The UND-CLR Binary Geothermal Power Plant Williston Basin, North Dakota*

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Abstract

The question of whether power production can be achieved economically using oil field fluids was answered positively in March 2016 when the UND-CLR Geothermal Power Plant in North Dakota produced power using a125 kW prototype high- efficiency ORC manufactured by Calnetix. NREL's' CREST model gives the LCOE for this US DOE demonstration project as $0.06 per kWh. Installation costs were $3000 per kW for the optimum ORC system and power grid costs in the region are $0.08 per kWh. As such, UND-CLR and other similar geothermal power plants have the potential to serve as economical distributed electric power generators, or as energy storage systems, in power grids. However, application of this demonstration to other oil-producing basins requires analysis of multiple factors. Economics of electrical power generation in oil and gas settings balances on several key parameters including resource temperature, fluid production capacity, efficiency of heat-to-power conversion, ability to adopt existing infrastructure, competitive costs, and time scale for ROI. Finding the economic nexus for success requires conjunction of geology, engineering, technology, and economics.

Geological factors that characterize the Williston Basin geothermal resource are temperature and fluid production capacity in permeable formations. Heat flow in the basin ranges from 50 mW m-2 to 70 mW m-2, and 100-130 ºC temperatures in the fluid-producing carbonates at 3 to 4 km depths are due to high geothermal gradients in 2 km of low thermal conductivity (1.0 to 1.2 W m-1 K-1) overlying fine-grained clastic rocks. The water supply at the UND-CLR site comes from two ~2.8 km deep X ~1.6 km long open-hole lateral wells. The temperature is 103 ºC at the well and 98 ºC at the ORC inlet located 400 m from the wellhead. The wells were drilled by CLR for a water-flood secondary recover project and although the pipelines are buried, they are not insulated. Water flow is routed through the ORCs before it enters the injection plant. Cooling of the water in the ORC benefits CLR by reducing heat stress on components of the injection pumps. The hydrostatic head for the producing formation, Lodgepole is at the ground surface and submersible electric pumps positioned at ~ 750 m depths in vertical section of the long lateral wells resulted in no drawdown of the fluid resource. The key points are that use of existing infrastructure avoids drilling costs for geothermal development and, horizontal drilling in the aquifers increases borehole exposure to the resource and significantly increases the capacity for fluid production.

Engineering and technological challenges in accessing the resource require information on the characteristics of the producing formation and in selection of the optimum ORC technology. CLR acquired formation permeability, water quality, and rock properties and UND was only involved as a beneficiary of CLR’s research. Selection of the optimum ORC system involved solicitation of bids from ORC manufacturers given, fluid production volumes, water quality, temperatures, and the need for air-cooled condensers. Significantly, recent advances in ORC technology promise to increase power production by 2 to 4 times over the currently installed system.

Reference Cited

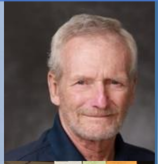
Blackwell, D.D., and M. Richards, 2004, Geothermal Map of North America: AAPG Map, scale 1:6,500,000, Product Code 423, 2004.

UND Geothermal Laboratory
The University of North Dakota

The UND-CLR Binary Geothermal Power Plant

AAPG 3rd Hydrocarbon – Geothermal Crossover Technology Workshop

Geneva, Switzerland 9-10 April 2019



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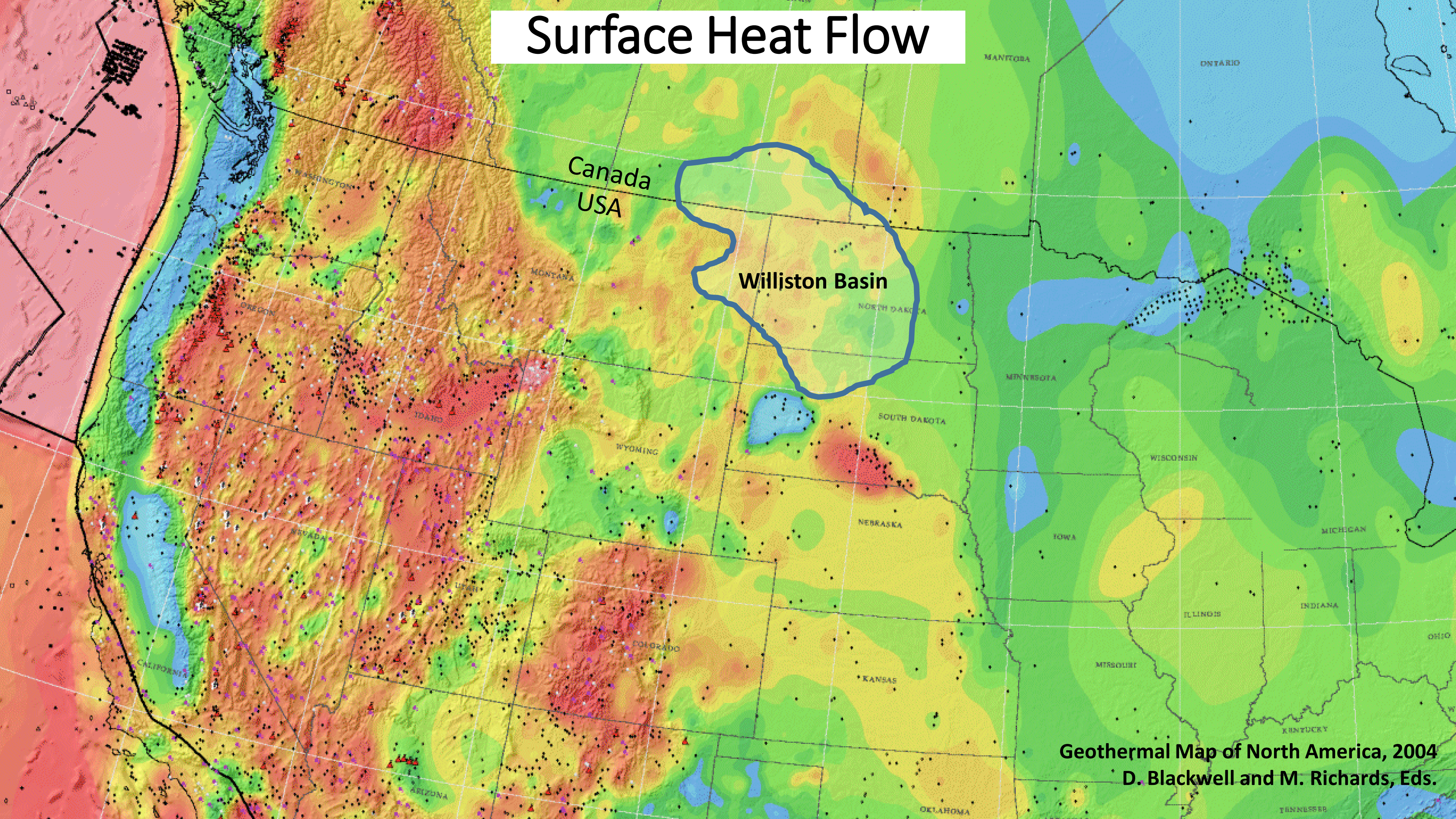
The UND-CLR Geothermal Power Plant

A University of North Dakota Partnership with Continental Resources, Access Energy, Olson Construction, Basin Electric Cooperative, and Slope Electric Cooperative

