STATUS OF NEVADA GEOTHERMAL RESOURCE DEVELOPMENT – SPRING 2002

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ABSTRACT

At least 40% of Nevada has potential for electric-power generation from geothermal resources, and much of the rest of the state has potential for direct use. Nearly all of Nevada's resources are related to deep fluid circulation in an area of crustal extension and high heat flow. Electric power is generated from geothermal resources at nine areas in northern Nevada, and several other areas have potential. Nevada produced about 1250 GWh of electric power from geothermal energy in 2001; this amount has remained relatively stable for the past nine years. Non-electric uses include vegetable dehydration, space heating, and spas; several aquiculture and space-heating applications have been discontinued over the past 10 years.

GEOLOGY

Over 40% of Nevada is believed to have potential for electric-power generation from geothermal resources, and another 50% of the state has potential for direct use of such resources. Surface and subsurface indications of these resources are demonstrated by >1000 thermal springs and wells in the state that represent several hundred resource areas.

Geothermal reservoirs in the northwestern part of the state have generally higher temperatures; these reservoirs are usually interpreted to be related to circulation of ground water to deep levels along faults in a region of higher-than-average heat flow (e.g., Hose and Taylor, 1974). In east-central and southern Nevada, the low- to moderate-temperature geothermal resources are generally believed to be related to regional intrabasin groundwater circulation in fractured carbonate-rock aquifers (e.g., Winograd, 1962; Mifflin, 1968). The maximum temperatures attained during deep circulation in eastern and southern Nevada could be 100-150ºC, but spring temperatures at discharge points are generally <65ºC. Temperatures slightly higher than 150ºC have been encountered in deep oil wells of eastern Nevada; assuming a gradient of 25ºC/km, circulation to depths of 6 km is likely.

GEOTHERMAL ELECTRIC POWER GENERATION

Electric power is generated using geothermal resources at nine geothermal areas of northern Nevada **(Fig. 1),** and characteristics of these areas are summarized in **Table 1**, with the geology of the areas summarized below. Nevada's geothermal generating capacity has remained stable since about 1993, shortly after the newest power plants were brought on line.

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TABLE 1. NEVADA GEOTHERMAL POWER PLANTS 2001

Map No.	Plant Name (year on line)	Prod. Capacity[1] (MW)	Plant type	Approx. Drilled Temp (°C)	Prod. (GWh) Gross (net sales)	Plant Operator	Prod. Fluid Temp.[2] (°C)	Ave. Prod. Well Depth, m (number)	Injection Fluid Temp.[2] (°C)	Ave. Injection Well Depth, m (number)
1	**Beowawe** (1985)	16.7 (16.6)	DF	199	129 (106)	Beowawe Power, LLC	143	2518 (3)	97	1808 (1)
2	**Bradys Hot Springs** (1992)	21.1 (26.0)	DF	186	121 (78)	Brady Power Partners	156	932 (6)	115	190 (8)
3	**Desert Peak** (1985)	9.9 (11.0)	DF	205	58 (48)	Brady Power Partners	156	1123 (2)	92	1220 (2)
4	**Dixie Valley** (1988)	66.0 (62.0)	DF	250	512 (460)	Caithness Dixie Valley, LLC	171	2825 (7)	110	2382 (10)
5	**Empire** (1987)	4.6 (4.8)	WCB	151	37 (31)	Empire Energy, LLC	149	540 (3)	100	204 (4)
6	**Soda Lake No. 1** (1987) **Soda Lake No. 2** (1991)	16.6 (26.1)	ACB	182	97 (76)	Constellation Operating Serv.	177	795 (5)	93	1373 (5)
7	**Steamboat I, I-A** (1986) **Steamboat II, III** (1992)	53.0 (58.7)	ACB	170	404 (300)	SB Geo, Inc.	157	331 (12)	88	573 (5)
8	**Stillwater** (1989)	13.0 (21.0)	ACB	158	79 (56)	Constellation Operating Serv.	146	909 (4)	89	573 (3)
9	**Wabuska** (1984)	1.2 (1.45)	WCB	107	6 (6)	Homestretch Geothermal	104	131 (2)	?	wetlands
10	**Steamboat Hills** (1988)	14.44 (14.44)	SF	236	97 (88)	Yankee Caithness J.V.L.P.	158	790 (3)	134	950 (1)
	TOTAL	216.5 (242.0)			1,540 (1,248)					

