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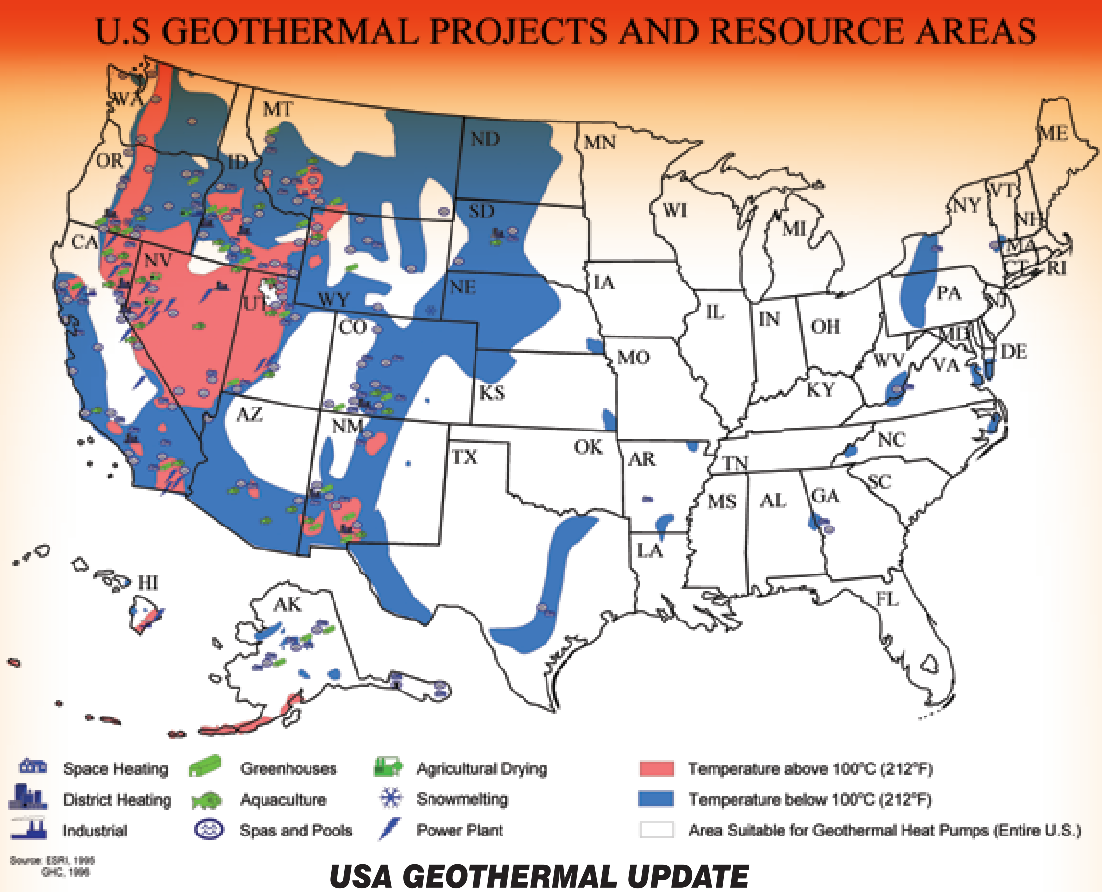
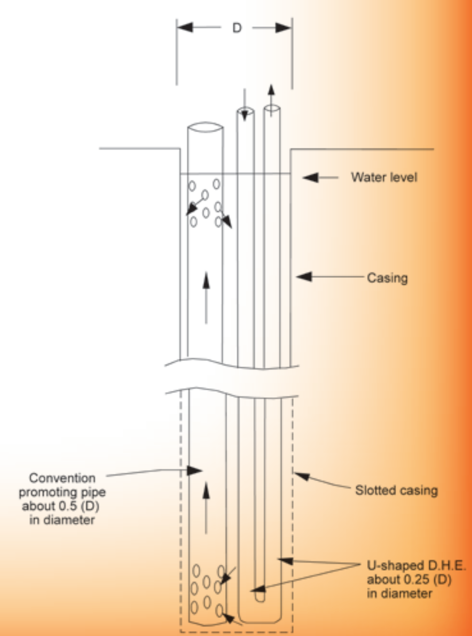
GEO-HEAT CENTER QUARTERLY BULLETIN



USA GEOTHERMAL UPDATE



OIT CAMPUS DEVELOPMENT

PROMOTER PIPE WITH DOWNHOLE HEAT EXCHANGER

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GEO-HEAT CENTER QUARTERLY BULLETIN

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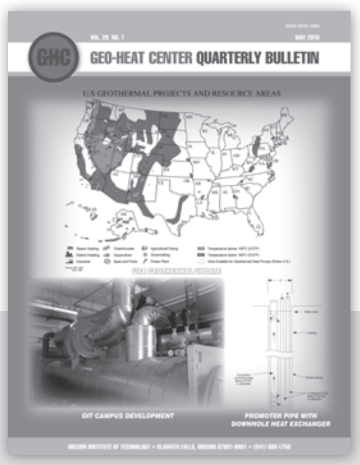
A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS



Cover - Upper figure: Geothermal projects and resource areas in the United Sates

Lower Left Figure: Picture of the 280 kW binary unit on the Oregon Institute of Technology campus showing the turbine generator set on the evaporator.

Lower Right Figure: Promoter pipe with downhole heat exchanger

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All articles for the Bulletin are solicited. If you wish to contribute a paper, please contact the editor at the above address.

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COMMENTS FROM THE EDITORS

We are back!! Our last Quarterly *Bulletin* was the January 2008 issue (Vol. 28, No. 4). With a reduction in the USDOE Office of Geothermal Technologies budget over the past years, no funds were available to continue the publication of the *Bulletin*. With the recent Stimulus Funds for geothermal and an increase in the Office of Geothermal Technologies budget, we have again been funded for at least three years to publish the *Bulletin*.

Much has happened in the past two years on campus. In February of 2009 the drilling of a deep geothermal well on campus was started (see article this issue). In just under 40 days, the well was drilled 5,300 ft (1,600 m) and intersection the high angle (70˚) normal fault on the east side of campus. We had hoped to reach around 300˚F (150˚C) geothermal fluids (based on geochemistry), but a subsequent pump test produced only 196˚F (91˚C) water, and the well proved to be isothermal over the entire length. Even though we only test pumped the well to 1,500 gpm (95 L/s) with a 23-ft (7-m) drawdown, it appears that we can pump up to 2,500 gpm (158 L/s) with only a 75-foot (23-m) drawdown. If this is proven and we obtain the water rights for the higher amount, this flow should be adequate for a 1.0 to 1.2 MWe (gross) binary power plant, which we hope to install by 2012.

The second major event on campus was the installation and commissioning of a 280 kW (gross) binary power plant (see article this issue). The plant, installed in our heat exchange building near our existing production wells, is a PureCycle¨ United Technology Corporation (UTC) unit (now under Pratt and Whitney). The plant was delivered on campus in March 2009 and was dedicated in an official ceremony April 20, 2010. It uses geothermal water from our existing wells, up to 600 gpm (38 L/s) at up to 196˚F (91˚C), and uses a wet cooling tower for the condenser water. The "waste water" is then used to heat campus. The electricity from the plant can either be used directly on campus or fed into the Pacific Power grid.

Much has happened to the original founders of the Geo-Heat Center in 1975. Paul Lienau, the first Director, passed away on Camano Island, Washington on September 27, 2008 after a long bout with cancer. John Lund and Toni Boyd attended his memorial service. Lars Svanevik has retired but continues as an adjunct professor of chemistry and renewable energy on campus. Unfortunately, he suffered a stroke in December 2009 and is convalescing in Klamath Falls. Gene Culver, retired for several years, continues to ranch and raise sheep and alpacas south of Klamath Falls. He also occasionally helps with research projects at the Center. John Lund, after working on campus for 43 years, both as a professor of Civil Engineering and then as Director of the Center will retire in June. Toni Boyd, who was hired 15 years ago, is still with the Center as the Assistant Director. A Mechanical Engineer and Program Manager will be hired and hopefully will be on board in July. The Center is now part of the Oregon Renewable Energy Center (OREC) established on campus in 2001. John and Toni have been teaching geothermal classes for the new Renewable Energy Engineer Bachelors degree that is offer both at our Portland and Klamath Falls campuses.

In August of 2010, the Geo-Heat Center along with the Geothermal Energy Association of Washington, D.C. held a two-day geothermal conference and field trip on campus. The emphasis was on the direct utilization of geothermal energy, with presentation by many local geothermal developers. The field trip visited the campus, the downtown district heating system, and various agri-business applications at "Gone Fishing" and the Liskey Ranch south of Klamath Falls. It was attended by over 100 persons.

Both John and Toni were actively involved with the recent World Geothermal Congress 2010 (WGC2010) that was held in Bali, Indonesia in late April. Around 2,500 persons from at least 85 countries attended the Congress, with over 1,000 papers and posters presented. John and Toni were involved with five papers, including the World Direct-Use Summary and the U.S. Geothermal Summary (see paper this issue). John was also convener of geothermal heat pump workshop at the Congress, and his son Thomas (age 16) as the youngest participant, presented a paper on the heating systems of the three Klamath Falls schools he had attended. Toni presented the other two papers published in this issue.

The Geo-Heat Center has received a number of contracts recently that has helped to continue the operation of the Center. These included:

> "A Review of the Geothermal Resources Underlying Glenwood Springs, Colorado and of the Technologies Appropriate for Use in Their Potential Development" (a feasibility study and final report was prepared and submitted to the City of Glenwood Springs in September, 2009).
>
> "Oregon Institute of Technology Geo-Heat Center" – a grant from USDOE Office of Geothermal Technologies for funding the drilling of the deep well and for the 1.0 to 1.2 MWe binary power plant. It also provides funding to continue the operation of the Center
>
> "National Geothermal Database" a contract to Boise State University of which the Center is a subcontractor. This is five-year contract.
>
> "The Potential Employment, Energy and Environmental Impacts of Direct-Use Applications" a USDOE subcontract under Bob Lawrence & Associates, Inc., Virginia. This is a three-year contract, and includes providing technical assistance and the publication of our Quarterly *Bulletin*.
>
> "Geothermal Workforce Education Development and Retention" to establish a geothermal training facility on the University of Nevada, Reno campus. The Center is subcontracted to provide the geothermal direct-use training. This is a one-year contract with possible extensions.

The Editors

THE UNITED STATES OF AMERICA COUNTRY UPDATE 2010

John W. Lund and Tonya L. Boyd, Geo-Heat Center, Oregon Institute of Technology
Karl Gawell and Dan Jennejohn, Geothermal Energy Association, Washington, DC

ABSTRACT

Geothermal energy is used for electric power generation and direct utilization in the United States. The present installed capacity (gross) for electric power generation is 3,048 MWe[1] (installed) with 2,024 MWe net (running) delivering power to the gird producing approximately 16,603 GWh per year for a 0.62 gross capacity factor and a 0.94 net capacity factor. Geothermal electric power plants are located in California, Nevada, Utah and Hawaii with recent installation in Alaska, Idaho, New Mexico, Oregon, and Wyoming, with 514 MWe being added the last five years. The two largest concentrations of plants are at The Geysers in northern California and the Imperial Valley in southern California. The Geysers continues to receive waste water from Clear Lake and Santa Rosa, California that is injected into the field and has resulted in the recovery of approximately 200 MWe of power generation. The lowest temperature installed plant is at Chena Hot Springs in Alaska, where binary cycle plants uses 74˚C geothermal fluids to run three units for a total of 730 kWe (gross). With the recent passing of the production tax credit by the federal government (2.0 cents/kWh) and renewable portfolio standards requiring investments in renewable energy, the annual growth rate for electric power generation over the past five years is 3.7 percent. The direct utilization of geothermal energy includes the heating of pools and spas, greenhouses and aquaculture facilities, space heating and district heating, snow melting, agricultural drying, industrial applications and ground-source heat pumps. The installed capacity is 12,611 MWt and the annual energy use is 56,552 TJ or 15,709 GWh. The largest application is ground-source (geothermal) heat pumps (84% of the energy use), and the next largest direct-use is fish farming and swimming pool heating. Direct utilization (without heat pumps) remained static over the past five years with gains balancing losses; however, ground-source heat pumps are being installed at a 13% annual growth rate with one million units (12 kW size) in operation. The energy saving from all geothermal energy use is about 7.3 million tonnes of equivalent fuel oil per year (48.5 million barrels) and reduces air pollution by almost 6.6 million tonnes of carbon and 18.8 million tonnes of CO2 annually (compared to fuel oil).

INTRODUCTION

Geothermal resources capable of supporting electrical generation and/or direct use projects are found primarily in the Western United States, where most of the recent volcanic and mountain building activity have occurred (Figure 1). The San Andreas fault, running through California from the Imperial Valley to the San Francisco area, and the subduction zone off the coast of northern California, Oregon and Washington and Cascade volcanism are the source of much of the geothermal activity in the United States. However, geothermal (ground-source) heat pumps extend the utilization to all 50 states. The total identified potential for electrical production is estimated at 21,000 MWe (above 150˚C) and 42 EJ (between 90˚ and 150˚C) of beneficial heat (Muffler, 1979), and a recent estimate by the U.S. Geological Survey estimates a mean probability of electrical power generation from identified geothermal resources in12 western states during the next 30 years of 8,866 MWe (USGS, 2008), which would nearly triple the existing electrical capacity.

