Applied Energy 98 (2012) 458–466

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

The potential role of data-centres in enabling investment in geothermal energy

Ashok A. Kaniyal [a,c,*], Graham J. Nathan [a,c], Jonathan J. Pincus [a,b]

[a] University of Adelaide, Centre for Energy Technology, North Tce, South Australia 5005, Australia
[b] University of Adelaide, School of Economics, North Tce, South Australia 5005, Australia
[c] School of Mechanical Engineering, University of Adelaide, North Tce, South Australia 5005, Australia

ARTICLE INFO

Article history:
Received 10 October 2011
Received in revised form 3 April 2012
Accepted 10 April 2012
Available online 15 May 2012

Keywords:
Techno-economic assessments
Stranded geothermal energy
Incremental investment
Fibre optic networks
Data centres
Direct use

ABSTRACT

A techno-economic analysis is presented, of the potential for data-centres and fibre optic networks to drive investment in geothermal resources. The concept is attractive because of data-centres' stable demand for electricity and refrigeration at a scale of <5 MW_e, corresponding to the output of a single well doublet; because the cost of establishing a fibre optic link is an order of magnitude less than augmenting an electricity transmission network; and because it offers an opportunity for geothermal systems to compete with the retail price of electricity. A comparison of energy delivery outcomes was performed for both engineered geothermal systems (EGS) and hot sedimentary aquifer (HSA) reservoirs to identify the minimum conditions that could make the concept economically attractive. For the high temperature EGS, a single and dual pressure binary organic Rankine cycle (EGS-ORC, EGS-2×ORC), a single stage flash (EGS-flash) and a hybrid flash-binary system (EGS-hybrid) were studied. The HSA system investigated the direct use (HSA-DU) of the geo-fluid in an absorption chiller for refrigeration and the use of coincidental natural gas resources to deliver electricity via an internal combustion engine. The technical performance of these systems was assessed for a range of well-head pressure (EGS only) and geo-fluid flow rate scenarios. The economic performance of the combined set of investments in optical fibre and energy infrastructure was examined by estimating the expected internal rate of return (E[IRR]). The HSA-DU option yielded an E[IRR] of 14%, following the installation of energy capacity equivalent to the output of one well-doublet assuming the displacement of the Australian retail price of electricity; and 12% for the US retail price. In comparison, the EGS-hybrid was found to have an E[IRR] of 8%, if the Australian retail price were displaced and 4% if the US retail price were displaced. The EGS-flash, ORC and 2×ORC scenarios were found to be progressively less attractive than the EGS-hybrid. To identify the conditions under which the concept could satisfy commercial hurdle rates, the sensitivity of the E[IRR] was investigated for the cost of an optical fibre link; the EGS resource depth; the retail price of electricity displaced; and a data-centres' energy consumption profile. Credits for CO_2 emissions abatement at $23/ton were found to have only a marginal influence on the economic performance of the EGS and HSA scenarios examined.

1. Introduction

Energy from hot rock (HR) geothermal resources could contribute significantly to the supply of large-scale renewable electricity worldwide. For example, both the US and Australia have an estimated resource base of 200 ZJ ($\times 10^{21}$ J) [1,2] with a temperature range of 200–350 °C. However, investment in these resources has been limited by uncertainty about reservoir permeability, above ground systems [3–6] and induced seismicity from hydraulic fracturing for engineered geothermal systems (EGS) [7]. Concern over induced seismicity suggests that large scale generating facilities are likely to be sited far from urban markets. Further, the profitable delivery of electricity to a grid is expected to require plants of 500–1000 MW_e, while EGS is yet to be reliably demonstrated even at scales of a few MW [7,8].

One alternative to the long-distance transmission of electricity is to use existing pipelines to transport methane produced by the methanation of hydrogen from electrolysis [9]. However, the technical challenges of a project of this magnitude—involving 50 MW_e of geothermal EGS capacity—were not fully addressed [9]; and a considerable public subsidy would be required.

Where induced seismicity is not an issue, a profitable use of (non-EGS) geothermal energy is to meet the combined heat and power requirements of established district communities (e.g. small towns or stranded industries) [10–16]. Although this approach can provide an attractive revenue stream by returning the retail price of electricity, the viability of a CHP system is sensitive to weather conditions [10–16]. More importantly, the number of suitable sites is limited.

* Corresponding author at: School of Mechanical Engineering, University of Adelaide, North Tce, South Australia 5005, Australia. Tel.: +61 403691321.
E-mail address: ashok.kaniyal@adelaide.edu.au (A.A. Kaniyal).

