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DIAGNOSTICS-WHILE-DRILLING: REDUCING THE COST OF GEOTHERMAL-PRODUCED ELECTRICITY

Michael R. Prairie[1] and David A. Glowka[2]
[1]Sandia National Laboratories, P O Box 5800, MS-1033, Albuquerque, NM 87185-1033, USA
[2]ENP Capital Resources, Inc., 811 Sussex Drive, Austin, TX 78745, USA

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ABSTRACT

The goal of this work is to estimate the potential impact of proposed new Diagnostics-While-Drilling technology on the cost of electricity (COE) produced with geothermal energy. A cost model that predicts the COE was developed and exercised over the range of conditions found for geothermal plants in flashed-steam, binary, and enhanced-reservoir (e.g., Hot Dry Rock) applications. The calculations were repeated assuming that DWD technology is available to reduce well costs and improve well productivity.

The results indicate that DWD technology would reduce the geothermal COE by 2-31%, depending on well depth, well productivity, and the type of geothermal reservoir. For instance, for a typical 50-MW, flashed-steam geothermal power plant employing 3-MW wells, 1,829 m (6,000 ft) deep, the model predicts an electricity cost of 4.9 cents/kWh. With the DWD technology envisioned, the electricity cost could be reduced by nearly 20%, to less than 4 cents/kWh.

Such a reduction in the cost of electricity would give geothermal power a competitive edge over other types of power at many locations across the U.S. and around the world. It is thus believed that DWD technology could significantly expand the role of geothermal energy in providing efficient, environment-friendly electric generating capacity.

1. DIAGNOSTICS-WHILE-DRILLING

Diagnostics-While-Drilling is a proposed new technology for dramatically reducing the cost of geothermal and oil and gas wells through significant improvement in the drilling process. As envisioned, DWD is a closed information loop that would carry data up and control signals down between the driller and tools at the bottom of the hole, while analyzing and displaying downhole and surface data that the driller could use to better control the drilling process [1].

For the first time in the history of drilling, the driller would actually know what is going on downhole and precisely how the entire drilling system is performing. This knowledge should create feedback in the drilling process that would greatly improve both rock penetration and well productivity, leading to a marked decrease in the cost of producing electricity with geothermal power.

DWD also embodies logging-while-drilling and seismic-while-drilling capabilities. The ability to characterize the reservoir and its fluids while drilling will reduce logging costs, reduce the number of dry wells, and improve well productivity.

The U.S. Department of Energy and Sandia National Laboratories propose to lead the development of a cost-effective DWD system in cooperation with the geothermal and petroleum drilling industries. Beginning with a series of Proof-of-Concept Tests, the cooperative effort will include development of a high-speed data link, artificial intelligence software, and other hardware and processes that will serve as the basis of a commercial DWD service industry.

The goals of the DWD development program are to:

- Decrease geothermal well costs by 25%;
- Reduce the number of dry geothermal wells by 25%; and
- Increase the average geothermal well productivity by 25%.

It is estimated that the envisioned DWD system will require 5 years and $50M of government and industry funds to develop.

2. IMPACT ON THE COST OF ELECTRICITY (COE)

2.1 Cost Model

A spreadsheet model for calculating the cost of electricity produced from geothermal power was developed. The equations used in the model are shown in the Appendix. The model includes two major cost components:

- Debt servicing of capital costs, including well costs, plant costs, and other non-well costs, over 30 years at 13% interest rate; and
- Operating and maintenance (O&M) costs.

The model was run for flashed-steam, binary, and enhanced-reservoir geothermal fields. An enhanced reservoir is one that has been modified to increase its permeability. Enhanced reservoirs require well stimulation, extra pumping capacity, and extra injection wells (See Appendix). Well depths ranging from "shallow" at 609.6 m (2,000 ft) to "ultra-deep" at 4,572 m (15,000 ft) were considered. Well productivity ranging from 3 to 10 MW/well was assumed. A 25% dry well rate was also assumed, which means that for every four productive wells, one dry well was drilled. The calculations were then repeated for a case where DWD technology was used to reduce well costs by 25%, reduce the dry well rate by 25%, and increase the average well productivity by 25%.