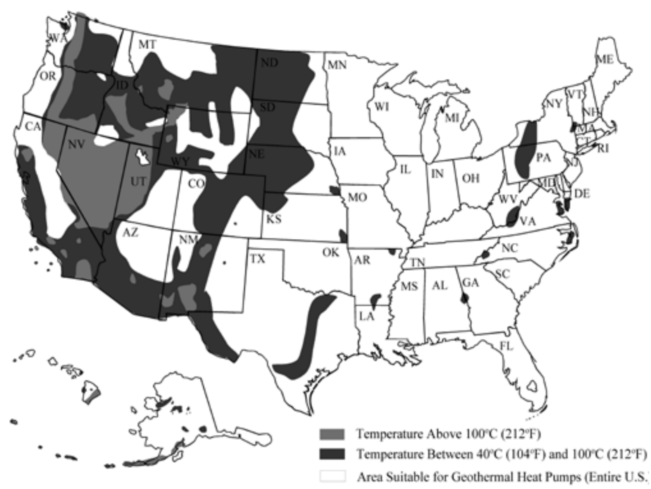

Figure 1: Geothermal resource map of the United States. Source:UURI(EGI)

Achieving this electric capacity potential will be dependent upon a number of factors including competing prices for energy and incentive programs that encourage development of renewable energy resources. Recently passed Renewable Portfolio Standards (RPS) in a number of states along with the extension of the Production Tax Credit (PTC) by Congress to 2015, which provides a 2.0 cent per kilowatt hour credit, have attracted developers to start new projects. Other incentives are the recent stimulus funds for geothermal energy, at US$400 million, approved by Congress which will shortly be allocated for various types of geothermal projects, along with a tax credit (30% of the cost up to US$1,500) for geothermal heat pump installations under the 2005 Energy Policy Act and extended by the American Recovery and Reinvestment Act of 2009. All of these measures will greatly improve geothermal's ability to compete with fossil fuel generation,

[1]The total installed capacity number (3,048 MWe) closely parallels estimates of recent reports such as the Geothermal Energy Associations U.S. Geothermal Power Production and Development Update which estimates installed capacity to be 3153 MWe (See Figure 2, page 6)

both for electrical energy and direct-use. The federal government has also approved a 30% investment tax credit as a grant for commercial operation of power plants. A recent report by the Energy Information Administration (EIA, 2009), confirms the continued growth of renewables as fossil fuel use plummet and nuclear power stalls.

The United States continues to lead the world in installed geothermal power capacity as well as in electrical generations, and along with geothermal heat pumps, is one of the leaders in direct-use applications. Geothermal energy remains, however, a small contributor to the electric power capacity and generation in the United States. In 2009, geothermal plants constituted about 0.27 percent of the total operable power capacity, and those plants contributed an estimated 0.48 percent of the total generation.

Since the last U.S. Country Update was completed in 2005 gross geothermal electrical production capacity has increased in the United States by approximately 514 MWe to a total an installed capacity of 3,047.66 MWe and a net running capacity of 2,023.51 MWe due to derating of plants in The Geysers, for a gross capacity factor of 0.62 and a net of 0.94. The low gross value is due to plants, especially in The Geysers, operating in a load following mode rather than in a base load mode and due to a reduction in pressure and output of the steam field. Total generation in 2007 was 14,974 GWh and the geothermal electric power generation accounted for 4% of the total renewable based electricity consumption in the United States. On a state level, geothermal electric generation is a major player in California and Nevada. It is a minor source of power in the other states. The generation in California provides about 4.5% of the state's energy consumption. It is also significant on the Big Island of Hawaii where it now provides approximately 20% of the electricity requirements. Recent projects have brought several new states into the electricity "club", including, Alaska, Idaho, New Mexico, Oregon and Wyoming. Alaska is most noted, as a 225 kW binary cycle generator installed in 2006 uses the lowest temperature geothermal fluid in the world to produce electricity at 74˚C, however, it should be noted that it also has 4˚C cooling water from a stream allowing for an acceptable "ΔT" (Lund, 2006). The growth in installed capacity during the 1980s was about 11 percent, however, from 1990-1998 it averaged only 0.14 percent due to a leveling off of new plant construction, and from 2000 to 2004 only approximately 70 MWe of new capacity was added. Since, 2005, the growth has been almost 20 percent.

The period 1990-2004 also saw a reduction at The Geysers geothermal field in northern California from 1,875 to around 1,529 MWe installed capacity and 945 MWe running capacity. Today, the installed capacity is 1,584 MWe and 844 MWe running capacity. This was due to the closing of four units and a reduction in the steam availability. Some capacity has been restored due to the construction of two effluent pipelines, one from Clear Lake and the other from Santa Rosa, that brings about 72,000 tonnes of water per day (19 million gallons/day) to The Geysers for injection. This has restored an estimated 200 MWe of capacity to the field.

Direct-use, other than geothermal heat pumps, has remained static with increases being balanced by closing of some facilities. The main increases has been in expanding the Boise City District Heating System from 48 to 58 buildings; adding additional wells for space heating in Klamath Falls; expanding the snow melting system on the Oregon Institute of Technology campus from 316 m2 to 3,753 m2, increasing the amount of aquaculture product being produced, mainly Tilapia; starting two biodiesel plants; adding an absorption chiller for keeping the Ice Museum at Chena Hot Springs in Alaska intact during the summer months, and adding additional space heating to the Peppermill Casino in Reno. Losses have been the closing of the district heating systems at the California Correctional Center (now using natural gas) and the New Mexico University heating system (due to difficulty with maintenance), and the closing of the Empire onion dehydration plant (due to competition with imported garlic from China) near Gerlach, Nevada.

Geothermal heat pumps have seen the largest growth, increasing from and estimated 600,000 to 1,000,000 equivalent 12 kWt installed units. The estimated installation rate is from 100,000 to 120,000 units per year, or about a 12 to 13 percent annual growth, with most of the growth taking place in the mid-western and eastern states. A few states have tax rebate programs for geothermal heat pumps, and as mentioned above, Congress has established a tax credit of 30% of costs up to $1,500 for installations. Otherwise, there is little support for implementing direct-use projects.

Enhanced (Engineered) Geothermal Systems (EGS) is the current R&D interest of the U.S. Department of Energy, Office of Geothermal Technologies as part of a revived national geothermal program. EGS includes the earlier hot dry rock technology, but now includes any other method in which to improve geothermal reservoir performance. EGS is associated with both magmatic and high heat producing crustal sources of geothermal energy commonly at depths of about 4 to 5 km to reach 200˚C, but also having applications with normal gradient resources. However, EGC projects are currently at an early experimental demonstration stage. Several technological challenges need to be met for widespread efficient use of EGS. The key technical and economic changes for EGS over the next two decades will be to achieve economic stimulation of multiple reservoirs with sufficient volumes to sustain long term production, with low flow impedance, limited short-circuiting fractures and manageable water loss (Tester et al., 2006). Over the next 10 to 30 years, lessons learned while deploying early EGS power plants can reasonably be expected to facilitate wider, efficient deployment of EGS technologies for both power production and direct use, or as in Europe in a combined heat and power installation. One of the public relations problems associated with EGS projects, is the generation of micro earthquakes (usually <3.5 on the Richter scale), that has slowed, threatened or shut down projects.

In a Massachusetts Institute of Technology (MIT)-led assessment (Tester et al., 2006), the U.S. geothermal resource was estimated to be 14 million EJ with a technically extractable capacity of about 1,200 GWe to depths of 10 km. The report estimated that with reasonable investment in R&D, EGS could provide 100 GWe or more of cost-competitive generating capacity in the next 50 years. It further stated: "…EGS provides a secure source of power for the long term that would help protect American against economic instabilities resulting from fuel price fluctuations or supply disruptions." Unfortunately, a current project near The Geysers has been placed on hold due to the inferred generation of micro earthquakes affecting nearby residences.

PRODUCTION OF ELECTRICITY

Table 1 presents operable electric production capacity and power generation in the United States from all sources for 2005-2008. All data in this table came from the USDOE Energy Information Administration (EIA, 2009).

Geothermal power production is summarized in Table 2 by plant and location. The total installed capacity in 2009 was 3,048 MWe producing 16,603 GWh from a running capacity of 2,024 MWe. A total of 514 MWe has been installed since the WGC2005 report, amounting to a 20 percent increase or 3.7 percent annual increase.

Table 1. Present and Planned Production of Electricity

	Geothermal		**Fossil Fuel**		**Hydro**		**Nuclear**		**Other Renewables**		**Total**	
	Capacity MWe	**Gross Prod GWh/yr**	**Capacity MWe**	**Gross Prod GWh/yr**	**Capacity MWe**	**Gross Prod GWh/yr**	**Capacity MWe**	**Gross Prod GWh/yr**	**Capacity MWe**	**Gross Prod GWh/yr**	**Capacity MWe**	**Gross Prod GWh/yr**
In Operation in December 2009	3,048	16,6	850,486	2,928	97,999	248.1	105,764	806.2	33,542	127.7	1,090,839	4,126.6
Under Construction in December 2009	0											
Funds committed, but not yet under construction in December 2009	4,239-6,643 132 projects											
Total projected use by 2015	7,482-9,676											

Ref: www.eia.doe.gov

Table 2. Utilization of Geothermal Energy for Electric Power Generation as of 31 December 2009

Locality	Total Installed Capacity MWe*	Total Running Capacity MWe*	Annual Energy Produced 2009 GWh/yr	Total under Construction or Planned MWe
ALASKA	0.73	1,626.80	3.94	50 – 95
CALIFORNIA	2,496.80	1,471.75	13,604.60	1,555 – 1,939
HAWAII	35	30.00	236.52	8
IDAHO	15.80	11.50	90.67	238 – 326
NEVADA	447.56	311.26	2,278.97	1,776 – 3,323
NEW MEXICO	0.24	0.15	0.54	20
OREGON	0.28	0.15	0.11	317 – 368
UTAH	51	43.00	387.54	272 – 332
WYOMING	0.25	0.15	0.48	0
Total	3,047.66	2,023.51	25,116	4,249 – 6,443

* Installed capacity is maximum gross output of the plant; running capacity is the actual gross being produced.

INSTALLED & FUTURE CAPACITY UPDATE

Alaska

Alaska's first geothermal power plant came online in 2006 in Chena Hot Springs. It is a small organic rankine cycle (ORC) unit (225 kWe gross) and produces electricity from the area's low temperature (74˚C) geothermal resource. Since coming online the power plant has added another 225 kWe unit as well as a 280 kWe unit, bringing total production capacity to 730 kWe (gross).

Alaska currently has 70 to 115 MWe of planned geothermal production coming down the pipeline. Of projects with potential to come online, the Southwest Alaska Regional Geothermal Energy Project, 25 MWe, is in an exploratory drilling and resource confirmation phase. Other notable projects are Tongass (20 MWe), Unalaska (10–50 MWe), Pilgrim Hot Springs (10 MWe), and Chena Hot Springs II (5-10 MWe).

Arizona

Geothermal power production does not currently occur in Arizona. However, the Arizona Public Service is currently planning a 2 – 20 MWe development known as the Clifton geothermal project. Also, although the scope of electricity production is not known, Northern Arizona University is planning a geothermal plant for which they have federal funding for drilling.

California

Current geothermal electricity production capacity in California is approximately 2,497 MWe. In 2007, 4.5% of California's electricity generation came from geothermal power plants, amounting to a net total of 13,605 GWh. The 50 MWe North Brawley facility is the states most recent geothermal power plant addition. Generally, geothermal power generation remains concentrated in California with the majority of production occurring at The Geysers in the north and Imperial Valley in the south.

California has approximately 1,841.8 – 2,435.8 MWe of planned geothermal resource production in various stages of development. Production drilling and facility construction are underway at Western GeoPower Corp.'s Unit 1 (35 MWe) at The Geysers as well as CHAR, LLC's Hudson Ranch I (49.9 MWe). Final permitting and PPA's are being secured for Ormat Technologies East Brawley project (30 MWe), Calpine Corporations Buckeye-North Geysers (30 MWe) and Wildhorse-North Geysers (30 MWe) projects, and CalEnergy's Black Rock 1, 2, and 3 units (53 MWe each) (California Energy Commission, 2009).

Colorado

Although there are no geothermal power plants currently producing electricity in Colorado, Mount Princeton Geothermal is currently conducting exploratory drilling and resource confirmation operations at its Mount Princeton Hot Springs project site. Total capacity of the project is expected to be 10 MWe once completed.

Florida

No geothermal power production is occurring in Florida at this time. However, Quantum Resources Management, and Pratt and Whitney (UTC Power) are in the early stages of developing a 200 kWe co-production geothermal power project. The project has the potential to produce 1 MWe of power.

Hawaii

There is only one geothermal power plant in all of Hawaii. Located on the big island, the Puna Geothermal Venture facility has a 35 MWe nameplate capacity and delivers 25–35 MWe of energy on a continuous basis and supplies 20% of the electricity needs of the big island. Ormat is in the process of securing a PPA and final permitting for an 8 MWe expansion of its Puna project.

Idaho

Idaho's first geothermal power plant, Raft River, came online in January 2008. Raft River is a binary plant that uses a 150˚C resource and has a nameplate production capacity of 15.8 MWe. Current net production output is between 10.5 and 11.5 MWe. US Geothermal is securing a PPA and final permitting for a 13 – 26 MWe expansion of the Raft River plant.

Another geothermal company, Idatherm, is developing a number of projects throughout Idaho. Idatherm has begun exploratory drilling and resource confirmation operations for its Willow Springs project (100 MWe). It is also planning to develop its China Cap (100 MWe), Preston Area Project (50 MWe), and Sulfur Springs (25 – 50 MWe) resources, but is still in the process of conducting initial exploratory drilling and securing rights to resource. Total potential geothermal production for Idaho is 238 to 326 MWe (Idaho Office of Energy Resources, 2009).

