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 $261,000
The North Dakota Department of Commerce $397,512
Basin Electric Cooperative $50,000

POWER PLAYS™

GEOTHERMAL ENERGY IN OIL AND GAS FIELDS

Conference & Workshop | April 25-26, 2016 | SMU Campus, Dallas, TX

Outline

- Steps to geothermal power in oil & gas settings
- The UND-CLR Geothermal Power Plant
- Stages in the UND-CLR project
- Humor?
- The site and the Access Energy ORC engine
- Development opportunities

Steps to geothermal power in oil and gas settings

- Curtice and Dalrymple

2004, World Oil:

  - Produced water from oil and gas wells in 7 contiguous southern states could generate between 986 MW (210 ^{o}F) and 5,334 MW (400 ^{o}F)

- Mckenna, Blackwell, Moyes, and Patterson

2005, Oil & Gas Journal:

  - Spatially integrated produced water from oil and gas wells in Texas could produce 25,000 MW. "…~30 wells/field to generate a useful flow rate." 1,000 gpm. "Collecting and passing the fluid… "

Steps to geothermal power in oil and gas settings

- Brasz and Holdmann

2005, GRC Transactions:

Development of ORC power plants that can use moderate-temperature geothermal resources – reverse engineering of Carrier air conditioning systems - Pratt & Whitney PureCycle 200

- The SMU geothermal laboratory conferences on geothermal power in oil and gas settings in: 2006, 2007, 2008, 2009, 2013, 2015

http://www.smu.edu/Dedman/Academics/Programs/GeothermalLab/Conference/PastPresentations

