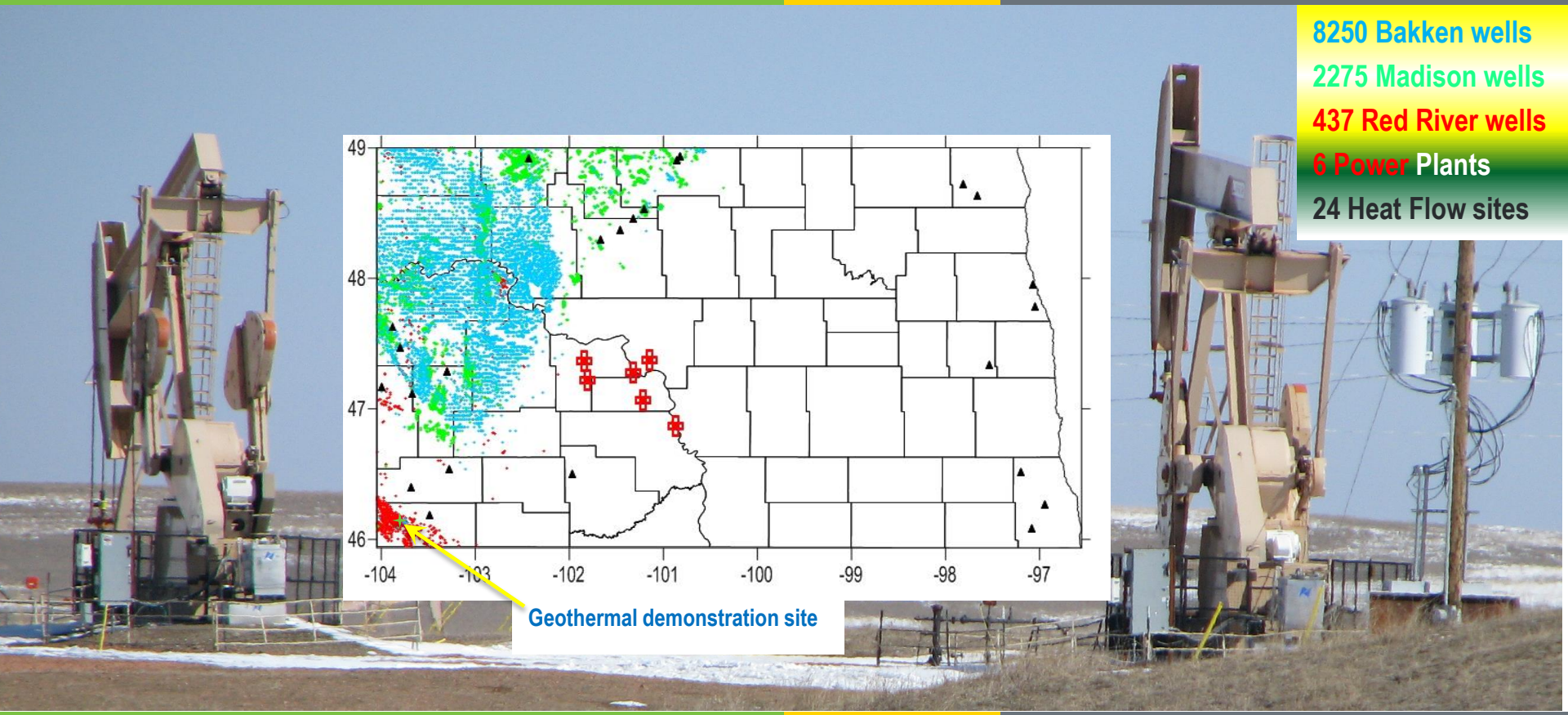

Electrical Power Generation From Low Temperature Geothermal Resources

Project Officer
Timothy Reinhardt

Total Project Funding:
$3,568,152

May 14, 2015

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University of North Dakota

Demonstration Project

Relevance/Impact of Research

Objective 1 Demonstrate the technical and economic feasibility of generating electricity from non-conventional low-temperature (150ºF to 300 ºF) geothermal resources.

Objective 2 Demonstrate that the technology can be replicated within a wider range of physical parameters including geothermal fluid temperatures, flow rates, and the price of electricity sales.

Objective 3 Widely disseminate the results of this study and develop a skilled work force in geothermics.