Nevada

In 2008 Nevada had 18 geothermal power plants with a total nameplate capacity of 333 MW and with a total gross output of 10,791 MWh. In 2009 Nevada increased its installed geothermal capacity with the addition of the Stillwater (ENEL, 47.3 MWe), Salt Wells (ENEL, 18.6 MWe), and the Blue Mountain "Faulkner 1" (Nevada Geothermal Power, 49.5 MWe) power plants. Currently Nevada has more developing projects than any other state and it is expected that gross capacity will increase significantly in the future. The following companies have begun production drilling and facility construction at various project sites: Vulcan Power (Salt Wells, 175 – 245 MWe), Presco Energy (Rye Patch, 13 MWe), and US Geothermal (San Emidio "Repower" Project, 8.4 MWe), Ormat (Jersey Valley, 18 – 30 MWe). Many other companies are in the process of securing PPA's and final permitting for a number of projects and other companies are in the early exploratory stages of developing numerous geothermal resources. Nevada currently has 1,876 to 3,473 MWe of geothermal capacity in development. (Nevada Bureau of Mines and Geology, 2009).

New Mexico

In July 2008, a 0.24 MWe pilot installation project came online at Burgetts Greenhouses near Animas. The pilot installation is part of a larger project known as Lightning Dock that aims to bring a 20 MWe capacity geothermal power plant online in 2009.

Oregon

While there is only one small unit producing geothermal electricity, significant developments are forthcoming. The Oregon Institute of Technology (OIT) has installed a 280kW (gross) binary units and is currently producing power for use on campus – the first campus in the world to generate its own power from a resource directly under campus. OIT has also completed production drilling of a 1,600-m deep well and will install a 1.0 to 1.2 MWe binary power unit by 2012 using the 93ºC resource at 158 L/s. Davenport Power, U.S. Renewables Group, and Riverstone are securing a PPA and final permitting for their 120 MW Newberry Geothermal project as is Nevada Geothermal Power for its 40 – 60 MWe Crump Geyser project. U.S. Geothermal, Inc. successfully completed the drilling of its second full sized production well at Neil Hot Springs (20 – 26 MWe) in October 2009. Overall there are 317.2 to 368.2 of potential geothermal power capacity in planning in Oregon.

Utah

Currently, Utah has three power plants online. Unit 1 of the Blundell Plant has a gross capacity of 26 MWe and Unit 2 has a capacity of 11 MWe. Utah's third power plant came online in December 2008 and was the first commercial power plant in the state in more than 20 years. The Thermo Hot Springs power plant, a Raser Techologies operation, came online in 2009 and has a gross capacity of 14 MWe and is expected to generate with a net capacity of approximately 10 MWe.

Shoshone Energy is currently working to secure a PPA as well as other final permitting for its 100 MW Shoshone Renaissance Geothermal Project. ENEL North America has begun exploratory drilling and resource confirmation operations at its Cove Fort (69 MWe) project site. Other companies have potential geothermal sites that are in the early stages of planning/development and overall Utah has 272.4 to 332.4 MWe of planned geothermal capacity for future production.

Washington

Although Washington is not currently producing power from any of its geothermal resources Vulcan Power is planning to develop the Mt. Baker geothermal resource. AltaRock Energy is pursuing an EGS project in Snohomish County.

Wyoming

In August 2008, a 250 kWe Ormat organic Rankine cycle (ORC) power unit was installed at Rocky Mountain Oil Test Site and a month later it began operating. As of January 2009, the unit had produced more than 485 MWh of power from 413,000 tonnes of hot water annually. The demonstration project will operate until September 2009. During its operation there will be an evaluation of how to reduce fluctuations of power and to generate more than 250 kWe.

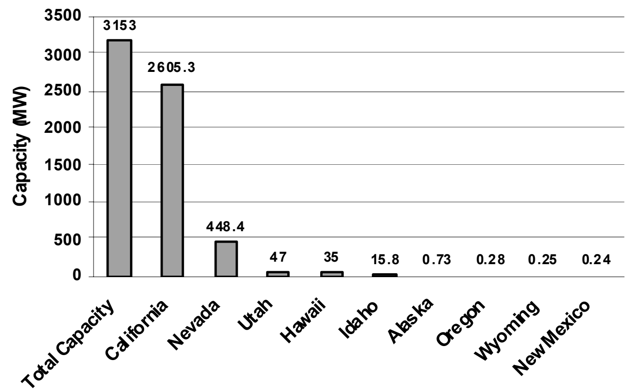

Figure 2. November 2009 Geothermal Power Capacity Online (MW). Source: GEA

Table 3. Developing projects by state.

State	Phase I to Phase IV (MWe)	TOTAL (with Unconfirmed) (MWe)
Alaska	5/50 – 95	6/70 – 115
Arizona	1/2 – 20	1/2 – 20
California	32/1,554.9 – 1,938.9	37/1,841.8 – 2,435.8
Colorado	1/10	1/10
Florida	1/0.2 – 1	1/0.2 – 1
Hawaii	2/8	2/8
Idaho	5/238 – 326	5/238 – 326
Louisiana	0	1/.05
Mississippi	0	1/.05
Nevada	60/1,776.4 – 3,323.4	64/1,876.4 – 3,473.4
New Mexico	1/20	1/20
Oregon	13/317.2 – 368.2	13/317.2 – 368.2
Utah	10/272.4 – 332.4	10/272.4 – 332.4
Washington	1/Unspecified	1/Unspecified
Total	132 Projects 4,249.1 – 6,442.9	144 Projects 4,699.9 – 7,109.9

Phase I: Indentify site, secured rights to resource, initial, exploration drilling. Phase II: Exploratory drilling and confirmation underway; PPA not secured. Phase III: Securing PPA and final permits. Phase IV: Production drilling underway; facility under construction. Unconfirmed: Proposed projects that may or may not have secured the rights to the resource, but some exploration has been done on the site. Source: GEA

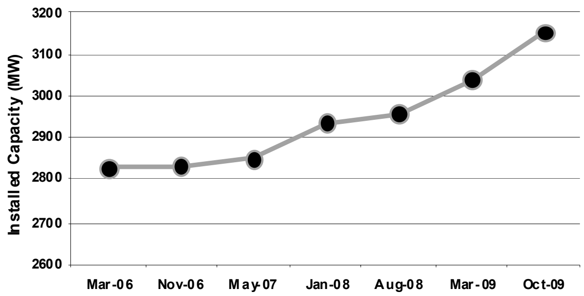

Figure 3. Total Installed Capacity 2006 – 2009. Source: GEA

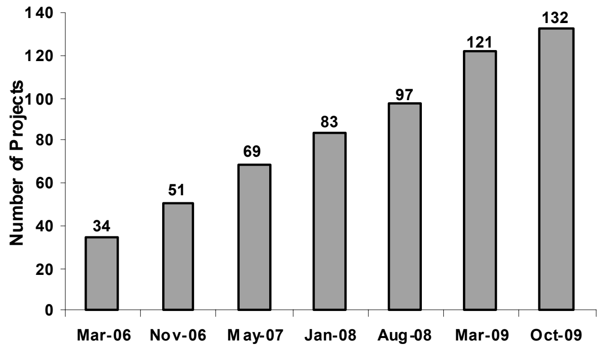

Figure 4. Total confirmed development project for electricity power 2006-2009. Source: GEA

GEOTHERMAL DIRECT UTILIZATION

Background

Geothermal energy is estimated to currently supply for direct heat uses and geothermal (ground-source) heat pumps 56,552 TJ/yr (15,709 GWh/yr) of heat energy in the United States. The corresponding installed capacity is 12,611 MWt. Of these values, direct-use is 9,152 TJ/yr (2,542 GWh/yr) and 611 MWt, and geothermal heat pumps the remainder. It should be noted that values for the capacity and energy supplied by geothermal heat pumps are only approximate (and probably conservative) since it is difficult to determine the exact number of units installed, and since most are sized for the cooling load, they are generally oversized in terms of capacity for the heating load.

Most of the direct use applications have remained constant or decreased slights over the past five years; however geothermal heat pumps have increased significantly. A total of 20 new projects have come on line in the past five years. Agricultural drying has decreased the most due to the closing of the onion/garlic dehydration plant at Empire, Nevada. Two district heating projects have also shut down; the Litchfield Correctional Facility in California and the New Mexico State University system. There have been slight increase in snow melting, cooling and fish farming, with a major increase in industrial process heating due to two biodiesel plants (Oregon and Nevada), a brewery (Oregon) and a laundry (California) coming on line. In summary, when considering direct-use without geothermal heat pumps, the distribution of annual energy use is as follows: 34% for fish farming, 28% for bathing and swimming pool heating, 15% for individual space heating, 9% for greenhouse heating, 8% for district heating, 3% for agricultural drying, 2% for industrial process heating, 1% for cooling and <1% for snow melting. Geothermal heat pumps accounts for 84% of the annual use, and has almost double (1.81 times) in the past five years with a 13% annual growth rate.

Table 4. Utilization of Geothermal Energy for Direct Heat as of 31 December 2009 (other than Heat Pumps)

Locality	Type *	Capacity (MWt)	Annual Utilization	
			Energy (TJ/yr)	Capacity Factor
Alaska	H,G,B,C	7.8	156.2	0.63
Arkansas	H	0.4	7.3	0.66
Arizona	H,F,B	23.5	317.4	0.43
California	D,H,G,F,B	105.1	2138.6	0.66
Colorado	D,H,G,F,B	29.5	627.6	0.67
Georgia	H,B	0.6	11.0	0.57
Idaho	D,H,G,F,B	89.3	1429.1	0.51
Montana	H,G,F,B	15.8	297.8	0.60
New Mexico	D,H,G,F,B	38.7	335.7	0.28
Nevada	D,H,F,A,B	74.8	1153.6	0.49
New York	H,B	0.9	12.1	0.44
Oregon	D,H,G,F,I,A,S,B	78.2	812.4	0.33
South Dakota	D,H,F,B	66.3	577.6	0.28
Texas	H,B	4.0	27.4	0.22
Utah	H,G,F,B	45.8	449.9	0.31
Virginia	H	0.3	3.1	0.30
Washington	B	1.9	45.5	0.76
West Virginia	B	0.1	3.7	0.80
Wyoming	H,G,F,S,B	28.3	701.0	0.79
TOTAL		611.5	9,151.8	0.47

I – Industrial Process Heat; A – Agricultural Drying; F – Fish Farming; S – Snow Melting; H – Individual Space Heating; D – District Heating; B – Bathing and Swimming; G – Greenhouse and Soil Heating

Table 5. Geothermal (Ground-Source) Heat Pumps as of 31 December 2009

Locality	Ground or Water Temp. (°C)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type *	COP	Heating Equivalent Full Load Hr/Year	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
States								
East: 20%	5-25	12.0		V=45%	3.5			
Midwest: 34%	5-25	12.0		H=45%	3.5			
South: 35%	5-25	12.0		W=10%	3.5			
West: 11%	5-25	12.0			3.5			
			1,000,000			2,000	47,400	29,600
TOTAL			1,000,000			2,000	47,400	29,600

*• V = vertical ground coupled; H = horizontal ground coupled; W = water source (well or lake water) ** Residential: V/H = 30%/70%, Commercial/ Industrial: V/H = 90%/10%. Ref: www.eia.doe.gov*

Figure 5 shows the direct-use development over the past 35 years, without heat pumps. A summary of direct-heat use by category is presented in Table 6.

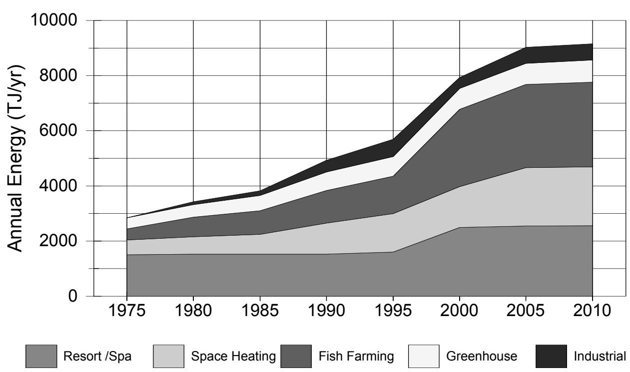

Figure 5. Direct-use growth in the United States.

Space Heating

Space heating of individual buildings (estimated at over 2,000 in 17 states) is mainly concentrated in Klamath Falls, Oregon where about 600 shallow wells have been drilled to heat homes, apartment houses and businesses. Most of these wells use downhole heat exchangers to supply heat to the buildings, thus, conserving the geothermal water (Culver and Lund, 1999). A similar use of downhole heat exchangers is found in the Moana area of Reno, Nevada (Flynn, 2001). Installed capacity is 140 MWt and annual energy use is 1,361 TJ (378 GWh).

District Heating

There are 20 geothermal district-heating systems in the United States, most being limited to a few buildings. The newest is a small project in northern California (Merrick, 2002 and 2004). In this rural community of Canby, geothermal heat is used for heating buildings, a greenhouse, and most recently driers and washers in a laundry (Merrick, 2009). The city system in Boise, Idaho has added 10 buildings to their system and will be extended to Boise State University next year. Klamath Falls system has expanded by adding a brewery and an additional greenhouse. Extensions have also been added for a future commercial develop on the edge of a local lake in town. The local hospital and Oregon Institute of Technology have both added new buildings to their systems (Lund and Boyd, 2009). Installed capacity is 75 MWt and annual energy use is 773 TJ (215 GWh).

