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Feasibility of Using Engineered Geothermal Systems For Heat Production in Oil Sands Processing in Northern Alberta, Canada

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Introduction

Geothermal energy has the potential to reduce both the production costs and greenhouse gas emissions associated with oil sands production in the Western Canada Sedimentary Basin (WCSB) in Northern Alberta. This is currently being investigated through the Helmholtz Alberta Initiative (HAI), a research collaboration between the Helmholtz Association of German Research Centers and the University of Alberta. The primary area of interest is in the Athabasca oilsands where the Phanerozoic sedimentary succession is thinning towards the northeast and subcropping onto the Canadian Shield. A second study area is located around Peace River where the sedimentary succession is around 2000 m in thickness.

Characterization of geothermal potential

Heat flow varies across Canada from values as low as 20mW/m^2 in parts of the Canadian Shield to values as high as 90-200mW/m^2 in the Canadian Cordillera and Garibaldi volcanic belt respectively. The geothermal gradient in the sedimentary veneer of the WCSB that overlies the Precambrian crystalline basement varies from some 20mK/m in the southwestern Alberta Rocky Mountain Foothills, to some 60mK/m in the north western corner of Alberta. This trend is controlled by several factors that include (a) heat flow reduction by deep groundwater recharge in the Foothills and (b) high heat flow due to high concentration of radiogenic elements that produce heat, notably in the WCSB portion of northeast British Columbia and adjacent regions of the Northwest Territories.

Our data analysis used commercial temperature records, with noisy and systematically skewed data removed. Corrections were made for the paleoclimatic reduction in heat flow in the depth range of 0 - 2km. Results reveal a low-grade geothermal resource within the WCSB with aquifer temperatures of 15-20^{o}C in the Athabasca region and 60-80^{o}C around Peace River. These resources are associated with a relatively thin low conductivity thermal blanket (effective conductivity 1.4-2.4W/m K). In the Athabasca region it is clear that the crystalline basement rocks have higher thermal conductivities (3-4 W/m K), which suggests a lower thermal gradient at depths below the base of sedimentary rocks. Wells drilled to depths of around 4km in these basement rocks could potentially provide us with temperatures >80°C.

The heat flow–heat generation relationship for the Precambrian Churchill province was studied, and included the results of the deep "Hunt Well" in Fort McMurray and the deep "Rumpell Lake Well" to the northeast of the Athabasca oilsands area. These data suggest a strong correlation (R=0.8) with reduced heat flow of 30mW/m^2 under the upper crustal layer some 13km thick. The search for basement rocks with high heat generation is therefore one of targets for the Helmholtz-Alberta-Initiative.

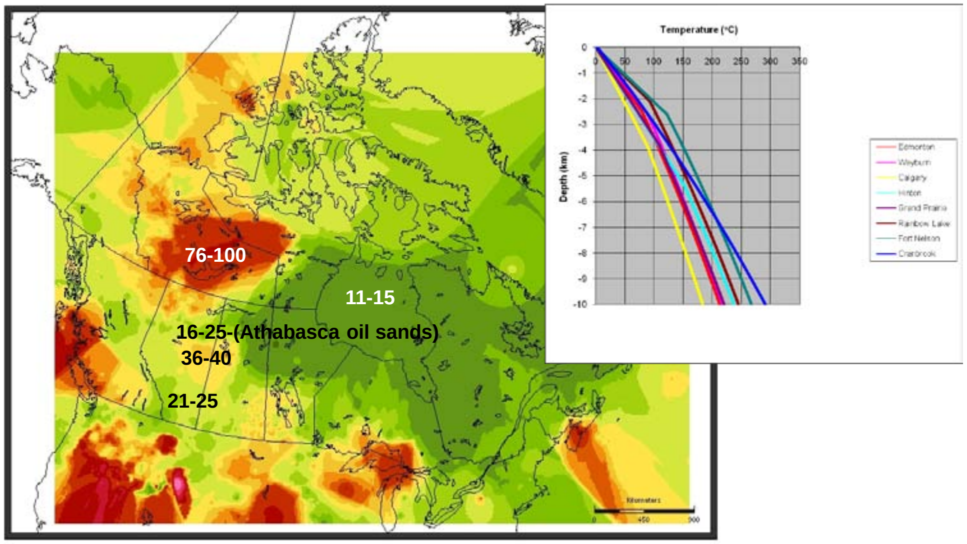

Figure 1: Geothermal gradient (in °C/km) across northern part of the North American continent (Majorowicz and Moore, 2008; Majorowicz, GSC 2010) and possible temperatures at locations in the Western Canadian Sedimentary Basin (WCSB) down to 10km depth (Majorowicz and Grasby, 2010).

