Deep Geothermal Resources: Estimated Temperatures on Top of the Red River Formation

Mott 100K Sheet, North Dakota

Lorraine A. Manz

2013

Geothermal energy is a renewable resource capable of producing an uninterrupted supply of electrical power and heat. In stable sedimentary basins, low-temperature geothermal energy (<40°C) is extracted from the shallow subsurface (~2–200 m [8-600 feet]) for use in domestic and commercial heating and cooling systems. Historically, deeper, hotter resources in these regions have not been developed because they typically lack one or more of the essential requirements that make high-temperature geothermal resources technically and economically viable.

Conventional methods of electricity generation using geothermal energy rely on hot (> 100°C) relatively shallow (<3,000 m [10,000 feet]), easily developed hydrothermal resources. Generally associated with active plate boundaries and/or volcanism, these high-grade hydrothermal systems are characterized by high thermal gradients, and highly fractured, porous reservoir rocks through which natural waters or steam can freely circulate. Large-scale, cost-effective electric power generation usually requires fluid temperatures above 150°C but smaller systems based on standard binary-cycle technology are capable of producing electricity using geothermal fluids at temperatures as low as 100°C.

Natural sources of high-grade hydrothermal energy are geographically limited. In the U.S. they are restricted to the western states and currently represent less than 1% of the nation's electrical power generating capacity (U.S. Energy Information Administration, 2011). Yet the amount of heat at depths less than 10,000 m (30,000 feet) below the surface of the continental U.S. is substantial. By replicating natural hydrothermal conditions it is possible, in some regions, to turn this heat into an economically viable resource. In 2005 an 18-member MIT-led interdisciplinary panel conducted a comprehensive technical and economic assessment of geothermal energy as a viable source of energy for the U.S. (Tester and others, 2006). The study estimated that, based on current technology, geothermal energy could be producing more than 100GW of affordable electricity by 2050, equivalent to roughly 10% of the U.S.' present-day capacity.

Enhanced (or engineered) geothermal systems (EGS) are engineered reservoirs designed to produce energy as heat or electricity from geothermal resources that are otherwise not economical due to lack of water and/or permeability (U.S. Department of Energy, 2008). EGS technology uses adaptations of techniques developed in the oil and gas, and mining industries to fracture hot, low-porosity rocks in the deep subsurface and extract the heat with water via a system of injection and production wells.

With infrastructures already in place and the abundance of horizontally drilled and/or artificially stimulated wells, hydrocarbon fields are prime candidates for the application of EGS technology. Of particular interest are those wells regarded as marginal or unproductive because they produce too much water. Geothermal waters that are coproduced with oil and gas are an expensive waste product that in North Dakota must be disposed of by re-injection into the subsurface. If sufficiently hot (>100°-150°C) and available in sufficient quantity, however, these waters may be capable of generating cost-effective electricity (McKenna and others, 2005).

The Ordovician-age Red River Formation is the deepest of four major geothermal aquifers that occur in the Williston Basin. The map shows calculated temperatures (°C) for the top of the Red River Formation in the vicinity of Mott in southwestern North Dakota.

There are no data sets for North Dakota that list accurate temperatures for Paleozoic rocks. Bottom hole temperatures from oil logs are unreliable and to assume that a simple linear relationship exists between temperature and depth would be incorrect. Although grossly linear the geothermal gradient in a simple linear lithosphere is significantly affected by thermal variables (heat flow and thermal conductivity) in the earth's crust and any method used to accurately calculate subsurface temperatures must take these factors into account. Provided the subsurface stratigraphy is known, Gosnold (1984) showed that at a given depth (Z) the temperature (T) can be represented by the following equation:

$$T = T_0 + \sum_{i}^{N} Z_i (Q/K_i)$$

Where:
T_0 = Surface temperature (in °C)
Z_i = Thickness of the overlying rock layer (in meters)
K_i = Thermal conductivity of the overlying rock layer
N = Number of overlying rock layers
Q = Regional heat flow

For the data set used to produce this map T_0 and K were assumed to be constants. Mean surface temperature ($T_0 = 8.0$°C [46.4°F]) was calculated from statewide average annual bare and turf soil temperatures at 79 North Dakota Agricultural Network climate monitoring stations for the period 1991 to 2010 (http://www1.ndsu.edu/ndsco). Thermal conductivities (K) for formations overlying the Red River Formation are shown in Table 1.