2.2 Results

The first results are shown in Figure 1. Note that the electricity costs predicted by the model range from 3.3 to 13.9 cents/kWh. This agrees well with the cost range that actually exists in the geothermal industry today.

Shown in Table 1 for comparison are reported COEs for various energy sources. These data illustrate the fact that geothermal power is already highly cost competitive with most other forms of power generation. This is particularly true when fossil energy supplies are short, such as in the early 1980s. In cases where geothermal power is only marginally cost competitive, it can be concluded that relatively small changes in well costs or productivity can make the difference as to whether geothermal or some other form of energy is selected.

The results shown in Figure 2 indicate that reaching the goals set for the DWD system would reduce the cost of geothermal-produced electricity by 2-31%, depending on the depth, productivity, and type of geothermal field. In general, the deeper and less productive a given geothermal resource, the greater the potential benefit of DWD. The predicted cost reductions could provide geothermal power a significant competitive advantage in locations where it is currently marginal.

For instance, if a high-temperature geothermal reservoir exists at 1,829 m (6,000 ft) below the surface and is relatively "tight" so that well productivity is limited to only 3 MW/well, the model predicts the COE to be about 4.9 cents/kWh. This may not be economically competitive if power can be generated in that location for 4.5 cents/kWh with natural gas. With the cost savings promised by DWD, however, the geothermal COE could be reduced by nearly 20%, to 4.0 cents/kWh. Thus, DWD could make the difference in getting geothermal selected as the energy source of choice.

3. ACHIEVING THE GOALS

DWD has a potential for *reducing geothermal well costs* by at least 25% through the following effects:

- Improved penetration rates, resulting in more footage per day, or less cost per foot;
- Increased bit life, resulting in fewer trips and bit purchases; doubling penetration rates and bit life would reduce geothermal well costs by about 15%;
- Reduced tool failures through the ability to closely monitor downhole tools and detect incipient problems before they occur; this would reduce the number of trips and service/repair costs, saving at least 5% of the costs of an average geothermal well; and
- Reduced hole problems through the ability to closely monitor hole conditions and diagnose events such as lost circulation and gas or steam kicks; this could eliminate problems such as stuck pipe and easily reduce average well costs by 10%

Reducing the number of dry wells drilled by 25% would result from the following developments due to DWD:

- Improved resource detection and real-time drilling course correction to re-drill sections of dry holes and turn them into producers; and
- Fewer hole problems such as stuck pipe and permeability damage that can cause abandonment of a well.

Increasing average well productivity by at least 25% would result from the following capabilities made possible by DWD:

- Multi-leg completions, which could increase well productivity two- or three-fold; made possible by improved directional drilling capability and increased use of surface-controllable downhole tools;
- Improved resource detection and real-time drilling course correction to intercept the maximum resource possible; well productivity should roughly increase in proportion to the length of hole drilled through the productive reservoir rock; and
- Improved underbalanced drilling operations that prevent well permeability damage due to drilling mud and rock chips; made possible by real-time measurement and diagnosis of downhole flow conditions; several-fold improvements in well productivity are possible with properly controlled underbalanced drilling.

4. CONCLUSIONS

It has been shown that significant reductions in the cost of geothermal-produced electricity could be obtained if a Diagnostics-While-Drilling system were available as envisioned. The cost/benefit ratio for developing DWD can be estimated by considering the previous example cited, whereby the COE would be reduced by 0.9 cents/kWh through the use of DWD.

For the single 50-MW power plant assumed in the analysis, this amounts to an annual savings of $3,517,650, or a 30-yr lifetime savings of $105,529,500. These accumulated savings are over twice the estimated cost of developing a viable DWD system, and yet they accrue from a single power plant.