Table 6. Summary Table of Geothermal Direct Uses as of 31 December 2009

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr = 10^{12} J/yr)	Capacity Factor
Individual Space Heating	139.89	1,360.6	0.31
District Heating	75.10	773.2	0.33
Air Conditioning (Cooling)*	2.31	47.6	0.50
Greenhouse Heating	96.91	799.8	0.26
Fish Farming	141.95	3,074.0	0.69
Agricultural Drying **	22.41	292.0	0.41
Industrial Process Heat ***	17.43	227.1	0.41
Snow Melting	2.53	20.0	0.25
Bathing and Swimming ****	112.93	2,557.5	0.72
Subtotal	**611.46**	**9,151.8**	**0.48**
Geothermal Heat Pumps	12,000.00	47,400	0.13
Total	**12,611.46**	**56,551.8**	**0.12**

** Other than heat pumps; ** Includes drying or dehydration of grains, fruits and vegetables; *** Excludes agricultural drying and dehydration; **** Includes Balneology*

Aquaculture Pond and Raceway Heating

There are 51 aquaculture sites in 11 states using geothermal energy. The largest concentration of this use is in the Imperial Valley in southern California and operations along the Snake River Plain in southern Idaho. There is a report that some of the facilities in the Imperial Valley have closed, but reliable information is lacking. A large facility at Kelly Hot Springs in northern California has been expanding and now produces slightly over half a million kg of tilapia annually. Two unique aquaculture related projects are in operation in Idaho and Colorado – that of raising alligators (Clutter, 2002). Recent trends in the U.S. aquaculture industry have seen a decline in growth due to saturation of the market and competition from imports. Installed capacity is 142 MWt and annual energy use is 3,074 TJ (855 GWh).

Greenhouse Heating

There are 44 greenhouse operations in nine states using geothermal energy. These cover an area of about 45 ha, have an installed heat capacity of 97 MWt and an annual energy use of 800 TJ/yr (222 GWh). The main products raised are potted plants and cut flowers for local markets. Some tree seedlings and vegetables are also grown in Oregon; however vegetable raising is normally not economically competitive with imports from Central America, unless they are organically grown. One unusual greenhouse product, started recently, is spider mites grown on lima bean plants at Liskey Farms south of Klamath Falls, Oregon. They are grown for their eggs which are then shipped south as feed for predator mites, which in turn are sold to farms to eat spider mites – a complicated process, as the mites and eggs are almost microscopic in size and difficult to see (Northwest Farm Credit Services, 2009).

Industrial Applications & Agricultural Drying

Industrial applications have increased significantly due to the addition of two biodiesel plants (Oregon and Nevada). These plants primarily use geothermal energy for the distillation of waste grease from restaurants, but one also used canola oil. Small industrial uses include clothes driers and washer installed in Canby, California, and a brewery using heat from the Klamath Falls district heating system for brewing beer and heating the building (Chiasson 2006, Merrick, 2009). The main loss is the closing of an onion/garlic dehydration plant at Empire, Nevada due to competition with imported garlic from China. The installed industrial capacity for these two applications is 40 MWt and the annual energy use 519 TJ/yr (144 GWh/yr) with nine facilities located in three states.

Cooling and Snow Melting

The two major uses of geothermal energy are for pavement snow melting, on the Oregon Institute of Technology (OIT) campus, and keeping the Aurora Ice Museum frozen year-round at Chena Hot Springs, Alaska. OIT has increase their campus snow melt system from 316 m2 to 3,753 m2 and the ammonia absorption chiller in Alaska keeps a 1,000 tonnes of ice frozen even though it reaches 32°C outside in the summer. Over 10,000 visitors a year visit the facility that has a bar, beds and many ice sculptures (Holdman and Erickson, 2006). The installed capacity for this application is 2.5 MWt and the annual energy use is 20 TJ/yr (6 GWh/yr).

Spas and Swimming Pools

This is one of the more difficult applications to quantify and even to find all the actual sites, as most owners do not know their average and peak flow rates, as well as the inlet and outlet temperatures. Most of the locations and some of the data, have come from a number of hot spring/spa publications available for most states. As a result, we often have to estimate the capacity and energy use based on our experience with similar facilities. There are 242 facilities in 17 states that we have identified, with an estimated installed capacity of 113 MWt and annual energy use of 2,557 TJ/yr (711 GWh/yr).

Geothermal (Ground-Source) Heat Pumps

The number of installed geothermal heat pumps has steadily increased over the past 15 years with an estimated 100,000 to 120,000 equivalent 12 kWt units installed this past year. Present estimates are that there are at least one million units installed, mainly in the mid-western and eastern states. The present estimates are that approximately 70% of the units are installed in residences and the remaining 30% in commercial and institutional buildings. Approximately 90% of the units are closed loop (groundcoupled) and the remaining open loop (water-source). Within the residential sector, of the closed loops systems, approximately 30% are vertical and 70% horizontal, as the latter are cheaper to install. In the institutional and commercial sector, 90% are vertical and only 10% horizontal, constrained by ground space in urban area. Presently, the ratio of new installation to retrofit installations is 3:1. The estimated full load hours in heating mode is 2,000/yr, and in cooling mode is 1000/yr. The installation cost is estimated at US$6,000 per ton (3.5 kWt) for residential and US$7,000 per ton (3.5 kWt) for commercial. The units are found in all 50 states and are growing 12 to 13% a year. It is presently a US$2 to US$3 billion annual industry. Even though the actual number of installed units is difficult to determine, input has been provided from various industry representatives for these estimates (personal communication: John Geyer, Warren (Trey) Austin, and Patrick Hughes, October, 2009, Dan Ellis, November 2009). The current installed capacity is 12,000 MWt and the annual energy use in the heating mode is 47,400 TJ/yr (13,1678 GWh/yr). The largest installation currently under construction is for Ball State University, Indiana where 4,100 vertical loops are being installed to heat and cool over 40 buildings.

Conclusions – Direct-Use

The distribution of capacity and annual energy use for the various direct-use applications are shown in Table 6 and are based on records keep at the Geo-Heat Center. We estimate that the estimates are anywhere from 10 to 20% under reported, due to their small sizes, lack of data and often isolated locations.

The growth of direct use over the past five years is all due to the increased use of geothermal heat pumps, as traditional direct-use development has remained flat as shown in Figure 4. Unfortunately, there is little interest for direct-use at the federal level, as their interests are mainly in promoting and developing Enhanced (Engineered) Geothermal Systems (EGS). There are few incentives for the traditional direct-use development, but as mentioned earlier, there are tax incentives for geothermal heat pumps at the federal level and in some states such as Oregon. Since, most direct-use projects are small, there are few, if any, developers and/or investors who are interested in supporting these uses.

WELLS DRILLED

Most wells drilled for geothermal use were for power generation. Assuming 3 MWe per well, and each approximately 2,000 meters deep (deeper at The Geysers and shallower in Nevada where most of the wells were drilled), the increase of 514 MWe added approximately 400 km (vertical) including exploratory and injection wells, and direct use added approximately 4 km. Most direct-use work concentrated on improving and refurbishing existing wells. See Table 7 for details. Geothermal heat pumps wells, which are not included in this table, probably added 200,000 vertical holes at 75 m each for a total of 15,000 km over the five years.

Table 7. Wells Drilled for Electrical, Direct and Combined Use of Geothermal Resources from January 1, 2005 to December 31, 2009 (excluding heat pump wells)

Purpose	Wellhead Temp.	Number of Wells Drilled			Total Depth (km)
		Electric Power	Direct Use	Combined	
Exploration *	(all)	50	0	50	25
Production	>150°C	100	0	100	200
	150-100°C	67	6	73	135
	<100°C	0	4	4	4
Injection	(all)	20	0	20	40
Total		**237**	**10**	**247**	**404**

** Includes thermal gradient well, but not ones less than 100 m deep*

PROFESSIONAL GEOTHERMAL PERSONNEL

Professional geothermal personnel with university degrees are higher mainly due to an increase in the installed capacity of power plants. Geothermal Power plants are estimated to employ 1.7 person/years per installed megawatt (Kagel, 2006). It is assumed that approximately 0.5 person/year is due to professional personnel. Due to limits on funding from USDOE Office of Geothermal Technologies, during the years 2005 to 2008, personnel in private industry as well as with the government institutions, as well as National Laboratories and Universities were reduced. Only about 50 person/years are due to direct-use geothermal. See Table 8 for details.

INVESTMENT IN GEOTHERMAL

Again, the majority of the investment in geothermal was for geothermal electric power plants. We estimate that US$4,000 (Western Governor's Association, 2006) is invested for every kilowatt of installed capacity. Thus, for the new 514 MWe of installed capacity over the past five years, US$2,000 billion was invested. Above half of this was for field and plant development and 25% each for R&D and for the operation. Direct-use only added about US$2,000 million; however, not shown in Table 9 is the approximately US$2.5 billion is spent annually on geothermal heat pump installations and equipment (personal communication, John Geyer, Oct. 2009).

Table 8. Allocation of Professional Personnel to Geothermal (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	2	2	10	0	0	1,200
2006	2	2	10	0	0	1,200
2007	2	2	10	0	0	1,000
2008	2	2	10	0	0	1,000
2009	2	2	10	0	0	1,500
Total	10	10	50	0	0	5,900

(1) – Government; (2) – Public Utilities; (3) – Universities; (4) – Paid Foreign Consultants; (5) – Contributed through Foreign Aid Programs; (6) – Private Industry

ENERGY AND CARBON SAVINGS

The total electricity produced from geothermal energy in the U.S. is equivalent to savings 28.3 million barrels (4.24 million tonnes) of fuel oil per years (generating at 0.35 efficiency). This produces a savings of 3.71 million tonnes of carbon annually. The total direct utilization including geothermal heat pump energy use in the U.S. is equivalent to saving 13.3 million barrels (2.01 tonnes) of fuel oil per years (producing heat at 0.70 efficiency). This produces a savings of 1.76 million tonnes of carbon annually. If the savings in the cooling mode of geothermal heat pumps is considered, then this is equivalent to an additional savings of 6.9 million barrels (1.03 million tonnes) of oil annually.

In total, the savings from present geothermal energy production in the U.S., both electricity and direct-use amounts to 48.5 million barrels (7.28 million tonnes) of fuel oil equivalent (TOE) per year, and reduces air pollution by 6.65 million tonnes of carbon annually. CO^2 reduction is estimated at 18.8 million tonnes

Table 9. Total Investments in Geothermal in (2009) US$

Period	Research & Development Incl. Surface Explor. And Exploration Drilling Million US$	Field Development Including Production Drilling & Surface Equipment Million US$	Utilization		Funding Type	
			Direct Million US$	Electrical Million US$	Private %	Public %
1995 – 1999	N/A	N/A				
2000 – 2004	250	200	100	200	80	20
2005 - 2009	500	1,000	2	500	95	5

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GEOTHERMAL USES AND PROJECTS ON THE OREGON INSTITUTE OF TECHNOLOGY CAMPUS

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ABSTRACT

Oregon Institute of Technology moved their campus to the present location in the early 1960s to take advantage of the geothermal hot water that could be used for heating the buildings. Three wells between 1,200 and 1,800 feet (365 and 550 m) deep were drilled, producing 192˚F (89˚C) water at a maximum flow of 980 gpm (62 L/s). There are presently 12 buildings being geothermally heated covering approximately 732,000 ft2 (68,000 m2) of floor space, saving approximately $1,000,000 annually in heating costs. Lineshaft pumps with variable frequency drives are used to produce the geothermal fluids from the well, and then the hot water is gravity fed to all buildings on campus. Plate heat exchangers are located in each building to separate the potentially corrosive geothermal fluids from the secondary "clean" water for heating the various rooms. The geothermal water is finally injected into two injection wells located approximately 2,000 feet (610 m) from the production wells. A 280 kWe (gross) binary power plant was installed on campus to use the existing well water to provide some of the electricity needs for the campus. In addition, a 5,300 foot (1,600 m) deep well was drilled to tap into a 196˚F (91˚C) geothermal resource in the fault system on the east edge of campus. The fluids would be used to power a 1.0 to 1.2 MWe (gross) binary plant to provide some of the electricity needs for campus. Thus, the campus would become the first in the world to provide some of its energy needs from a geothermal resource found on its property. Finally, the "waste" fluid from the heating system would be used to provide heat for experimental greenhouses and aquaculture facilities on campus. All of these future uses would be available for student projects and as a demonstration site for interested investors and developers of geothermal energy.

HISTORICAL BACKGROUND (PURVINE, 1974, LIENAU, 1996)

In 1959 the Oregon State Board of Higher Education was awarded a State appropriation of $150,000 for use in exploration related to the selection of a new campus for Oregon Institute of Technology. The old campus was a military facility, built for the treatment of malaria victims from World War II. These funds were to be used for the master plan of the new campus and for exploration to determine the availability of geothermal water for space heating. At that time, approximately $100,000 per year was spent on coal and oil heating for the campus. Since the Board wished this to be a decision based on good information, a study was made as to the location of hot wells, hot springs, faults, and other factors useful in determined the potential location of the campus. This study was carried out by Gene Culver, a Mechanical Engineering Technology faculty member and later one of the founders of the Geo-Heat Center. One of the early observations was the existence of a broad series of normal faults running from Ft. Klamath (south of Crater Lake) in the north to Alturas in northern California in the south. At various locations along this broad fault zone were hot springs and hot water wells. The fault zone seemed to be the source of subsurface hot water which many of the wells had encountered.

Local well drillers were interviewed based on their experience with drilling geothermal wells in the area. In addition the Oregon State Engineer's Office was consulted, and based on a US. Geological Survey map that was in preparation, it indicated that the fault system in the area consisted on northwest-southeast trending fracture zone with perpendicular offsets producing faults in echelon. Finally, to confirm the locations of these faults and the potential for producing hot water, then President Winston Purvine noticed that for one area being considered for the new campus, the frost and light snowfalls would be melted off by as early as 8:30 to 9:30 in the morning, too early to be influenced by the sun. This was assumed to indicate that the soil was being warmed by subsurface hot water, and thus the site was a prime candidate for geothermal drilling.