Relevance/Impact of Research

Objective 1- Feasibility: Challenges: - Solutions

- Identification and access to suitable water supply
  - Temperature: heat flow, BHT data, NGDS
  - Aquifer selection: geological data, oil and gas data, formation properties, NDGS
  - Fluid volume: oil and gas data, formation properties
- Selection of optimum power generation system
  - Resource temperature, flow volume, cost per kW
- Contractual delays
  - Liability, market pressures, cost volatility
- Gaining industry Interest and support
  - Developing geothermal fluids from oil field fluids during an oil boom

Relevance/Impact of Research

Meeting challenges: Temperatures and aquifers

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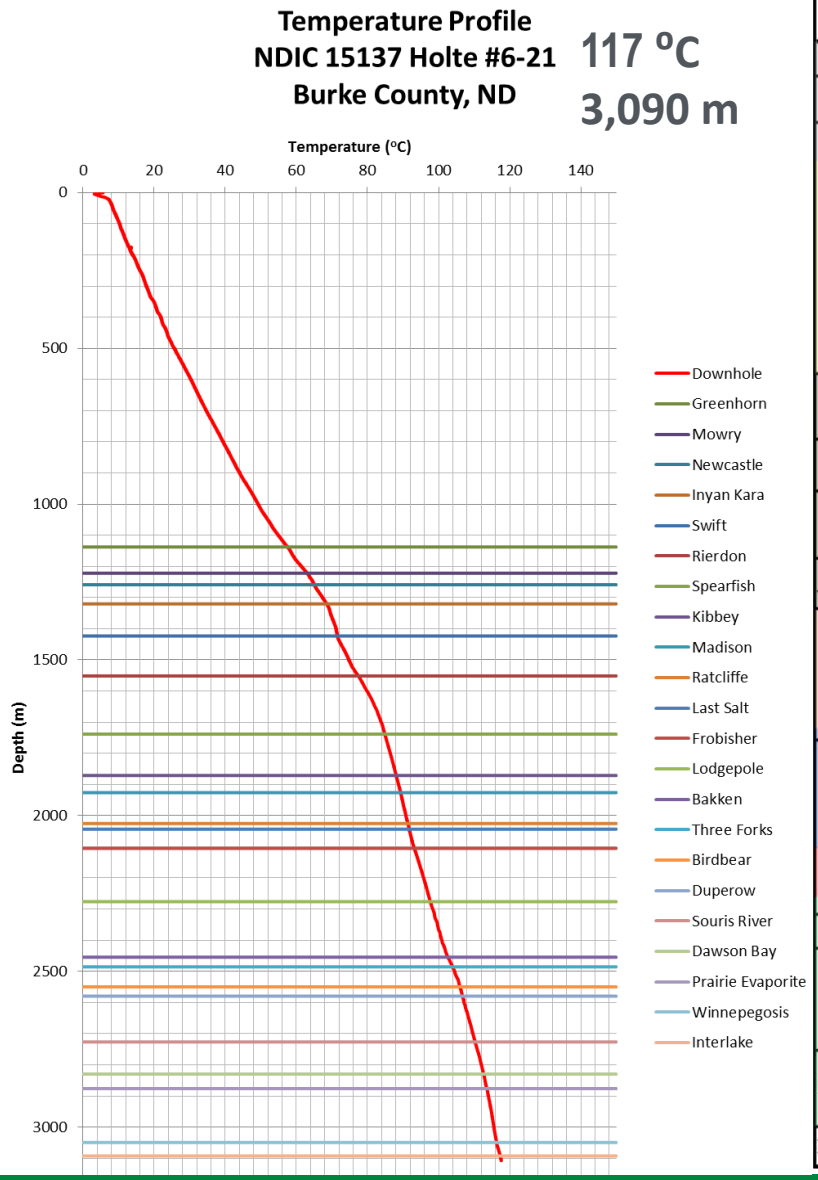