The low-to-intermediate temperature geothermal resource is huge

- Estimated energy in major aquifers in sedimentary basins

100,000 ExaJoules

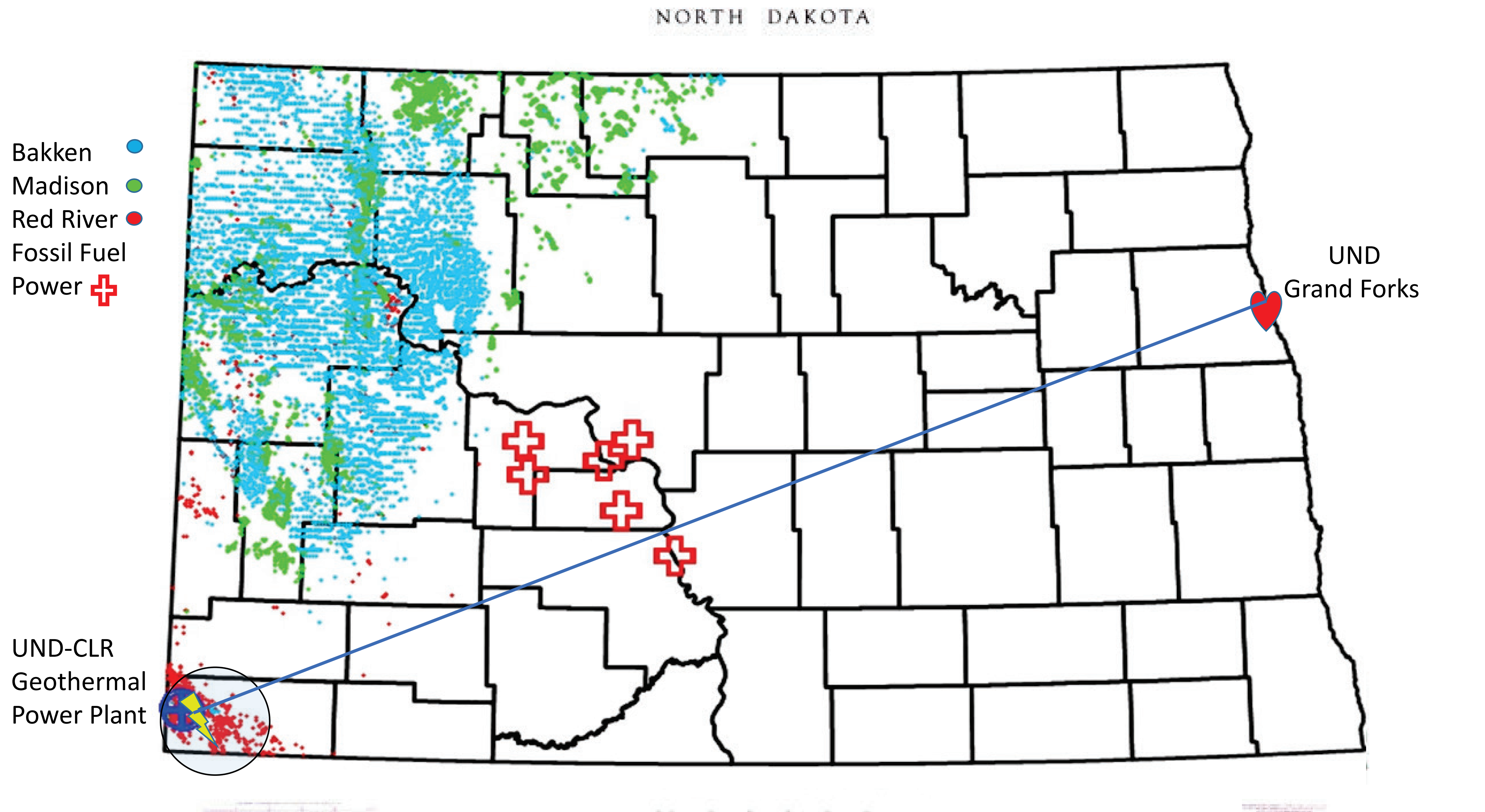
Includes 1 or 2 formations per basin

(Future of Geothermal Energy) (2006)

- Estimated energy in all oil and water producing formations in sedimentary basins