After these preliminary studies the location for the geothermal wells and potential campus was selected in the northern edge of the City of Klamath Falls. The first well (OIT #1) was drilled in 1959 to a depth of 1,200 feet (366 m) and produced 510 gpm (32 L/s) of 78˚F (26˚C) water, which was later used for the domestic water supply. Moving further west and south within the border of the new campus, a second 1,200-foot (366 m) well (OIT #2) was drilled in 1960. This was more successful, producing 170 gpm (11 L/s) of 176˚F (80˚C) geothermal water (Fig. 2). Two other wells (OIT #5 and #6) were later drilled in 1963 in the same area to depths of 1,716 feet and 1,800 feet (523 and 549 m) both producing 191˚F (88˚C) geothermal water at 442 gpm and 250 gpm (28 and 16 L/s) of geothermal water respectively (Fig. 2). This temperature, with time, increased to 192˚F (89˚C). We later learned that the first or cold water well was drilled into the up-throw (hanging wall) of the normal fault and the latter three in the down-throw (foot wall) of the fault block tapping the outflow zone of the geothermal water from the fault. At the time, these two deeper wells were drilled for about $32,000 each or $18 per foot!!! The wells penetrated at mixture of volcanic ash (tuff) and diatomaceous earth (locally called "chalk rock"), then into various layers of dense basalt and andesite, clayey tuffs, broken lava and cinders. The casing varied from 12 inches (30.5 cm) at the surface to 6 inches (15 cm) at the bottom. The static water level was at 358 feet (109 m) for the deeper wells. The original wells were set in a cellar, but were later raised to ground level and enclosed in a building in 1970 (Fig. 3).

Enclosed lineshaft pumps with the bowls set at around 550 feet (168 m) with 26 stages are used in the deeper wells. The original pumps were basically irrigation well water pumps with direct-coupled motors, open lineshaft with rubber bear-

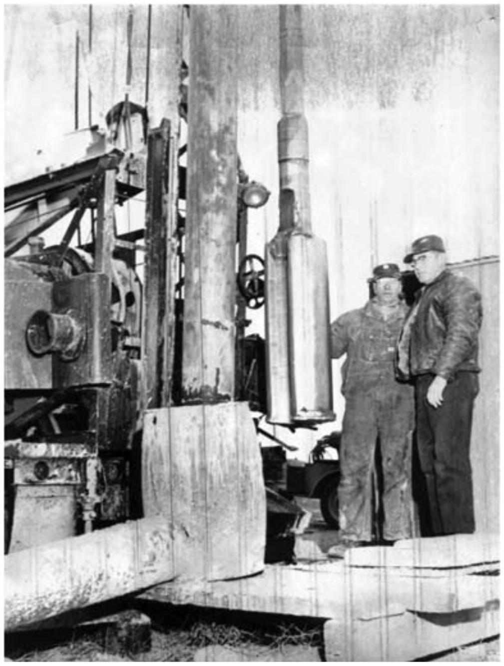

Figure 1: 1963 photograph of Storey Drilling, completing one of the deep geothermal wells with a cable tool.

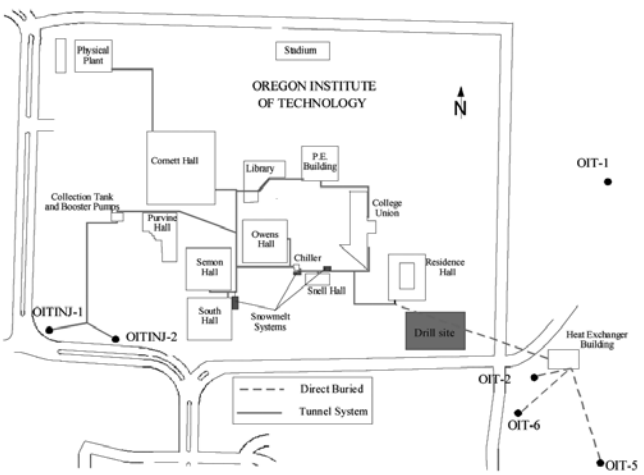

Figure 2: OIT campus map showing the location of wells and distribution pipelines.

ings and standard lateral pumps with bronze bearings and impellers. Problems were experienced with broken line-shafts, motors overheating, pump impellers loosened on the shaft due to differential expansion and bronze bearings corrosion (Culver, 1994). Since hot water does not lubricate the bearings well, an oil drip system had to be installed within an enclosed lineshaft, and allowance had to be made for the difference in thermal expansion between the line shaft and the impellers – which can be as much as 5.5 inches (14 cm) as the system is heated during the initial startup (Rafferty and Keiffer, 2002). The wells are pumped with 75 hp (56 kW) pumps, and a variable speed fluid drive to regulate the amount of water needed was added in 1970. These were later replaced with variable frequency drives. The water is then piped into a heat/water collection building where it enters a settling tank for removal of sand and to meet peak demands. From here the water is then gravity fed into the various buildings on campus. Initially the geothermal water was used directly in the heating systems, but due to 2 ppm (2 mg/L) of hydrogen sulfide which attacked the copper and solder in the radiators, isolation plate heat exchangers had to be installed in each building (Fig. 4) at a later date. In the beginning, the waste water was disposed into a drainage ditch and eventually ended up in Upper Klamath Lake, about one mile (1.6 km) to the west. However, based on a 1990 ordinance passed by the City of Klamath Falls, all geothermal water produced has to be returned to the reservoir. As a result, two injection wells (INJ #1 and INJ #2) were drilled in 1990 to 2,005 and 1,675 feet (611 m and 510 m) on the southwest side of campus, approximately 2,000 feet (610 m) from the production wells. These two well can handle up to 2,500 gpm (158 L/s).

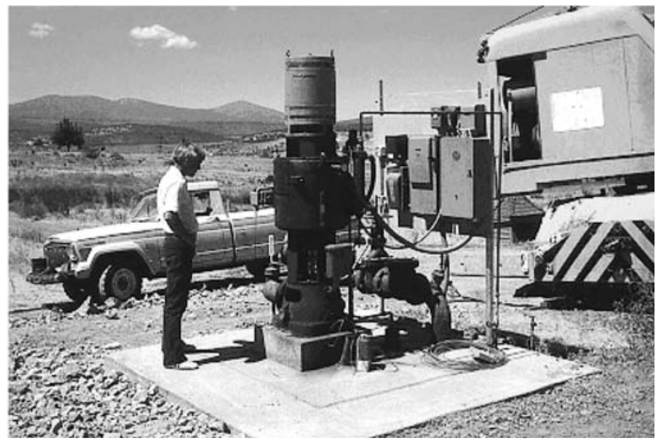

Figure 3: Gene Culver at well #6 showing the 75 hp (56 kW) motor and fluid coupling drive. The well house is moved for maintenance.

The distribution pipeline around campus initially consisted of steel pipe covered by a rigid foam glass insulation buried directly in the ground between buildings. Unfortunately, the metal pipe would expand and contract depending upon flow rate which changed with the supply temperature of the geothermal water, however, the insulation did not. Thus, ground water leaked into the cracks in the insulation and corroded the steel pipe. Oxygen was introduced into the water from a vent in the storage tank causing some minor internal corrosion of the pipes as well. Also, since the pipe was direct buried, it was often dug up by accident, since the exact location was not well documented. Thus, in 1980 a utility tunnel at 6 feet (1.8 m) on a side was constructed to house most of the pipeline, as well as other utilities on campus being added later (Fig. 5) (Lund and Lienau, 1980). Where possible, the tunnel was located under sidewalks, so any residual heat would melt the snow and ice above. The cost at that time was about $160/ft. ($525/m). A 312 ton (1,095 kW) lithium-bromide/water absorption cycle chiller was installed on campus in 1980 using the 192˚F (89˚C) geothermal water to provide cooling in the summer for about half of campus (Lund and Lienau, 1980). Chilled fluid at 44˚F (7˚C) was delivered to the space cooling system in several of the buildings. Unfortunately, the unit at that time required 240˚F (116˚C) geothermal water to operate at 100% efficiency, thus the machine only produced half of the normal output. For this reason, and the

Figure 4: Plate heat exchanger in the College Union building.

required high geothermal flows (600 gpm – 38 L/s), high discharge temperature and corrosion of the copper pipes in the generator section, the unit was replaced with an electric chiller in 1998 (Lienau, 1996).

In the beginning the geothermal water, which could be pumped up to 750 gpm (47 L/s) using two wells, heated 440,000 ft2 (40,900 m2) of floor space in six buildings using either forced air for interior rooms or base-board hot water for exterior building walls. An average of 2.8 million Btu/hr (3.0 GJ/hr) with a maximum of 24.8 million Btu/hr (26.1 GJ/hr) was used on campus, costing about $12,000 to $14,000 per year compared with $94,000 to $100,000 per year on the old campus with conventional fuel. A standby oil fired boiler from the old campus was installed in the Heat Exchange building, however, it was never used and was eventually removed in the 1990s. Today, only one well is normally used, with two being required during extreme cold weather (below 0˚F or -18˚C). The third well is used for standby, and allows maintenance to be performed without interrupting the usage.

PRESENT CAMPUS OPERATION (BOYD, 1999)

Today, geothermal water is produced from three wells at a temperature of 192˚F (89˚C), which are located in the southeast corner of the campus (Fig. 2). Well water temperature can vary between 192˚ and 196˚F (89˚ and 91˚C), depending on the pumping rate and location of the well. The

Figure 5: OIT utility tunnel with geothermal pipe and other utilities.

water is pumped individually from each well, with a maximum total flow of all the wells at 980 gpm (62 L/s). The water is then collected in a 4,000-gallon (15 m3) settling tank in the Heat Exchange building before it is delivered to each building via gravity through the distribution system according to the demand on the system. The settling tank provides the necessary head for the gravity flow system and allows the fines from pumping to settle out of the water. Due to pipe failures from the direct buried distribution system, a concrete utility tunnel was constructed in 1980. When new extensions to the tunnel are added, corrugated galvanized steel culvert are used instead of concrete, costing about 25% of the tunnel cost.

In the original design, the geothermal water was used directly in each of the building mechanical systems. This "once through" approach eliminated the need for circulation pumps in the buildings. The direct use of the geothermal fluids caused problems due to the corrosive nature of the water. The original chemical analysis of the water failed to consider the effect of hydrogen sulfide and ammonia on the copper alloys used in the mechanical system. There were a number of different types of failures identified that occurred as a result of using the water directly. The more important ones were:

- Failure of the 50/50 tin/lead solder connections,
- Rapid failure of 1% silver solder,
- Wall thinning and perforation of copper tubing was a common occurrence,
- Control valve failure where plug (brass) was crimped to the stem (stainless steel). The threaded ones experienced no problems, and
- Control valve problems associated with packing leakage.

To address these problems, the geothermal water was isolated from the building heating systems using plate heat exchangers. The type selected consists of 316 stainless steel plates and Buna-N gaskets. The heat exchanger for the campus swimming pool failed due to the chlorine in the pool water, and thus, had to be replaced with titanium plates, which was eventually replaced with a brazed plate heat exchanger due to the cost of the titanium plates.

The original discharge temperature of the waste effluent was initially quite high (135˚F - 57˚C in winter and 170˚F 77˚C in summer) when it was delivered to a drainage ditch. This method presented a safety hazard and was stopped when the City Ordinance was put into effect in 1990, as mentioned earlier. Two injection wells were drilled, that can now handle up to 2,500 gpm (158 L/s). To reduce the effluent temperature, when Purvine Hall was constructed, it was designed to use the effluent from the rest of campus. The temperature of the effluent as it enters the building is around 155˚F (68˚C) and leaves at a temperature of around 130˚F (54˚C). The main components of this building's heating system are a 4,000-gallon (15-m3) storage tank, circulating pumps and heat exchangers. On the building heating side, space heating is accomplished by 54 variable air volume terminals equipped with hot water coils.

The newest additions to the OIT geothermal system are sections of sidewalks, stairs and handicap ramps equipped with geothermal snow melting system. In 2009 approximately 37,000 ft2 (3,400 m2) of sidewalk and driveway systems were installed in front of the administration building (Snell Hall) (Fig. 6). The pipes in the concrete are 5/8- to 3/4-inch (1.6- to 1.9-cm) diameter cross-linked polyethylene tubing (PEX), placed 8 to 10 inches (20 to 25 cm) apart. The system should be able to maintain a slab surface temperature of 38˚F (3˚C) at -5˚F (-21˚C) air temperature and 10 mph (16 km/h) wind when the entering 50/50 propylene glycol/water temperature is 144˚F (62˚C). Each major area has a separate plate heat exchanger and the system will activate when the outside air is 30˚F (-1˚C). The total amount installed on campus to date covers around 40,400 ft2 (3,750 m2).

Figure 6: Installation of PEX pipe for the campus entrance snow melting system in 2008.

At present twelve buildings are heated totaling 732,000 ft2 (68,000 m2). At peak use, the system provides 16 million Btu/hr (16.9 GJ/h) or a capacity of 4.7 MWt. The annual use is approximately 64.4 billion Btu (67.9 TJ), saving around $1,000,000 annually in heating costs as compared to natural gas.

FUTURE CAMPUS PROJECTS

Five new geothermal projects are being planned and some are already underway for the campus. These include: (1) a low-temperature, 280 kWe (gross) binary power plant using the existing well water, (2) completing a deep well on campus producing 196˚F (91˚C) geothermal water, (3) a 1.0 to 1.2 MWe (gross) binary power plant to use the energy from the deep well, (4) an incubator greenhouse facility, and (5) an incubator aquaculture facility. Each of these projects is described in detail below.

