# ONGOING RESOURCE ASSESSMENT OF GEOTHERMAL ENERGY FROM SEDIMENTARY BASINS IN TEXAS

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# ABSTRACT

A Texas resource assessment study documents a large untapped heat resource within deep sedimentary basins. Long considered a liability by the oil and gas industry and uninvestigated by the geothermal industry, this sleeping heat energy giant boasts many thousands of exajoules waiting for electrical power production. Subsurface temperature-depth (t-d) recordings from O&G log headers provide minimum temperatures found underground. Temperatures from 250 (121) to over  $400^{\circ}$ F ( $204^{\circ}$ C) occur at varying depths and in different geographical areas. Presently five large areas are defined that have strong potential for developing geothermal electric. A sixth area may exist as an independent geologic environment.

## TEXAS GEOTHERMAL ELECTRIC POWER

Geothermal electric power conjures images of volcanoes, geysers, and hot springs, of which only hot springs are in Texas. However Texas has thousands of oil and gas (O&G) wells, of its 600,000 drilled wells, that are sufficiently deep to reach temperatures of over  $250^{\circ}$ F ( $121^{\circ}$ C) and sometimes  $400^{\circ}$ F ( $204^{\circ}$ C) (Swift et al, 1999; Erdlac et al, 2004; McKenna et al, 2005; Erdlac et al, 2006).

Five major and one minor region within Texas have a potential for geothermal electrical power production (Fig. 1). These include East Texas, the Gulf Coast, the Delaware-Val Verde Basins, the Trans-Pecos, and the Anadarko Basin where it enters the Texas Panhandle. A sixth area (Maverick Basin) lies along the Texas-Mexico border southeast of the Delaware-Val Verde Basin (DVVB) complex. Only the Trans-Pecos region has geothermal dominated by a volcanic system; the other five regions are within sedimentary areas with O&G production. A brief discussion of four of these regions is presented in this paper.

# **GULF COAST GEOPRESSURED REGION**

In the late 1970's through the 1980's the DOE



Fig. 1. Valenza (1995) developed this map to show the approximate location and boundaries of geothermal areas in Texas. The map has been modified as a result of work conducted by Erdlac et al (this paper).

investigated the Texas and Louisiana Gulf Coast for developing geothermal electric power. Three forms of energy, chemical from dissolved methane, thermal from hot brine over  $225^{\circ}$ F (107°C), and mechanical from high brine flow rates (>20,000 bbls/day – 583 gpm) and high wellhead pressure, were considered. Only chemical and thermal energy conversion was achieved. The Wilcox and Frio/Vicksburg strata were target reservoirs, and while most of the investigated wells were in Louisiana, Pleasant Bayou #2 in Brazoria County, Texas became the first successful hybrid binary cycle system used in a deep sedimentary basin.

The well was drilled on the flank of the Chocolate Bayou salt dome (Fig. 2), down dip from O&G production. Brine flow was estimated at a minimum of 20,000 bbl/day with 22 SCF gas/bbl (Campbell and Hattar, 1991) but the plant operated on only 10,000 bbl/day (292 gpm). Scale and corrosion inhibitors were effective over the operating range of brine temperatures. The minimum well rating was 1.191 MW, with the binary cycle turbine producing 541 kW and the gas engine generating 650 kW. Parasitic load was –209 kW. Plant availability was 97.5%, capacity factor was 80%, and a total of 3,445 MWh was produced and sold to a local distributor. At least twice this power was possible from the well.



Fig. 2. Structure map on top of T5 marker, which begins at -13,600 feet (-4,145 m). Red arrow points to well location. Insert shows plant.

The well was successful technically but never commercialized due to low cost of fossil energy. In 1989-1990 no Texas renewable energy mandate existed. Texas Senate Bills 7 and 20 have changed that situation. Nor were most people concerned about additional electrical availability. This was before the California and Northeast U.S. blackouts.

## **DELAWARE – VAL VERDE BASINS**

Detailed investigations of the DVVB region covers  $18,812 \text{ mi}^2 (48,723 \text{ km}^2)$  with 44,525 wells and well spots from 0 down to 30,000 feet (9,144 m), as identified by Geological Data Services (GDS). Of these, 2,242 wells are between 12,000 (3,657) and 30,000 feet (9,144 m) while 8,802 wells were drilled to between 5,000 (1,524) to 11,999 feet (3,657 m).

