Energy Lab System Advisor Model (NREL-SAM) tool based on the U.S. Department of Energy's Geothermal Electricity Technology Evaluation Model (GETEM) was used for the simulations of the current paper. The total resource energy density potential was taken to be 227 MW-g/cc, and the central portion of Paris is assumed to intersect the Liassic layer at a depth of 2000 meters. The Liassic layer itself is assumed to be 500 meters thick. The pumping parameters for input to the NREL SAM software were taken from the National Geodetic Survey (NGS) database. The SAM software allows for the simulation of a hydrothermal well with a width of 400 m, height of 100 m and permeability of $\kappa=0.25$. the distance from injection to the production wells is taken to be 1200 m. This affords a computed design with an average pressure change across the reservoir of 26.24 bar, an average reservoir temperature of 200 °C, and production bottom hole pressure of 155 bar. For the simulation of a flash conversion plant results show 19.4 MW for six production wells. At the end of the first year, the system would produce 96,313 MW-hr offering a Power Purchase Agreement (PPA) of $0.2032 per kW-hr. This PPA would increase 1% each year, creating a nominal PPA of $0.2203 per kW-hr. The internal rate of return is found to be 11%. The paper will present all inputs, assumptions are outputs from the SAM modeling and simulation. The Levelized Cost of Energy (LCOE) for the case study was found to be $ 0.075 per kW-hr.

1. INTRODUCTION

This paper presents the results of a performance and financial analysis of a geothermal power plant in Paris, France. This location was chosen because Paris has the second most concentrated geothermal energy in the world, next to Iceland (New York Times, 2014). The Paris basin is the largest on-shore sedimentary basin in France occupying a large region of Northern France (100,000 km^2) and extending north toward Belgium and lying below the English Channel. The origin of the Paris Basin if linked to a period of geological rifting activity during in the Permo-Triassic era. The Paris Basin, has artesian aquifers (ESAC, 2010, Gulliocheau *et al.,* 2000), which lie about approximately two to three kilometers below the Earth's surface and the network has a length of 13 kilometers. Because of this the hydrothermal convection system type was chosen for the simulation discussed in this paper. The temperature of the resource was determined using the fact that the geothermal gradient for regions of France equivalent to or north of Alsace (which includes Paris) are, on average, 10 °C per 100 meters of depth (0.1 °C/m), as seen in Figure 1.

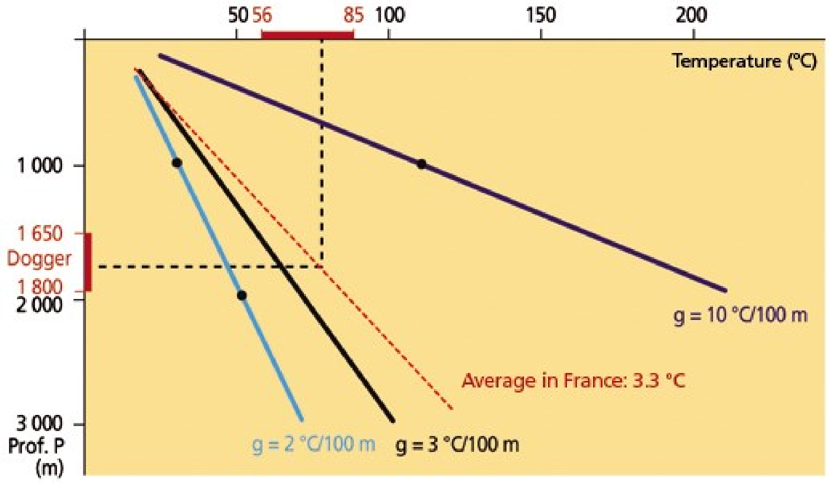


Figure 1: Geothermal gradient for various regions of France (cf. Electerre de France, 2016)

Because the resource temperature was 200 °C, flashed steam conversion was designed to be used in the plant. The energy output was taken to be 16.5 MW, and the total resource potential was taken to be 227 MW-g/cm^3. The Paris Basin has six sedimentary layers, as shown in Figure 2.

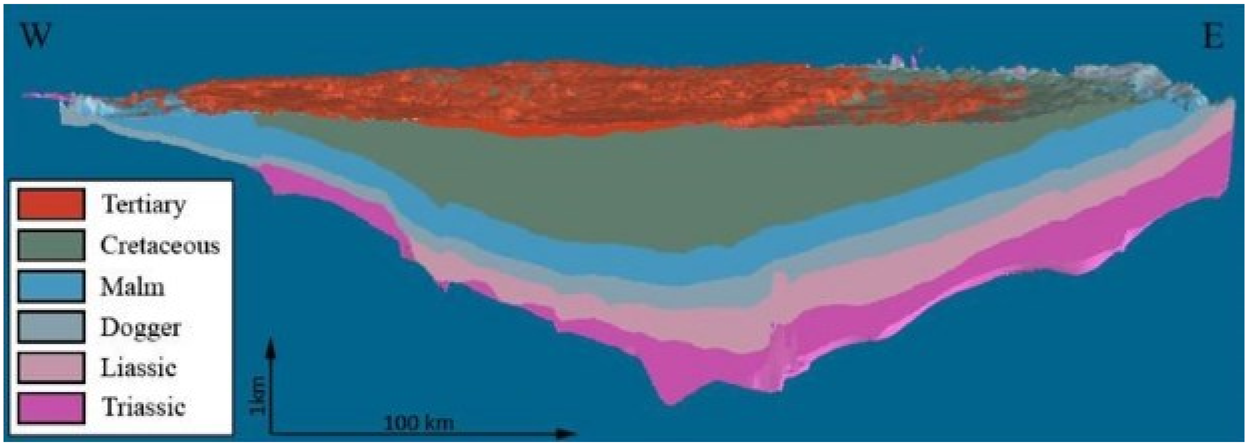


Figure 2: East-west profile showing the six layers of the Paris basin (cf. Bonte, D. *et al.*, 2015)

The central part of the Paris basin intersects the Liassic layer at a depth of 2000 meters. The Liassic layer is about 500 meters thick, as shown in Figure 3.

