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Full Length Article

Modeling Reservoir Circulation and Economic Performance of the Neal Hot Springs Geothermal Power Plant (Oregon, U.S.): An Integrated Case Study

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ABSTRACT

We review the key factors that facilitated the successful development of a geothermal reservoir at Neal Hot Springs (NHS), Oregon, by a private company. The NHS geothermal field development plan, financing tools, and fluid circulation model provide a template for the development time, financing and well rates required to sustain geothermal power generation in similar setups elsewhere. The early economic performance and life-cycle analysis are specified using company data, applying a financial evaluation tool developed by the National Renewable Energy Laboratory (NREL). The Neal Hot Springs geothermal project was enabled by a combination of financing sources: U.S. federal loan guarantee and cash grant, state tax credit and private equity. Flow patterns in the NHS geothermal reservoir are visualized using a novel streamline simulation tool applying known well rates and benchmarking the residence time of re-injected brine based on tracer tests performed by the company. Temperature of produced brine has stayed remarkably constant over the first years of NHS plant operations, which we ascribe to advection of heat by an upwelling far-field flow beneath the plant's production wells.

BETC	Business energy tax credit
CCF	Cottonwood creek fault
CIF	Climate investment fund
DD&A	Depreciation, depletion and amortization
DOE	Department of energy
EPC	Engineering, procurement, and construction
FERC	Federal energy regulatory commission
HBF	Hope butte fault
IPUC	Idaho public utilities commission
NF	Neal fault
NHS	Neal hot springs
NPV	Net present value
NREL	National renewable energy laboratory
OPEX	Operating expense
PPA	Power purchase agreement
TOF	Time of flight
SBF	Sugarloaf butte fault
SCADA	Supervisory Control and Data Acquisition

1. Introduction

As of 2015, the world's installed geothermal power capacity amounts to 13.3 GW, of which 3.7 GW generated in the United States makes it by far the world's leading geothermal energy producer (GEA, 2016). Although global geothermal power supply is growing at an annual rate of 4–5% (GEA, 2014), the world's currently installed geothermal capacity of 13.3 GW is still very small, corresponding to just over half of the 22.5 GW power capacity of China's Three Gorges Hydropower Project (Gleick, 2008). The World Bank which traditionally provided low-interest loans for hydropower projects in developing nations also provides such loans for geothermal projects through the Climate Investment Fund (CIF; Haughey, 2009; Micale and Oliver, 2015). Commercial financing opportunities and government incentives are assumed to be more readily available for developed nations, so the CIF support for geothermal projects is strictly limited to developing nations.

This paper provides an integrated case study of a successful geothermal power project operated at Neal Hot Springs (NHS) near Vale, Oregon (Fig. 1). The project was advanced through private equity funding. Construction was enabled by a direct U.S. federal loan as part of Title XVII of the Energy Policy Act of 2005 with a loan guarantee by the Department of Energy, plus a federal Section 1603 cash grant in combination with an Oregon state tax credit. Reservoir evaluation for the NHS project began in earnest after geothermal energy rights were

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Nomenclature

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acquired by U.S. Geothermal in 2006. The first production size well was drilled in early 2008, which followed up on a slim-hole drilled by Chevron Resources in the late l970s. Additional slim-hole wells (8 inch diameter) were drilled to establish the geothermal gradient and three more production wells (121/4 inch diameter) were completed by the end of 2010. An independent reservoir engineer working on behalf of the Department of Energy (DOE) issued a geothermal reservoir certificate in 2011 attesting that the reservoir was able to sustain the production necessary for the planned 22 MW (net) power plant from the four production wells. The geothermal plant proved suitable for economic power production using binary cycle heat exchangers under a long term (25 year) power purchase agreement (PPA) with a regional utility. The building of a 22 MW (net) power plant was commissioned in early 2011 and completed in the second half of 2012, with first power sales in the final quarter of 2012. The power is sold to an Idaho utility company under a 25 year power purchase agreement.

Our study uses a novel streamline simulation tool (Weijermars et al., 2016; Weijermars and Van Harmelen, 2016, 2017) to visualize the flow patterns in the NHS geothermal reservoir using historic well rates and tracer tests performed by the company. The results suggest that the produced fluid is drawn from an open fracture system with continuous fluid influx from a deeper level to explain the homogeneous temperature of the reservoir. Operational and financial performance data were abstracted from annual reports by U.S. Geothermal Inc., which developed the field and a subsidiary of which operates the power plant. Additional field data was kindly provided by the company. Our study showcases the practical use of NREL's Cost of Renewable Energy Spreadsheet Tool (CREST), described in detail by Gifford and Grace (2013); the pertinent spreadsheet template is freely available (NREL, 2016).