Funding Support

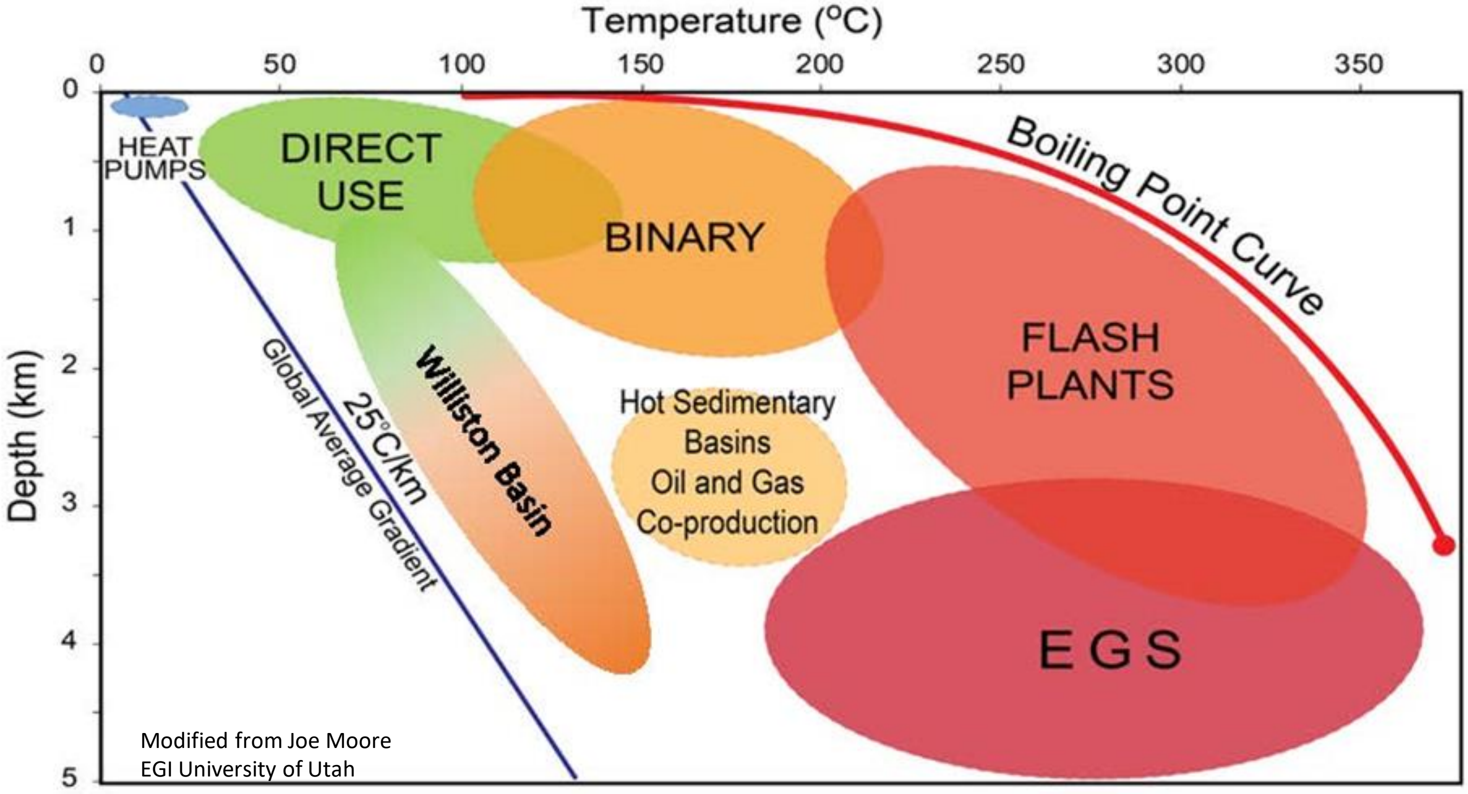
US Department of Energy $1,734,976,
North Dakota Industrial Commission $192,000
The North Dakota Department of Commerce $297,512
Basin Electric Cooperative $50,000
Access Energy supplied two 125 kW ORCs

Surface Heat Flow



Geothermal Map of North America, 2004
D. Blackwell and M. Richards, Eds.

Geothermal resources:
Characterized by temperature, depth, and application



Modified from Joe Moore
EGI University of Utah

GENERALIZED STRATIGRAPHY OF WILLISTON BASIN

The geothermal energy stored in permeable strata in the Williston Basin is known from heat flow research beginning in the 1960s and geothermal research beginning in the 1980s.

The total energy exceeds 20 x 10^{18} J. (Roughly equivalent to 20 Tcf of natural gas vs Groningen ~100 Tcf)

Clastics (shale dominated) Avg thermal conductivity ~1.2 W/m/k

Carbonate dominated. Avg thermal conductivity ~3.0 W/m/k

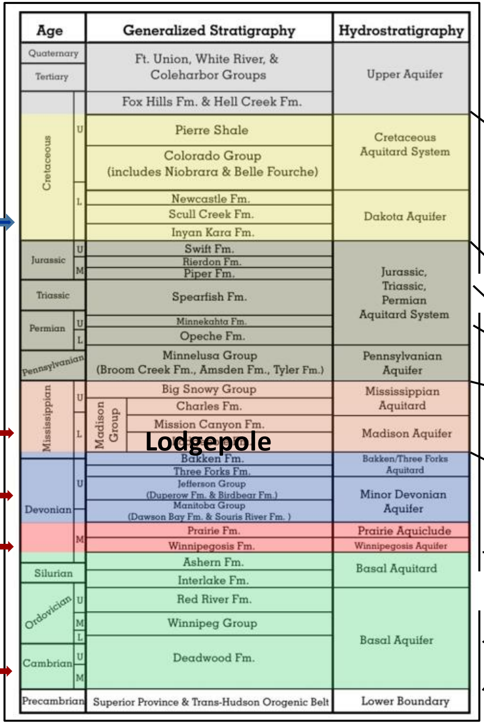
60°C

130°C

140°C

150°C

160°C

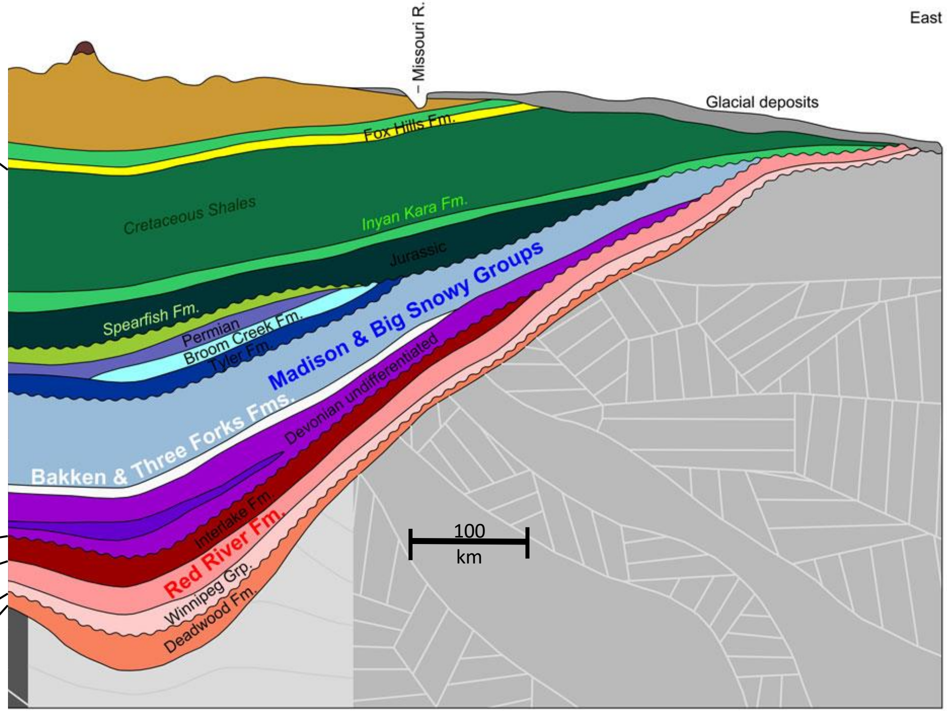


Age	Generalized Stratigraphy	Hydrostratigraphy
Quaternary / Tertiary	Ft. Union, White River, & Coleharbor Groups	Upper Aquifer
	Fox Hills Fm. & Hell Creek Fm.	
Cretaceous U	Pierre Shale	Cretaceous Aquitard System
	Colorado Group (includes Niobrara & Belle Fourche)	
Cretaceous L	Newcastle Fm.	Dakota Aquifer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