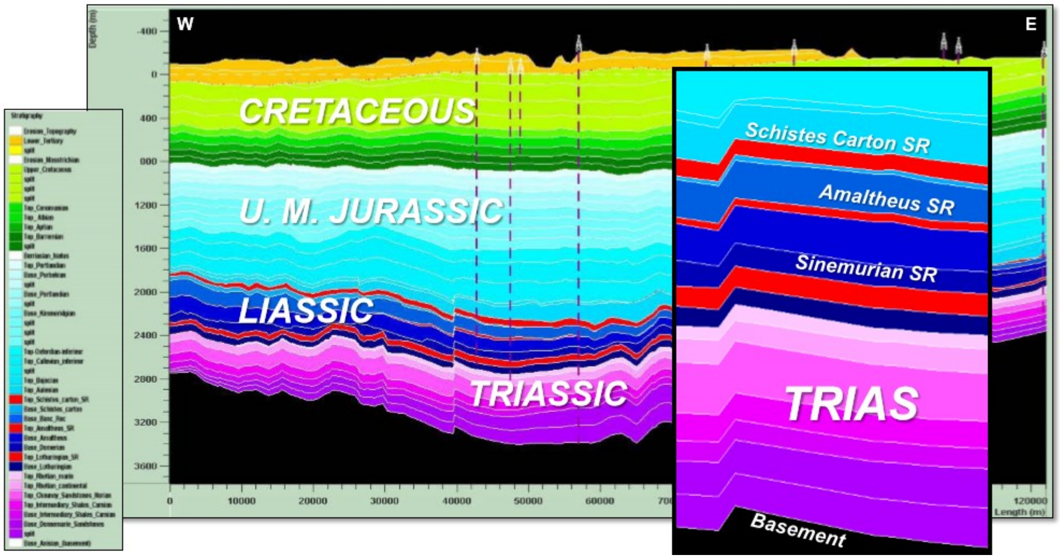


Figure 3: Shale oil potential of the Paris basin, France (cf. Search and Discovery, 2016)

The porosity, ϕ in the Liassic layer ranges from $5\% < \phi < 20\%$, so an average value of $\phi = 12.5\%$ was used to obtain the results of the current study. The pumping parameters were taken from The National Geological Survey's first generation of doublet designs, shown in Figure 4 (Ungemach, 2011). As illustrated in Figure 4, for the first generation doublets, there are two vertical wells. Where P represents the production well, I represents the injection well, d represents well head spacing, and D represents the doublet spacing at the top reservoir. In this version, d and D are equal. More recently implemented generations exist; in these versions, d is much smaller than D. Typical diameter (Ungemach, 2011) are P: 13 3/8 inches (340 mm) by 7 inches (178 mm) or 10 inches (254 mm) by 7 inches (178 mm), I: 7 inches (178 mm), with doubled 9 5/8 inches (245 mm) by 7 inches (178 mm) of casing protection for Albaian/Neocomian aquifers. The doublet technology has several advantages including i) there are no environmental impacts, since the cooled geothermal brine is fully re-injected, ii) production flow rates are maintained vs. a single well where the due to exploitation the pressure variation over time affects pumping conditions, iii) to the pressure interference the exploitation pressures are stabilized and the area impacted by pressure variation is limited.

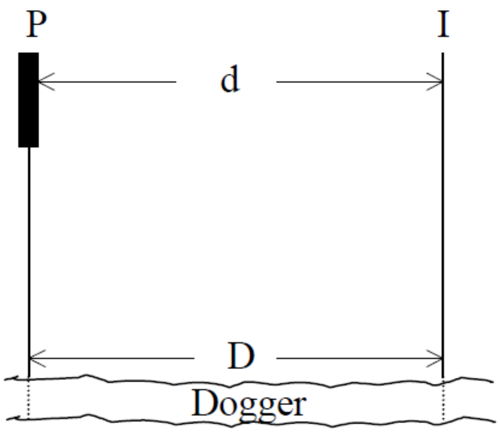


Figure 4: First generation doublet injection wells (cf. Ungemach, 2011)

As discussed later, since the NREAL SAM GETEM software program only has one input box for the distance between wells, it was determined that the generation where the distances are equal would provide accurate results. When this design was implemented by four different companies from 1974 to 1983, the distance between the wells ranged from 1000 m to 1400 m, so an average of 1200 m was applied to this project. This system also proved to have a life of 20 to 25 years. Additionally, evaporative cooling was chosen for the case study presented herein as it has proven to be up to 25% more energy efficient than air cooling (The News Magazine, 2016). It should be mentioned that the Dogger aquifer referred to in Figure 4 has become the topic of recent discussion in the geothermal engineering sector. In recent reviews (Lopez *et al.* 2010, Lopez, *et al.* 2012) it is reported that geothermal energy has been supplying heat to district networks in the Paris Basin for over 40 years. The main target area of exploration projects has traditionally centered around the Dogger aquifer which is approximately 2000 m deep. The Dogger aquifer is shown in Figure 5.

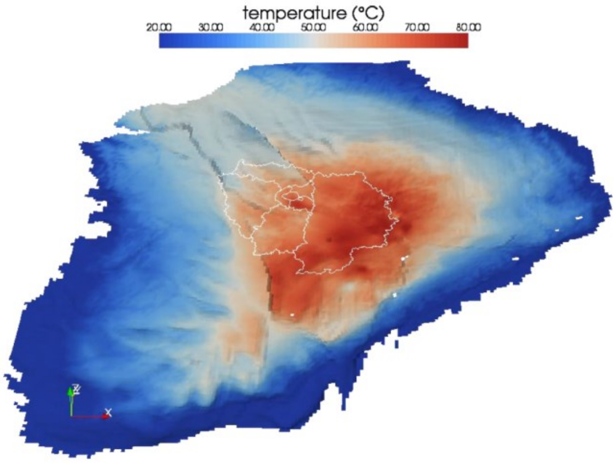


Figure 5: 3-d view of Dogger aquifer and associated temperatures, where white wirelines highlight the Ile de France region with Paris at its center (cf. Lopez et al. 2012)

Injection of cooled brines leads to progressive exhaustion of the resource. An up to date thermal model of the Dogger aquifer has recently been made created (Lopez et al. 2012) in order to aid in decision making regarding regulation of the resource and to better allow stakeholders to plan and carry out new operations.