Estimated regional steady state heat flow $Q = 70.0$ mW/m² (Blackwell and Richards, 2004).

Rock units and thicknesses were obtained from oil well log tops (March 2012 update). The map was compiled using 20 data points (wells).

Table 1. Thermal conductivity estimates for principal lithostratigraphic units overlying the Red River Formation in the Williston Basin.

Formation(s)	Thermal Conductivity (W/m K)[1]	Formation(s)	Thermal Conductivity (W/m K)[1]
Quaternary, Neogene and Paleogene systems, Hell Creek, Fox Hills	1.75	Broom Creek, Amsden (eroded)	3.20
Pierre, Niobrara, Carlile	1.46	Broom Creek	3.10
Greenhorn	1.25	Tyler	1.40
Mowry, Newcastle	1.72	Big Snowy Group	1.30
Inyan Kara	2.66	Kibbey (limestone marker bed)[2]	1.40
Swift	1.41	Madison Group	3.10
Rierdon	2.13	Three Forks	1.40
Spearfish	2.99	Birdbear, Duperow	3.50
Minnekahta	3.10	Souris River	3.80
Opeche	2.70	Dawson Bay, Interlake, Stony Mountain	3.50

[1] Thermal conductivities for formations above, and including, the Spearfish were estimated using data from temperature-depth logs for Hess Corporation's Tioga-Madison Unit O-143HR well in SW4, NW4, Sec. 17, T15SN, R94W. All other thermal conductivities are from Gosnold (2009).
[2] The Kibbey Lime is a limestone bed in the Kibbey Formation that is a prominent marker on electronic logs.

References

Blackwell, D.D., and Richards, M., 2004, Geothermal map of North America: American Association of Petroleum Geologists, 1 sheet, scale 1:6,500,000.

Gosnold, W.D. Jr., 1984, Geothermal resource assessment for North Dakota. Final report. U.S Department of Energy Bulletin No. 44-66-MMERB44.

Gosnold, W.D. Jr, 2009, Geothermal power from low-temperature resources: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 463.

McKenna, J., Blackwell, D., Moyes, C., and Patterson, P.D., 2005, Geothermal electric power supply possible from Gulf Coast, Midcontinent oil field waters: Oil & Gas Journal, Sept. 5, 2005, p. 34-40.

Tester, J.W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., Garnish, J., Livesay, B., Moore, M.C., Nichols, K., Petty, S., Toksoz, N., Veatch, R., Augustine, C., Baria, R., Murphy, E., Negraru, P., Richards, M., 2006, The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century: Massachusetts Institute of Technology, DOE Contract DE-AC07-05ID14517, Final Report.

U.S. Department of Energy, 2008, Enhanced geothermal systems. http://www1.eere.energy.gov/geothermal/enhanced_geothermal_systems.html (Version 11/22/2008).

U.S. Energy Information Administration, 2011, Renewable Energy Consumption and Electricity Preliminary Statistics 2010, D. C., 13p. http://www.eia.gov/renewable/annual/preliminary (Retrieved 2 November 2011).

Geologic Symbols

Top of Red River Formation (feet above sea level)

129 • Data Points (wells)

Temperature °C

130 128 126 124
124 122 120 118
118 116 114 112
112 110 108 106
106 104 102 100

Other Features

Water
Marsh - Wetland
River/Stream - Perennial
River/Stream - Intermittent
Section Corners
County Boundary
US Highway
22 State Highway
Paved Road
Unpaved Road
100K Border

Scale 1:100,000

Mercator Projection
1927 North American Datum
Mott 100K Sheet, North Dakota
Standard parallel 46°00'
Central meridian 102°30'

Cartographic Compilation: E. L. Kadrmas

Note: This map was expanded beyond the normal Mott 100K Sheet to include an additional height of four miles south to the South Dakota border.