Such savings would not only give geothermal projects a competitive edge over other forms of power generation, they would also provide incentive for investors to provide venture capital for the geothermal industry. Both of these effects would help the geothermal industry to significantly expand its role in providing efficient, environment-friendly electric generating capacity.

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APPENDIX

The following assumptions and equations were used to calculate the cost of electricity produced by a 50-MW geothermal power plant.

Plant Size = 50 MW, assumed

Producing Hours/Year = 7817 hours/yr, [2], accounts for 89% effective capacity factor

% Debt Amortization/Year = 13.3% = (Principal + Interest for 30-yr loan @ 13% interest, 1 pmt/yr)/Total Power Project Cost

Non-Drilling Plant Cost/kW = $869/kW for flashed-steam [2], $1,819/kW for binary [2]; $1,866/kW for enhanced-reservoir (assumed by doubling the cost of the pumps for a binary plant)

Total Non-Drilling Plant Cost = Non-Drilling Plant Cost/kW * Plant Size (MW) * 1000 kW/MW

O&M Cost/kWh = $0.0123/kWh for flashed-steam [2]; $0.0112/kWh for binary [2]; $0.0123/kWh for enhanced-reservoir (assumed same cost as for flashed-steam plant)

Well Cost/m = $886/m for 610 m (2,000-ft) wells [4]; $984/m for 1,829 m (6,000-ft) wells (interpolated); $1,083/m for 3,048 m (10,000 ft) wells [4]; $1,206/m for 4,572 m (15,000-ft) wells (extrapolated)

Total Cost/Well = Well Depth * Well Cost/m

No. of Wells (Flashed-Steam & Binary) = # of producers + # of injectors = Plant Size/Well Productivity * (1+% Injectors/100) + 1 spare producer + 1 spare injector = 27 for 3 MW/well; 15 for 6 MW/well; 10 for 10 MW/well

% injectors = # injector wells/# producing wells = 50% assumed; ratios as high as 100% and as low as 10% are common practice

No. of Wells (Enhanced-Reservoir) = # of producers + # of injectors = 2 * # of producers = 2 * (Plant Size/Well Productivity + 1 spare) = 35 for 3 MW/well; 19 for 6 MW/well; 12 for 10 MW/well

Well Field Cost (Flashed-Steam & Binary) = Total Cost/Well * No. of Wells / (1-Dry Well Rate/100)

Well Field Cost (Enhanced-Reservoir) = Total Cost/Well * No. of Wells / (1-Dry Well Rate/100) + Enhanced Reservoir Stimulation Cost/Well Pair * No. of Wells / 2

Stimulation Cost/Well Pair = $1,000,000 assumed.

Dry Well Rate = number of dry wells / total # of wells = 25%, assumed; dry wells are defined as unusable for production or injection; dry well rates as high as 75% occur in some areas

Total Power Project Cost = Total Non-Drilling Plant Cost + Well Field Cost

Debt Amortization Cost/kWh = Total Project Cost / Plant Size (MW) / (1000 kW/MW) / (Producing Hours/Year) * % Debt Amortization/Year

Total Cost of Electricity (COE) = Debt Amortization Cost/kWh + O&M Cost/kWh

The results of Figure 1 were obtained by making the above calculations for well depths of 610, 1,829, 3,048, and 4,572 m (2,000, 6,000, 10,000, and 15,000 ft) and for an average well productivity of 3, 6, and 10 MW/well. Results in Figure 2 were obtained by repeating the calculations assuming: 1) a 25% reduction in the Total Cost/Well; 2) a 25% reduction in the Dry Well Rate; and 3) a 25% increase in Average Well Productivity.