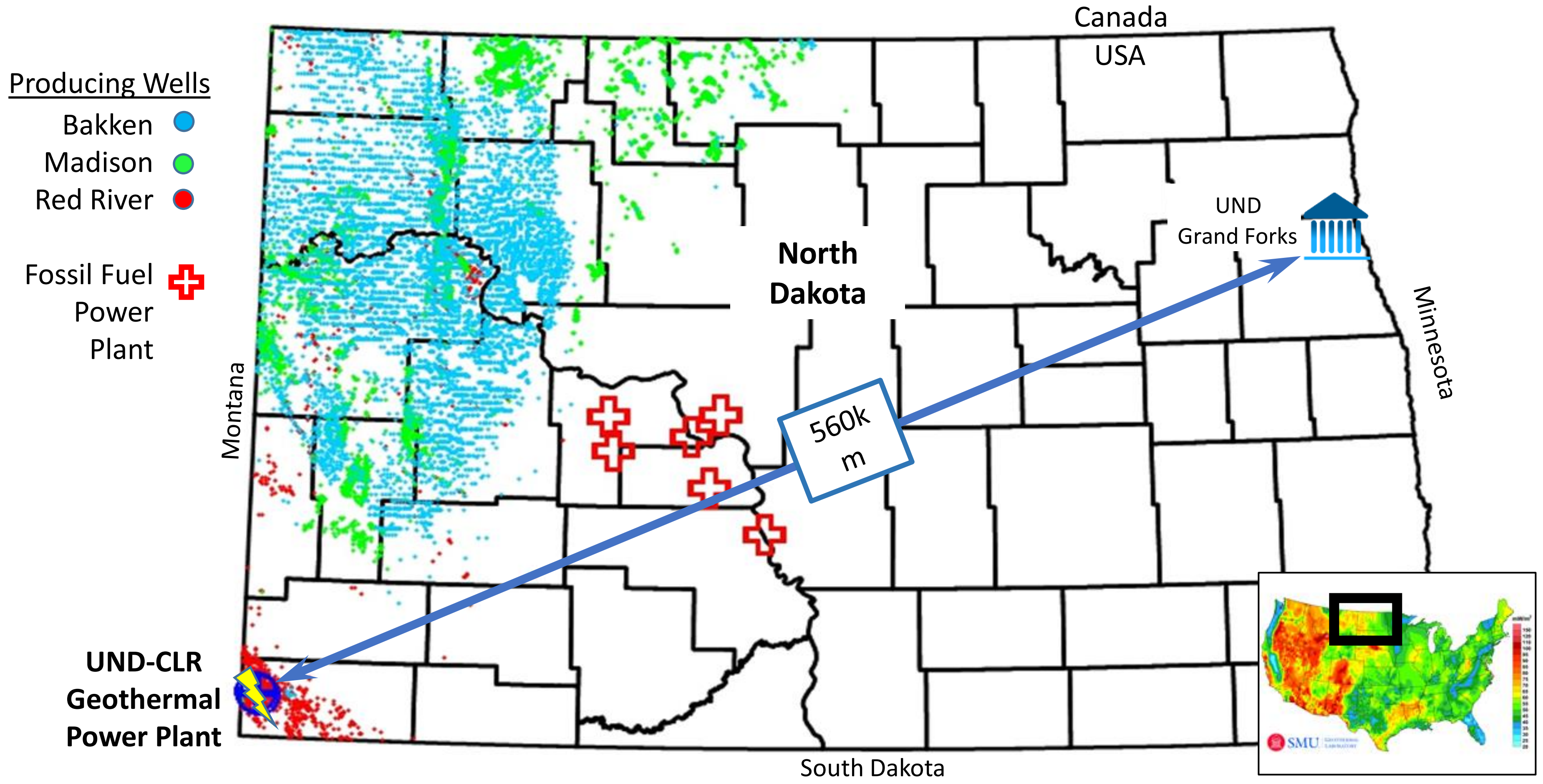
0

2 km

4 km



North Dakota Williston Basin



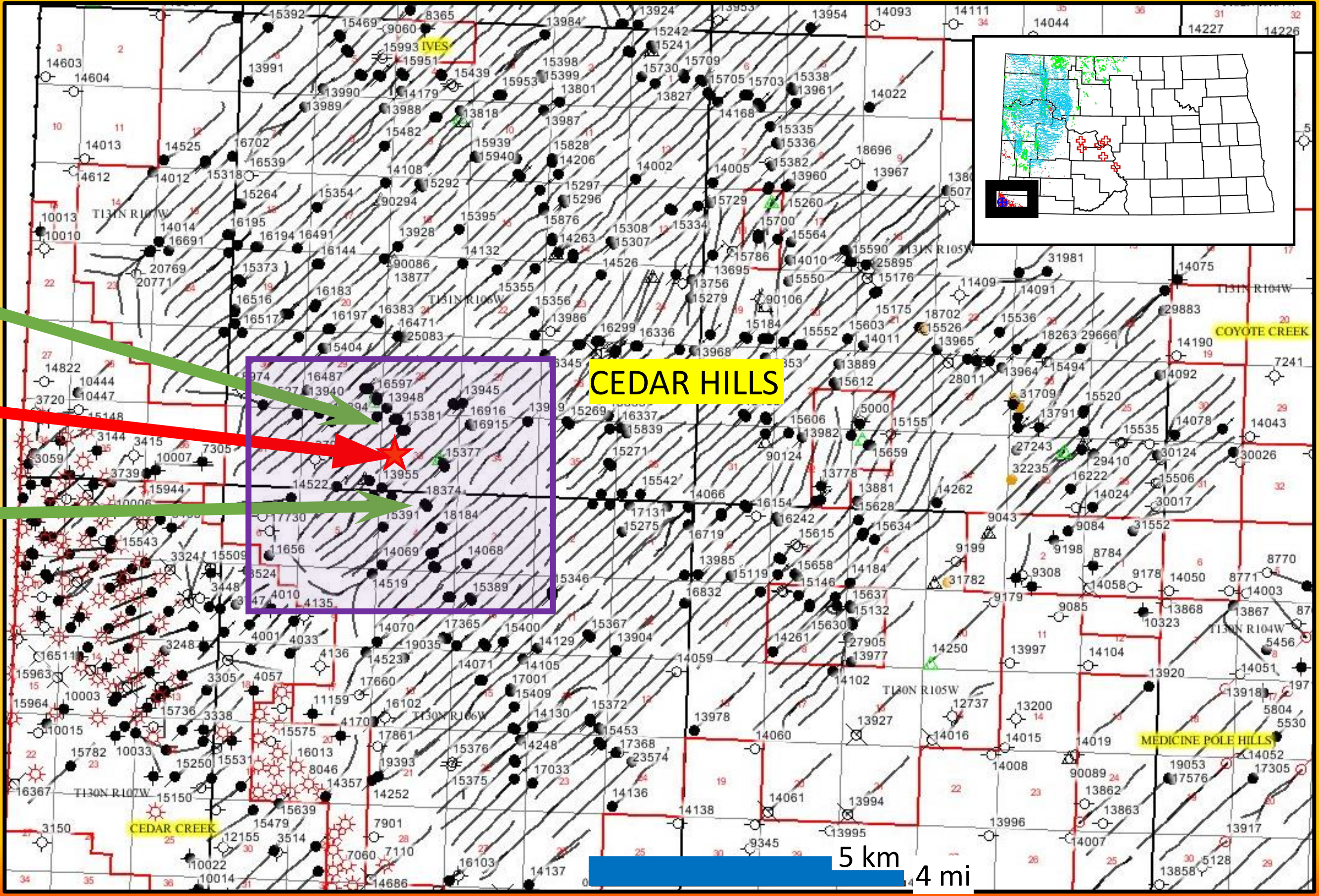
Cedar Hills Red River B Unit Location

- ● Oil well (surface location)
- ⁄ Lateral borehole

Davis 44-29 Water Supply Well

UND-CLR Geothermal Power Plant

Homestead 44-33 Water Supply Well



Wells oriented parallel to σ_1 to maximize flow to the production wells.