This study proceeds as follows. The NHS project stages, instructive and exemplary for any geothermal development project, are highlighted in Section 2. The economic analysis is outlined in Section 3. The geological description and a reservoir model developed by us for the NHS geothermal field are outlined in Section 4. Advanced model results accounting for thermal upwelling and advection of (hot) fluid by a far-field flow are presented in Section 5. A discussion is given in Section 6 and conclusions in Section 7.

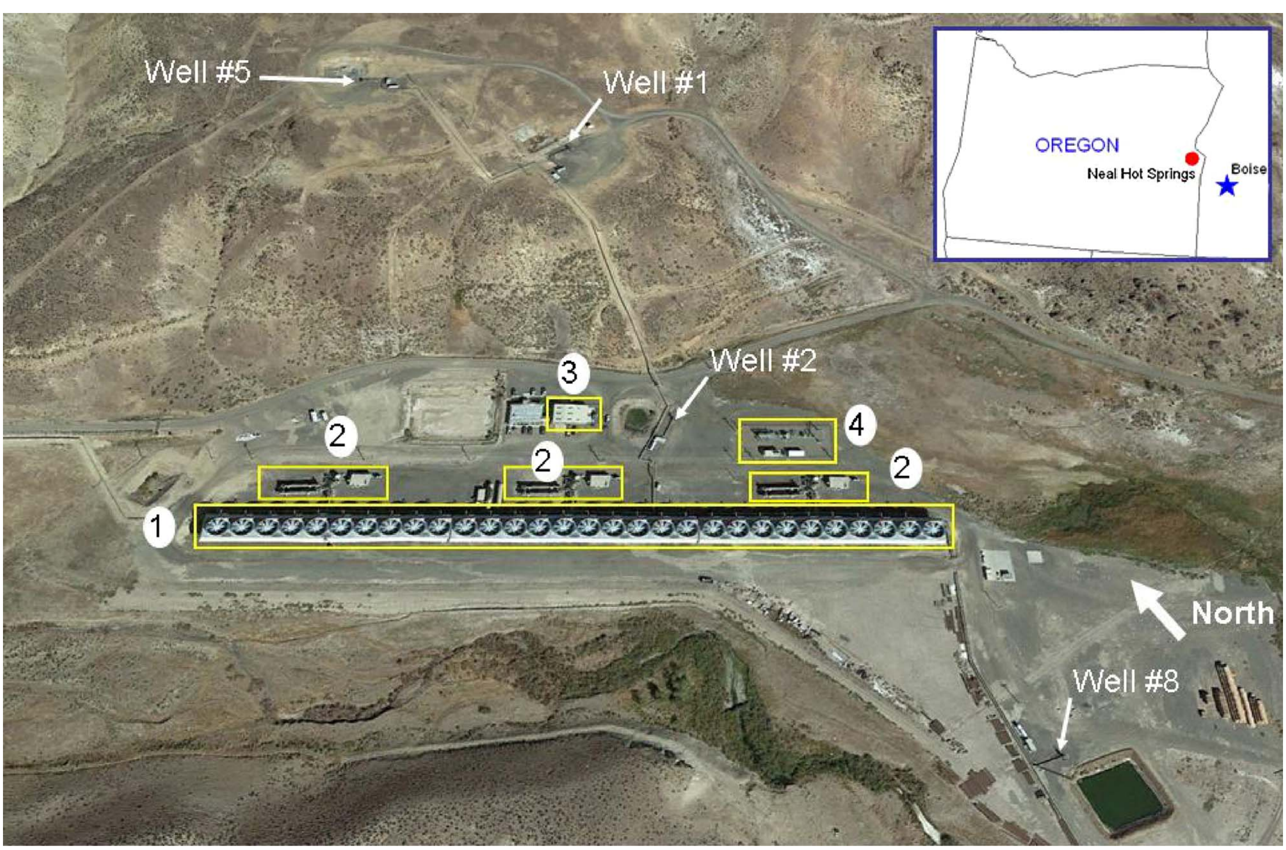

Fig. 1. Oblique Google Earth view of the Neil Hot Spring (NHS) geothermal power plant. The 4 producing feeder wells are marked (Wells 1, 2, 5 and 8). The plant outlay is labeled as follows: 1. Air-cooled condenser unit (0.4 km or 0.25 mile long); 2. Power conversion islands (three similar units); 3. Control room with SCADA system operators; 4. Power transmission station. The natural hot spring (NHS) is approximately located 0.5 km to the left of the image area.