Water flow from subsurface strata is minimized or choked off to focus on O&G production. No effort has been undertaken to determine the amount of hot water that can be produced from. Wallace (1982) indicated geopressured-geothermal areas in the United States that included the Delaware Basin.

Our work focused on developing a temperature-depth

(t-d) database within the basin complex. Over 5,000 wells (8,050 t-d points) were plotted and color-coded on a county by county basis to determine how each



Fig. 3. Plots of 8,050 t-d points in eight counties included within the DVVB study. The t-d points are color-coded to the county from which it is derived. A) Normal-normal plot. B) Log-normal plot.

county compared to the other (Fig. 3 A, B). Empirical curve fitting showed that a linear t-d fit was statistically less accurate than a non-linear curve, specifically a log-normal curve. Shallow data displayed a rapid increase of depth as temperature rose, followed by a rapid rise in temperature as depth increased for deeper data. Although small, this nonlinear aspect of the data is seen in Fig. 3A.

Data also shows that there is substantial scatter of the t-d distributions defined within each county. This scatter was investigated by defining a log-normal curve for each distribution, giving an equation of the form z = (A)Ln(T) - B where A and B are constants evaluated for each distribution, z is depth, and T is temperature (Fig. 4A, B). This equation is rewritten in the form of  $T = e^{C(z + B)}$  where C is the new constant 1/A. Taking the derivative gives the form of  $dT/dz = (C) e^{C(z + B)}$  or dT/dz = (C) T by substitution.

All temperature data is from log header information. In transferring the data we encountered one well (Amoco #1 University EY) in Terrell County that had a continuous temperature log recorded in 1976 from surface to 8,690 feet (2,649 m). Although not very deep, the well provided information to establish a

non-linear t-d relation. The data were measured from surface to TD and plotted at 10-foot (3 m) intervals (Fig. 5). Temperatures were measured from the log to within  $0.2^{\circ}$ F (0.1°C).



Fig. 4. Plots of the average logarithmic gradient defined for each of the counties in the study. Each curve is color-coded to the county from which it is derived. A) Normal-normal plot. B) Log-normal plot.

Three different non-linear solutions (logarithmic, 6<sup>th</sup> order polynomial, hyperbolic) were devised for this well data. The polynomial was a slightly better statistical fit than the log function; however forward modeling of the polynomial failed in its predictability beyond the data distribution. The polynomial peaked and began a downward turn in an unrealistic manner. A visual examination of the distribution also suggested a hyperbolic function as a solution. An equation of the form T =  $\sqrt{(3.9439 \times 10^{-4})z^2 + 4970.3}$ gave a 98.25% fit, and though slightly lower in percentage than the log and polynomial curves, the ability of this curve to be well constrained by the data at shallow low temperatures made it a better construct for the entire data set. Both the log and hyperbolic functions can be forward modeled to greater depths in a continuous manner with increasing T with depth.

Because of the size of the study, was not possible to use a single t-d relation, whether linear or non-linear, to represent the t-d profile. Both the basement and sedimentary complex change in nature sufficiently to require a more detailed analysis. Similarly, the need to generate maps within target formations, rather than at constant depth, necessitates multiple t-d profiles over the study region.



Fig. 5. Temperature-depth log plot for the Amoco #1 University EY well. Light blue dots represent 870 t-d pairs measured from the log. Red represents a logarithmic function, green a 6<sup>th</sup> order polynomial, and purple a hyperbolic function for curve solutions. Graph plotted in feet and °F due to nature of original data.

As with O&G production, target reservoirs are numerous depending on the temperature of water that is desired. Three specific formations stand out as being ideal over a larger aerial extent. These include the Devonian (31 Formation), Fusselman, and Ellenburger formations (Fig. 6) comprised of various amounts of limestone and dolostone, and occasional chert. These formations show a wide variation of porosity and permeability (Table 1). Natural fracture permeability plays an important role in fluid flow within these formations for oil and gas extraction and will do so for high volume water extraction. In numerous places the Ellenburger is known to display 'cavernous' porosity from past near surface weathering soon after deposition.