Cedar Hills Red River B Unit Wells

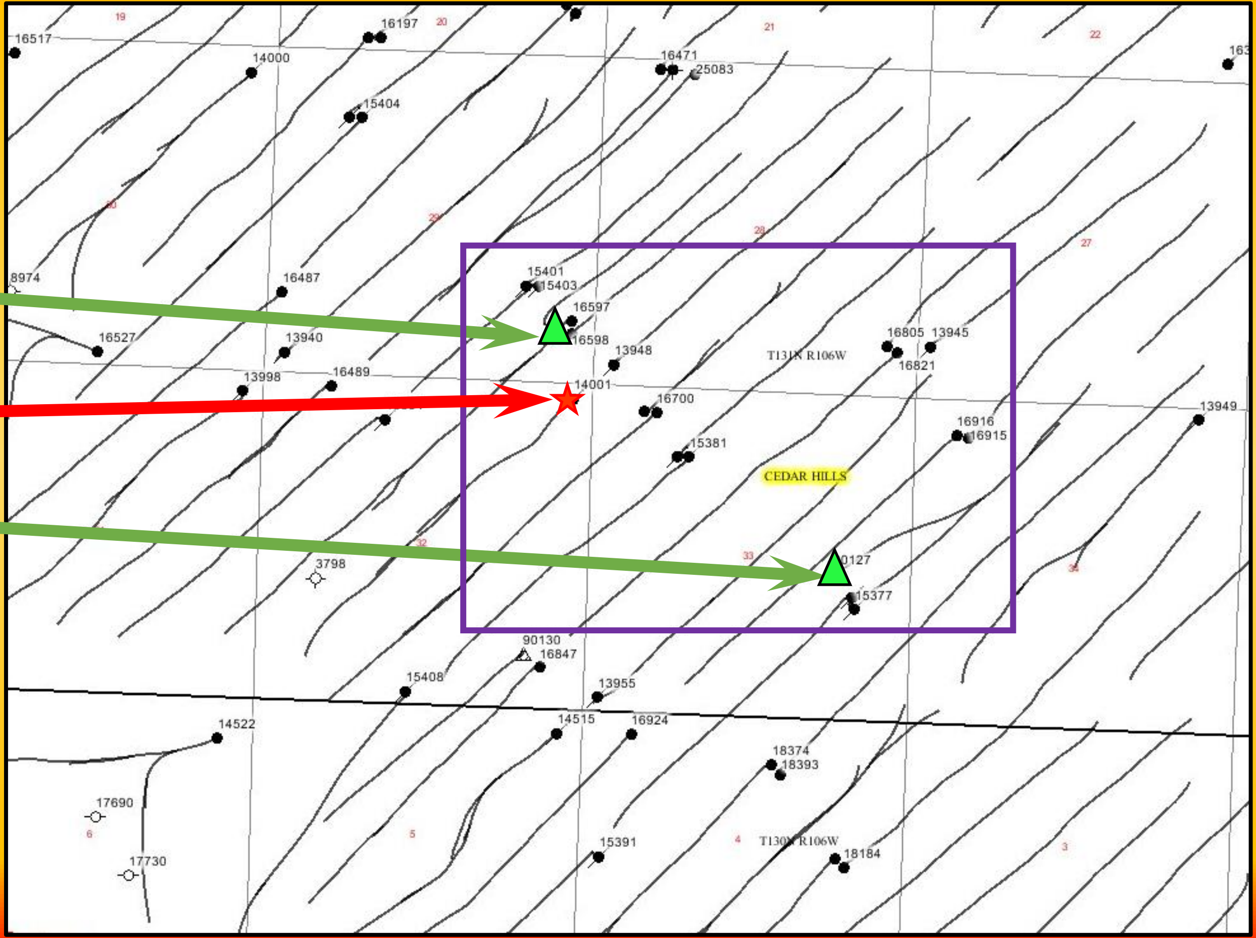
● Oil well (surface location)