Age		Generalized Stratigraphy	Hydrostratigraphy
Quaternary / Tertiary		Ft. Union, White River, & Coleharbor Groups	Upper Aquifer
		Fox Hills Fm. & Hell Creek Fm.	
Cretaceous	U	Pierre Shale	Cretaceous Aquitard System
	U	Colorado Group (includes Niobrara & Belle Fourche)	
	L	Newcastle Fm.	Dakota Aquifer
	L	Scull Creek Fm.	
	L	Inyan Kara Fm.	
Jurassic	U	Swift Fm.	Jurassic, Triassic, Permian Aquitard System
	U	Rierdon Fm.	
	M	Piper Fm.	
Triassic		Spearfish Fm.	
Permian	U	Minnekahta Fm.	
	L	Opeche Fm.	
Pennsylvanian		Minnelusa Group (Broom Creek Fm., Amsden Fm., Tyler Fm.)	Pennsylvanian Aquifer
Mississippian	U	Big Snowy Group	Mississippian Aquitard
	U	Madison Group: Charles Fm.	
	L	Madison Group: Mission Canyon Fm.	Madison Aquifer
	L	Madison Group: Lodgepole Fm.	
Devonian	U	Bakken Fm.	Bakken/Three Forks Aquitard
	U	Three Forks Fm.	
	U	Jefferson Group (Duperow Fm. & Birdbear Fm.)	Minor Devonian Aquifer
	U	Manitoba Group (Dawson Bay Fm. & Souris River Fm.)	
	M	Prairie Fm.	Prairie Aquiclude
	M	Winnipegosis Fm.	Winnipegosis Aquifer
Silurian		Ashern Fm.	Basal Aquitard
		Interlake Fm.	
Ordovician	U	Red River Fm.	Basal Aquifer
	M	Winnipeg Group	
	L		
Cambrian	U	Deadwood Fm.	
	M		
Precambrian		Superior Province & Trans-Hudson Orogenic Belt	Lower Boundary

Depths to geothermal aquifers in the Williston Basin range from 3.0 to 4.5 km.

All aquifers below the Pennsylvanian System are a potential resource

Geothermal Resource 100 °C to 110 °C

Geothermal Resource 110 °C to 120 °C

Geothermal Resource 130 °C to 150 °C

Relevance/Impact of Research

Meeting challenges: fluid volume

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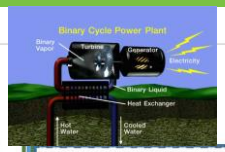
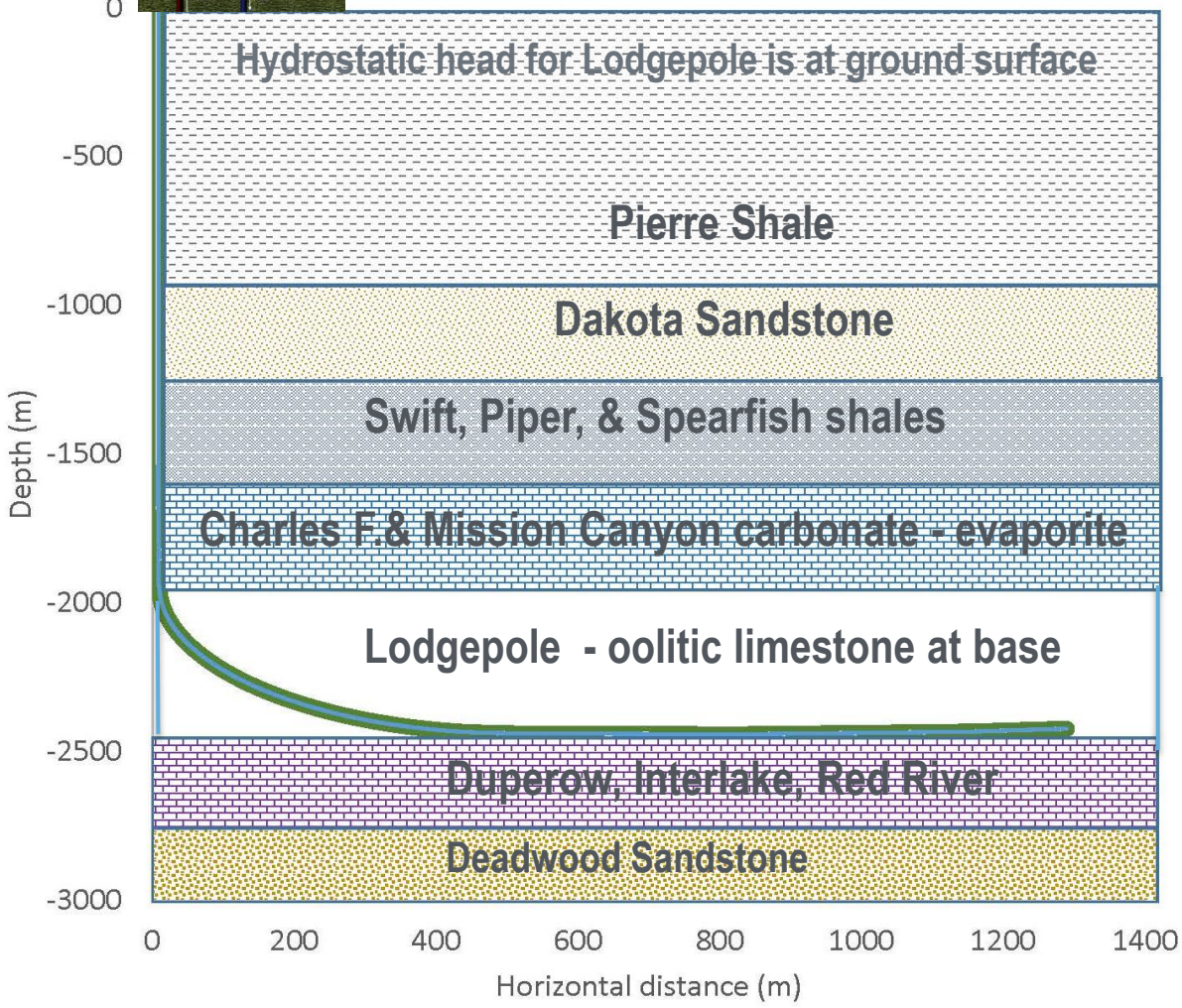