360 MYA	Osagian			Mit	ssissippian Lime	
	Kinderhookian		Woodford		Woodford	
Devonian	Upper					
408 MYA	Lower	1000	Devonian		Devonian	
Sturian	Upper	Silurian			Silurian	
438 MYA	Lower	Fusselman			Fusselman	
	Upper	Montoya		Montoya		
	Middle	÷.	Bromide	\$	Bromide	
		Sro.	Tulip Creek	- ē	Tulip Creek	
Ordovician		pson 6	McLish	6	McLish	
504 MYA			Oil Creek	- S	Oil Creek	
		Sim	Joins	Sim	Joins	
	Lower	Ellenburger		$\gamma$	Ellenburger	
Cambrian 570 MYA	Upper	Wilberns			Wilberns	
Precambrian		$\sim$	Precambrian	$\uparrow \uparrow$	Precambrian	

Fig. 6. A part of the stratigraphic column as found within the Delaware and Val Verde Basins of West Texas and New Mexico.

Demoise	Table 1	2 +- 258/
Devoluali	Porosity Kange	2 10 23%0
	Avg. Porosity	<b>6 10 8</b> %0
	Fracture Permeability Range	1 to 2,840 md
	Avg. Permeability	10.5 md
Fusselman	Porosity	3 to 11%
	Avg. Porosity	4 to 5%
	Fracture Permeability Range	2 to 26 md
	Avg. Permeability	8.5 md
Ellenburger	Porosity	2 to 14%
	Avg. Porosity	4%
	Fracture Permeability Range	0.1 to 2,250 md
	Avg. Permeability	75 md

### MAVERICK BASIN

The Maverick Basin is a small basin along the Texas-Mexico border, from Maverick to Zapata Counties southeast of the DVVB complex (Fig. 1). It has produced oil from Upper Cretaceous serpentine plugs (Lewis, 1989) and is being actively explored for additional O&G.

Temperature data from 12 wells were provided by a Midland O&G company. These wells, drilled to depths of 13,000 feet (3,962 m) to a over 17,000 feet (5,182 m), range from 320 (160) to  $435^{\circ}$ F (224°C). The temperatures are the highest in wells drilled to these depths found so far in Texas. The t-d values for these wells were graphed (Fig 7) for testing best-fit trend lines using log-normal and linear solutions. The coefficient of determination R<sup>2</sup> for both solutions



Fig. 7. Graph of t-d values for 12 wells in Zapata County within the Maverick Basin of Texas.

was identical, indicating no statistical preference for the t-d curve. Choosing the simpler linear function and determining dT/dz gave an average temperature gradient of 55.1°C/km. This is a high gradient, one that merits further investigation as to its nature.

### TRANS-PECOS REGION

The Trans-Pecos region of West Texas includes western Culberson, Hudspeth, El Paso, Jeff Davis, Presidio, and Brewster Counties. It is represented by Precambrian, Paleozoic, Mesozoic, and Cenozoic sedimentary rocks overlain by Tertiary volcanic rocks (48 to 17 m.y.) deposited from several volcanic centers in Texas and Mexico. The region displays folds and faults (strike-slip, thrust, and normal) of Ouachita-Marathon, Laramide, and Basin and Range tectonism. Locally surface data suggests Quaternary faulting in the form of extension.

Previous investigations of hot springs and water wells using silica geothermometry (Henry, 1979; Hoffer, 1979) identified at least seven areas in the region with subsurface water above  $257^{\circ}$ F ( $125^{\circ}$ C). In areas like the Presidio and Hueco Bolsons geothermal gradients were abnormally high (30 to  $40^{\circ}$ C/km). However no investigations were conducted using well data from O&G operations in the region.

A brief look at this region was undertaken with 65 t-d points from O&G wells scattered in Pecos, Jeff Davis, and Brewster Counties (Trentham, personal communication) and from shallow t-d data available from the SMU geothermal website. Two linear functions were calculated to fit shallow and deep temperature gradients (Fig. 8A). Coefficient of determination calculations were low, suggesting that insufficient data was available for determining separate shallow and deep linear gradients. By contrast a log-normal function displayed a better statistical correlation (Fig. 8B). A plot of the Trans-



Fig. 8. Plots of 65 t-d points within the Trans-Pecos area. Blue diamonds are O&G well BHT data. Purple squares are temperature data from SMU. A) Normal-normal distribution. B) Log-normal distribution.