/ Lateral borehole

Davis 44-29 Water Supply Well

UND-CLR Geothermal Power Plant

Homestead 44-33 Water Supply Well



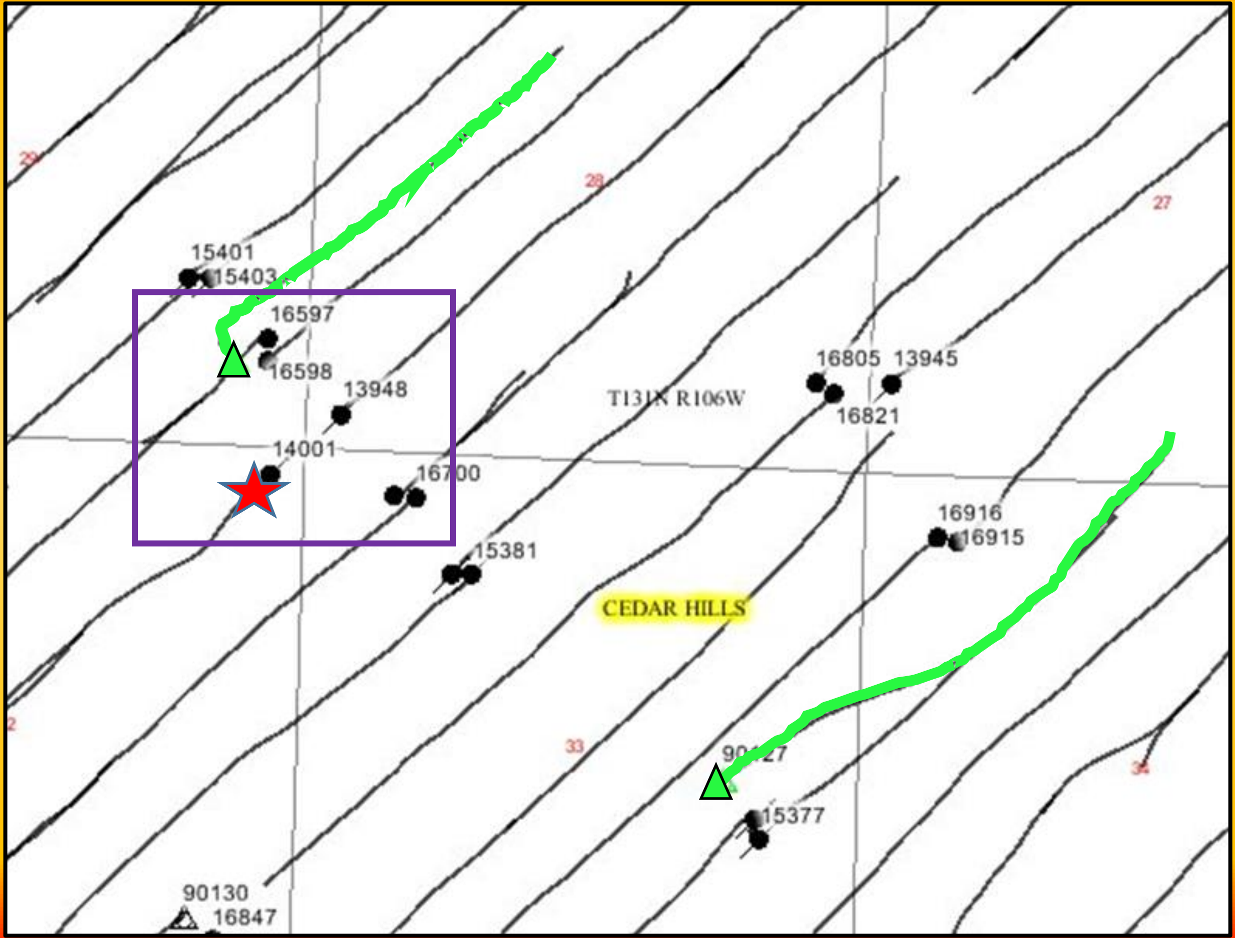
1 mile

1 km

Cedar Hills Red River B Unit Detail

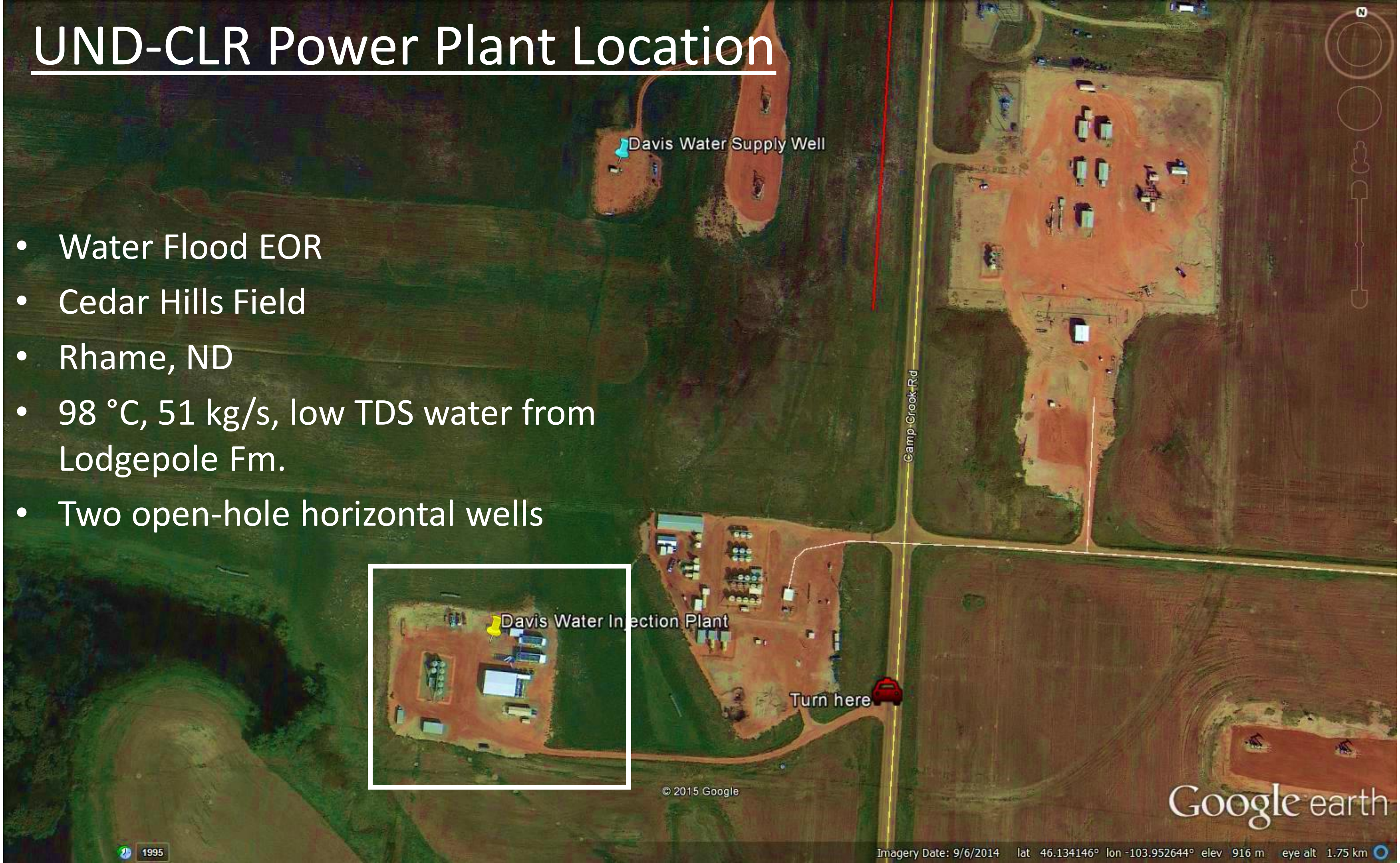
Davis and Homestead water supply wells were drilled into the Lodgepole Formation.

The other horizontal wells were drilled into the Red River Formation.