2. NREL SAM FINANCIAL MODEL

The National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) (Blair et al., 2014,) is a valuable turn-key tool which allows systems engineers as well as program managers to trade one technology against another with ease. The System Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry: Project managers and Engineers, Policy analysts, Technology Developers, Researchers. System Advisor Model makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that are specified by the user as inputs to the model. Projects can be either on the customer side of the utility meter, buying and selling electricity at retail rates, or on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement (PPA). System Advisor Model's performance models make hour-by-hour calculations of a power system's electric output, generating a set of 8,760 hourly values that represent the system's electricity production over a single year. The current version of SAM includes performance models for the following technologies: photovoltaic systems (flat-plate and concentrating), battery storage model for photovoltaic systems, parabolic trough concentrating solar power, power tower concentrating solar power (molten salt and direct steam), Linear Fresnel concentrating solar power, Dish-Stirling concentrating solar power, Conventional thermal, solar water heating for residential or commercial buildings, wind power, geothermal power and geothermal co-production, and biomass power. The financial model of SAM (Short et al., 1995, Mendehsohn et al., 2012) calculates financial metrics for various kinds of power projects based on a project's cash flows over a user specified analysis period. Residential and commercial projects are financed through either a loan or cash payment, and recover investment costs through savings from reduced electricity purchases from the electricity service provider. For electricity pricing, SAM can model simple flat buy and sell rates, monthly net metering, or complex rate structures with tiered time-of-use pricing. For these projects, SAM reports the following metrics: Levelized cost of energy (LCOE = sum of costs over lifetime / sum of energy produced over lifetime), electricity cost with and without renewable energy system, electricity savings, after-tax net present value, and payback period. System Advisor Model calculates financial metrics from project annual cash flows representing the value of energy savings for projects using retail electricity rates, and the value of revenue from electricity sales for projects selling electricity under a power purchase agreement. System Advisor Model can perform either parametric analysis, sensitivity analysis, or stochastic modeling.

3. NREL SAM GEOTHERMAL MODEL

The geothermal power model used by SAM is based on the U.S. Department of Energy's Geothermal Electricity Technology Evaluation Model (GETEM, 2016). The GETEM model calculates the annual and lifetime electrical output of a utility-scale geothermal power plant, and the levelized cost of energy LCOE and other economic metrics for the plant. The geothermal power model calculates the output of a power plant that uses heat from below the surface of the ground to drive a steam electric power generation plant. The GETEM model analyzes the plant's performance over its lifetime, assuming that changes in the resource and electrical output occur monthly over a period of years. The GETEM tool can be used to answer the following kinds of questions i) Given a known configuration and resource, what is the LCOE of a geothermal power plant ? ii) How does changing the design of the plant affect its output and LCOE ? iii) What plant size is required to meet an electric capacity requirement ? iv) Given a known number of wells, what would the plant's electric capacity be? The GETEM software models the following types of systems: i) Hydrothermal resources, where the underground heat reservoir is sufficiently permeable and contains sufficient groundwater to make the resource useful without any enhancements, and ii) Enhanced Geothermal Systems (EGS) which pump water or steam underground to collect heat stored in rock. These systems involve drilling or fracturing the rock to improve heat transfer. Over time (typically years), as heat is collected from the rock, its temperature decreases, and more drilling is required. Recapitalization cost accounting for the cost of these improvements to reach new resources is modeling in NREL SAM GTEM. The NREL SAM GETEM can model by both flash and binary conversion plants. A flash power plant is shown schematically in Figure 6 (Jalilinasradbady,S. and Itoi, 2012).

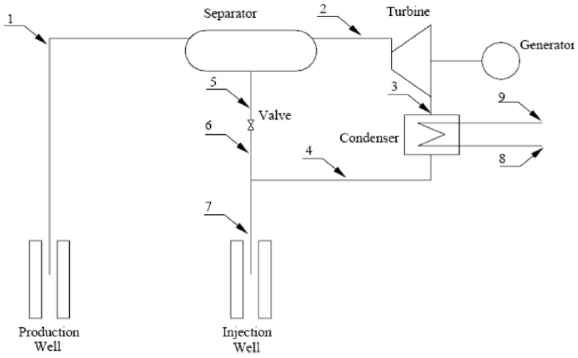
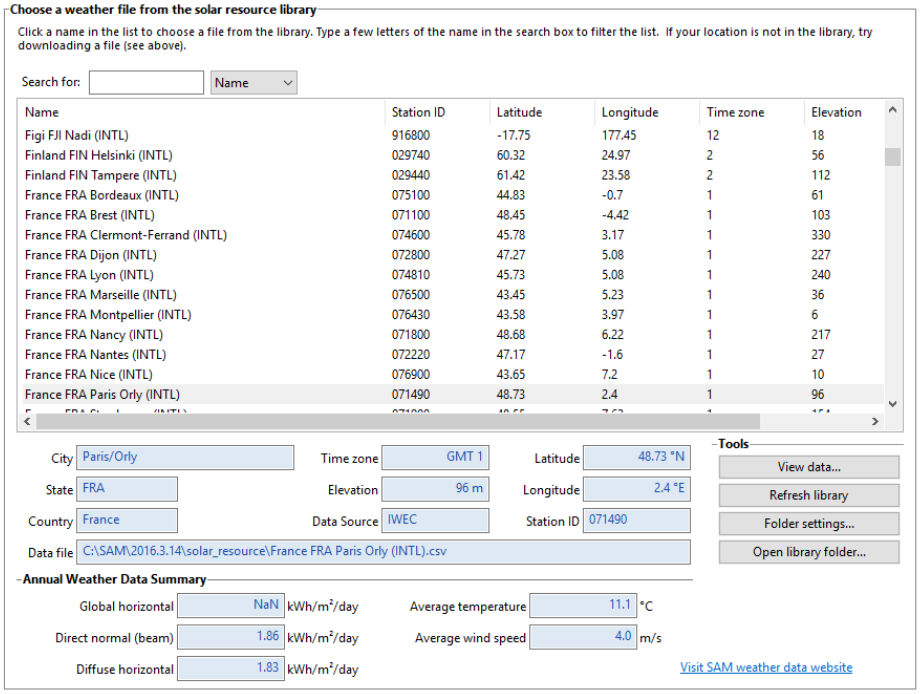


Figure 6: Flash power plant (cf. Jalilinasradbady and Itoi, 2012)

Single flash steam technology is used where the hydrothermal resources are in liquid form as shown in Figure 6. The produced fluid goes into a separator, which is held at a lower pressure than the fluid, causing it to flash (vaporize rapidly to steam). The steam is then passed through a turbine coupled to a generator as for dry steam power plants. The majority of the geothermal fluid remains liquid, and this liquid is re-injected into the reservoir. For the analysis herein, the flash power plant technology of Figure 4 and Figure 6 was employed.