A parametric study was performed to determine the effects of several of the above-listed parameters on the % Reduction in COE plotted in Figure 2. The most important variables were varied over their plausible ranges and the results plotted in Figure 3. Shown are the % reductions in COE due to DWD, plotted as a function of several variables relative to their baseline values. The baseline parameter values used were:

Reservoir Type = Flashed-Steam

Well Depth = 1, 829 m (6,000 ft)

Average Well Productivity = 6 MW/well

Plant Size = 50 MW

Producing Hours/Year = 7817 hours/yr

% Debt Amortization/Year = 13.3%

Non-Drilling Plant Cost/kW = $869/kW

Total Non-Drilling Plant Cost = $43,450,000

O&M Cost/kWh = $0.0123/kWh

Well Cost/m = $984/m

Total Cost/Well = $1,800,000

No. of Wells = 14.5

% injectors = 50%

Dry Well Rate = 25%

Well Field Cost = $34,800,000

Total Power Project Cost = $78,250,000

Debt Amortization Cost/kWh = $0.0266/kWh

Total Cost of Electricity (COE) = $0.0390

% Reduction in COE = 13.0%

The Figure 3 results were obtained by varying one variable at a time. For instance, if the Dry Well Rate is assumed to be 300% of its baseline value of 25% (i.e. if 75% of all wells are "dry") while maintaining all other variables at their baseline values, then a 37% Reduction in the COE would result with the use of DWD.

These results indicate that the most sensitive variables in the model are: Dry Well Rate, Average Wellbore Productivity, Well Depth, and % Injectors. The baseline values of these parameters used to obtain the results shown in Figures 1-3 were selected to be reasonable, moderate values for typical geothermal power plants. Figure 3 shows that the projected COE savings for the baseline case is probably somewhat conservative because it falls within the lower portion of the range of possible values using other possible parameter values.

The parameter study also shows that the rather modest goals set for the DWD technology development program are reasonable and would result in significant reductions in the geothermal COE. Higher goals are not necessary to make the use of DWD economically attractive.

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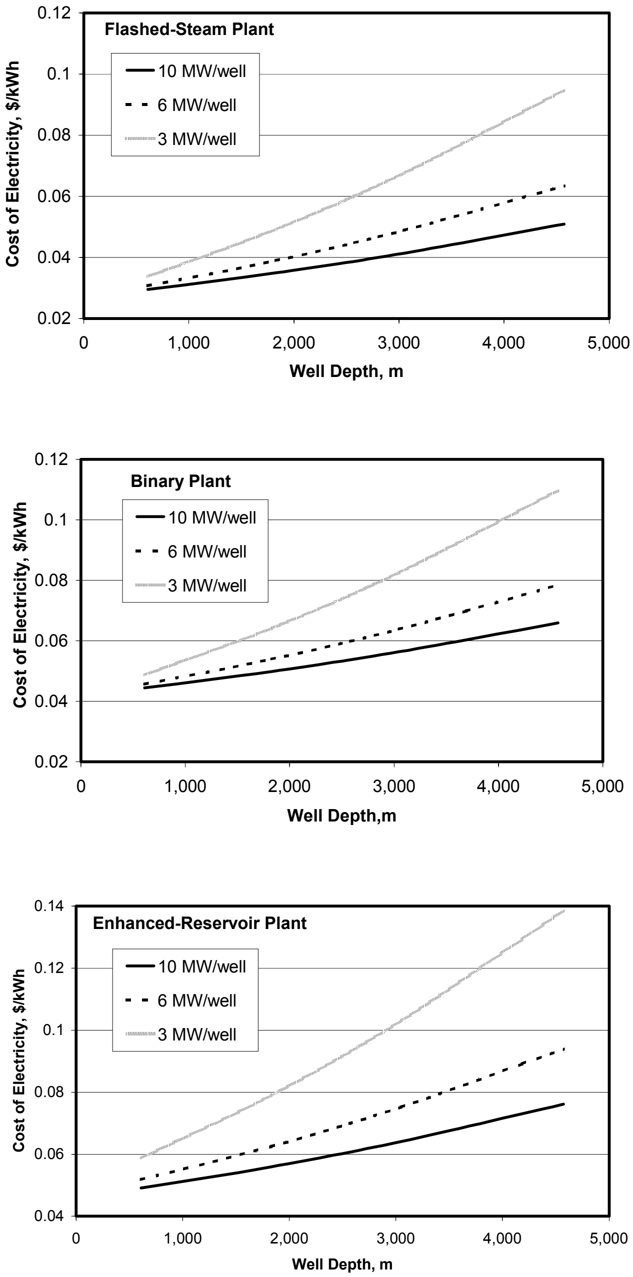