Schematic of Water Supply Wells at CLR Davis Water Injection Plant



- Two 125 kW ORC engines
- 98 ºC water 875 gpm
- Two 8.75” open-hole drilled horizontally 1.29 km and 0.85 km in the Madison Fm. at vertical depths of 2.3 km and 2.4 km.
- Concept – 8 horizontal wells drilled radially from a single pad could produce 3,500 gpm. Power yield ranges from 8.75 MW to 17.5 MW depending on air temperature.

Relevance/Impact of Research
ORC selection AE XLT 125 kW

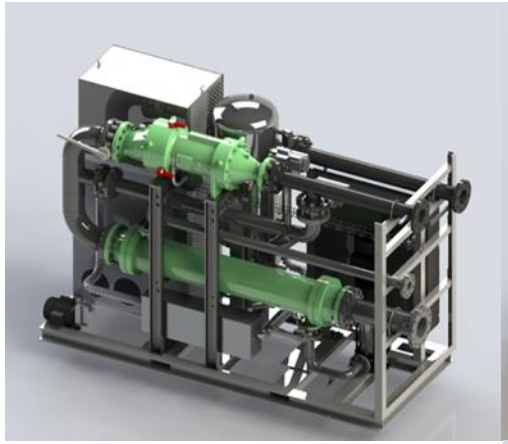
Working Fluid HFC-R245fa

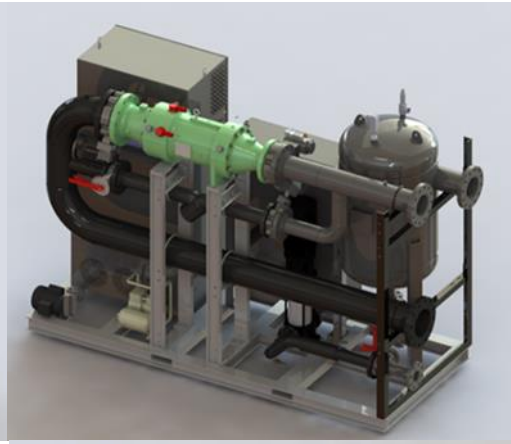
Integrated Power Module (IPM) – Contains Turbine Expander and Generator

- Hermetically Sealed Module
  - Eliminate seal systems
  - Integrated expander wheel
  - No possibility of leaks between rotating parts
- Magnetic Bearings
- Single Stage Turbine: 26,500 rpm – No Vibration
- High-speed 2 pole rare earth magnet generator 125 kWe gross

Power Conditioning

- Bi-Directional Power Electronics – used in motoring mode to assist in start up
- Programmable at factory to customer requirements. Output 380-480V, 3 phase, 3 wire (no neutral), 50/60 Hz





95.6° C (204° F) and above, full gross power of 125 kW produced

95.6° C (204° F) and below, partial power produced

Relevance/Impact of Research

Meeting challenges: Contracts & costs

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1. Assumption of liability not permitted by state but required by Continental Resources (CLR).
   - Solving this problem cost more than a year of time.
   - Access Energy assumed liability.
   - Olson Construction currently has liability.

2. Installation normally requires only a gravel bed but CLR requires a cement pad and burial of all pipes and wires. Thus, installation cost increased from $30,000 to $277,000.
   - Successful proposal to ND Renewable Energy Council provided an additional $100,230
   - Additional funding has been received/committed from Basin Electric Cooperative, Montana-Dakota Utilities and Access Energy to provide remaining cost of installation and monitoring.
   - The ND Renewable Energy Council has been asked to provide a 1:1 match any new dollars that will be coming in from BEPC, MDU and AE.