4. MODEL INPUT PARAMETERS

The input values described above for the SAM system were entered accordingly as shown in Figures 7 through 11 below. Figure 7 allows the user to specify the weather data for the geothermal resource site study. The geothermal performance model runs a simulation over the life of the plant (defined by Analysis Period) on the Financial Parameters page in order to account for the annual decline in resource temperature. The SAM software assumes that the data in the weather file represents typical ambient conditions at the power block over the entire analysis period. Because the weather file contains data for a single year, SAM reads data from the weather file multiple times to complete a multi-year simulation. For an hourly simulation, SAM reads hourly data from the weather file, for a monthly simulation, SAM calculates average temperature, pressure, and humidity values from the hourly values in the weather file, and uses them to represent the average ambient conditions for each month of the year. The same set of twelve monthly average values for each year of the plant's life is used by SAM.



Choose a weather file from the solar resource library

Click a name in the list to choose a file from the library. Type a few letters of the name in the search box to filter the list. If your location is not in the library, try downloading a file (see above).

Search for: Name

Name	Station ID	Latitude	Longitude	Time zone	Elevation
Figi FJI Nadi (INTL)	916800	-17.75	177.45	12	18
Finland FIN Helsinki (INTL)	029740	60.32	24.97	2	56
Finland FIN Tampere (INTL)	029440	61.42	23.58	2	112
France FRA Bordeaux (INTL)	075100	44.83	-0.7	1	61
France FRA Brest (INTL)	071100	48.45	-4.42	1	103
France FRA Clermont-Ferrand (INTL)	074600	45.78	3.17	1	330
France FRA Dijon (INTL)	072800	47.27	5.08	1	227
France FRA Lyon (INTL)	074810	45.73	5.08	1	240
France FRA Marseille (INTL)	076500	43.45	5.23	1	36
France FRA Montpellier (INTL)	076430	43.58	3.97	1	6
France FRA Nancy (INTL)	071800	48.68	6.22	1	217
France FRA Nantes (INTL)	072220	47.17	-1.6	1	27
France FRA Nice (INTL)	076900	43.65	7.2	1	10
France FRA Paris Orly (INTL)	071490	48.73	2.4	1	96

City: Paris/Orly
State: FRA
Country: France
Time zone: GMT 1
Elevation: 96 m
Data Source: IWEC
Latitude: 48.73 °N
Longitude: 2.4 °E
Station ID: 071490
Data file: C:\SAM\2016.3.14\solar_resource\France FRA Paris Orly (INTL).csv

Annual Weather Data Summary

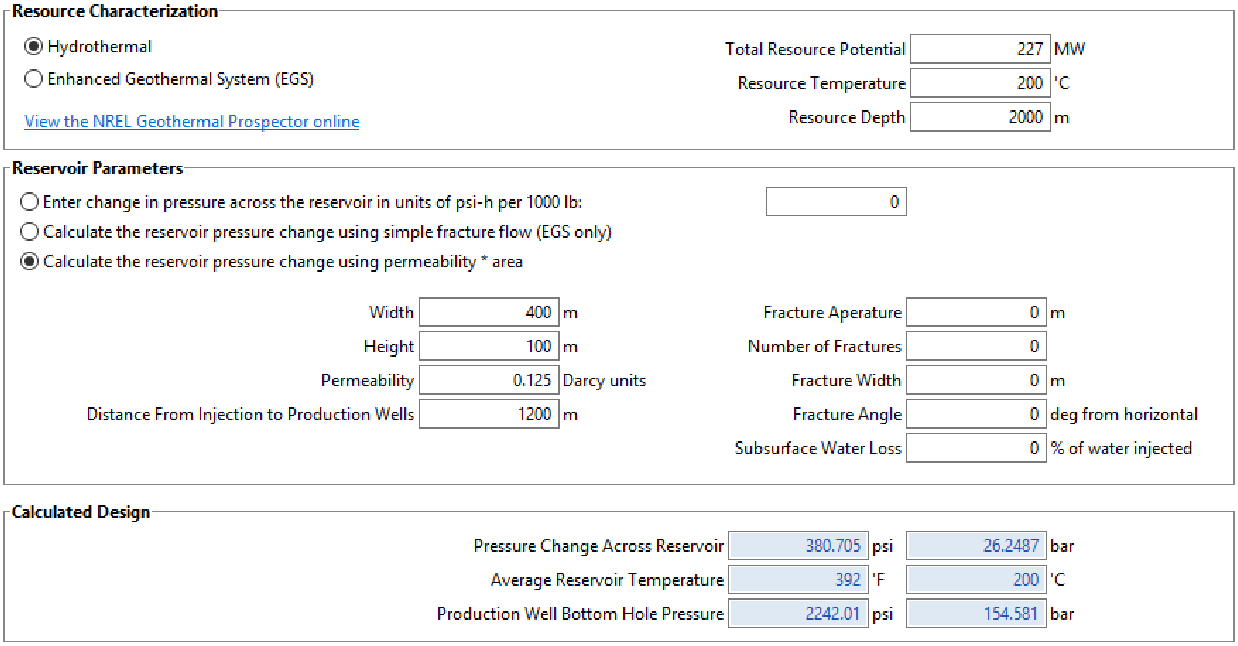
Global horizontal: NaN kWh/m²/day
Direct normal (beam): 1.86 kWh/m²/day
Diffuse horizontal: 1.83 kWh/m²/day
Average temperature: 11.1 °C
Average wind speed: 4.0 m/s

Figure 7: Weather file specification dialog in NREL SAM

Figure 8 is the dialog box showing how the user can set up either a Hydrothermal or EGS study. The resource characterization in SAM is as follows i) the Hydrothermal resource assumes that the rocks have sufficient permeability, heat and water to be useful immediately, ii) the Enhanced Geothermal System (EGS) resource assumes that there is heat, but either water or permeability, or both are lacking and must be added during the project development and operation. The total resource potential is an estimate of the total size of the energy in the underground reservoir of the resource under investigation. The total resource potential is used to compute the number times over the duration of the project's lifetime that new drilling would be required to renew the resource based on the reduction of the reservoir's temperature over time. The resources depth is the depth below ground at which the temperature specified by the resource temperature exists. The resource temperature is the temperature of the reservoir at the depth given by the prescribed resource depth. Typically, the higher the temperature of the resource, the lower the cost of energy generated by the plant. The SAM software does not model systems which operate at extremely high steam temperatures requiring special equipment. The reservoir parameters describe the geologic formations. SAM has three options for computing the change in reservoir pressure, each option affect's the plant's overall efficiency.