Heat flow estimates in the primary area of oilsands production around Fort McMurray are based on measurements in the 2.34 km deep "Hunt Well" where equilibrium temperature logs have been recorded. The thermal conductivity (TC) was determined from deep granitic core samples. The GSC Calgary based XRD semi-quantitative analysis for "Hunt Well" sample reveals the following composition: quartz 47%; albite, calcian 28%; and orthoclase 25%. Optical based analysis of the same core lot at U of A shows 40% qtz. The total feldspar abundance (plagioclase + potassium feldspar) definitely exceeds that of quartz and it would be about 60%. As quartz TC is 7.69W/ m K, feldspar 2.32-2.42W/mK and Plagioclase 1.5-2.4W/m K this content can not explain laser method measured TC 1.75W/m K on small core plugs . This composition predicts a high thermal conductivity value of ~ 4 W/m K for XDR result and some 3W m K for the optical analysis result. Measured TC on bigger sections than core plugs gave 2-3.85 W/m K range. Geothermal gradient in granites is 21mK/m and heat flow was found to be somewhere between 40-80 depending on the assumed TC (likely 62mW /m^2). This is related to heat generation due to granitic composition of the basement rocks (1.5-7.8, mean=2.8μW/m^3). The "Hunt Well" penetrates some 1.8 km well into the granites down to near 2.4km depth of the Churchill.

Economics of geothermal heat use in oil sands processing

There are two major incentives for using geothermal energy in oilsands processing: 1) the cost of natural gas and 2) reduction in greenhouse gas emissions. Oilsands recovery and processing depends on scalable, reliable heat sources for heating water and generating steam. This energy is currently provided by burning natural gas, enhanced with heat recovery techniques such as cogeneration. In the case of in-situ oilsands operations, low-grade geothermal heat would reduce the overall natural gas demand, with the advantage of limited degradation in thermal content by recycling the thermal fluids rather than extracting them.

Initial calculations shown below confirm earlier published estimates suggesting geothermal heat can compete economically with burning natural gas. Earlier estimates, however, excluded explicit carbon mitigation costs, which will make geothermal systems more competitive. This situation will be further improved with advances in drilling technology and cost reduction.

Preliminary assessment of the current cost to heat up 10 Mbbl/day of water needed for an increase in oil sands by a temperature of 60 °C will give us a cost per year of $880 million with the following assumptions:

2 Mbbl/day bitumen production	10 Mbbl/day water required
1 bbl = 160 litres = 160 kg	4200 J/kg-C thermal capacity
50% efficiency in boiler	$3/GJ cost of natural gas

In order to realize a cost reduction through the implementation of cleaner geothermal energy, costs for drilling, stimulation and sustainable operation of a geothermal reservoir at about 80°Cin the crystalline basement need to be economically competitive.

Heat resource in the oil sands areas

The thermal modeling suggests that elevated temperatures beneath the Athabasca oilsands will require drilling into crystalline rocks. Based on the results of the “Hunt Well” we predict a temperature of 83°C would be found at a depth of 4 km and 123°C at depth of 6 km.