Low Temperature Power Plant

A contract was signed with United Technology Corporation of Connecticut (now Pratt and Whitney, Co.) for a 280 kWe (gross) binary power plant that can use the 192˚F (89˚C) geothermal from the existing wells on campus. We are taking approximately 15˚F (8˚C) off the top, and then the remaining 177˚F (81˚C) is still adequate to supply the heating needs of campus. Maximum flow would be 600 gpm (38 L/s). In summer and warmer periods, the reject temperature can be reduced to as low as 150˚F (66˚C), when the campus heating demand is less. This unit purchased uses a single-cell wet cooling tower with 70˚F (21˚C) cooling water and produce an average net output of 85 to 140 kWe depending on the outside temperature and humidity. This will provide approximately 10% of the campus electrical energy demand and save $100,000 annually. In addition, the project will serve as a demonstration site and student laboratory, mainly for students in the new Renewable Energy Engineering Program. Real time monitoring would be available for students on our campus and at other universities.

Figure 9. The low-temperature power plant inside the building.

Figure 10. Building housing the low-temperature power plant and the associated cooling tower.

Deep Well Drilling Project

To produce additional electrical energy for campus, we drilled a deep (5,308 feet – 1,618 m) geothermal well that intersected the high angle normal fault on the east side of campus. The geothermally heated fluid upwelling along the fault is already tapped by our existing geothermal wells. Geochemistry predicted that up to 300˚F (150˚C) geothermal fluids might be found at depth – however, the depth and amount could not be predicted. Unfortunately, the highest temperature found in the well was just under 200˚F (93˚C). We have tested the well at 1,500 gpm (95 L/s) and proposed to test it at 2,500 gpm (158 L/s) which can supply a 1.0 MWe to 1.2 MWe (gross) power plant, depending upon the final temperature and flow rate of the fluid. The surface water level is at 320 feet (97.5 m) below the surface, which is typical of the other wells in the area. The drawdown at 1,500 gpm (95 L/s) was only 23 feet (7.0 m) and predicted to be 75 feet (23 m) at 2,500 gpm (158 L/s). Funding was provided by the US Department of Energy and the Oregon University System in a matching grant.

The following projects were completed prior to drilling the well to better define the resource and drilling target. In 2008, we contracted for and completed a reflection seismic survey of campus to better locate the fault and thus located the drilling site. Approximately 64 2.2 lb (1 kg) dynamite charges at 18 feet (6 m) depth were set off on campus and surrounding property to bounce energy waves off subsurface structures. The seismic survey can be viewed at http://geoheat.oit.edu/oit/Sesimic_Final _Report.pdf. This investigation determined the optimum drilling target at about the 3,000 to 4,000 foot (900 to 1,040 m) depth (Fig. 7). The drill site was located in the southeast corner of the upper parking lot.

As a part of the USDOE grant requirements, we completed an environmental assessment (EA) under the NEPA requirements. The final EA can be viewed at http://geoheat.oit.edu/oit/OIT-Deep-Geothermal-Well-andPower-Plant-Project-FEA_0908.pdf.

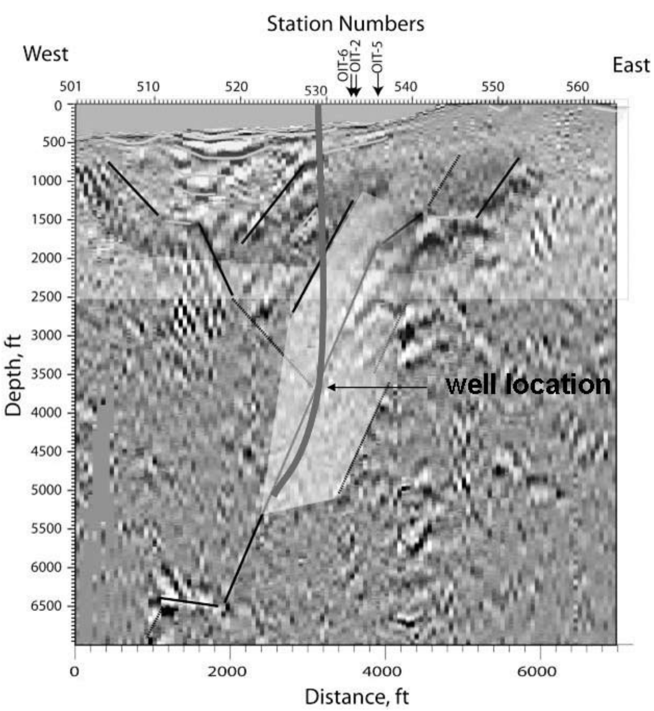

Figure 7: East-west seismic profile showing the fault and fracture zone with the deep well location

A Request for Proposal (RFP) for drilling the deep well was prepared and a contract was awarded to ThermaSource, Inc. of Santa Rosa in December 2008. Drilling of the 30foot (9-m) deep surface casing (conductor pipe) of 30 inch (76 cm) was completed in early January by a local contractor. ThermaSource had their drilling rig on site and started their drilling by the 2nd week of January 2009 (Fig. 8). They then drilled to 300 feet (91 m) and set and cemented a 20-inch (51-cm) diameter casing. This was followed by a 2,500-ft (760 m) hole for a 13-3/8-inch (34cm) casing cemented back to the surface. The well was finished with a 9-5/8-inch (24-cm) diameter production liner that was slotted at selected intervals. Deviated drilling was used to better intersect and tap the fractured fault zone from 3,200 ft (975 m) to bottom. The only problem that we experience on campus was complaints by student due to lack of parking, as the drill site had temporally taken out about 75 parking spaces. Noise was not a problem with the residence hall or the adjacent hospital that are located only 500 ft (150 m) on either side of the project site.

Figure 8: ThermaSource drilling rig on the OIT campus.

Moderate Temperature Power Plant

A 1.0 to 1.2 MWe power plant (gross) would be design to use the fluids from the deep well. It will be a binary type (organic Rankine cycle using a secondary low boiling point hydrocarbon) supplying around 0.8 MWe to 1.0 MWe (net) to campus, enough to cover approximately half of the electric energy requirements. This would save the campus round $300,000 per year.

The cost of the well and the 1.0 to 1.2 MWe (gross) power plant would be around $11.7 million, however, the "waste water" from the power plant at around 175˚F (80˚C), could then be sold to adjacent property owners or used to supplement the existing and new OIT heating demands, generating additional income or savings. The site would also become a demonstration site and student laboratory with real time monitoring available. Funding for the projects will come from a US Department of Energy grant, and from Oregon State bonds and grants. Additional support will be provided from the Energy Trust of Oregon and the Climate Trust.

Incubator Greenhouse Facility

We are proposing to construct two geothermally heated greenhouses on campus. The greenhouses would be 100 by 60 feet (31 by 18 m) covering 6,000 ft2 (560 m2) and designed to grow a variety of cut flowers, potted plants and vegetables. Different heating and cooling systems would be provided to each greenhouse as a research and demonstration project. All heating and cooling in the greenhouse would be monitored and controlled by a computer system. The greenhouses would be an incubator facility for interested investors/developers to test the feasibility of growing their crop in a controlled environment utilizing geothermal energy. The facility would also provide research projects for students on campus and for the local agricultural programs at the community college and rural high school. The facility would require around 140˚F (60˚C) and 60 gpm (4 L/s), that could easily be met from our existing geothermal wells, mainly by cascading the effluent water from the campus heating system.

Incubator Aquaculture Facility

We are also proposing to construct two geothermally heated outdoor aquaculture ponds and a covered nursery tank facility on campus. The outdoor ponds would be 100 by 30 feet (31 by 9 m) of 3,000 ft2 (280 m2) and the indoor covered facility would be of greenhouse construction 100 by 60 feet (31 by 19 m) covering 6,000 ft2 (560 m2). Different heating systems would be provided to each pond as a research and demonstration project. The covered facility would consist of a series of fiberglass tanks, heated by the geothermal water. All heating systems would be monitored and controlled by computer. Various fish species, hard-shell aquatic species and even various algae could be tested. Effluent water from the campus geothermal heating system at around 140˚F (60˚C) and 150 gpm (9 L/s) would be required, that could easily be met by cascading. The facility would provide an incubator facility for potential developer/investors and also be used as a laboratory for campus students.

CONCLUSIONS

The campus was built on its present location mainly to take advantage of the geothermal energy that is provided by water moving up along the high-angle normal fault on the east side of campus. Using three geothermal wells that tap a 192˚F (89˚C) fluid and are pumped up to 600 gpm (39 L/s), provides an installed capacity of 3.8 MWt and annual supply of 64.4 billion Btu (67.9 TJ), saving an estimate $1,000,000/yr in heating costs.

A 280 kWe (gross) binary power plant has been installed and is operating providing between 80 and 140 kWe of net energy to campus, which satisfies about 10% of the campus electric needs and saves approximately $100,000 annually. This is the first combined geothermal heat and power plant installed and operating in Oregon, and also the first on a university campus.

With the deep well completed and when the 1.0 to 1.2 MWe (gross) power plant is up and running on campus, Oregon Institute of Technology will be the first campus in the world to supply all its heating and a majority of its electrical energy from a geothermal resource directly under campus. We will be a showplace for all forms of geothermal utilization. Along with our Renewable Energy Engineering Program and technical assistance provided by the Geo-Heat Center (http://geoheat.oit.edu), we will be a leader for renewable geothermal energy utilization.

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USE OF PROMOTER PIPES WITH DOWNHOLE HEAT EXCHANGERS IN KLAMATH FALLS, OREGON

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ABSTRACT

A promoter pipe is simply a pipe that is open at both ends that is placed in a well with a downhole heat exchanger. These have been used extensively in Rotorua, New Zealand. The promoter pipe sets up a convection cell that is necessary to increase the temperature of the water over the length of the downhole heat exchanger. It is used when the well casing has not been perforated just below the low water line and the live water flow at the bottom of the well, thus preventing the hot water flow from mixing sufficiently along the entire well-bore length. The temperature and heat output of the downhole heat exchanger can be significantly increased if a convection cell is set up in the well. Several examples of wells that have promoter pipes installed in them in Klamath Falls are documented, comparing the temperature output before and after installation.

INTRODUCTION

The downhole heat exchanger (DHE) exchanger consists of a system of pipes or tubes suspended in the well through which "clean" secondary water is pumped or allowed to circulate by natural convection, thus eliminating the problem of disposal of geothermal fluid, since only heat is taken from the well. These systems offer substantial economic savings over surface heat exchangers where a single-well system is adequate (typically less than 0.8 MWt, with well depths up to about 500 ft (150 m) and may be economical under certain conditions at well depths to 1500 ft (460 m)(Lund, et al., 1975; Culver and Lund, 1999).

Several designs have proven successful; but, the most popular are a simple hairpin loop or multiple loops of iron pipe (similar to the tubes in a U-tube and shell exchanger) extending to near the well bottom (Figure 1). An experimental design consisting of multiple small tubes with "headers" at each end suspended just below the water surface appears to offer economic and heating capacity advantages in shallow wells (Culver and Reistad, 1978).

Downhole heat exchangers extract heat by two methods– extracting heat from water flowing through the aquifer and extracting stored heat from the rocks surrounding the well, the former being most significant.

In order to obtain maximum output, the well must be designed to have an open annulus between the well bore and the casing, and perforations at the well bottom for the inflow aquifer and just below the lowest static water surface. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus and back inside the casing through the upper perforations. If the design parameters of bore diameter, casing diameter, heat exchanger length, tube diameter, number of loops, flow rate and inlet temperature are carefully selected, the velocity and mass flow of the natural convection in the well may approach those of a conventional shell-and-tube heat exchanger. However, this balance is often difficult to achieve, and is usually done by trial and error or based on local experience.

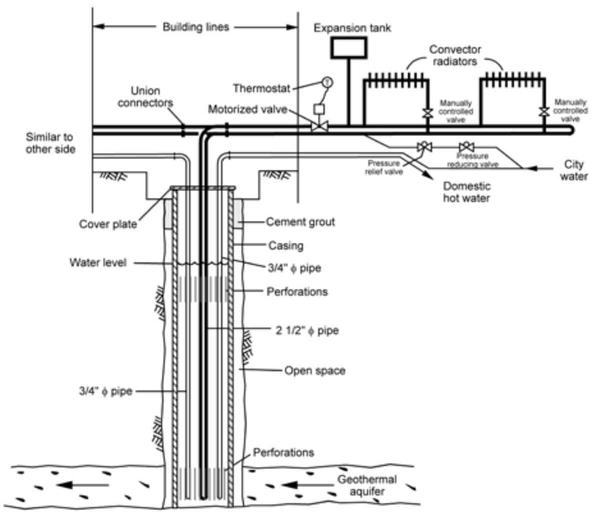

Figure 1: Typical downhole heat exchanger systems in Klamath Falls, Oregon.

The interaction between the fluid in the aquifer and that in the well is not fully understood; but, it appears that outputs are higher where there is a high degree of vertical fluid mixing in the well bore indicating that somewhat permeable formations with high flows are preferred. Although the interaction between the water in the well, water in the aquifer, and the rock surrounding the well is poorly understood, it is known that the heat output can be significantly increased if a vertical convection cell can be set up in the well. Also, there must be some degree of mixing (i.e., water from the aquifer) continuously entering the well, mixing the well water, and water leaving the well to the aquifer. There are two methods of inducing convection in the past: 1) casing perforations, and 2) "pumping and dumping".