Pecos "Rim Rock" area data overlain on the DVVB data displays a broader distribution than any single DVVB county (Fig. 9). This broader distribution suggests a more complex temperature regime, which is expected due to tectonic and volcanic activity in the region. Overall the Rim Rock data is hotter than the basin data at a given depth but appears to overlap the data recorded for Crockett County (light blue). This is surprising considering the distance between these areas and the different geologic regimes.

Further investigations with the O&G data (Trentham, personal communication) suggest that at least two different thermal gradient regimes are present. The O&G data were plotted in depth versus well entry number (Fig. 10, blue points) to show the variation in depth of the wells drilled in the region. Temperature gradients per well were calculated assuming a linear gradient and an average surface temperature of  $70^{\circ}$ F ( $21^{\circ}$ C). These gradients were then plotted (Fig. 10, purple points), showing a generally steady increase of



Fig. 9. Plots of Trans-Pecos "Rim Rock" t-d data (orange circles) on top of DVVB data. A) Normal-normal distribution. B) Log-normal distribution.

gradient with depth. One point at the left end of the plot has a high thermal gradient for the depth at which the well was drilled; however most of the points follow two well-defined straight lines (green and orange lines). There is a pronounced threshold jump that occurs at a gradient value of 2.753°C/100 m. The points defining each well gradient were then plotted as t-d values (Fig. 11), with purple and blue values combined representing all of the BHT records and with blue values alone representing t-d points below the 2.753°C/100 m gradient threshold change.

The purple lines represent linear and log-normal curves for all of the t-d values, and blue lines are for linear and log-normal curves for only the blue points.



Fig. 10. Plot of Trans-Pecos "Rim Rock" O&G data only showing the depth (blue) and the temperature gradient (purple) versus the sequential well number.



Fig. 11. Plot of Trans-Pecos "Rim Rock" O&G data only. Purple and blue dots combined represent all of the data, whereas the blue data represent everything below the 'step' jump in the gradient plot of Fig. 10.

When compared to all of the data points, the blue lines have high correlation coefficients (>86%). No effort was made to physically compare the well locations to each other to determine if the gradient represents threshold change variations in stratigraphic, structural, or tectonic boundaries. It is striking that when the t-d points below the 2.753°C/100m gradient threshold are plotted with the DVVB data, the data falls nearly on top of data from Terrell County (Fig. 12). Terrell is adjacent to the Trans-Pecos region and it is reasonable that these two data sets might coincide rather than with the data from Crockett County. More work is necessary to understand the regional significance and t-d correlations that might exist between the Trans-Pecos and the DVVB data sets.

### **RESOURCE AMOUNT ESTIMATES**

As the only Texas geothermal energy well, Pleasant



Fig. 12. Plot of Trans-Pecos "Rim Rock" t-d data on Delaware-Val Verde Basin data. Solid orange circles are Rim Rock data for only points that are found below the 2.753°C/100m gradient threshold.

Bayou #2 provides the starting point for calculating the potential recoverable resource. A 1979 Texas General Land Office publication investigated geothermal resources on public lands within areas defined by Brazoria, Matagorda, and Corpus Christi fairways (Fig. 13). The area within each fairway was 908, 353, and 632 mi<sup>2</sup> respectively (2351, 614, and 1637 km<sup>2</sup>). Estimates were also made of the producing wells possible within each of these fairways (Table 2).

Although Pleasant Bayou #2 was about 1.2 MW, this included the burning of natural gas on site to generate electricity. Over twice that amount could have been generated if full water production (>20,000 bbls/d) had been possible. Thus electrical generation from geothermal heat from a single zone in the Frio would have been 0.9 to 1.1 MW per well. Applying these numbers to the three fairways resulted in estimated electrical production of 156.6 to 191.4 MW, equivalent to 0.0827 to 0.1011 MW per mi<sup>2</sup>. The surface area displayed in Fig. 13 represents 32,067 mi<sup>2</sup> (83,053 km<sup>2</sup>). Thus minimum production from a target formation in this region is 2,652 to 3,242 MW.

A similar approach for the Delaware and Val Verde Basins, using  $18,812 \text{ mi}^2$  ( $48,723 \text{ km}^2$ ) for the area and the same production rate as at the Brazoria geothermal well, gives an electric production range of 1,556 to 1,902 MW. Geopressured systems have been found in the region; however these estimates may be too high. A 50% reduction in output, for example, results in values of 778 to 951 MW and may be a more reasonable minimum for the region.