1. Production (Prod.) capacity from currently developed geothermal resources (equipment capacity in parentheses).
Sources: Plant operators, Nevada Division of Minerals, and NBMG files. DF, dual flash; SF, single flash; ACB, air-cooled binary; WCB, water-cooled binary

2. As reported to Nevada Division of Minerals. Temperature drop not representative of energy extracted for flash systems.

Table 1: **Nevada geothermal power plants**

Beowawe

The field is located within the northern Nevada rift, a long, narrow, north-northwest trending zone of middle Miocene volcanic rocks. The geothermal reservoir is associated with the Malapis fault, an east-northeast striking, down to the northwest, normal fault that cuts across the northern Nevada rift. The Malapis fault is parallel to graben-bounding faults to the north in the Midas trough and at the Argenta Rim: all of these probably began to form at about 8 Ma (John et al., 1999). In the subsurface, Miocene volcanic rocks overlie Paleozoic chert, shale, and quartzite of the Valmy Formation. Production is from highly fractured and permeable zones in the Valmy below 2040 m; initial reservoir temperatures were 213-216ºC (Benoit and Stock, 1993). Production wells are equipped with fiber optic monitoring.

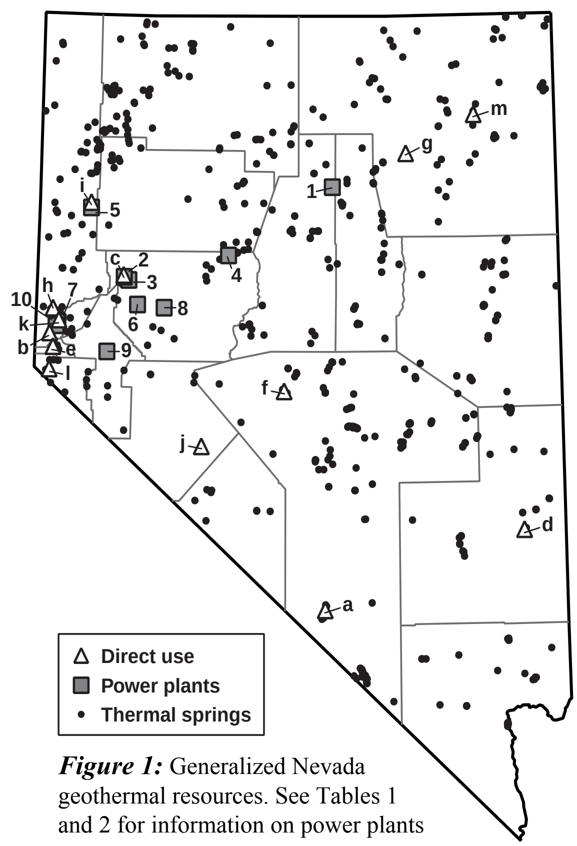

Figure 1: Generalized Nevada geothermal resources. See Tables 1 and 2 for information on power plants and direct-use sites.

Bradys Hot Springs

The geothermal wells at Bradys produce from permeable zones in Tertiary volcanic rocks in the hanging wall of the Bradys fault, a steeply dipping, north-northeast-striking fault with down-to-the-northwest normal displacement. Left lateral strike-slip offset is also possible, as the fault is apparently continuous with a possible drag fold about 7 km to the northeast (Stewart and Perkins, 1999). The stratigraphic displacement (throw) on the fault is believed to be about 150 m (Benoit et al., 1982, p. 8), and northwest-striking cross faults and hanging-wall faults parallel to the Bradys fault may control fluid flow. Mesozoic metamorphic rocks were penetrated at depth in the low permeability footwall block, where temperatures up to 210ºC are reported (Robertson-Tait and Lovekin, 2000). Western States Geothermal Co. sold the plant to ORMAT International, Inc. in July of 2001.