Figure 9 is the power plant configuration dialog, allowing the user to select between either flash or binary system and the pumping scenario. The plant and equipment configuration described the plant's conversion technology and how it is modeled. SAM allows the used to specify the plant output in kW, and then SAM compute the plant size required to ensure that the net plant output meets the desired requirement with suffice margin for parasitic loads. The plant and equipment dialog allows the used to select the exact number of wells, the steam-to-electricity conversion plant type (aka brine effectiveness), the binary plant efficiency, the overall plant steam to electricity conversion efficiency (percentage of theoretical maximum Carnot conversion efficiency) and whether or not flash technology is to be used. For availability and curtailment, SAM reduces the system's hourly electricity output by the loss percentage that the user inputs. The temperature decline parameters determine when and how often the project will require that new wells be drilled, and are related to the total resource potential. The pumping parameters (production well flow rate and resource temperature) define how much energy is available to the plant for conversion into electricity. The target the flow rate, the more steam moves through the system, making thermal energy available for conversion, which translates into fewer wells having to be drilled and thus a lower capital expense.

Figure 10 is the power block dialog allowing the user to specify parameters for the steam boiler design. The power block dialog allows the user to set the parameters of a power block that converts thermal energy from the geothermal resource into electric energy using a conventional steam Rankine cycle power plant. The power cycle can use either an evaporative cooling system for wet cooling, an air-cooled system for dry cooling, or a hybrid cooling system with both wet and dry cooling. In hybrid cooling a wet-cooling system and dry-cooling share the heat rejection load. Although there are many possible theoretical configurations of hybrid cooling systems, SAM only allows a parallel cooling option. The parameters available to simulate the cooling system include the ambient temperature, reference condenser water temperature rise, approach temperature, initial temperature difference between the steam at the turbine outlet (condenser inlet) and the ambient dry-bulb temperature, condenser pressure ratio, and cooling system part load levels SAM allows for monthly power block output of monthly and hourly power block outputs. The power block design point is set by the rated cycle conversion efficiency, design inlet and outlet temperatures, boiler operating pressure, and steam cycle blowdown fraction (the fraction of the steam mass flow rate in the power cycle that is extracted and replaced by fresh water.) The default value of 0.013 for the wet-cooled case represents makeup due to blowdown quench and steam cycle makeup during operation and startup. A value of 0.016 is appropriate for dry-cooled systems to account for additional wet-surface air cooling for critical Rankine cycle components.



Resource Characterization

● Hydrothermal
○ Enhanced Geothermal System (EGS)

Total Resource Potential 227 MW
Resource Temperature 200 'C
Resource Depth 2000 m

Reservoir Parameters

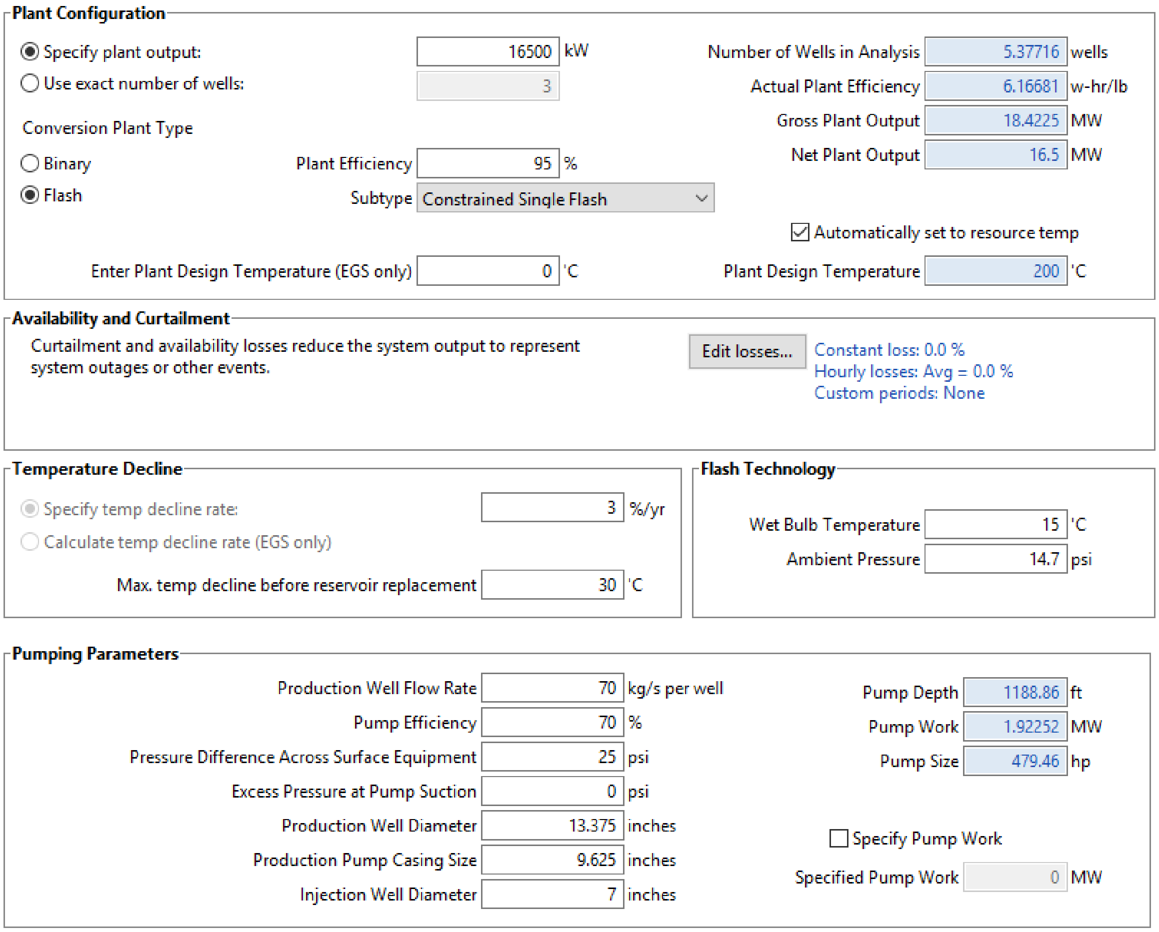
○ Enter change in pressure across the reservoir in units of psi-h per 1000 lb: 0
○ Calculate the reservoir pressure change using simple fracture flow (EGS only)
● Calculate the reservoir pressure change using permeability * area