0306-2619/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2012.04.009

Nomenclature

ΔT_p	pinch point temperature difference
0	thermodynamic dead state condition (subscript)
$	refers to US dollars (2011), assuming parity with Australian dollar
AGEA	scenario based on the delivery of electricity to the grid from Australian Geothermal Energy Association report
bar-g	gauge pressure in bars
CO_2-e	CO_2 equivalent emissions
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CHP	combined heat and power
d	depth in feet (subscript)
e	electricity (subscript)
$\dot{E}_R$	exergy of the geo-fluid with respect to the dead state temperature of 303 K
$\dot{E}_{CHP}$	useful heating effect of the geo-fluid after it passes through the electricity generation cycle in exergy terms
EGS	engineered geothermal system
E[IRR]	expected internal rate of return - averaged across all geo-fluid production conditions (and uncertain sensitivity parameters where indicated)
E[NPV]	expected net present value – averaged across all geo-fluid production conditions and (uncertain) sensitivity parameters
EPCM	engineering, procurement, construction and management
Flash	single stage flash cycle
GHG	greenhouse gas
gf	geo-fluid (subscript)
HSA	hot sedimentary aquifer
HSA-DU	direct use of geo-fluid from HSA to deliver refrigeration via an absorption chiller
Hybrid	hybrid single pressure flash-binary cycle
ICE	internal combustion engine
IT	information technology (refers to data-centre server infrastructure)
ORC	single pressure binary organic Rankine cycle
2×ORC	dual pressure ORC
LCOE	levelised cost of electricity (US$/kWh$_e$)
P_{wf}	thermodynamic cycle working fluid pressure
P_{wh}	geo-fluid pressure at the well-head
PH	ORC pre-heater (subscript)
PUE	power usage effectiveness is the ratio of the total electrical load of a data-centre to the electricity delivered to the facility's IT infrastructure
E	ORC evaporator (subscript)
η_{th}	first law thermodynamic efficiency of cycle
η_u	utilisation (second law) efficiency of thermodynamic cycle
NG	natural gas
r	refrigeration (subscript)
t	turbine (subscript)
th	thermal (subscript)

The final possibility for connecting a remote geothermal site to market is to bring customers, like data-centres and telephone exchanges, to the geothermal site. Owing to their stable demand for electricity and refrigeration [17,18], these types of facility offer the potential to mitigate some of the disadvantages of the options described above. Like, district communities, data-centres offer geothermal resources the potential to displace the retail price of electricity. Data-centres also offer greater flexibility in geothermal site selection given their modularity, the ubiquity of optical fibre networks and their low cost of extension (see Fig. 1) [3,9,19]. However, to induce them to co-locate with a geothermal facility, it is necessary to offer energy prices to data-centres that are no higher than in an urban area.

The energy demands of co-located data centres could be met by EGS, using a single well doublet. Alternatively, the technical risks associated with EGS could be avoided altogether [5], by the direct use of the geo-fluid from shallower lower temperature (<150 °C [11]) hot sedimentary aquifers (HSA-DU) in an absorption chiller [13]. However, this latter option requires a supplementary source of power for data-centre's electrical load. Here, it is assumed that supplementary power is provided by natural gas, given the strong correlation between high grade geothermal resources and natural gas production and/or distribution infrastructure. This confluence has arisen in part from the use of historical data from exploratory gas (also oil and water) wells to predict subterranean temperatures [2,5,9,20]. Further, urban data-centres often use natural gas internal combustion engines to generate electricity [21,22], demonstrating both the technical and economic feasibility of this approach.

Although the complementarities between geothermal resources and data-centre's load have been noted previously by commercial operators, there has been no systematic assessment in the open literature [23,24] of the potential synergies between natural gas infrastructure and geothermal resources, to satisfy data-centres' electrical and refrigeration load.

Given this background, the objectives of the present assessment are:

- to design energy delivery systems that can meet a data-centre's demand for electricity and refrigeration using:
  - a high temperature EGS CHP or electricity only plant by employing:
    - a single (EGS-ORC) or dual pressure (EGS-2×ORC) binary organic Rankine cycle,
    - a single pressure flash system (EGS-flash),
    - a hybrid flash-binary system (EGS-hybrid),
  - or a lower temperature HSA direct use (HSA-DU) system incorporating a natural gas internal combustion engine for electricity generation;
- to evaluate the economic prospects of a combined set of investments in energy and optical fibre infrastructure, and their sensitivity to data-centre load profile, geological characteristics of EGS/HSA reservoir and proximity to the fibre network.

2. Methodology

The technical and economic performance of each geothermal energy delivery system, data-centre combination was calculated for the cumulative energy output from a series of up to four well doublets that are assumed to yield the same geo-fluid temperature and flow-rate. All energy delivery scenarios assume the geo-fluid to be pure water. For the economic assessment, a real options approach was taken, so that no further aboveground plant is installed unless warranted by the production conditions of the first well doublet.

2.1. Data-centre energy consumption profile

A data-centre's power usage effectiveness ratio was used to determine its refrigeration and electrical load. The PUE is defined