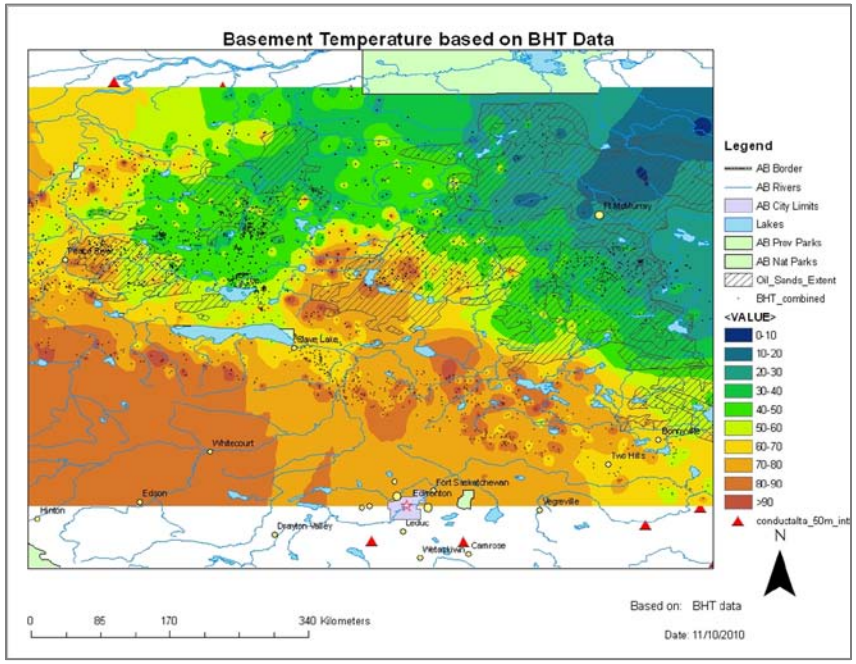

Figure 2: New map of the Precambrian basement temperature (in ^{o}C). Oilsands areas are shown by pattern.

The use of hot water for the production of electrical power from EGS would require the use of organic Rankin cycle turbines that have an efficiency in the range of 8-12% (Tester et al., 2006).

The costs of this type of heat production were estimated using the following assumptions: (1) no exploration or technical risks/costs, (2) efficiency of generator = 10%, (3) flow rate of 50 litres per second per production well, (4) temperature range= 150 °C to 50 °C. For a triplet well system (one injector/two producers) these assumptions predict that the cost of electricity will reach some $10 million per MW in the Peace River oil sands area. In the Athabasca area, the thermal blanket of low conductivity sediments is only a few hundred meters thick and the expected temperature gain with depth in crystalline rocks is some 20mK/m. It is very unlikely that direct electricity generation using geothermal energy could be economic.

While electricity generation may be uneconomic, direct heat extraction may be possible. This process has a thermal efficiency of 50-80% and would require drilling to around 4 km. This process would be feasible providing the rock can be fractured to produce a reservoir. Since hot water can only be transmitted over a distance of some tens of kilometres, this reinforces the need to focus geothermal investigations close to the locations where oilsands production (surface or in situ) will occur in the foreseeable future.

Evaluation of geothermal potential in Northern Alberta

A number of approaches are being used as part of the Helmholtz – Alberta Initiative to determine optimal locations for geothermal heat production in Northern Alberta.

Stress directions are being analysed across Alberta to determine the best locations for fracturing the rocks. Televiewer data is also being analysed to look for pre-existing fractures. Reservoir simulation is being used to determine how much heat can be extracted from granitic basement rocks in Northern Alberta. Geological models for the region are being revised, both for the crystalline basement and overlying sedimentary basin. Geophysical data are also being used in this regional characterization. It is anticipated that HRAM (high resolution aero magnetic) could map faults and lineaments, and perhaps give indirect evidence for changes in the concentration of the elements that generate heat. Seismic reflection profiles could assist in mapping the regional distribution and orientation of fractures and faults. Magnetotelluric data would help identify zones of fracturing, and would be sensitive to fluids in these fractures.

Summary

The research is focussed on an evaluation of potential heat sources for oilsands processing in areas with existing leases. This includes (a) within the Precambrian basement in the Athabasca oilsands at Fort McMurray and (b) within the Western Canada Sedimentary Basin in the Peace River area. Economic factors appear favourable, and it is expected that this research will determine the feasibility of heat production using geothermal energy in these areas.

Acknowledgements

The idea of using geothermal heat for oilsands processing was previously investigated by an industrial consortium "Geopowering the Oilsands" from 2005-2008. We thank Alison Thompson, Dan Yang and Peter McConnacchie for discussions about their previous studies in this area.

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