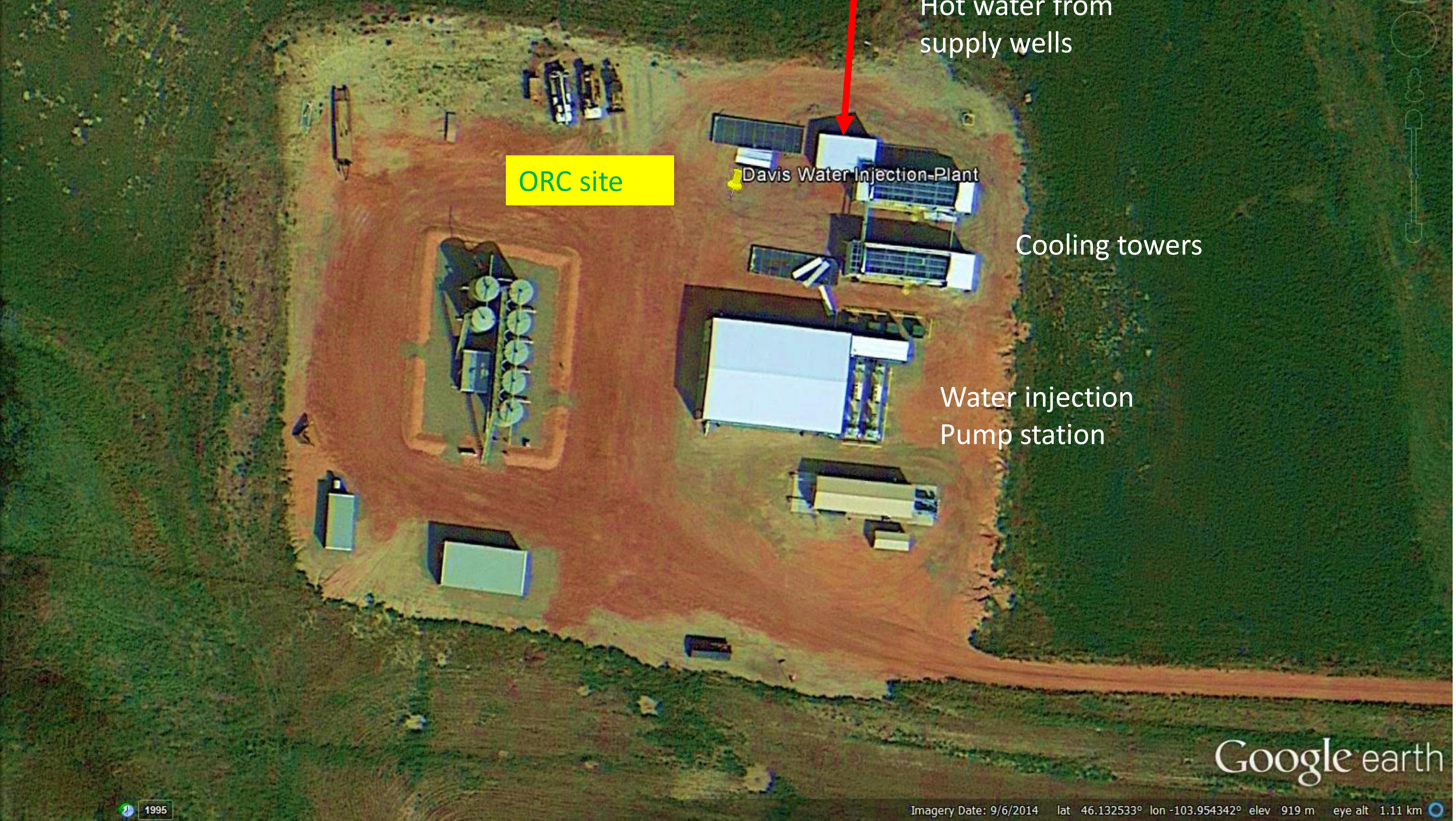


UND-CLR Power Plant Location

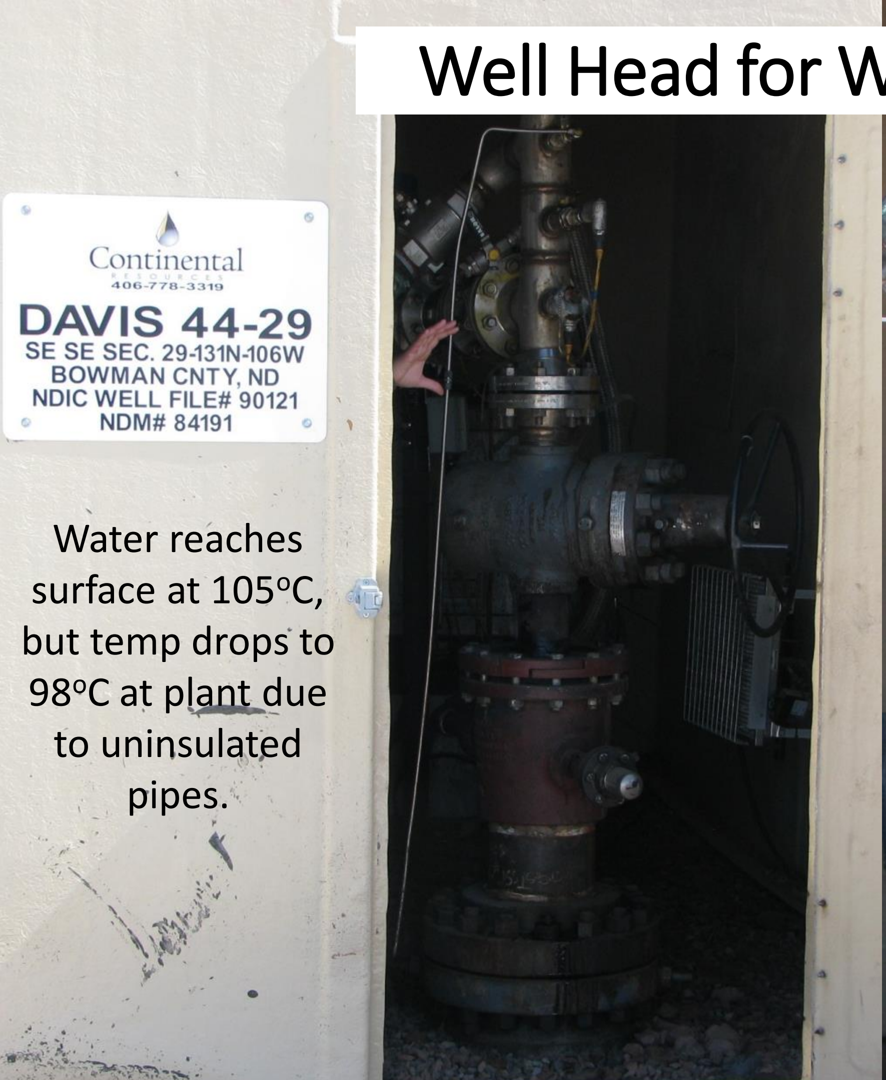
- Water Flood EOR
- Cedar Hills Field
- Rhame, ND
- 98 °C, 51 kg/s, low TDS water from Lodgepole Fm.
- Two open-hole horizontal wells



UND-CLR Power Plant Site

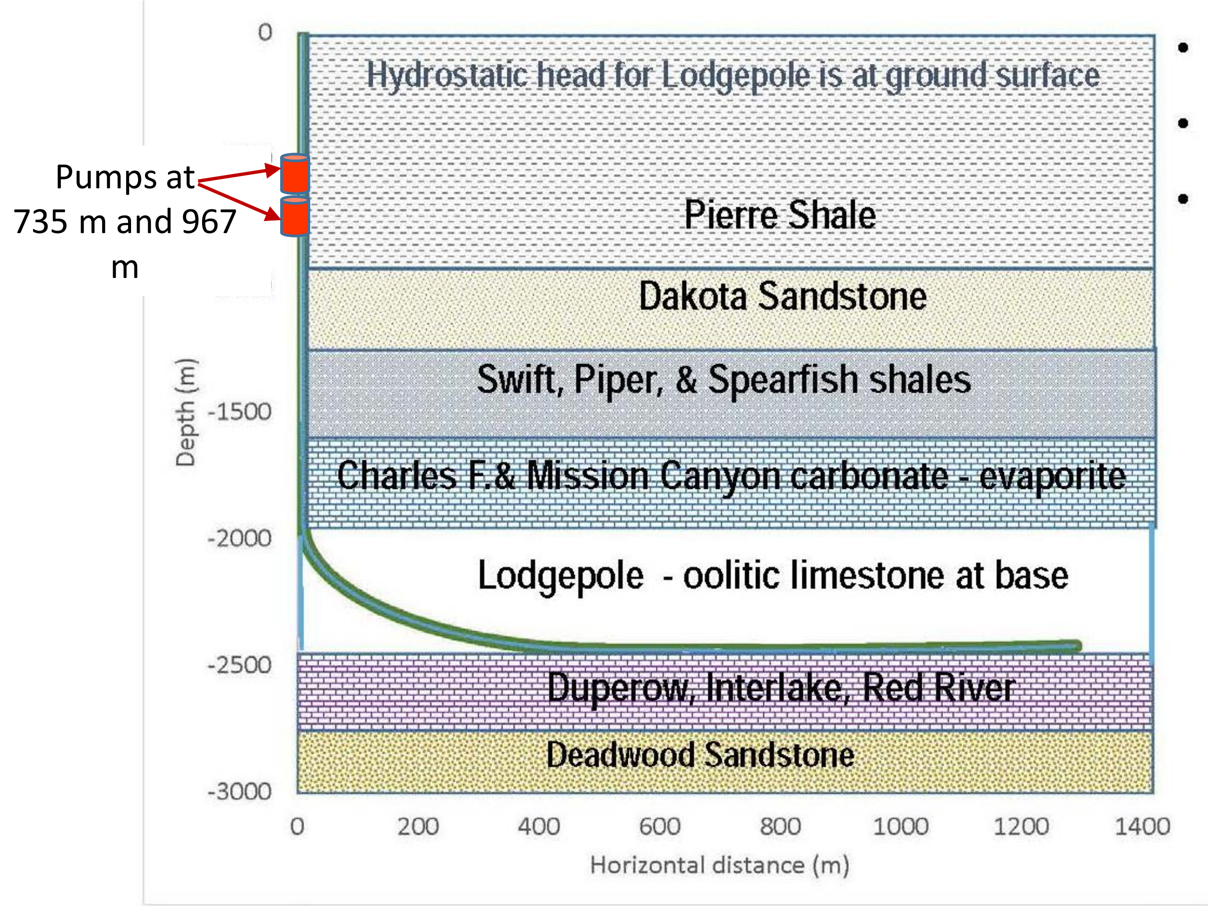


Well Head for Water Production Well



Water reaches surface at 105°C, but temp drops to 98°C at plant due to uninsulated pipes.