- Objective 2 Demonstrate that the technology can be replicated within a wider range of physical parameters including geothermal fluid temperatures, flow rates, and the price of electricity sales.
  - Temperatures in aquifers at 2.3 km and deeper in the Williston Basin are sufficient for electrical power generation with ORC systems.
  - The oil and gas industry will need an additional 3.2 GW_e to produce oil from the Bakken and Three Forks fields during the next 30+ years.
  - The heat contained in oil field fluids in North Dakota can be converted to 3.6 GWh of base load electrical power at a levelized cost of electricity of $0.05 per KWh.

- Objective 3 Widely disseminate the results of this study and develop a skilled work force in geothermal energy.
  - UND will have a web site with real time reporting on the project.
  - The UND Geothermal Laboratory team has produced 26 peer-reviewed articles and made 62 presentations at professional meetings.
  - The team has received 10 grant awards totaling $9,078,695 for geothermal research that is either related to or impacted by this project. Projects include the National Geothermal Data System with geothermal assessments of ND, MN, and NE and developing the NGDB with SMU and the Arizona Geological Survey.
  - Through this demonstration project and links with related projects the UND geothermal program has graduated 5 Doctoral students, 9 MS students, 3 BS students and has employed 16 BS students in geothermal research.

Scientific/Technical Approach
Project Pathway

- 2008 DOE FOA
  - Contacted North Dakota Industrial Commission for water production data
  - Assembled UND team
    - Gosnold: Geothermics
    - Mann: Energy Engineering
    - Salehfar: Electrical Power
    - Proposed project to oil field operator
  - Added industry partner for cost share
  - Prepared and submitted proposal

Scientific/Technical Approach Project Pathway

- 2009 Project start
  - Evaluated water supply, temperature, chemistry, flow rate
  - Contacted ORC & other energy conversion suppliers
  - Selected Calnetix for ORC. New 125 kW system operating at 96 ºC to be designed based on 50 kW system that operates a 135 ºC
  - Analyzed power potential of Williston Basin oil fields
    - Heat flow, BHT, thermal conductivity, stratigraphy, rock properties, fluid composition, oil and water production
- 2010 Phase I Report -Contract and liability challenges
- 2012-Installation cost challenges
- 2014-Recognized potential application in Bakken-Three Forks production
  - Acquired additional funding from ND Renewable Energy Council
- 2015-Acquired additional funding from BEPC and MDU
  - Site construction begun - project startup scheduled for April/May 2015

Scientific/Technical Approach
Testing Assumptions

- Water supply
  - Fluid production from conventional oil and gas operations is too low for economic geothermal development.
  - Conventional vertical water wells may be inadequate due low-permeability, drawdown and lift.
  - The CLR water flood uses open-hole lateral wells to produce high volumes of water.
  - Multi-well pads in the Bakken produce enough total fluid to generate 2 to 4 MW per field.

- Critical data for resource temperature identification and evaluation are:
  - Heat flow, BHT, thermal conductivity, stratigraphy, rock properties, fluid composition, oil and water production.

Scientific/Technical Approach
Testing Assumptions

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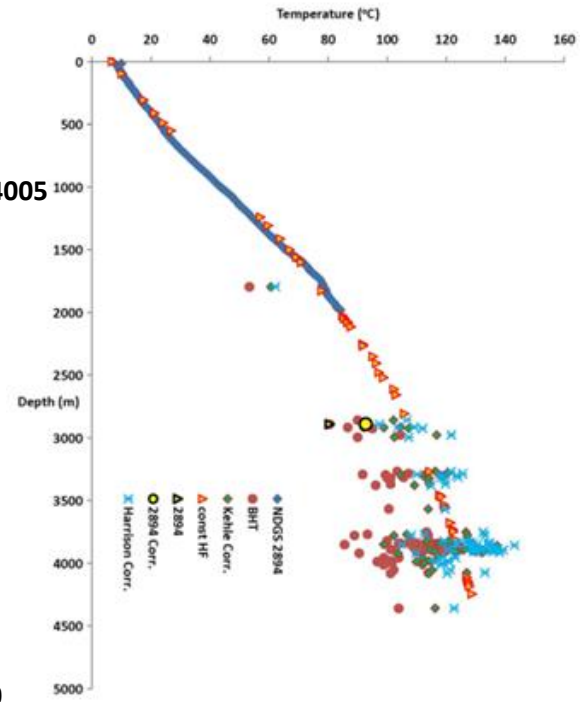
NGDS 3479 Latitude 48.9217, Longitude -102.4333
Bullard method yields **q = 47.8 mW m^{-2}**
Fourier method yields **q = 48.7 mW m^{-2}**
D = 125 m – 940 m, dT/dz = 45.5 R^2=0.9902, λ=1.15
BHT method yields **q = 45.8 mW m^{-2}**
TSTRAT method yields **q = 54 mW m^{-2}**
Mean value is 49 mW m^{-2} **GMNA 65 < q > 70**