Desert Peak

The Desert Peak field is a concealed resource with no obvious surface expression that was discovered by shallow and deep temperature-gradient drilling, which began to the north at the Bradys geothermal area (Benoit and Butler, 1983). Tertiary volcanic and sedimentary rocks are present to depths of ≈1000 m (Benoit et al., 1982; Faulder and Johnson, 1987), and they overlie a basement of Mesozoic metavolcanic, metasedimentary, and plutonic rocks whose complex relationships are poorly understood. The reservoir is at a depth of 900-1000 m; fracturing, particularly in greenstones, is believed to be a major control on porosity and permeability (Faulder and Johnson, 1987).

Dixie Valley

The Caithness Dixie Valley plant, the largest single geothermal power plant in Nevada, was purchased from Oxbow Geothermal Corp. in 2000. A pilot study has shown that high-quality silica can be extracted from the geothermal fluid; this process could both reduce silica scaling and produce a valuable mineral product (Lin et al., 2000). Pressure augmentation has included combining post-flash brine with water from a shallower local water well (Goerenger Well) prior to re-injection The production zone at 2-3 km depth is believed to be related to highly permeable fractures in and adjacent to the Dixie Valley fault, the major range-bounding fault on the west margin of Dixie Valley. It is uncertain whether the Dixie Valley fault is a single fault or several faults; if it is interpreted as single fault, the dip is ≈50° east (Benoit, 1999). Fluid flow is apparently up the fault from depth, and into fractured Mesozoic meta-igneous rocks and overlying Tertiary volcanic rocks (e.g., Desormier, 1987).

Empire/San Emidio Desert

The Empire Energy binary plant shares the geothermal resource with an onion and garlic dehydration plant to the north. The U.S. Department of Energy has provided funds ($1.6 million over 4 years) to help construct a small-scale geothermal power plant adjacent to the dehydration facility (http://www.eren.doe.gov/geothermal/).

Geothermal potential in the San Emidio Desert was apparently not known until the late 1960s, when hot water was encountered in shallow drill holes exploring for sulfur in alluvial material along the east side of the Desert (valley) over 1 km west of the bedrock forming the Lake Range. H.F. Bonham noted mercury for the first time in about 1966 (NBMG mining district files), and described a ≈4.4 km long zone, presumably the surface expression of a fault, having hydrothermal alteration in addition to mercury and sulfur (Bonham, 1969, p. 95-96). Water in shallow drill holes was found to be 53ºC at 1 m below the ground surface (Garside and Schilling, 1979), but no surface springs were identified. Thus, it appears the San Emidio resource was concealed until discovered by drilling for sulfur.

The San Emidio Desert is an east-tilted half graben, with major fault displacement on a fault near the east side of the valley. Wells (≈ 500-m deep) for the power plant and dehydration facility produce from Miocene volcaniclastic rocks which overlie Mesozoic metasiltstone and quartzite. The productive area is at the intersection of NNW- and NNE-striking faults about 1.5 km west of the mountain-front fault (Trexler, 2002).

Soda Lake

Soda Lake, 10 km northwest of Fallon, is a Holocene phreatic explosion feature related to shallow basaltic magmatism (Garside and Schilling, 1979). Geothermal activity was apparently unknown or very poorly known in the area until drilling for a water well encountered boiling water north of the lake in 1903. Alteration in Quaternary sediments exposed at the surface probably indicates shallow subsurface boiling (Olmstead et al., 1975); a hot spring may have discharged at this site through the end of the 19^{th} century (Hill et al., 1979).

At Soda Lake, several hundred to more than 1000 m of Quaternary and Tertiary sedimentary and volcanic rocks overlie a Mesozoic metamorphic basement. Geothermal fluids in the Soda Lake area are believed to originate deep within the Carson basin to the east and northeast, and migrate up dip along permeable beds in a late Tertiary sedimentary unit. A northeast striking (?) fault is thought to allow vertical fluid migration between offset portions of a permeable pumice tuff unit that makes up the reservoir (McNitt, 1990). A new, 1500-m production well commenced drilling in April 2002.