Water Supply Well Schematic - CLR Davis Water Injection Plant



- Two 125 kW ORC engines
- 98 °C water 875 gpm (55 l/s)
- 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.

Cedar Hills Field Water Supply Wells

Flow rates and water quality in Cedar Hills Waterflood

Name	Bradac	Hegge	Ostrow	Davis	Hegge	Homeste
ID2	34-27	1-36	14-35	44-32	43-36	
Well Type	WSW	WSW	WSW	SWI	WSW	WSW
gpd	273,000	420,000	273,000	630,000	1,224,000	594,000
gpm	190	292	190	438	850	413
TDS	12,920	2,702	8,618	NA	2,830	3,026
pH	5.87	7.78	7.33	NA	7.37	7.42
NaCl	11,973	1,137	7,184	NA	1,049	1,049
Litres/sec	12	18	12	28	54	26

CLR Water Injection Plant: Water Supply Lines

The UND-CLR Geothermal Power Plant takes water from the large manifold

CLR Water Injection Plant: Cooling Towers

Designed to remove heat from the water injection system.

The UND-CLR system is installed between the supply wells and the cooling towers and it is expected that one or both of these cooling towers could be taken offline

(This is mid-July!)

Access Energy (Calnetix) ORC Modules

November, 2015:
Two AE ORCs
delivered to CLR site

Installed ORCs

March, 2016:
Two AE ORCs connected to CLR water supply with air-cooled condensers installed

Project Stages

- 2006 – Initial inspiration after SMU Conference highlighted new ORC systems
- 2007 - Successful application to US Dept of Energy and State (North Dakota) resulted in grants to fund 10 year project
- Recruited Continental Resources (CLR) as partner (hot water and site). Later joined by Access Energy (Calnetix).
- November, 2015 Access Energy delivered two 125 kW ORCs
- **Purchase and installation of equipment for electric grid tie in**
- **February, 2016 CLR required a buried tank and water line to sump**
- March, 2016 All construction complete, system awaiting R245fa
- April 18, 2016 AE engineers arrive to charge ORCs with R245fa

"Houston, we have a problem……" (Apollo 13)

April 21, 2016

Team,

If I am relaying this correctly, the ORCs were shipped with fresh water in the cooling systems for the transformers. The cooler radiators have frozen and broken, and when the cooling plates in the transformers are inspected, they will probably be compromised too. It is also probable that the circulating pumps for the cooling system are also broken, will know more tomorrow.

Thanks,

Gary N. Johnson
Injection Superintendent

Working, finally!

April 24, 2016

Will,

The south unit was put on line this weekend, and shut down for the evening. They made one of the coolers work by stealing parts from the other one. It should be back on line today and was putting out 124 kW.

Gary N. Johnson
Injection Superintendent

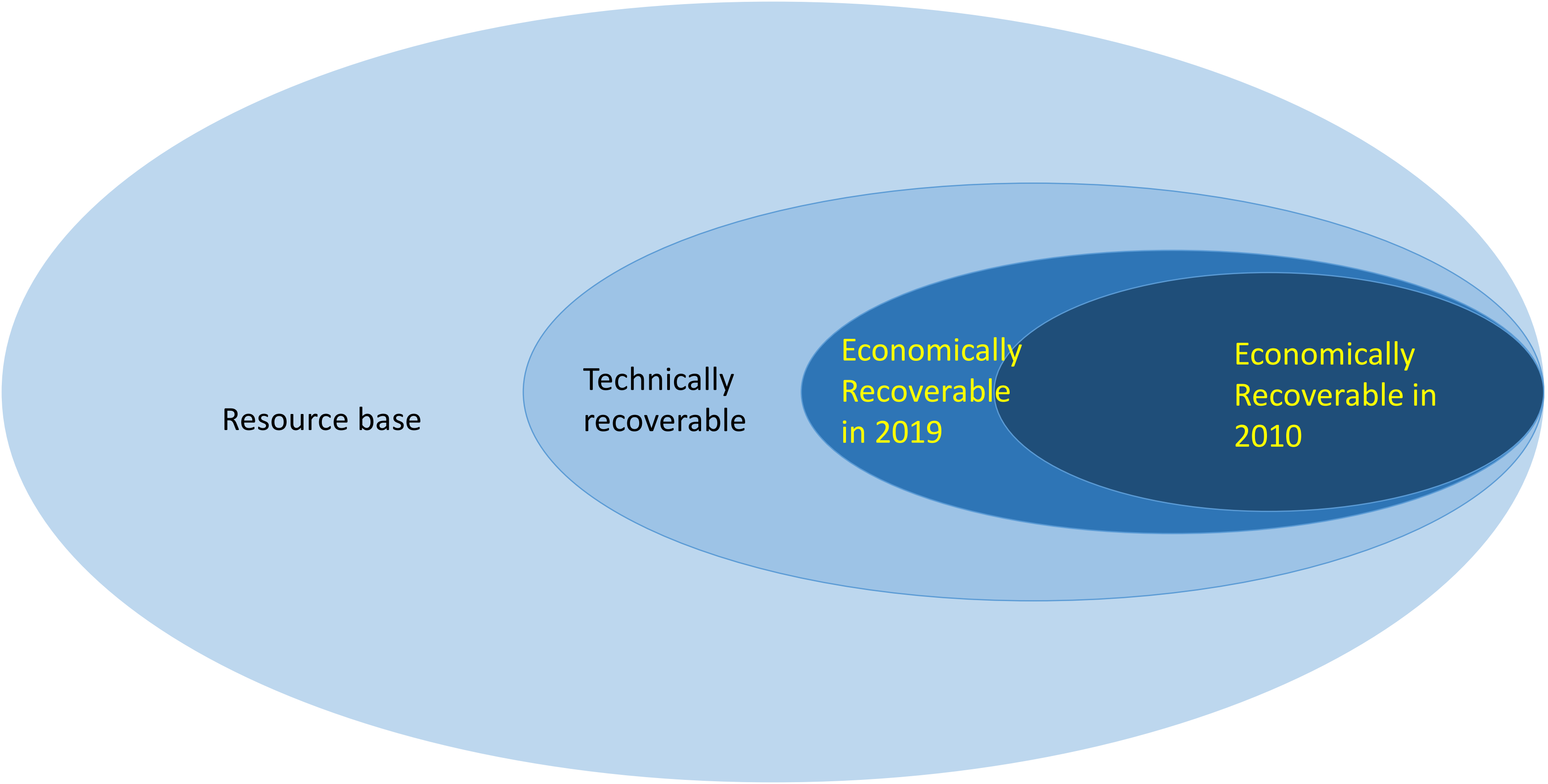
UND-CLR Geothermal Power Plant - Summary