Figure 1 – Computed Cost of Electricity for 50-MW flashed-steam, binary, and enhanced-reservoir geothermal power plants.

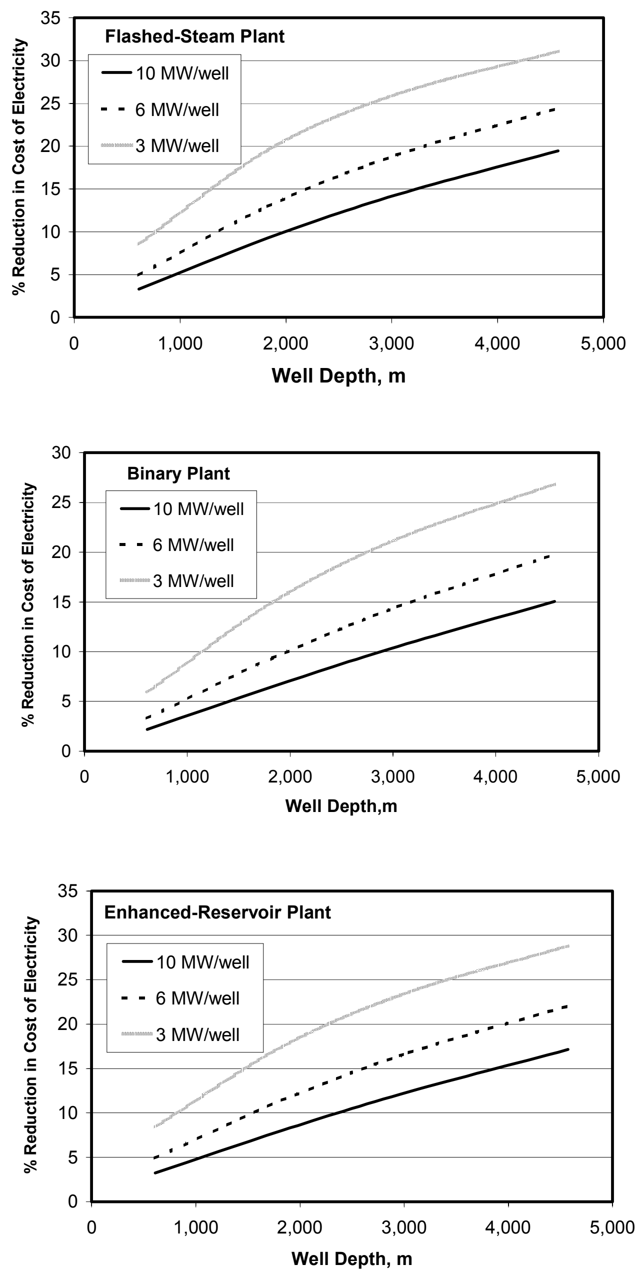

Figure 2 – % Reduction in the Cost of Electricity for 50-MW flashed-steam, binary, and enhanced-reservoir geothermal power plants, assuming a 25% reduction in Well Costs, a 25% reduction in the Dry Well Rate, and a 25% increase in Average Well Productivity.