Steamboat Springs

The Steamboat Springs geothermal resource is developed by two electric generating facilities. SB Geo, Inc. operates four generating plants as a combined facility located near the junction of U.S. Highway 395 and State Route 431, and Yankee Caithness operates a plant about 3 km to the southwest near the top of the Steamboat Hills. Thermal waters at both plants are believed to be related to a single high temperature fluid that rises from depth beneath the Steamboat Hills and cools along a path to the area of the SB Geo plant (Mariner and Janik, 1995).

The SB Geo wells produce from fractured Cretaceous granodiorite along a north-northeast-striking fault zone. The granodiorite is overlain by 15-75 m of Quaternary material and 30-60 m of Tertiary volcanic rocks (Goranson, 1991). Submersible pump technology application studies at the plant are ongoing, and a high-efficiency turbine retrofit was completed in 2001. The U.S. Department of Energy has provided initial funds ($200,000) to Steamboat Envirosystems, LLC, to evaluate enhanced geothermal systems technology at Steamboat, and $270,000 for geothermal resource exploration and definition through the GeoPowering the West program (http://www.eren.doe.gov/geothermal/). SB Geo drilled a 610-m temperature slim hole (MTH 24-33) in fractured granodiorite on its Meyberg Property, 1.5 km south of the SB Geo plants in 2001. Maximum encountered temperatures were 162ºC between 335 and 427 m in fractured granodiorite, with temperatures decreasing below this interval (Goranson, 2001).

The Yankee Caithness wells produce from hydrothermally altered granodiorite and metamorphic rock near the intrusive contact between the Cretaceous granodiorite and Triassic metasedimentary rocks. North- and northeast-striking faults predominate in the Steamboat Hills area, and probably provide the main conduits for fluid flow to the resource areas tapped by the two companies. A new well (24-5) with significant flow was brought into production in July, 2000 at a temperature of 248ºC. Although the flow rate did not diminish, the production temperature had dropped to 219ºC within one year, and the well currently produces 8 MW of electricity (De Rocher, 2002). The U.S. Department of Energy has provided $1.875 million over 3 years for resource exploration and definition as part of the U-boat project (http://www.eren.doe.gov/geothermal/).

Stillwater

This geothermal field is located near the small community of Stillwater, ≈20 km east of Fallon and just south of the Stillwater National Wildlife Refuge.

The Stillwater area is a blind geothermal resource discovered when hot water was encountered in a water well in 1919 (Garside and Schilling, 1979). The rock units at depth consist of unconsolidated Quaternary lacustrine sediments overlying poorly consolidated Tertiary lacustrine sedimentary rocks that are intercalated with discontinuous basalt flows (Forest et al., 1995). Production is mainly developed in a poorly consolidated Quaternary sand and locally, in fractured basalt. Geothermal fluid flow is thought to have moved from north to south in the sand before production (Forest et al., 1995). To the north, higher subsurface temperatures could be related to hot fluid movement upward from considerable depth along a northerly striking fault (Olmsted et al., 1975). There has been recent exploration interest in an area of private land north of the plant, where temperatures as high as 182ºC have been recorded in a slim hole. Stillwater Geothermal Co. sold the plant to Geothermal Management Services in April 2002.

Wabuska

The Wabuska geothermal plant, Nevada's first, consists of two small binary units that discharge spent fluids to wetlands. A retrofit in 1997 changed the working fluid from fluorocarbon to isopentane. The plant was purchased by the Egbert family from the Townsend family in 2000.

The Wabuska geothermal area is located at the margin of Mason Valley, where both the valley margin and the thermal springs coincide with a northeast-trending zone of faults (Stewart, 1999) referred to as the Wabuska lineament (Stewart, 1988). Production is apparently from Quaternary gravels and sands; geothermal fluid may circulate along faults related to the Wabuska lineament as well as an unconformity above Mesozoic metasedimentary rocks possibly present at depth (NBMG files).