- Water supply from two open-hole horizontal wells drilled into permeable limestone (Lodgepole Fm., lower member of Madison Group, Miss.)
- Well depths 2,300 m and 2,400 m
- Horizontal lengths 1,227 m and 802 m
- Hydrostatic head at ground surface
- Pumps set at 735 m and 967 m depth
- Water use in secondary oil recovery in Cedar Hills Red River B Unit
- CLR is operating two air-cooled heat exchangers to reduce water temperature for safe handling in the injection pumps

- **The resource:** 98 °C at 51 kg/s TDS 2,000 to 3,000 mg/l Continuous pumping since 2008
- **Power:** 250 kW from two 125 kW air-cooled Access Energy organic Rankine cycle engines on line April 25, 2016

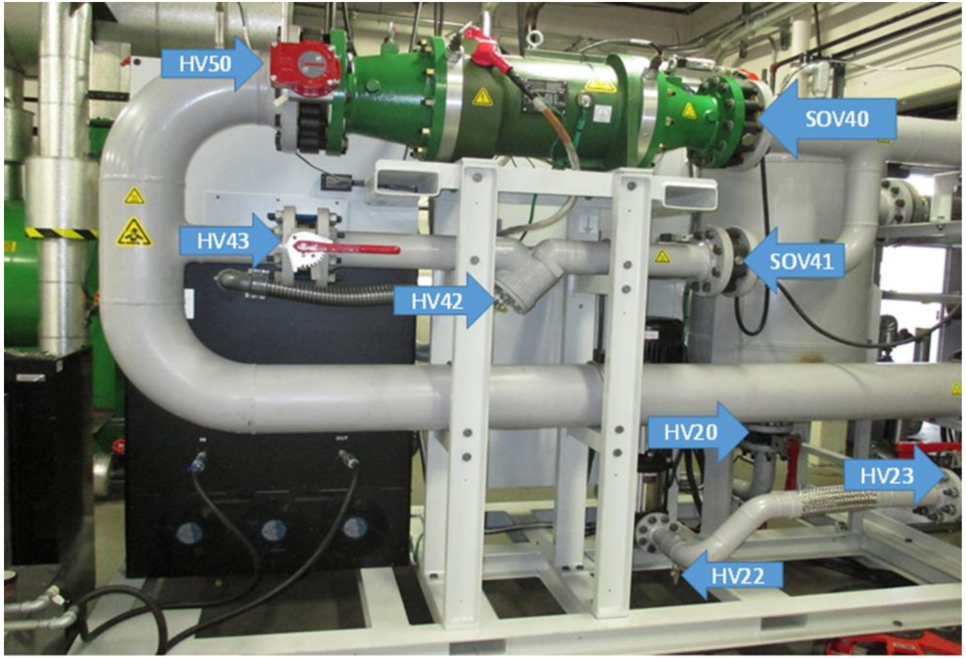
Looking toward the future

Advances in technology will improve economics



Access Energy XLT 125 kW Power Plant

- **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
  - *<u>Magnetic Bearings</u>*
  - 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



Valve location on XLT skid.

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

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

Climeon c3 Technology

C3 TECHNOLOGY

- ✓ *Vacuum based, 2,5 bar(a) nominal working pressure*
- ✓ Direct Contact Condenser
- ✓ Future proof working media with no GWP, non-toxic, low cost
- ✓ Efficiency above >50% of Carnot

CLIMEON HEAT POWER

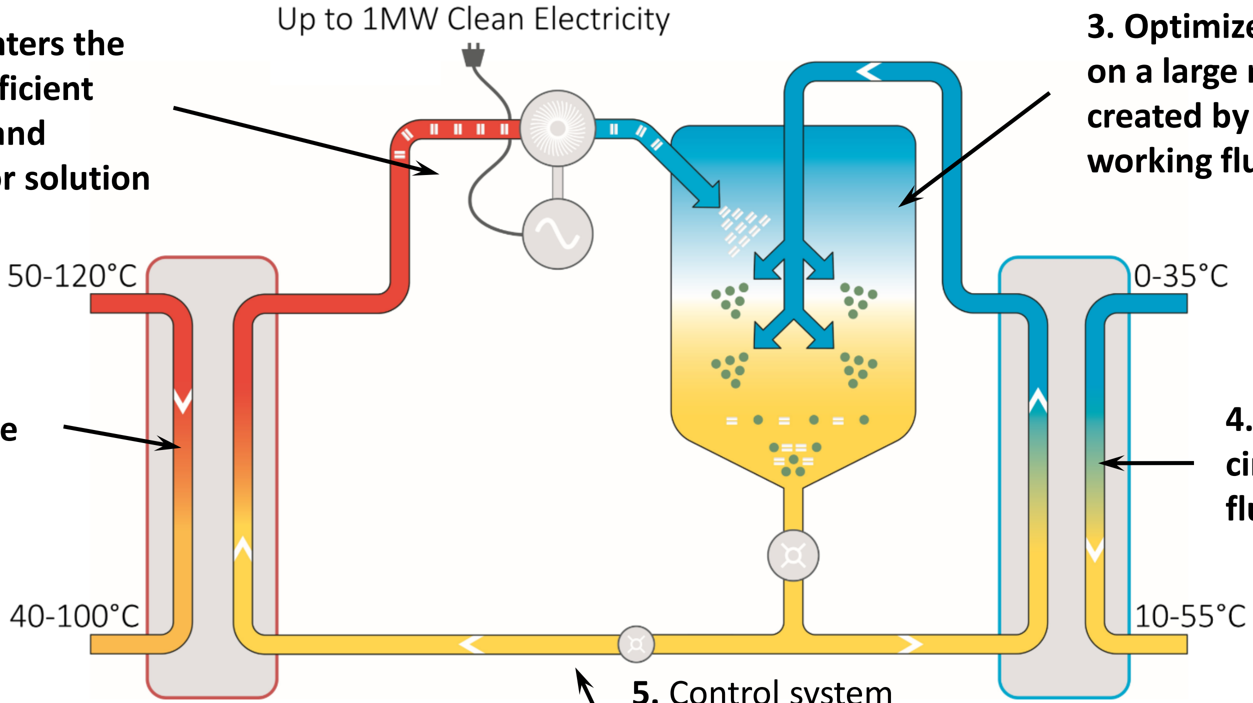
- ✓ 150kW modules
- ✓ Stackable enables 1,8MW$_{el}$ on 24m^2 (260ft^2) footprint
- ✓ Serial and parallel setup
- ✓ Plug & Play

>12 patents/applications and counting...

C3 Technology – Rankine Cycle

2. Gas enters the highly efficient turbine and generator solution

3. Optimized condensation on a large reaction surface created by spraying cold working fluid.



1. Optimized evaporation of the working fluid

4. Cooling of the circulating working fluid

5. Control system automatically adapts to variations in incoming temperatures

Modular and Flexible

- ✓ Enhanced efficiency
- ✓ Off-the-shelf
- ✓ Cost effective redundancy
- ✓ Adaptive Control System

Learnings and Recommendations

- **It worked!** (even if only briefly…) **and demonstrates the potential for successful crossover between petroleum and geothermal industries**
- Economics improving due to improved ORC efficiency
- Working with multiple stakeholders can lead to a variety of challenges
- Work with senior personnel at oil company partner and sign MOU to cover various contingencies
- Understand local electricity market – obtain a PPA before committing.
- Be prepared for delays

A great opportunity for distributed power

- 2,600 MW additional power needed to produce Bakken and Three Forks by 2032
- Existing power for ND-MT is from 6 coal or gas-fired power plants on Missouri River.
- Current supply for the boom is from diesel, propane & produced gas at 5 X grid power cost per kWh ~ 28 ¢/kWh
- The UND-CLR plant could generate power 1.97 x 10^6 kWh in year 1 at a cost of 6 ¢/kWh
- Co-production looks viable now and economics will improve
- More about future potential this afternoon!