Table1 - Reported Cost of Electricity (COE) for Several Generating Technologies

Technology	Configuration	COE, cents/kWh
Geothermal (Ref. 2)	Flashed-Steam Binary Enhanced-Reservoir	3.3 3.9 10.9
Wind (Ref. 2)	Horiz.-Axis Turbines - Class 4 wind regime - Class 6 wind regime	 6.4 5.0
Biomass (Ref. 2)	Direct-Fired Gasification-Based	8.7 7.3
Solar Thermal (Ref. 2)	Power Tower Parabolic Trough Dish Engine-Hybrid	13.6 17.3 17.9
Photovoltaics (Ref. 2)	Util.-Scale Flat-Plate Concentrators Neighborhood	51.7 49.1 37.0
Natural Gas (Ref. 3)	Gas Turbine, 1984 Gas Turbine, 1995	7.2 3.1
Oil (Ref. 3)	Oil-Fired Steam, 1984 Oil-Fired Steam, 1995	9.4 4.3
Coal (Ref. 3)	Coal-Fired Steam, 1984 Coal-Fired Steam, 1995	5.5 3.0
Nuclear (Ref. 3)	Light-H2O Reactor, 1984 Light-H2O Reactor, 1995	5.6 3.8

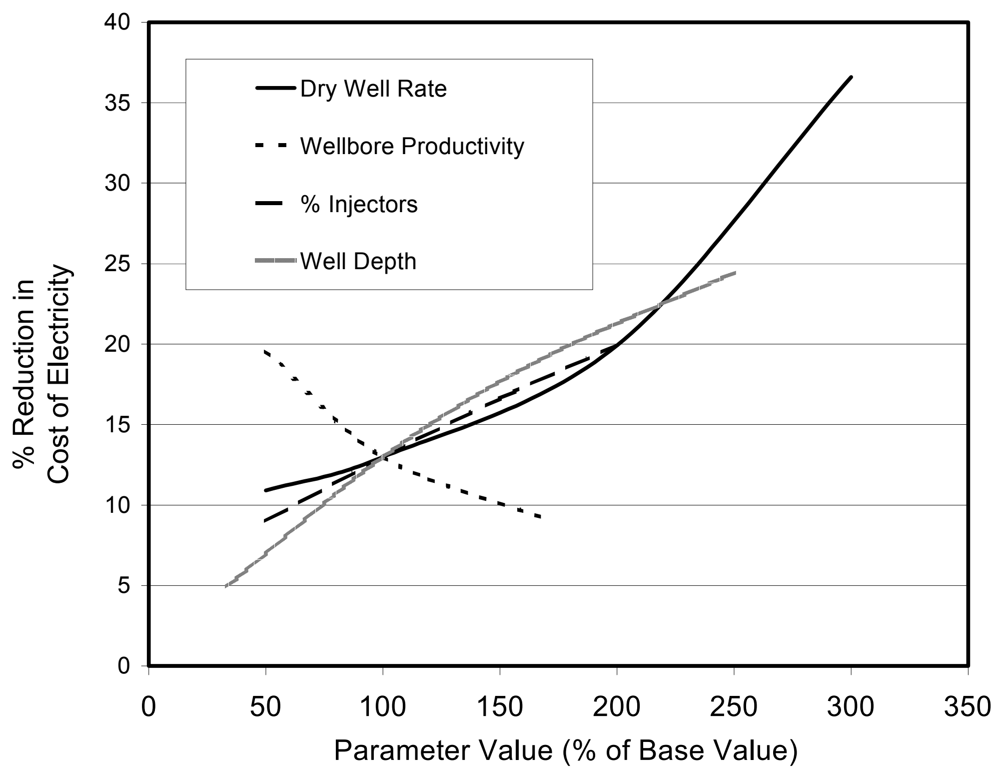

Figure 3

Figure 3 – Parametric Study Results for a Flashed-Steam Plant: % Reduction in the Cost of Electricity as a function of several parameters whose values are expressed in % of their baseline values: Dry well rate = 25%; Well Productivity = 6MW/well; % injectors = 50%, and Well depth = 1,829 m (6,000 ft).