FUTURE ELECTRIC-POWER DEVELOPMENTS

A number of areas in Nevada with elevated subsurface temperatures have the potential to develop electric power generation capability. Some of these include Hot Sulfur Springs, New York Canyon, Fish Lake Valley, Fallon Navy Air Station, Rye Patch, Salt Wells, Gerlach, Fly Ranch, Round Mountain, and Blue Mountain. Developments at some of these areas are described below.

Fallon Naval Air Station

The U.S. Navy has conducted studies of the geothermal potential of the Naval Air Station south of Fallon since the late 1970s, and in mid 2001, the Navy expressed an interest in entering into an agreement with a geothermal developer. In 1993 the Navy drilled a 2119-m observation hole ≈11 km southeast of Fallon with a reported bottom-hole temperature of 193ºC. The well penetrated 686 m of sediments, 1372 m of basalt flows and volcaniclastic rocks, and entered basement (Mesozoic metasedimentary and granitic rocks) at 2057 m (U.S. Navy, unpublished data, 2001). The reservoir appears to be highly fractured Mesozoic rocks (Combs et al., 1995) probably related to north-northwest-striking faults parallel to the west side of the Bunjug Mountains and Grimes Point just east of the geothermal area. Geothermal fluid is known to exist below an area of 10 km^2 or more (U.S. Navy, unpublished data, 2001).

Fish Lake Valley

In 1970, an oil exploration well drilled in northern Fish Springs Valley reported a bottom-hole temperature of 159ºC at a depth of 2775 m (Garside and Schilling, 1979). Exploration in the area by Steam Reserve Co. (a division of Amex Exploration) in the mid 1980s found >200ºC fluids at a depth of 2485 m (The Geyser, 1984) Tertiary sedimentary rocks are reported to depths of about 1000 m; below that, fractured lower Cambrian phyllite and sandstone (Harkless Formation) are found (NBMG files).

Rye Patch

Geothermal drilling at Rye Patch in the late 1980s and early 1990s resulted in one successful well; other wells were too cold or had no fluid flow (Feigner et al., 1999). Mt. Wheeler Power recently sold the project to Presco Energy LLC of Englewood, CO. The U.S. Department of Energy has agreed to provide funding ($1.62 million) to study and help define the resource at Rye Patch (http://www.eren.doe.gov/geothermal/)

The Rye Patch geothermal area is located in the Humboldt River valley west of a major north-striking range-front fault that bounds the Humboldt Range. No thermal springs are known from the area, but Pleistocene(?) sinter crops out nearby. Triassic rocks are encountered below several hundred meters of Tertiary sedimentary and volcanic rocks (including sinter). A sandstone and siltstone unit, at ≈1000-m depth, was intersected within the predominantly carbonate-rock section of the Triassic Natchez Pass Formation. The sandstone and siltstone unit is apparently the productive part of the stratigraphic interval; faults may control fluid migration in the reservoir (Feighner et al., 1999).

Blue Mountain

Hot ground waters (up to 88ºC) were encountered in gold exploration drill holes 35 km west of Winnemucca in the early 1990s. No hot springs or spring deposits were known from the area (Parr and Percival, 1991). The hot fluids are believed to circulate along numerous north-striking normal faults in Triassic metasedimentary rocks present in the subsurface along the west flank of Blue Mountain. The U.S. Department of Energy has agreed to provide funding ($657,000 over 3 years) to Noramax Corporation to study and help define the resource (http://www.eren.doe.gov/geothermal/); drilling of an exploration core hole commenced in April 2002.

NON-ELECTRIC LOW- AND MODERATE-TEMPERATURE APPLICATIONS

The majority of Nevada's population is concentrated in two areas, Reno-Carson City and Las Vegas. Many of the state's geothermal resources are remote from any population centers, thus limiting some potential applications. Although 50 or more small to large communities are located within 8 km of geothermal systems, resources have only been effectively and continuously used in a few areas. Although, technical and engineering problems (resource size and temperature, heat loss during transport, etc.) have been factors limiting use, economic factors (high capital outlays, long payout, under-capitalization of projects) and perceptual problems (unconventional vs. conventional technology, short vs. long term cost evaluations, uncertainties about long-term economic risks) have probably been more significant in limiting resource use.