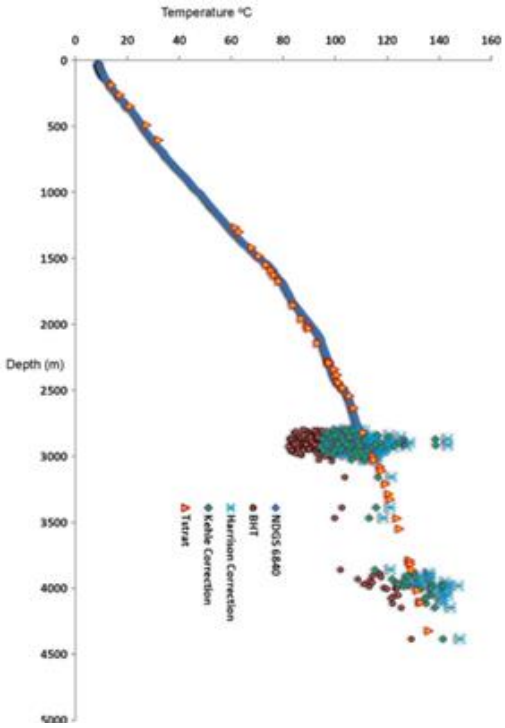
NGDS 6840 Latitude 47.628358, Longitude -103.8774871
Bullard method yields **q = 51.4 mW m^{-2}**
Fourier method yields **q = 47.5 mW m^{-2}**
D = 560 m – 1000 m, dT/dz = 44.6 R^2=0.9988, λ=1.15
BHT method yields **q = 50.0 mW m^{-2}**
Tstrat method yields **q = 51.0 mW m^{-2}**
Mean value is 50 mW m^{-2} **GMNA 60 < q > 65**

NDGS 2894 Latitude 47.1093548, Longitude -103.6684005
Bullard method yields **q = 49.0 mW m^{-2}**
Fourier method yields **q = 51.0 mW m^{-2}**
D = 549 m – 1245 m, dT/dz = 44.4 R^2=0.9992, λ=1.15
BHT method yields q = 52. mW m^{-2}9
Tstrat method yields **q = 49.0 mW m^{-2}**
Mean value is 49 mW m^{-2} **GMNA shows 60< q > 65**

NGDS 3342 Latitude 48.935, Longitude -100.8267
Bullard method **q = 45.0 mW m^{-2}**
Fourier method **q = 62.0 mW m^{-2}**
D = 775 m – 1020 m, dT/dz = 53.7 R^2=0.9990, λ=1.15
BHT method yields **q = 52.9 mW m^{-2}**
Tstrat method yields **q = 49.0 mW m^{-2}**
Mean value is 52 mW m^{-2} **GMNA shows 65 < q > 70**

Heat flow, thermal conductivity, & stratigraphy and BHT data have led improved heat flow and subsurface temperature determinations.