These estimates are very uncertain as data for only one well is available. How those well conditions will change in different areas is dependent upon the drilled geological environment that. Production may be higher or lower depending upon the number of zones, the area of interconnectivity and water flow, and many other factors. Nevertheless Texas has a potential for producing in a range of at least 3,430 to 4,193 MW from the Gulf Coast and the deep Permian Basin alone.



Fig. 13. Map of geopressured geothermal area along Texas Gulf Coast. From Bebout et al., 1978.

	Т	able 2			
Fairway					
rarameter	Brazoria	Matagorda	Corpus Christi	Total	
Fairway extent (sq mi.)	908	353	632	1893	
Fraction of fairway producible (%)	100	100	100	xxx	
Production wells per fairway	48	54	72	174	
Estimated rating on heat alone (1.1 MW/well)	52.8	59.4	79.2	191.4	
Estimated rating on heat alone (1 M W/well)	48	54	72	174	
Estimated rating on heat alone (0.9 MW/well)	43.2	48.6	64.8	156.6	

#### **RESOURCE VALUE ESTIMATES**

As O&G energy costs rise, services such as drilling have also risen. The geothermal industry is thus not insolated from costs impacting O&G acquisition. For the geothermal industry to focus only on traditional geothermal areas is to limit future growth of this resource. For the O&G industry to continue treating hot water as waste is equivalent to flaring natural gas as was once the custom.

Opportunity exists to develop joint energy ventures. Expanding geothermal into sedimentary basins will result in finding unanticipated O&G reserves. Any company that develops geothermal energy in a sedimentary basin must be able to produce associated O&G. The geothermal industry knows how to produce hot water and generate electric power. But the O&G industry understands sedimentary rocks for maximizing O&G production. Partnering with O&G companies brings their expertise and data into the picture that a standalone geothermal operator would have to develop internally at its own expense.

Is such an endeavor worth the effort? Investigations to evaluate Texas heat reserves and resource value suggest that a Texas geothermal industry could rival the existing Texas O&G industry in economic value.

Around 600,000 wells have been drilled in Texas O&G development. Presently around 150,000 wells produce in the state. To compare energy resource values we used produced Texas O&G from 2003 and applied economic values to these produced reserves. In August 2004, the Midland Reporter-Telegram reported the crude oil price at \$43.00/bbl and natural gas at \$5.298/mcf. Using these values for the Texas yearly production in 2003 gave over \$15 billion for oil and over \$30 billion for natural gas (Table 3).

Table 3

Energy Resources	bbls	mcf	Value (Aug 2004)
Texas Oil Prod 2003	357,240,000		\$15,361,320,000
Texas Gas Prod 2003		5,670,211,962	\$30,040,782,975

To compare the potential Texas geothermal value to O&G production, which decreases each year, three models, were used to define possible electrical power value (Table 4). In all three cases 5.1 cents per kWh was assumed for electric evaluation. For all three cases we determined the number of wells that might be used throughout the state as a percentage of the entire 600,000 wells. Thus 1,000 wells were equal to 0.17% of the total and 100,000 wells were 16.67%.

Γa	ble	4

	Production Estimate One		Production Estimate Two			Production Estimate Three				
Number Wells	96 of ~600,000 Wells Drilled in Texas	GeothermEx Delaware Basin heat calculation (.438 MW)	x 10 <sup>9</sup> kWh/yr	Value (at 5.1 cents / kWh)	Brazoria power plant calculation (1.082 MW)	x 10 <sup>9</sup> kWh/yr	Value (at 5.1 cents / kWh)	Ormesa I binary isopentant plant, 149°C ss reservoir (2.65 MW)	x 10° kWh/yr (at 60% lead)	Value (at 5.1 cents / kWh)
1,000	0.17	438	3.8	\$195,680,880	1,082	95	\$483,394,320	2,650	13.9	\$710,348,400
5,000	0.83	2,190	19.2	\$978,404,400	5,410	47,4	\$2,416,971,600	13,250	69.6	\$3,551,742,000
10,000	1.67	4,380	38.4	\$1,956,808,800	10,820	943	\$4,833,943,200	26,500	139.3	\$7,103,484,000
25,000	4.17	10,950	95.9	\$4,892,022,000	27,050	237.0	\$12,084,858,000	66,250	348.2	\$17,758,710,000
50,000	8.33	21,900	191.8	\$9,784,044,000	54,100	473.9	\$24,169,716,000	132,500	696.4	\$35,517,420,000
75,000	12.50	32,850	287.8	\$14,676,066,000	81,150	710.9	\$36,254,574,000	198,750	1044.6	\$53,276,130,000
100,000	16.67	43,800	383.7	\$19,568,088,000	108,200	947.8	\$48,339,432,000	265,000	1392.8	\$71,034,840,000