There have been attempts to use Nevada's low- and moderate-temperature geothermal resources at more than 20 areas, mainly in the late 1980s and early 1990s. Additionally, economic and/or technical appraisals of a number of other areas have been conducted, but for a variety of reasons projects were not completed. **Table 2** summarizes the current and past direct use applications in Nevada. Numerous other areas (e.g., **see Fig. 1**) throughout the state could be developed for a variety direct uses.

TABLE 2. NEVADA GEOTHERMAL DIRECT USE

Map Letter	Area	Use	Year Began	Temp (°C)	Depth (m)	Status
	Ash Springs	Spa, irrigation, domestic	?	31-36	springs	Inactive commercial spa
a	**Baileys (Hicks) HS**	Spa	1906	42.8	springs	Active
b	**Bowers Mansion**	Pool	1864	47	63	Active; part of Washoe County Park
c	**Bradys**	Vegetable dehydration	1978	156	932	Active; inactive spa from1929; fluid from power plant
d	**Caliente**	Spa, pool, space heating	1958?	37-79	30-40	heat motel, trailers; hospital and pool inactive
	Carlin HS	Space Heating	1986	31	280	Inactive, scaling problems
e	**Carson City**	Pool	1849	49	shallow	Active
f	**Darroughs HS**	Spa, heap leaching	1988(heap)	82	285	Heap leaching inactive
	Duckwater	Catfish	1982	33	spring	Inactive
g	**Elko**	Bathhouse	1868	66-89	springs	Inactive
		Pool, space heating	1982	82-86	260	16 commercial, 2 residential, school district
	Florida Canyon	Heap leaching	1990s	100	174	Inactive
	Gabbs	Mine process water	1960s	21-68	60-190	Inactive
	Gerlach	Spa	many yrs	84-boiling	spring	Inactive, denied permit
		Space heating	1985	35-36	60	Two homes
	Hobo HS	Tropical fish, prawns	~1988	45.6	spring	Inactive
	Jackpot	Catfish	1988	40	483	Inactive, insufficient fluid
h	**Moana**	Space heating, pool	~1900	71-85	50-240	>250 wells for home, district, casino, church heating
i	**San Emidio Desert**	Vegetable dehydration	1993	130	107	Active
	Saratoga	Lobster	1987	50	spring	Inactive, facility not constructed
j	**Sodaville**	Bathhouse, ore smelter	1880s	<38	spring	Inactive
		Freshwater crayfish	1990s	<38	spring	Crayfish growing, small greenhouse
k	**Steamboat**	Spa, space heating	1860s	30-80	spr/wells	Active spa; <12 homes use space heating
	Wabuska	Greenhouse, aquaculture, ethanol	1972	21-108	678	Inactive
l	**Walleys HS**	Spa, space heating	1862	<71	spring	Active
	Warm Springs Valley	Alligators	1990s	68	well	Inactive
m	**Wells**	Geothermal heat pump	1987	32-34	244	Heating elementary school, rural electric building

Note: Data to construct this table came from personal knowledge of the authors, Nevada Bureau of Mines and Geology files, Garside and Schilling (1979), Garside and Hess (1994), http://www.travelnevada.com/ and http://geoheat.oit.edu, and files from Converse Consulting (Dean Alford, pers. comm.).

SUMMARY

Numerous geothermal areas in Nevada are currently being utilized for both electrical power generation and a variety of direct-use applications, yet there are considerably more areas that could be exploited in an attempt to diversify the state's economy and use these environmentally friendly, renewable resources. A considerable amount of new work is being conducted by both industry and academia to identify, assess, utilize and expand geothermal resources in Nevada. These accelerated activities are, in part, in response to renewed interest in renewable energy resulting from a recent energy crisis in California, a renewable portfolio standard passed in Nevada, and increasing concerns over reliance on foreign oil.

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Table 2: **Nevada geothermal direct use**

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