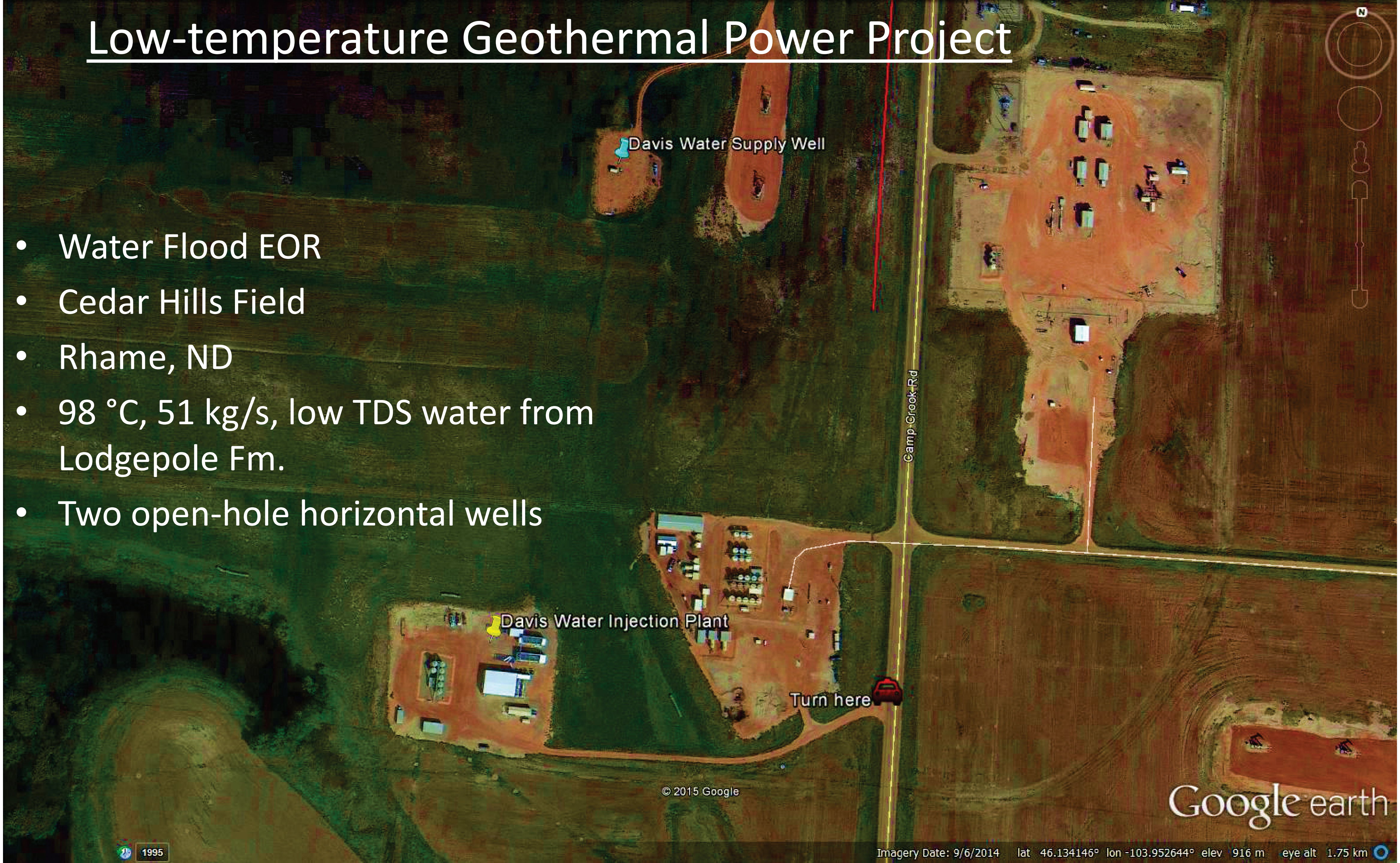
400,000 ExaJoules

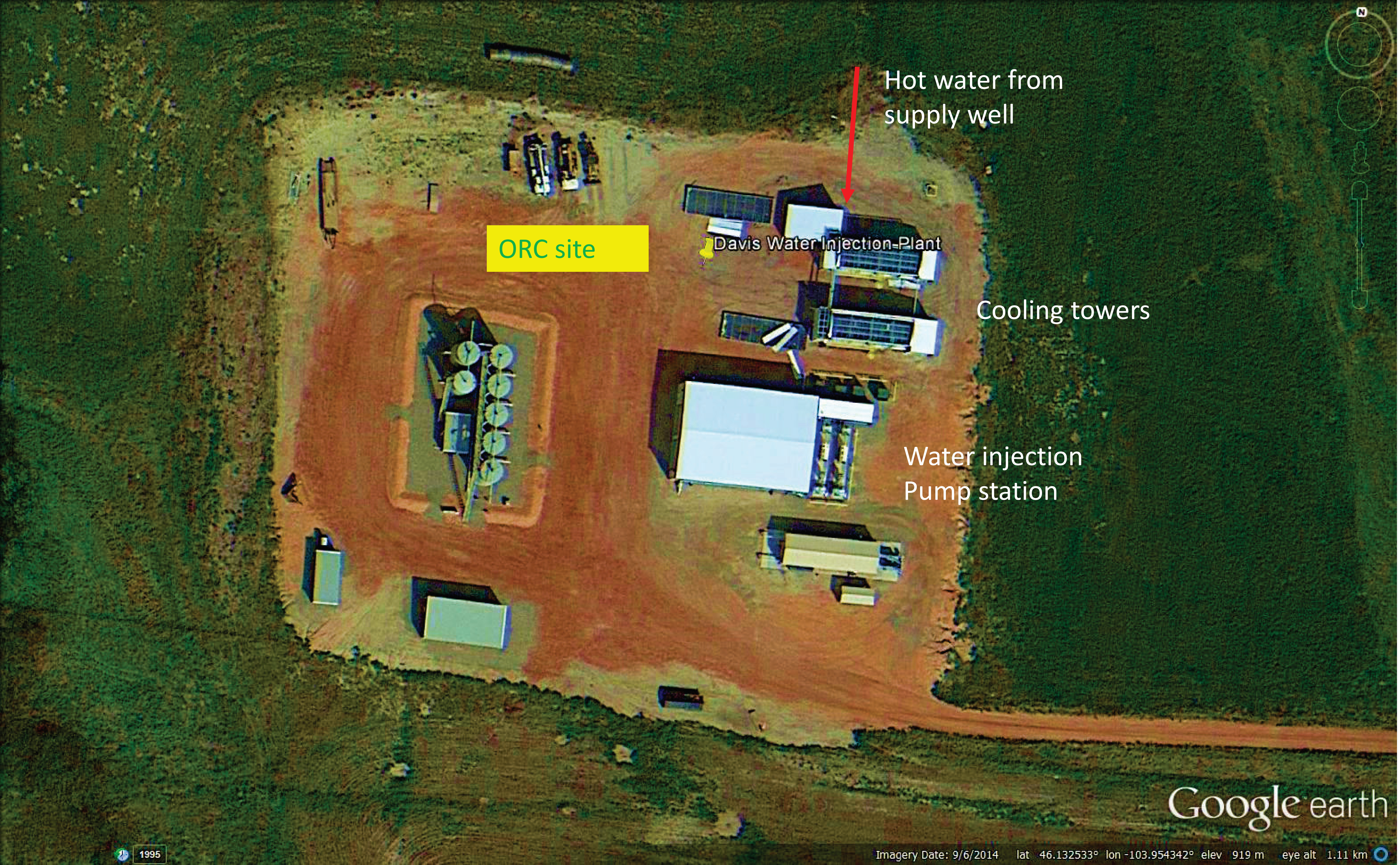
Includes all producing formations


NORTH DAKOTA
Bakken
Madison
Red River
Fossil Fuel
Power
UND
Grand Forks
UND-CLR
Geothermal
Power Plant