Width 400 m
Height 100 m
Permeability 0.125 Darcy units
Distance From Injection to Production Wells 1200 m
Fracture Aperature 0 m
Number of Fractures 0
Fracture Width 0 m
Fracture Angle 0 deg from horizontal
Subsurface Water Loss 0 % of water injected

Calculated Design

Pressure Change Across Reservoir 380.705 psi 26.2487 bar
Average Reservoir Temperature 392 'F 200 'C
Production Well Bottom Hole Pressure 2242.01 psi 154.581 bar

Figure 8: Geothermal resource specification dialog in NREL SAM



Plant Configuration

● Specify plant output: 16500 kW
○ Use exact number of wells: 3

Number of Wells in Analysis 5.37716 wells
Actual Plant Efficiency 6.16681 w-hr/lb
Gross Plant Output 18.4225 MW
Net Plant Output 16.5 MW

Conversion Plant Type
○ Binary
● Flash

Plant Efficiency 95 %
Subtype Constrained Single Flash

☑ Automatically set to resource temp

Enter Plant Design Temperature (EGS only) 0 'C
Plant Design Temperature 200 'C

Availability and Curtailment

Curtailment and availability losses reduce the system output to represent system outages or other events.

Constant loss: 0.0 %
Hourly losses: Avg = 0.0 %
Custom periods: None

Temperature Decline

○ Specify temp decline rate: 3 %/yr
○ Calculate temp decline rate (EGS only)
Max. temp decline before reservoir replacement 30 'C

Flash Technology

Wet Bulb Temperature 15 'C
Ambient Pressure 14.7 psi

Pumping Parameters

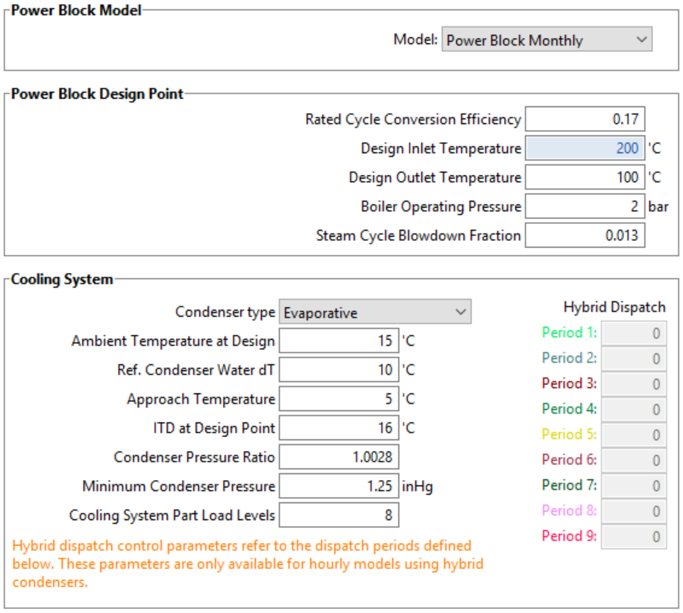
Production Well Flow Rate 70 kg/s per well
Pump Efficiency 70 %
Pressure Difference Across Surface Equipment 25 psi
Excess Pressure at Pump Suction 0 psi
Production Well Diameter 13.375 inches
Production Pump Casing Size 9.625 inches
Injection Well Diameter 7 inches

Pump Depth 1188.86 ft
Pump Work 1.92252 MW
Pump Size 479.46 hp

☐ Specify Pump Work
Specified Pump Work 0 MW

Figure 9: Geothermal power plant configuration specification dialog in NREL SAM

Figure 11 is the user input dialog box to specify the number of wells and associated financial inputs related to pumping. The NREL SAM GETEM software compute the number of production wells needed based upon the input of the plant and equipment dialog. The drilling and associated costs are comprised of exploration and confirmation costs, production and injection costs, surface equipment, and installation and stimulation costs.



Power Block Model

Model: Power Block Monthly

Power Block Design Point

Rated Cycle Conversion Efficiency	0.17	
Design Inlet Temperature	200	'C
Design Outlet Temperature	100	'C
Boiler Operating Pressure	2	bar
Steam Cycle Blowdown Fraction	0.013	

Cooling System

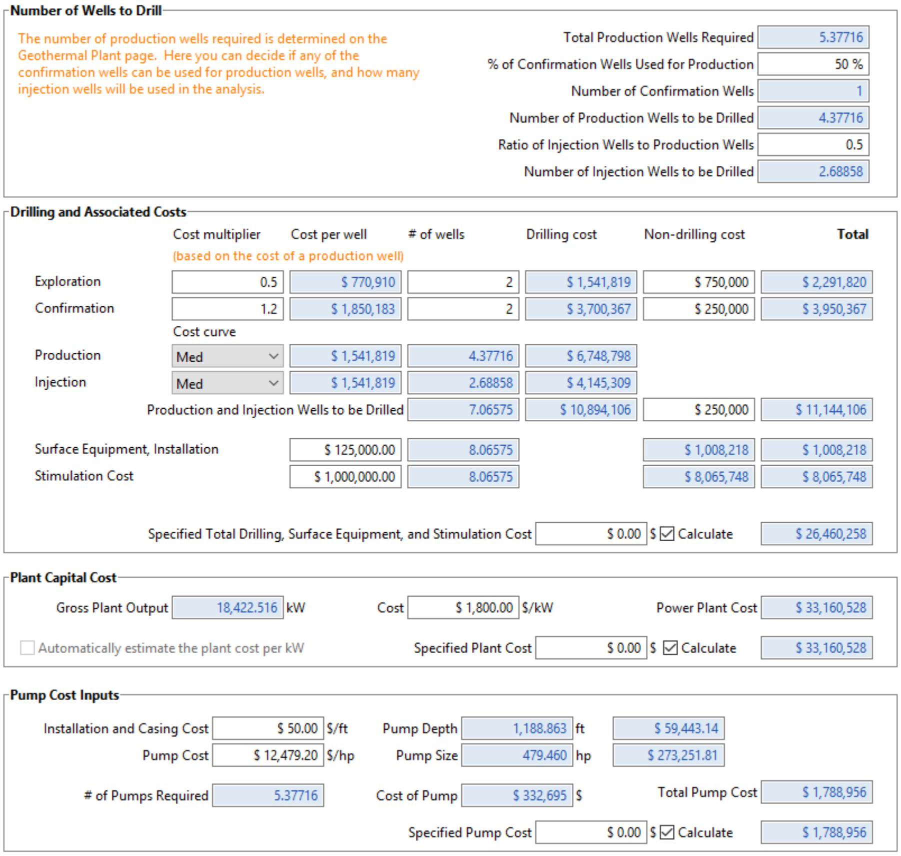
Condenser type	Evaporative	
Ambient Temperature at Design	15	'C
Ref. Condenser Water dT	10	'C
Approach Temperature	5	'C
ITD at Design Point	16	'C
Condenser Pressure Ratio	1.0028	
Minimum Condenser Pressure	1.25	inHg
Cooling System Part Load Levels	8	