In the first case, GeothermEx had conducted a proprietary study of a well in the Delaware Basin (Sanyal, personal communication). The estimated electrical production from geothermal heat alone within a single zone and from a single well was 0.438 MW. This does not include dissolved natural gas nor variations in temperature and water flow that might occur in different wells. Based upon the 600,000 wells drilled, the model ran through various scenarios as to the number of wells that might produce heat for electrical power generation. The resource value

started at about \$200 million and increased into the billions of dollars. Dollars marked in green are electric values on par with oil production value and dollars in red are on par with natural gas production value.

The second case assumed a well rating of 1.082 MW based upon projections from the Brazoria, Texas power plant. Considering that the O&G industry does everything possible to close off water zones, this value may be reasonable even outside the Gulf Coast especially if multiple hot water zones are perforated within a well. The rate of resource value increased at over twice that of the first case, reaching into the billions of dollars with fewer producing wells.

Finally, the third case used information from the Ormesa I binary isopentane plant in California. An average of 2.65 MW per well was used to estimate the possible Texas resource amount. A load availability of 60% was assumed, which created an equivalent of 1.59 MW per well. Again the resource value reached into the many tens of billions of dollars. Thus the value of the resource that might be developed is not small, and would have great impact on the local and state economy.

## **DISCUSSION AND CONCLUSIONS**

The work presented here represents analyses of recently collected t-d data, estimates on potential Texas electrical production, and estimates of the potential value of the resource. This study focused at a basin level analysis, initiating with data collection towards the eventual development of subsurface maps. This t-d data represents the newest available collection of recordings since the 1976 publication by the USGS/AAPG that used BHT data from O&G wells throughout North America, including Texas.

The reader may wonder if the investigation of sedimentary rocks is significant for future geothermal electrical power development. At the 2006 Geothermal Resources Council Meeting, the Enhanced Geothermal Systems (EGS) Committee presented summary results of a one year study conducted through MIT that assessed the impact of EGS on the United States for the 21<sup>st</sup> Century. The 'Summary Report' presented a table (reproduced with permission) estimating the U.S. geothermal resource base to 10 km depth within various categories (Table 5). Although crystalline rock holds the highest individual heat content, sedimentary rock and geopressured systems hold the second and third highest heat contents. Sedimentary rock means all sedimentary rock, not just where O&G is found. Coproduced fluid means water produced along with O&G, and geopressured systems represent Gulf Coast style subsurface systems.

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Category of Resource	Thermal Energy, in Exajoules (1EJ = 10 <sup>18</sup> J)	Reference		
Conduction-dominated EGS				
Sedimentary rock formations	100,000	This study		
Crystalline basement rock formations	13,300,000	This study		
Supercritical Volcanic EGS*	74,100	USGS Circular 790		
Hydrothermal	2,400 - 9,600	USGS Circulars 726 and 790		
Coproduced fluids	0.0944 - 0.4510	McKenna, et al. (2005)		
Geopressured systems	71.000 - 170.00**	USGS Circulars 726 and 790		

\* Excludes Yellowstone National Park and Hawaii.

\*\* Includes methane content.

In considering sedimentary rock and geopressured systems only, much of the deep hot water is probably still behind pipe. If only 0.1% of this water could be used to produce electricity, this represents between 171-270 EJ, the equivalent to 47-75 billion MWh of electricity or 29-46 billion bbls of oil. In 2005, the U.S. consumed 41.6 quadrillion BTU to generate electricity, or about 44 EJ.

The significance of a thorough investigation of deep sedimentary basins for deep permeable strata geothermal electrical power production is evident. Further work must be conducted in numerous U.S. basins for developing this resource. Similarly, deep O&G basins in other parts of the world hold an untapped energy resource that can bring a new future to geothermal electrical power production.

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