When a well is drilled in a competent formation and will stand open without casing, an undersized casing can be installed. If the casing is perforated just below the lowest static water level and the near the bottom at the hot aquifer level, a convection cell is induced and the well becomes very nearly isothermal between the perforations (Figure 2). Cold surface water and unstable formations near the surface are cemented off above a packer. If a DHE is then installed and heat extracted, a convection cell is induced, flowing down inside the casing and up in the annulus between the well wall and casing. The driving force is the density difference between the water surrounding the DHE and water in the annulus. The more heat extracted, the higher the velocity. Velocities of 2 ft/s (0.6 m/s) have been measured with very high heat extraction rates; but, the usual velocities are between 0.03 - 0.3 ft/s (0.01 – 0.1 m/s).

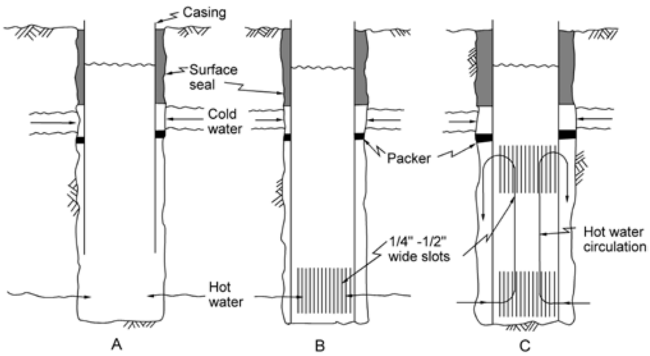

Figure 2: Well completion systems for DHE (type c with the vertical convection cell – preferred).

Many of the earlier wells drilled in Klamath Falls were not completed with the two sets of casing perforations that would generate the convection cells to maximize the output of the downhole heat exchangers (DHE). To provide for this vertical convection of the hotter water from the bottom of the well, they were equipped with a small suction pump that pumped water from the well to the storm sewer – locally referred to as "pumping and dumping." This pumping provided approximately the same energy transfer to the downhole heat exchanger as the convection cell. Approximately 60 wells in the City had these pumps, and could be identified by the steam rising from the storm water grates adjacent to the well. In addition, larger users, such as Oregon Institute of Technology, who could not generate enough energy from a downhole heat exchangers, pumped water for the plate heat exchangers in the various buildings on campus, and dumped the waste water to surface drainage.

In Klamath Falls, it has been experimentally verified that when a well is drilled there is no flow in the wellbore (see Figure 3). When the undersized perforated casing is installed, a convection cell is set up flowing up the inside of the casing and down the annulus between the casing and well wall. When a DHE is installed and heat is extracted, the convection cell reverses flowing down in the casing (around the DHE) and up the annulus. Similar circulation patterns were noted in New Zealand using convection promoters.

The convector pipe is simply a pipe open at both ends suspended in the well above the bottom and below the static water level (Figure 4). The DHE can be installed either in the convector or outside the convector, the latter being more economical since a smaller convector is used. Both lab and field tests indicate that the convection cell velocities are about the same in optimized designs and are similar to those measured in the undersized casing system. A summary of the New Zealand research can be found in the following references: Allis and James, 1979; Freeston and Pan, 1983; Dunstall and Freeston, 1990; Hailer and Dunstall, 1992.

Promoter pipes had been tried on a limited scale in Klamath Falls previous, but not documented to any extent (see Chiasson, et al., 2005; Chiasson and Swisher, 2007).

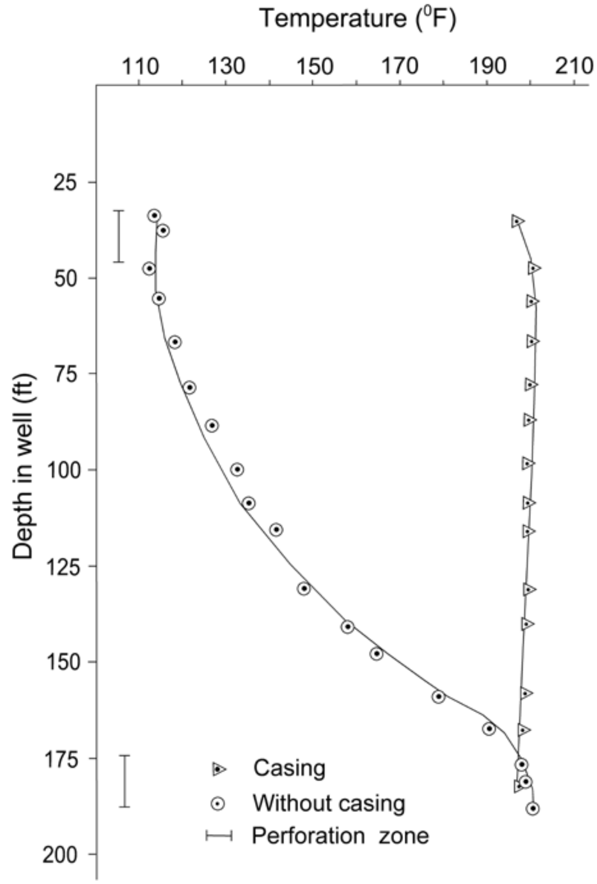

Figure 3: Temperature vs. depth for a geothermal well (with and without perforations).

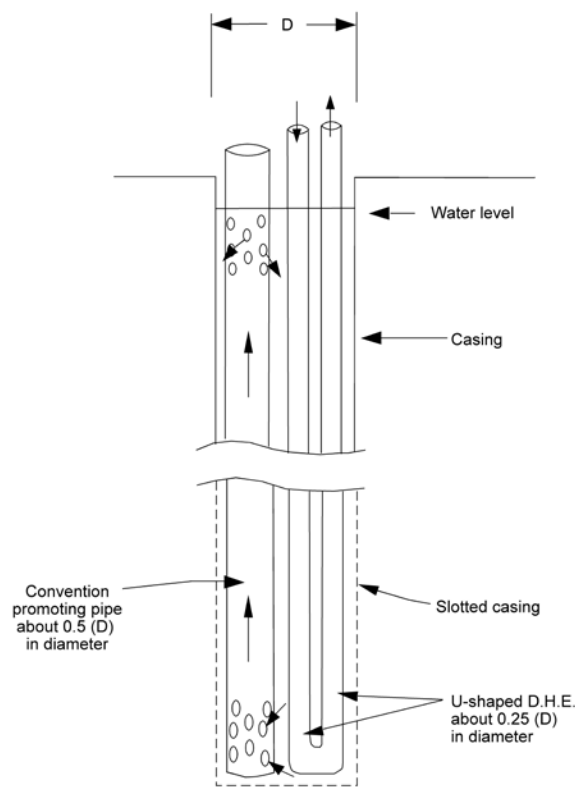

Figure 4: Convector promoter and DHE (New Zealand type) (Allis and James, 1979).

SYSTEM ONE

The first well system investigated was originally completed in 1929 as either a type A or B as shown in Figure 2. It has a 10-in (25-cm) diameter hole with an 8-in (20-cm) casing. The type was determined from the temperature probe completed in September 2008 (Figure 5) since we were not able to find a well log from the original drilling. The well had been losing temperature over time and was having trouble heating the two homes connected to the system.

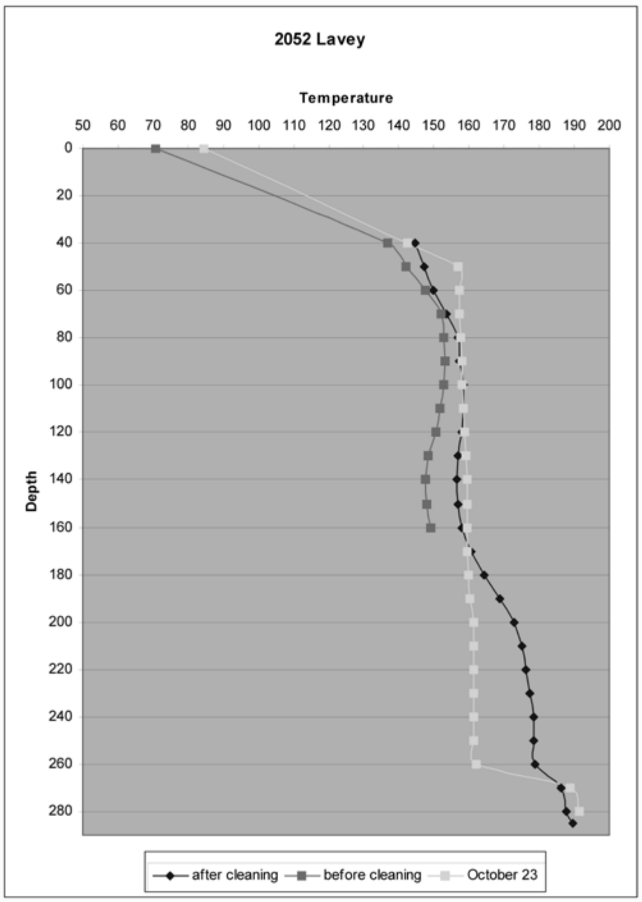

Figure 5: Temperature vs. depth profile of System One well before and after the operation of the promoter pipe.

The well was cleaned out in September to remove all the lose materials in the well since our first temperature probe stopped at 160 ft (49 m) and the owner knew the well was deeper than that. From the temperature probe we were able to determine that there was no convection cell which did not allow the hotter water to circulate and that a promoter pipe should be installed to help with the circulation of the hot water. The perforations should be placed at the live water zone and just below the lowest static water level on the well. According to the new well log the static water level was at 56 ft (17 m).

The unconventional promoter pipe (Figure 6) that was installed in the well had three tee openings. There were located at 1) 50 feet (15 m) below the top of the casing, 2) 30 feet (9 m) from the bottom of the well and 3) 10 feet (3 m) from the bottom of the well. Eight inch perforations were also placed at the top and bottom of the second tee opening. There were also 4 loops of ¾-in (1.9-cm) PEX tubing installed in the well for use as downhole heat exchangers for the homes. Figure 7 shows the installation of the promoter pipe along with the PEX downhole heat exchanger.

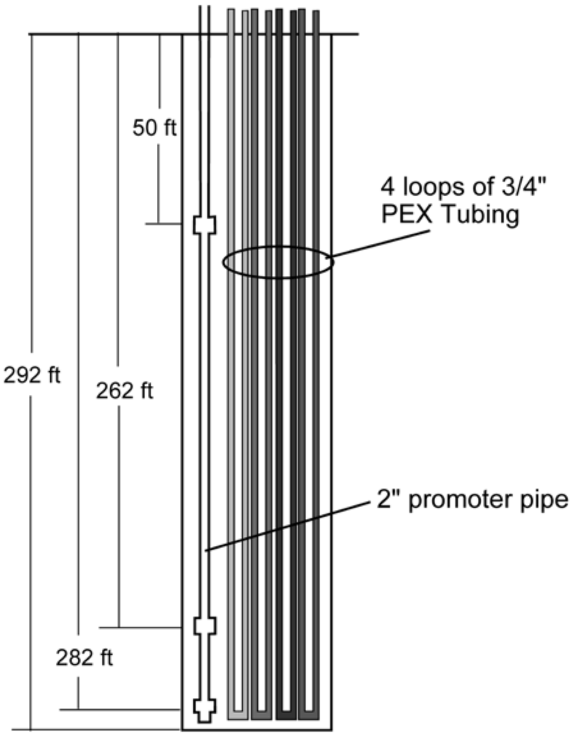

Figure 6: Schematic of System One well.

Figure 7: Placing the promoter pipe and PEX tubing into the System One well.

Another temperature probe was completed in October 2008 to see how the system was performing. The system was in operation at the time of the temperature probe. As can be seen from Figure 5, the temperature from the top tee to the second tee the temperature is constant, which shows that a convection cell has been obtained. This was probably due to the fact that the system was in operation and not from the promoter pipe since the top tee is unfortunately above the water level of the well. If the water level happens to increase enough to cover the first tee then the temperature curve from 50 ft to 262 ft should shift to the right.

SYSTEM TWO

The second system had an 8-in (20-cm) well drilled in 2002 to 370 ft (113 m). The well was originally cased with a 6-in (15-cm) casing and perforated with the lower perforations located in the "live water" zone 10 to 20 ft (3 to 6 m) from the bottom of the well and the perforations in the upper part of the casing (170 to 190 ft (52 to 58 m) from the top of casing) placed at the estimated lowest static water level. Static water at the time was 170 ft (52 m) below the casing and the temperature coming into the home was 175˚F (79˚C). Temperature probes were completed after the well was drilled and after the casing was installed as can be seen in Figure 8 and shows that a convection cell was obtained in the well.

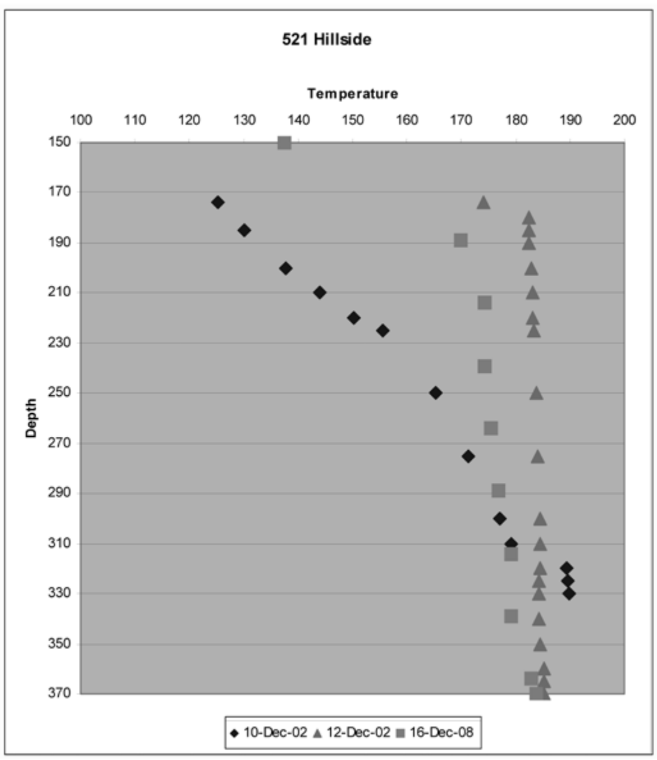

Figure 8: Temperature vs. depth profile of the System Two before and after casing installation and after installation of the promoter pipe.