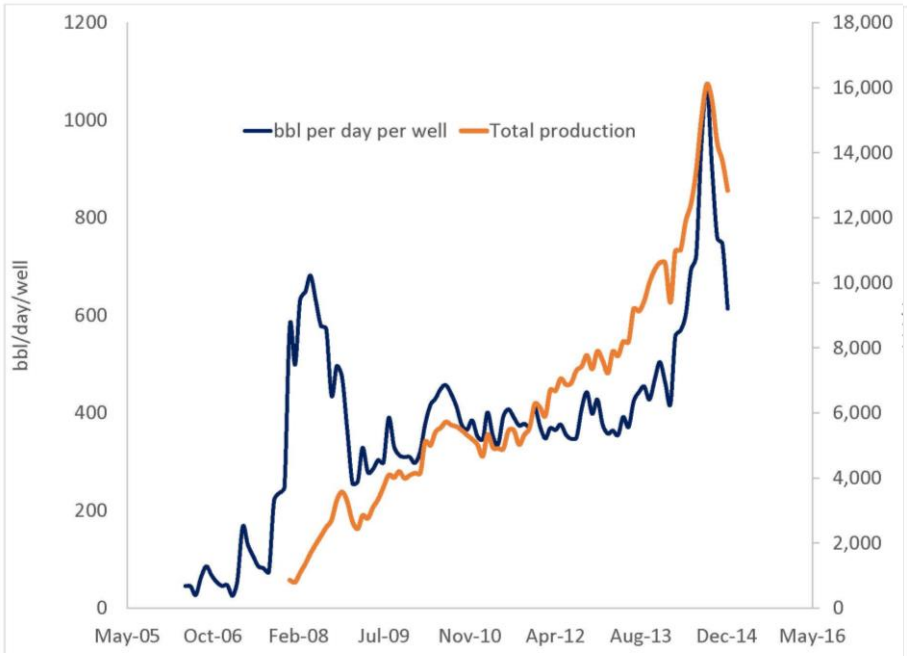


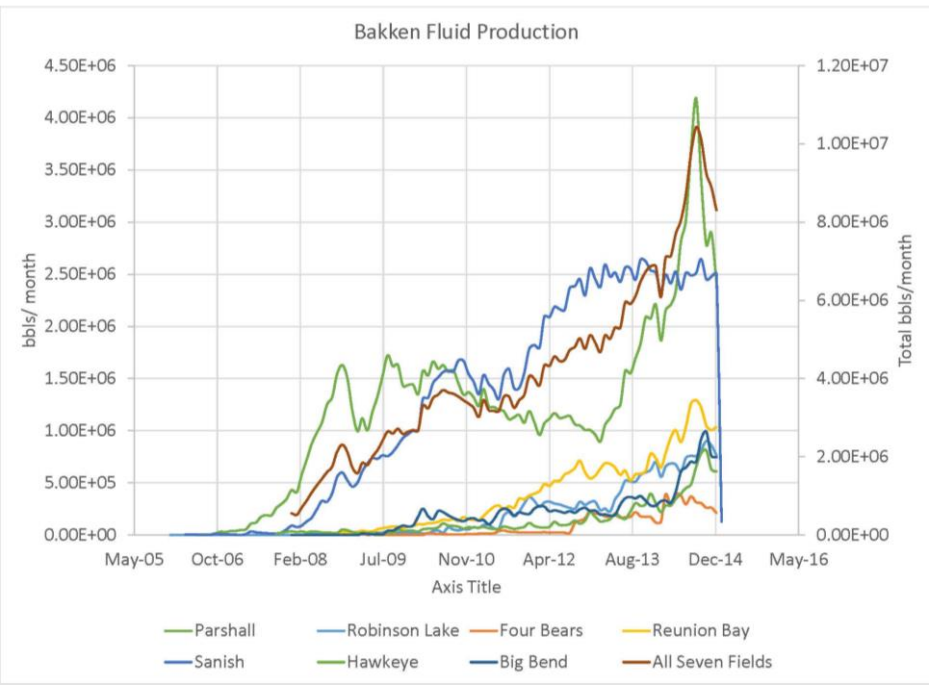
Scientific/Technical Approach
Identify main water producing formations

Individual oil wells do not produce enough fluid to be a resource

Pool	bbls per month Oil	bbls per month Water	O/W Ratio	Oil- gpm/well	Water-gpm/well
BAKKEN	30,831,847	2,3783,224	0.7	4.3	3.3
RED RIVER	561,842	3,872,197	6.7	1.6	10.9
MADISON	644,669	7,640,889	11.9	0.4	4.8

Multi-well pads produce enough total fluid to generate 2 to 4 MW per field





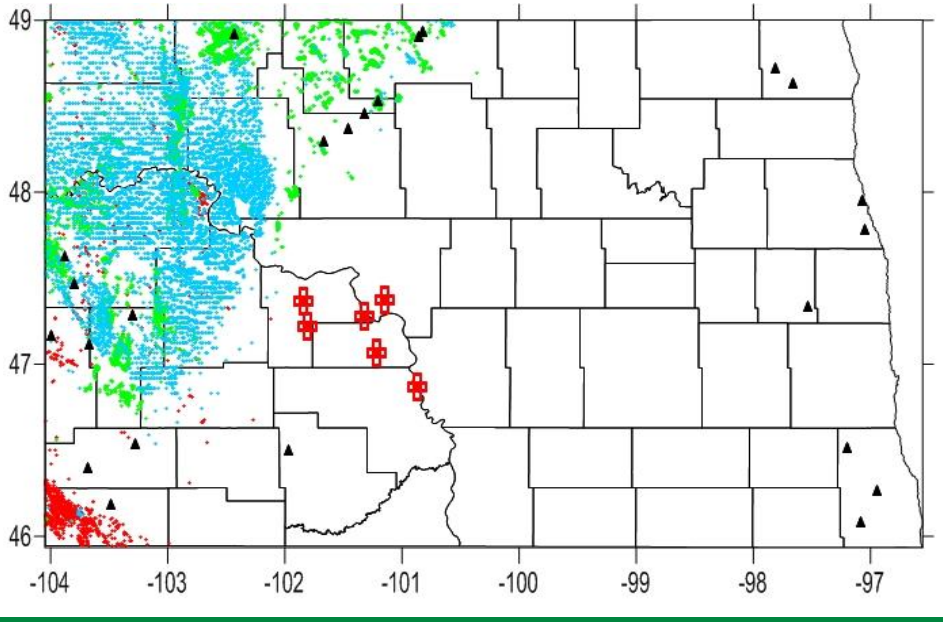
Future Directions
Get the electric power industry involved

