Co-Produced Geothermal Power*

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Abstract

Advances in binary energy conversion technology, i.e. small organic Rankine cycle engines, have generated interest in the potential for electric power generation from low-to-intermediate temperature fluids in deep sedimentary basins. Estimates of the power that could be produced have been based on calculations of the energy stored in permeable formations, formation properties relevant to reservoir productivity and on total fluid production data from oil and gas databases. These general estimates indicate that large quantities of power could be extracted from many intracratonic basins using co-produced fluids and fluids pumped from hot permeable formations.

Estimates of the resource potential for the Williston Basin are on the order of 1020 Joules which implies a resource potential of several GW of electrical power. However, the water-to-oil production ratio (WOR) for the Williston Basin is low, 1.22:1 based on 8,013 working wells in 2013. Other than the Bakken, the Madison (Mississippian) and the Red River (Ordovician) formations produce the greatest fluid volumes from the basin. Power production for the top ten producing wells in the Madison and Red River formations based on an exit temperature of 160 °F (71.1 °C) and an ambient air temperature of 60 °F (15.6 °C) for an ORC with 6 percent efficiency are approximately 671 kW and 814 kW respectively. Repeating the calculations for the unitized Madison and Red River fields yields co-production potentials of 3 MW for the Madison and 4 MW for the Red River. Thus, actual power production from co-produced fluids in the Williston Basin may be several orders of magnitude less than was predicted in earlier estimates.

Selected Reference

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AAPG Rocky Mountain Section
Sept. 23, 2013

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Harold Hamm School of Geology and Geological Engineering
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Advances in ORC and other energy conversion technologies make low temperature (90 °C-150 °C) geothermal waters a promising electric power resource.

Initial assessments over-estimated the resource by using total water production for states or regions.

Co-produced resource assessment must include oil and water production data by well, unit, field and formation.

Water production in the Williston Basin is too low for most conventional production settings.

Distributed binary systems in unitized or watered-out fields could provide a significant power resource although energy extraction technology could be improved.

Increasing development of multi-well pads will make co-produced water from the Bakken - Three Forks boom a power resource.
The potential power production using oil field waste waters with ORC technology is estimated to be at least 5.9 GW and could be as high as 21.9 GW.

Co-produced power would be economically competitive with 1,000 gpm and temperatures of at least 90 °C (192 °F).

(McKenna et al., 2005; MIT - 2007)
Optimism for co-produced waters

“Collecting and passing the fluid through a binary system electrical power plant is a relatively straightforward process.”

“Piggy-backing on existing infrastructure should eliminate most of the need for expensive drilling and hydrofracturing operations, thereby reducing the risk and the majority of the upfront cost of geothermal electrical power production.”

Co-Produced Project Dickinson, ND

- Water Flood EOR
- Eland-Lodgepole Field
- 210 °F, 400 gpm, high TDS water from Lodgepole Fm.
- Twelve wells collecting fluids at a central location
- Ormat & Pratt & Whitney estimated 350 kWe
- Local electric utility highly interested
**Estimated U.S. geothermal resource base to 10 km depth by category**

<table>
<thead>
<tr>
<th>Category of Resource</th>
<th>Thermal Energy, in Exajoules (1EJ = 10(^{18}) J)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction-dominated EGS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedimentary rock formations</td>
<td>100,000</td>
<td>MIT - 2007</td>
</tr>
<tr>
<td>Crystalline basement rock formations</td>
<td>13,300,000</td>
<td>MIT - 2007</td>
</tr>
<tr>
<td>Supercritical Volcanic EGS*</td>
<td>74,100</td>
<td>USGS Circular 790</td>
</tr>
<tr>
<td>Hydrothermal</td>
<td>2,400 – 9,600</td>
<td>USGS Circulars 726 and 790</td>
</tr>
<tr>
<td>Coproduced fluids</td>
<td>0.0944 – 0.4510</td>
<td>McKenna, et al. (2005)</td>
</tr>
<tr>
<td>Geopressured systems</td>
<td>71,000 – 170,000</td>
<td>USGS Circulars 726 and 790</td>
</tr>
</tbody>
</table>

* Excludes Yellowstone National Park and Hawaii
** Includes methane content

Resource Assessment

\[ Q = \rho C_p V \Delta T \]

\( \rho \) is rock density
\( C_p \) is volumetric heat capacity
\( V \) is volume of rock
\( \Delta T \) is the temperature difference between the geothermal fluid and temperature exiting the heat exchanger
Resource Assessment

- **Heat Flow**
  - Temperature and temperature gradient
    - Measured or derived from BHT data
  - Thermal conductivity
    - Measured or from literature

- **Rock Formation Properties**
  - Porosity
  - Permeability
  - Thickness
  - Depth
  - Composition – mineralogy – fabric
  - Fluid composition
  - Fluid production
Determine subsurface temperature at any depth where heat flow, \( q \), and thermal conductivity, \( \lambda \), are known

\[
T(z) = T_0 + \sum_{i=1}^{n} \frac{qZ_i}{\lambda_i}
\]
Wm k\(^{-1}\)

- 2.5
- 2.2
- 4.0
- 2.2
- 2.7

2.49 ± 0.048

1.10 ± 0.20

3.13 ± 0.73

3.19 ± 0.51

2.92 ± 0.48
The geothermal gradient varies inversely with thermal conductivity.