After 6 years of operation, during the early part of 2008, the owner of the system reported that he was having trouble heating his home. The temperature of the DHE entering the home was down to 130˚F (54˚C). At that time it was determined that the water level in the well dropped to 188 ft (57 m) and has apparently dropped below the top level of the perforations in the upper level, causing the convection cell of the well to decrease or disappear all together thus decreasing output temperature of the DHE. The home owner put water down into the well for 4 hours to raise the level of the water into the well. This seemed to help and the temperature into the house did increase. The temperature again decreased in the later part of 2008 and we were able to determine that the water level has again dropped below the bottom part of the upper perforations.

It was then decided to insert a 2-in (5-cm) diameter promoter pipe into the well to get a convection cell started. The perforations in the 2-in (5-cm) promoter pipe were torch cut 1/2-in X 3-in, spaced approximately every 12 inches (30.5 cm) alternated in three areas along 18ft (5.5-m) of two lengths. The promoter pipe perforations are now placed from approximately 336 ft to 316 ft (102 to 96 m) and 210 ft to 190 ft (64 to 58 m) as shown in Figure 9. The length of the DHE was also extended another 21 ft (6 m). After the promoter was placed in the well another temperature probe was completed and as seen in Figure 8 it shows that convection cell has returned. As a result of this improvement, the home's DHE incoming temperature is approximately 170˚F (77˚C).

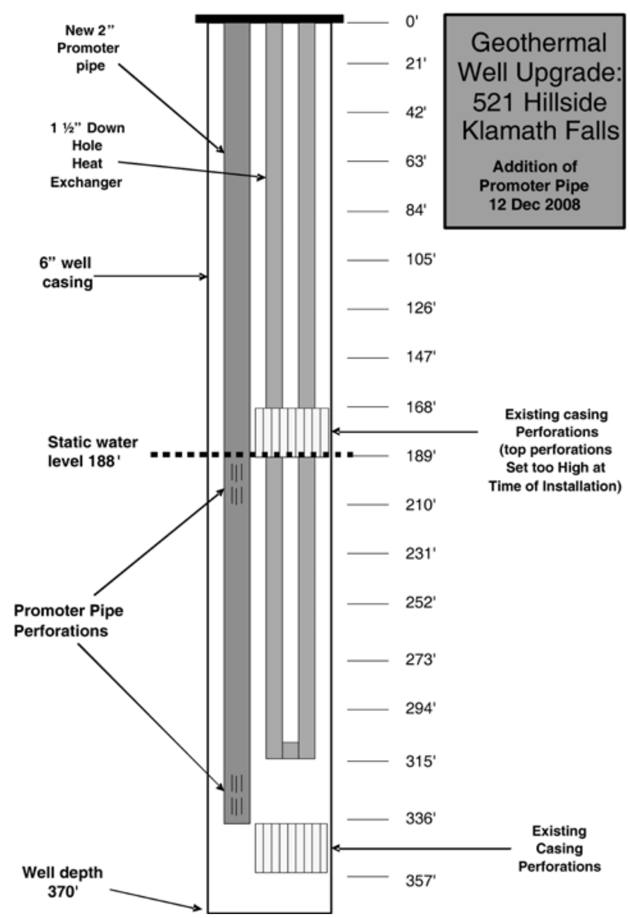

Figure 9: Schematic of System Two well.

SYSTEM THREE (Lund et al., 2008)

The third system, at time of completion, was cased with a 12-in (30.5 cm) diameter casing from the surface to 219 ft (67 m) and then with a 10-in (25-cm) casing from 210 ft (64 m) to the bottom at 354 ft (108 m). It only had perforations at the bottom to allow for hot water inflow from the fractured basalt aquifer as can be seen in Figure 10. Due to the way this well was completed there was no natural convection cell generated. This well was considered a "pumper and dumper" for they used a suction pump to bring the heat from the bottom of the well and then discharged to the storm sewer.

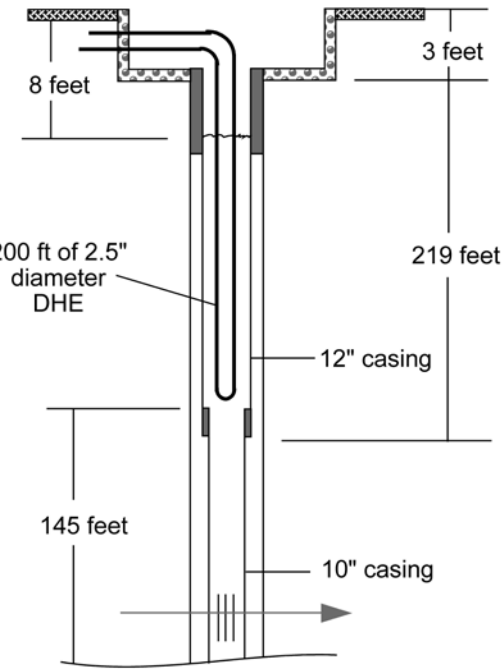

Figure 10: Schematic of System Three well.

System Three was having trouble heating the facility even when the pump was running. This was especially true for cold mornings and warm afternoon where the system had to adjust to the changing weather conditions. The problem was researched and discussed and there were several options on how to fix the problem. The options were rip the casing to produce the necessary openings for a convection cell, install a smaller perforated casing inside, lengthen the downhole heat exchanger or install a promoter pipe. It was decided the best solution was to install a 4-in (10-cm) diameter promoter pipe then the estimated 200 ft (61 m) of downhole heat exchanger pipes would not have to be removed.

CONCLUSIONS

In early March, 2008, 354 ft (108 m) of 4-in (10-cm) diameter promoter pipe was installed. Very few problems were encountered getting the pipe past the downhole heat exchanger and the casing size change. Approximately 1-in (2.5- cm) diameter holes were torch cut in the pipe 7 to 10 ft (2 to 3 m) off the bottom and 15 to 20 ft (4.5 to 6 m) from the top (Figure 11). The casing was hung from a plate at

Figure 11: Cutting the 1-in diameter perforations in the promoter pipe for System Three.

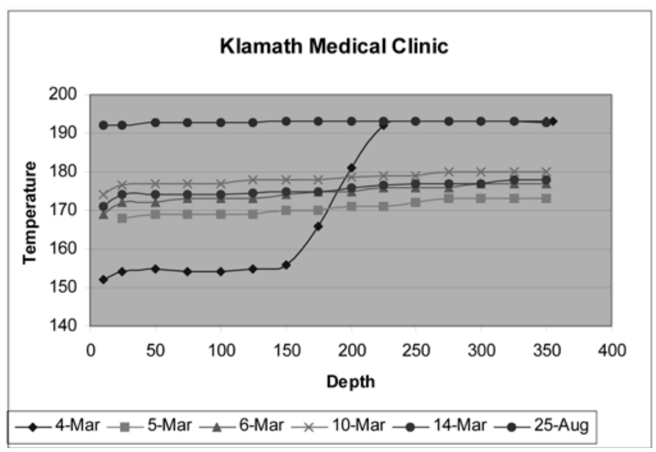

Figure 12: Temperature vs. depth profile of System Three well before and after the operation of the promoter pipe.

the casing top – which is about 3 ft below street level. We elected to hang the casing off the bottom, as setting it on the bottom might bury the lower holes in fines sloughed into the bottom, thus preventing the circulation cell from working. The static water level was about 8 ft (2.4 m) below the surface. Before the top holes were cut, we measured the water temperature inside the promoter pipe as show in Figure 12 the following day. The problem with the well is readily shown, with only about 154˚F (68˚C) for the first 150 ft (46 m) and then increasing to 192˚F (89˚C) from 225 ft (69 m) to the bottom. Thus, the downhole heat exchanger was only exposed to the cooler temperature which is marginal for this type of installation, and since there was no convection cell, would cool even more with heating demand.

The top holes in the promoter pipe were then cut and the pipe installed. We then measured the water temperature profile the next day and received encouraging results. The promoter pipe was working and providing around 171˚F (77˚C) over the entire well depth and obviously creating a convection cell bringing hot water up from the bottom (see Figure 12). Subsequent reading produced similar results as shown in Figure 12. The slight variations are due to variations in heating demand for the building, lower readings on cold days and higher reading on warm days. The readings were taken from March 5 through March 14 (all around 1:00 PM) where the low temperatures were around 28˚F (-2˚C) and the highs around 50˚F (10˚C). Another temperature probe was completed in August which shows the temperature has increase from 175˚F to 192˚F (79 to 89˚C).

As can be seen from the three systems described above the design and placement of the convection cell system is very important to the operation of the downhole heat exchanger. The three systems have been completed differently and the results have varied greatly. System One will probably encounter problems in the future unless they decide to lower the location of the top tee or the water level increases. One of the owners has replied that the temperature coming in to his home is adequate, but not as high as he expected considering the temperature at the bottom of the well. When System Two was completed the perforations should have been placed lower that they were for they were placed just below the water level. With the installation of the promoter pipe the system seems to be operating in a satisfactory matter at this time and the owner is pleased with the temperature coming in to his home. The less costly option for System Three was the installation of the promoter pipe and they have reported they are getting very adequate and uniform heat into the building now.

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OREGON'S FIRST GEOTHERMAL COMBINED HEAT AND POWER PLANT DEDICATION

Kristina Hakanson Maupin and John W. Lund, Oregon Institute of Technology
Photographs by Kristina Hakanson Maupin

Oregon Institute of Technology (OIT) dedicated its new geothermal electric generation project in a ceremony on April 20, 2010. The event was followed by tours of the power plant located on the southeast corner of the campus adjacent to the existing geothermal wells.

This "small" power plant is the first geothermal combined heat and power plant in Oregon, and the only geothermal electric plant currently operating in the state. It is also the first geothermal power plant in the world to operate on a campus from a resource directly underfoot. It has a maximum installed capacity of 280 kilowatts gross power utilizing existing geothermal wells on the campus.

John Lund, Director of the Geo-Heat Center

The emcee for the event was John W. Lund, Professor Emeritus and Director of the Geo-Heat Center who outlined the geothermal development on campus from 1959 to present. Other speakers at the event were: Oregon State Representative Bill Garrard; Bob Simonton, Assistant Vice Chancellor for Capital Programs, Oregon University System; and Peter West, Director of Energy Programs for Energy Trust of Oregon. Mr. West presented a check for $487,000 from the Energy Trust of Oregon to help cover the cost of the geothermal plant. Funding support was also provided by the Oregon University System, Oregon Department of Energy and a "Blue Sky" grant from Pacific Power. The Klamath Union High School Jazz Band performed before and after the event.

Bill Garrard, Oregon State Representative

Dave Ebsen, OIT Director of Facilities along with staff members, Scott Keiffer and Don Depuy, were instrumental in insuring that the plant was operational in time for the dedication.

The OIT campus has been entirely heated with geothermal energy since the early 1960s, saving approximately $1,000,000 per year in heating costs. These wells produce 600 gallons per minute (38 liters per second) of 192 to 196˚F (89 to 91˚C) water. After the geothermal water passes through the power plant and 15 to 20˚F (8 to 11˚C) is extracted, the water is then used to heat campus buildings before it is injected into wells on the lower part of campus. The power plant produces net electricity from 150 to 200 kW, depending upon the season, which is either used on campus or fed into the Pacific Power grid.

A second "big" geothermal power plant is planned, too. The 1.0 to 1.2 megawatt proposed project will utilized a 5,300-foot (1,600-meter) deep well drill on campus in 2009. The big project is expected to be complete in 2012.

Bob Simonton, Assistant Vice Chancellor, Oregon University System

Right: Presentation of the check from Energy Trust of Oregon. From left to right: Peter West, OIT President Chris Maples, John Lund, OIT Interim Vice President for Finance and Administration Mary Ann Zemke, OIT Geo-Heat Center Assistant Director Toni Boyd, OIT Director of Facilities Dave Ebsen, and Bob Simonton.

The power plant inside the building.

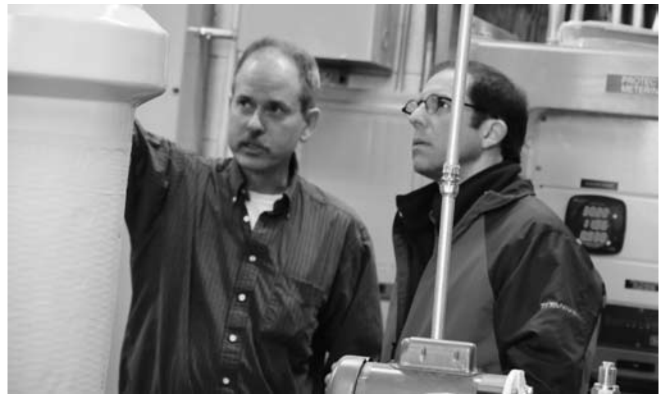
Klamath Union High School Jazz Band led by Drew Langley.

John Lund describing plant operation to Bob Simonton, with State Senator Doug Whistett and Brian Brown in the background.

The power plant building with cooling tower.

Toni Boyd conversing with a visitor about the power plant.

Dave Ebsen discussing the power plant operation with Brian Brown.



Scott Keiffer describing the plant operation with Peter West.

Don Depuy conversing with Mike Ronzello about the power plant.

Pratt & Whitney representative Mike Ronzello.

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