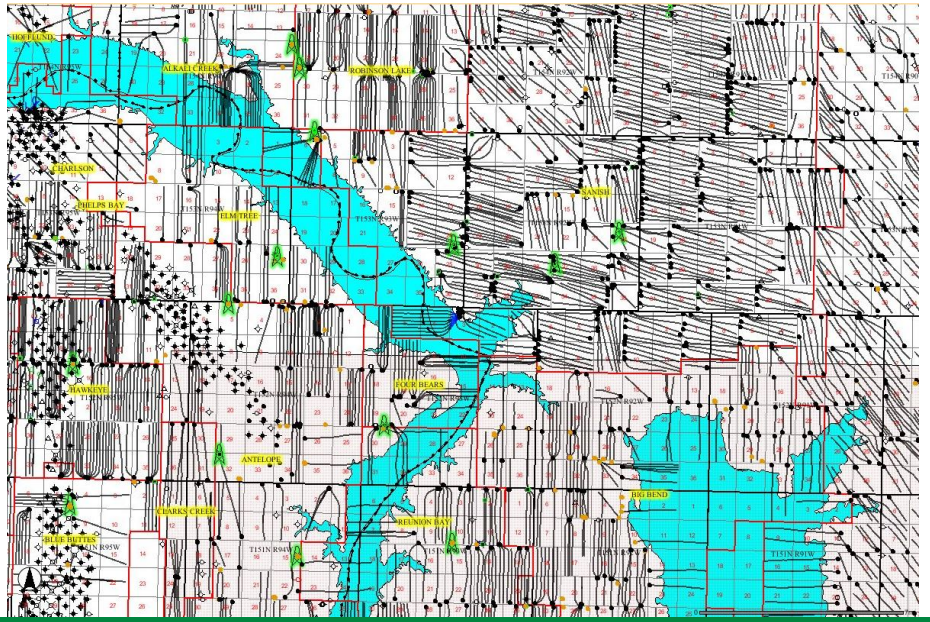
An additional 3.2 GW_e will be needed to produce the Bakken and Three Forks fields during the next 30+ years.

Six coal-fired power plants located along the Missouri River provide all power at present. Multi-well pads in Bakken-Three Forks fields produce enough total fluid to generate several MW of power per pad.

A distributed ORC network could preclude construction of new fossil fuel burning power plants and the construction of a power grid that will be unneeded when the Bakken oil boom ends.

Production of the power from low temperature geothermal could avoid generation of approximately 10 million metric tons of CO2 that would be generated by burning fossil fuels.





Summary Slide

- Two Access Energy ORC engines are generating 250 kW using 98 ^{0}C water produced at 875 gallons per minute (55.2 liters per second) from two 8.75” (0.222 m) diameter water supply wells that were drilled horizontally 1.4 km and 0.85 km in the Madison Fm. at vertical depths of 2.3 km and 2.4 km.
- The CLR site demonstrates that a promising option for geothermal development is multiple horizontal open holes drilled radially from a single pad.
- Initial partners in the project, CLR, Access Energy, and Slope Electric Cooperative, have been joined by Olson Construction, Basin Electric Power Cooperative and Montana-Dakota Utilities. The electric power industry is involved in geothermal power using oil field fluids.
- A distributed network of binary ORC power plants could generate power at a levelized cost of electricity of $0.05 per KWh in the Williston Basin.
- The oil and gas industry will need an additional 3.2 GWe to produce oil from the Bakken and Three Forks fields during the next 30+ years.
- Production of the power from low temperature geothermal could avoid generation of approximately 10 million metric tons of CO2.