Temperature and gradient vs. depth in NDGS 6840 near the ND-MT border.

\[ \frac{dT}{dz} = 46.9 \pm 11.6 \] for Cretaceous shales.

\[ \frac{dT}{dz} = 21.4 \pm 9.2 \] for Jurassic & Triassic Clastics, Paleozoic Carbonates.
Thermal Stratigraphy and BHTs

\[ T_z = \sum_{i=1}^{n} \frac{q_z i}{\lambda_i} \]
Resource estimate for Williston Basin

\[ Q = \rho C_p V \Delta T \]

GIS mapped formation volumes at 10 °C intervals with water volumes determined from published data on formation porosity

Table 2. Volume and Energy Totals for the Williston Basin.

<table>
<thead>
<tr>
<th>Temp Range</th>
<th>90°-100°C</th>
<th>100°-110°C</th>
<th>110°-120°C</th>
<th>120°-130°C</th>
<th>130°-140°C</th>
<th>140°-150°C</th>
<th>150°C +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Volume</td>
<td>65,167.9 km³</td>
<td>51,673.1 km³</td>
<td>48,174.2 km³</td>
<td>44,626.1 km³</td>
<td>26,213.4 km³</td>
<td>11,696.9 km³</td>
<td>8,825.8 km³</td>
</tr>
<tr>
<td>Water Volume</td>
<td>4,037.2 km³</td>
<td>3,091.9 km³</td>
<td>2,891.5 km³</td>
<td>2,723.3 km³</td>
<td>1,594.7 km³</td>
<td>726.3 km³</td>
<td>530.2 km³</td>
</tr>
<tr>
<td>Thermal Energy</td>
<td>$6.88 \times 10^{18}$ J</td>
<td>$6.81 \times 10^{18}$ J</td>
<td>$7.57 \times 10^{18}$ J</td>
<td>$8.17 \times 10^{18}$ J</td>
<td>$5.49 \times 10^{18}$ J</td>
<td>$2.80 \times 10^{18}$ J</td>
<td>$2.36 \times 10^{18}$ J</td>
</tr>
<tr>
<td>Power Availability</td>
<td>$2.15 \times 10^9$ MW</td>
<td>$1.89 \times 10^9$ MW</td>
<td>$2.10 \times 10^9$ MW</td>
<td>$2.27 \times 10^9$ MW</td>
<td>$1.52 \times 10^9$ MW</td>
<td>$7.78 \times 10^8$ MW</td>
<td>$6.56 \times 10^8$ MW</td>
</tr>
</tbody>
</table>
Can co-production yield significant power?

The main oil and water producing formations in the Williston Basin

<table>
<thead>
<tr>
<th>Pool</th>
<th>BBLs Oil</th>
<th>BBLs Water</th>
<th>WOR Ratio</th>
<th>BBl Oil/well</th>
<th>BBl Water/well</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAKKEN</td>
<td>20,046,962</td>
<td>13,818,929</td>
<td>0.7</td>
<td>4,163</td>
<td>2,869</td>
</tr>
<tr>
<td>RED RIVER</td>
<td>829,559</td>
<td>3,305,592</td>
<td>4.0</td>
<td>1,659</td>
<td>6,611</td>
</tr>
<tr>
<td>MADISON</td>
<td>699,470</td>
<td>8,119,405</td>
<td>11.6</td>
<td>366</td>
<td>4,253</td>
</tr>
</tbody>
</table>

Numbers are BBLs per month for Oct. 2012
The average temperatures of the main producing formations were determined from corrected BHTs.

<table>
<thead>
<tr>
<th>Pool</th>
<th>BBLs Oil</th>
<th>BBLs Water</th>
<th>Max T °C at 1 Σ</th>
<th>Min T °C at 1 Σ</th>
<th>Avg T °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAKKEN</td>
<td>20,046,962</td>
<td>13,818,929</td>
<td>128</td>
<td>116</td>
<td>122</td>
</tr>
<tr>
<td>RED RIVER</td>
<td>829,559</td>
<td>3,305,592</td>
<td>147</td>
<td>113</td>
<td>130</td>
</tr>
<tr>
<td>MADISON</td>
<td>768,496</td>
<td>8,691,561</td>
<td>118</td>
<td>92</td>
<td>105</td>
</tr>
</tbody>
</table>

The energy that can be extracted from produced waters was calculated assuming a temperature drop to 70°C and efficiencies varying by formation temperature for the Access Energy XLT.