Hybrid Dispatch

Period 1:	0
Period 2:	0
Period 3:	0
Period 4:	0
Period 5:	0
Period 6:	0
Period 7:	0
Period 8:	0
Period 9:	0

Hybrid dispatch control parameters refer to the dispatch periods defined below. These parameters are only available for hourly models using hybrid condensers.

Figure 10: Geothermal power block specification dialog in NREL SAM



Number of Wells to Drill

The number of production wells required is determined on the Geothermal Plant page. Here you can decide if any of the confirmation wells can be used for production wells, and how many injection wells will be used in the analysis.

Total Production Wells Required	5.37716
% of Confirmation Wells Used for Production	50 %
Number of Confirmation Wells	1
Number of Production Wells to be Drilled	4.37716
Ratio of Injection Wells to Production Wells	0.5
Number of Injection Wells to be Drilled	2.68858

Drilling and Associated Costs

	Cost multiplier (based on the cost of a production well)	Cost per well	# of wells	Drilling cost	Non-drilling cost	**Total**
Exploration	0.5	$ 770,910	2	$ 1,541,819	$ 750,000	$ 2,291,820
Confirmation	1.2	$ 1,850,183	2	$ 3,700,367	$ 250,000	$ 3,950,367
	Cost curve					
Production	Med	$ 1,541,819	4.37716	$ 6,748,798		
Injection	Med	$ 1,541,819	2.68858	$ 4,145,309		
Production and Injection Wells to be Drilled			7.06575	$ 10,894,106	$ 250,000	$ 11,144,106
Surface Equipment, Installation		$ 125,000.00	8.06575		$ 1,008,218	$ 1,008,218
Stimulation Cost		$ 1,000,000.00	8.06575		$ 8,065,748	$ 8,065,748

Specified Total Drilling, Surface Equipment, and Stimulation Cost $ 0.00 $ ☑ Calculate $ 26,460,258

Plant Capital Cost

Gross Plant Output 18,422.516 kW Cost $ 1,800.00 $/kW Power Plant Cost $ 33,160,528

☐ Automatically estimate the plant cost per kW Specified Plant Cost $ 0.00 $ ☑ Calculate $ 33,160,528

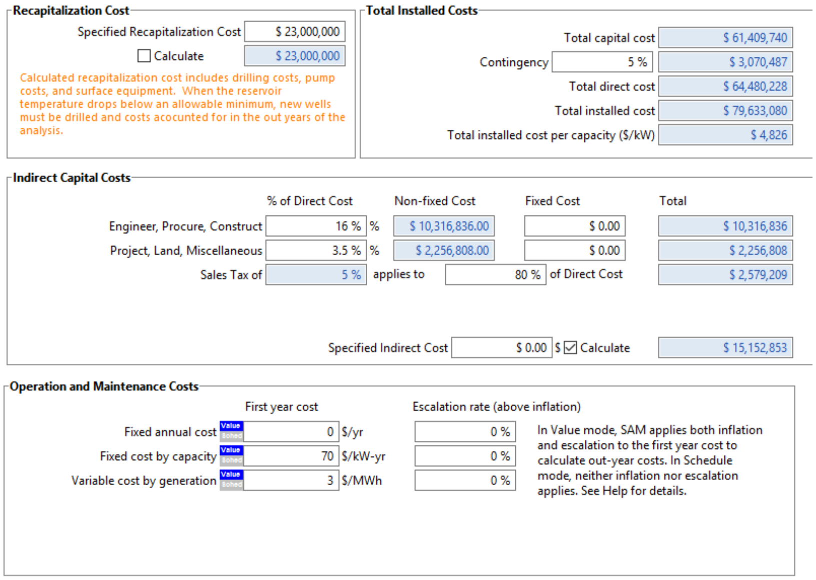
Pump Cost Inputs

Installation and Casing Cost	$ 50.00 $/ft	Pump Depth	1,188.863 ft	$ 59,443.14
Pump Cost	$ 12,479.20 $/hp	Pump Size	479.460 hp	$ 273,251.81
# of Pumps Required	5.37716	Cost of Pump	$ 332,695 $	Total Pump Cost $ 1,788,956

Specified Pump Cost $ 0.00 $ ☑ Calculate $ 1,788,956

Figure 11: Geothermal well configuration specification dialog in NREL SAM

Figure 12 is the financial cost model input dialog box for NREL SAM whereby the user inputs the costing and investment portion of the simulation. Pump cost inputs may be input as a function of the pump depth and pump size compute base on the inputs of the plant and equipment dialog boxes. Recapitalization cost are added each time the resource has to be re-drilled. Total installed costs are the sum of all the direct and indirect capital costs specified by the user. This value is used by SAM to compute the project's net capital cost (installed costs minus incentives plus additional financing costs). The total installed cost per capacity (USD/kW) is provided for reference only, SAM does not use this value in the case flow calculations. Indirect capital costs are broken down into three types: i) engineering, procurement, and construction ii) project, land, and miscellaneous, and iii) and sales tax. The first two can be entered as a percentage of direct costs, as a standalone value, or both (which will be summed to calculate a total). The sales tax percentage is entered on the Financial Parameters page and is applied to some portion of the direct cost. These three types of indirect costs are summed to calculated the total indirect cost.