<table>
<thead>
<tr>
<th>Pool</th>
<th>T °C</th>
<th>kWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAKKEN</td>
<td>122</td>
<td>10,946</td>
</tr>
<tr>
<td>RED RIVER</td>
<td>140</td>
<td>2,021</td>
</tr>
<tr>
<td>MADISON</td>
<td>105</td>
<td>4,011</td>
</tr>
<tr>
<td>Cedar Hills</td>
<td>105</td>
<td>348</td>
</tr>
</tbody>
</table>

The total from the GIS analysis is 656 MWe.
## Power Production from top Madison and Red River Units in Co-Production Scenario

<table>
<thead>
<tr>
<th>Unit</th>
<th>Oil bbl</th>
<th>Water bbl</th>
<th>No. Wells</th>
<th>Water gpm</th>
<th>kWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar Hills S. Red RR B</td>
<td>292,351</td>
<td>2,282,671</td>
<td>117</td>
<td>2,045</td>
<td>1,170</td>
</tr>
<tr>
<td>Cedar Hills N. Red RR B</td>
<td>385,634</td>
<td>605,212</td>
<td>115</td>
<td>542</td>
<td>426</td>
</tr>
<tr>
<td>Medicine Pole Hills RR</td>
<td>27,908</td>
<td>127,200</td>
<td>22</td>
<td>114</td>
<td>62</td>
</tr>
<tr>
<td>Renville Madison</td>
<td>10,009</td>
<td>786,028</td>
<td>18</td>
<td>704</td>
<td>384</td>
</tr>
<tr>
<td>T.R. Madison</td>
<td>24,564</td>
<td>416,072</td>
<td>23</td>
<td>373</td>
<td>235</td>
</tr>
<tr>
<td>Eland Lodgepole</td>
<td>21,388</td>
<td>318,719</td>
<td>12</td>
<td>286</td>
<td>146</td>
</tr>
</tbody>
</table>
Co-produced vs. Water Only

The top producing individual oil wells in the Madison, Red River and Bakken formations do not yield sufficient water to be economic as a co-production electrical power system.

If the wells were produced solely for water, the power production would be significant.

<table>
<thead>
<tr>
<th>Madison Oil bbl/day</th>
<th>100 °C H₂O bbl/day</th>
<th>Fluid bbl/day</th>
<th>gpm</th>
<th>lb/hr</th>
<th>Co-produced Moderate power (kW)</th>
<th>Rate (kW)</th>
<th>High Rate (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>3511</td>
<td>3539</td>
<td>98</td>
<td>46809</td>
<td>110</td>
<td>2,200</td>
<td>22,000</td>
</tr>
<tr>
<td>92</td>
<td>3006</td>
<td>3099</td>
<td>84</td>
<td>40084</td>
<td>80</td>
<td>1,600</td>
<td>16,000</td>
</tr>
<tr>
<td>36</td>
<td>2722</td>
<td>2758</td>
<td>76</td>
<td>36287</td>
<td>73</td>
<td>1,460</td>
<td>14,600</td>
</tr>
</tbody>
</table>
New Developments
multi-well pads and high density infill drilling

Horizontal drilling and fluid production in the Heart Butte Bakken field have increased exponentially since February 2011.

Fluid production has averaged 37,317 bbl per day since April, 2013.

Estimate of power using oil water mix before separation: > 2 MWe
Horizontal drilling and fluid production in the Sanish Bakken field have increased linearly at a rate of 1,235 bbl/month since February 2008.

Fluid production has averaged 80,264 bbl per day since April, 2013.

Estimate of power using oil water mix before separation: >4 MWe
Current data (August 2013) show that the unitized Madison, Red River and Bakken formations do yield sufficient water to be economic for co-produced electrical power.

The table shows power that could be produced by using the water-oil mix prior to separation.

<table>
<thead>
<tr>
<th>Pool</th>
<th>Oil bbl/day</th>
<th>H₂O bbl/day</th>
<th>gpm</th>
<th>Total MW</th>
<th>MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red River 130°</td>
<td>1,534,083</td>
<td>12,016,573</td>
<td>350,483</td>
<td>1,569</td>
<td>210</td>
</tr>
<tr>
<td>Madison 100°</td>
<td>710,216</td>
<td>8,212,515</td>
<td>239,532</td>
<td>1,052</td>
<td>114</td>
</tr>
<tr>
<td>Bakken 122°</td>
<td>23,028,598</td>
<td>15,240,015</td>
<td>444,500</td>
<td>3,222</td>
<td>380</td>
</tr>
<tr>
<td>Total</td>
<td>25,272,897</td>
<td>35,469,103</td>
<td>1,034,516</td>
<td>5,843</td>
<td>704</td>
</tr>
</tbody>
</table>

The total from the GIS analysis is 656 MWe
Impact on oil industry

• Installing binary power systems for power generation using co-produced oil field fluids has potential to make a positive impact on oil field economics

• An economic model based on oil and water production rates, water temperature, O & M, oil futures, and electrical cost, shows that power generation using co-produced fluids could generate millions of dollars in additional revenue by saving on electrical costs, extending the Estimated Ultimate Recovery (EUR), and facilitating early development of the field.
Summary

- We have compiled data and developed methods that have enabled us to reach a clear understanding of the geothermal potential of the Williston Basin.
- Water production in the basin is too low for most conventional production settings.
- Distributed binary systems in unitized or watered-out fields could provide a significant power resource although energy extraction technology could be improved.
- Increasing development of multi-well pads and infill drilling will make co-produced water from the Bakken - Three Forks boom a power resource.