Recapitalization Cost

Specified Recapitalization Cost: $ 23,000,000
☐ Calculate: $ 23,000,000

Calculated recapitalization cost includes drilling costs, pump costs, and surface equipment. When the reservoir temperature drops below an allowable minimum, new wells must be drilled and costs acocunted for in the out years of the analysis.

Total Installed Costs

Total capital cost: $ 61,409,740
Contingency: 5 % $ 3,070,487
Total direct cost: $ 64,480,228
Total installed cost: $ 79,633,080
Total installed cost per capacity ($/kW): $ 4,826

Indirect Capital Costs

	% of Direct Cost		Non-fixed Cost	Fixed Cost	Total
Engineer, Procure, Construct	16 %	%	$ 10,316,836.00	$ 0.00	$ 10,316,836
Project, Land, Miscellaneous	3.5 %	%	$ 2,256,808.00	$ 0.00	$ 2,256,808
Sales Tax of	5 %	applies to	80 %	of Direct Cost	$ 2,579,209

Specified Indirect Cost: $ 0.00 $ ☑ Calculate: $ 15,152,853

Operation and Maintenance Costs

	First year cost		Escalation rate (above inflation)
Fixed annual cost	0	$/yr	0 %
Fixed cost by capacity	70	$/kW-yr	0 %
Variable cost by generation	3	$/MWh	0 %

In Value mode, SAM applies both inflation and escalation to the first year cost to calculate out-year costs. In Schedule mode, neither inflation nor escalation applies. See Help for details.

Figure 12: Geothermal well financial model dialog in NREL SAM

For the analysis of the hydrothermal power plant of Metropolitan Paris case study presented herein, typical parameters per experience and practice (Watson, 2013, DiPippo, 2015, Grant and Bixley, 2011) were selected as shown in the dialog boxes of Figure 7 to Figure 12, respectively.

5. RESULTS

From the simulation set up of Figure 7 through 12 above NREL SAM outputs the financial cost information associated with the geothermal study. At the end of the first year, the system would produce 96,313 MW-hr, offering a Power Purchase Agreement of \$0.2032 per kW-hr. This PPA would increase 1% every year, creating a nominal PPA of \$0.2203 per kW-hr. The internal rate of return was 11%. Figure 13 displays the annual energy produced for the proposed 25-year life of the system.

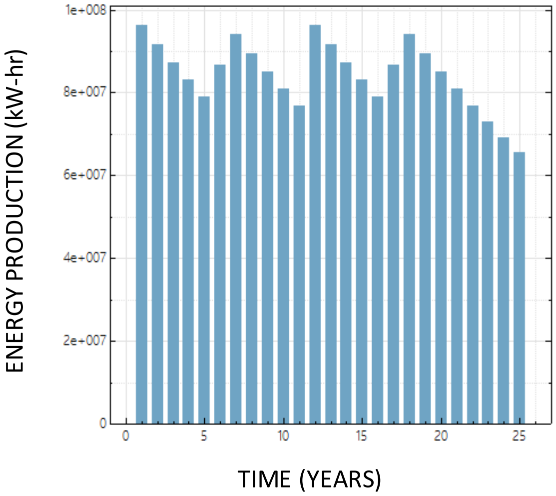


Figure 13: Energy produced (kW-hr) versus time (years)

Figure 14 compares these annual energy values to the annual expenses and revenue, showing that this system would be financially successful. From the data of Figure 14, the LCOE is found to be 0.075 USD/kW-hr

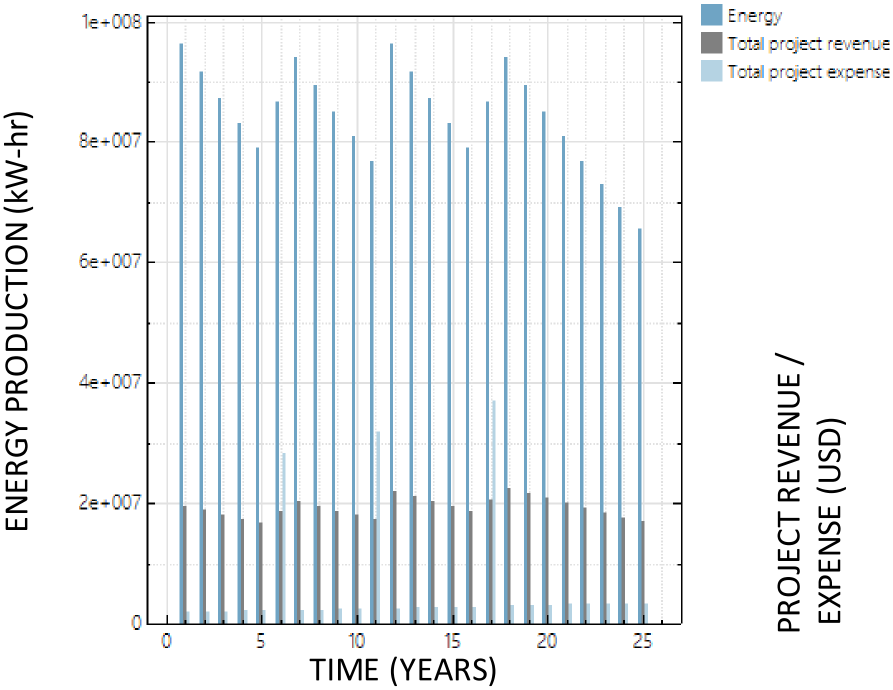


Figure 14: Annual energy produced (kW-hr), total project revenue (USD), total project expense (USD), versus time (years)

6. CONCLUSION

This paper has presented a case study of modeling a Geothermal Power Plant in the Metropolitan Paris France region using the NREL SAM GETEM simulation software suite of tools. For an assumed design power output of 16.5 MW, the system produced 18.4 MW, which is 9.24% more energy than was expected of the system. This shows that the system worked with the parameters that were decided on, as shown in this report. The 9.24% difference may be due to the fact that the system called for 5.3 production wells to be created, implying that six productions well would have to be built. The percent difference between 5.3 and 6 percent is 11.3%; when considering system efficiencies and losses, this difference would drop, showing why the system ended up producing slightly more heat than its initial design. The LCOE is 0.075 USD/kW-hr (7.5 ¢/kW-hr).

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