Low-temperature Geothermal Power Project

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

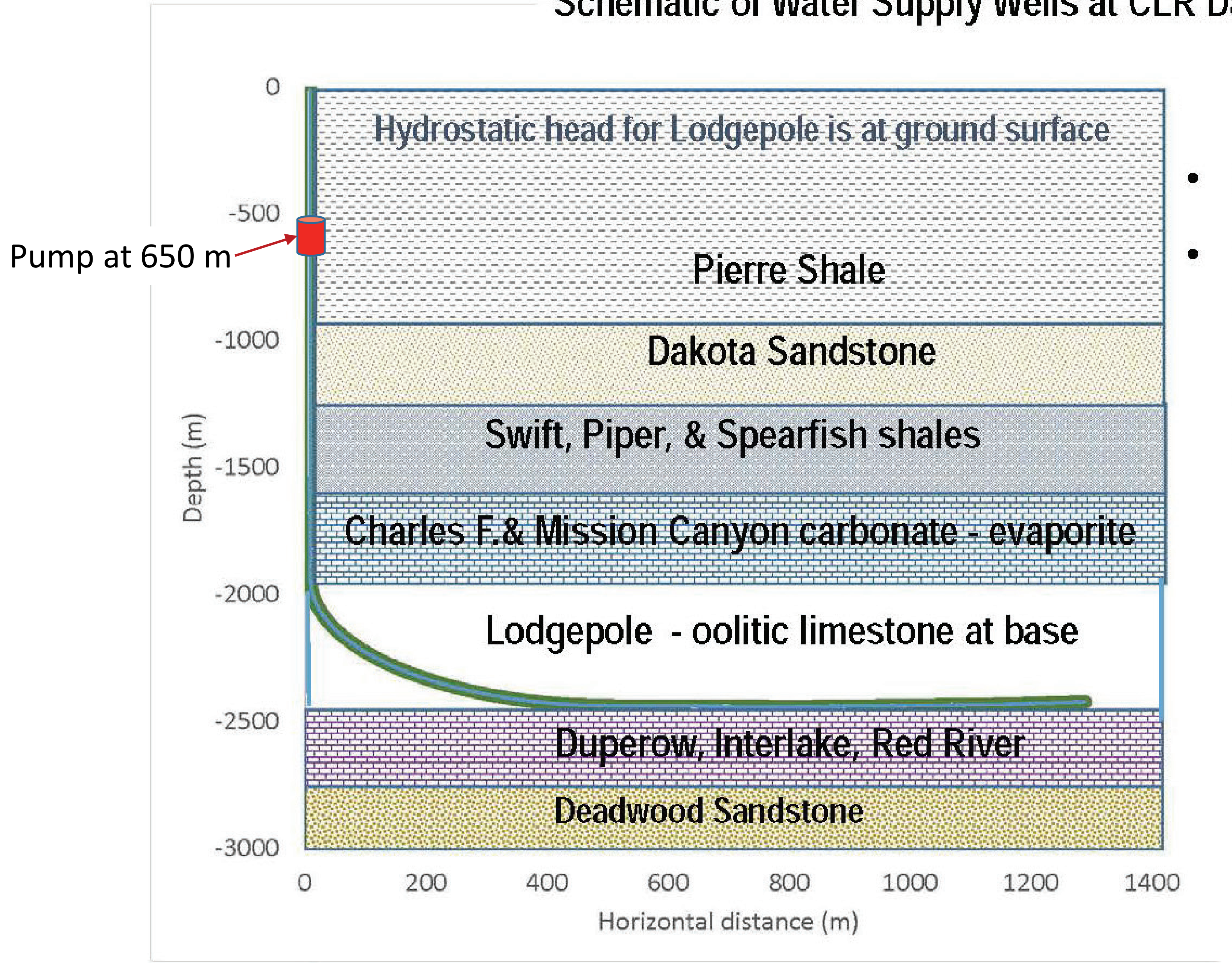



Hot water from
supply well
ORC site
Davis Water Injection Plant
Cooling towers
Water injection
Pump station
Google earth
1995
Imagery Date: 9/6/2014 lat 46.132533° lon -103.954342° elev 919 m eye alt 1.11 km

UND-CLR Geothermal Power Plant

- Two open-hole horizontal wells drilled into a permeable limestone
- Well depths 2,300 m and 2,400 m
- Horizontal lengths 1,290 m and 860 m
- Hydrostatic head at ground surface
- Pumps set at 650 m depth
- 98 °C at 51 kg/s TDS <3,000 Continuous pumping since 2008
- 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

Schematic of Water Supply Wells at CLR Davis Water Injection Plant



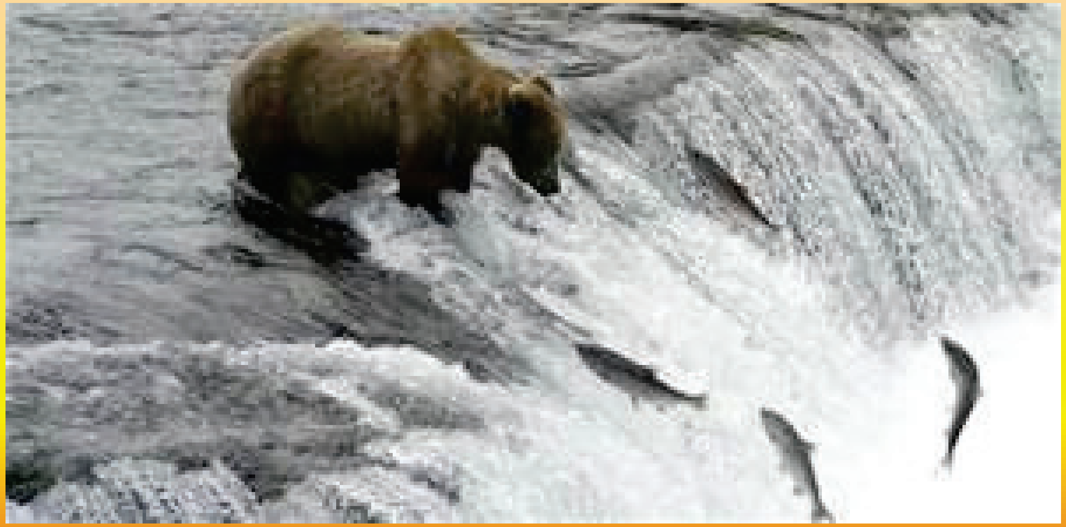
- 98 °C water 875 gpm
- Two 8.75” open-hole drilled horizontally 1.29 km and 0.85 km in the Madison Fm. at vertical depths of 2.3 km and 2.4 km.

Project Stages

- SMU Conference –UTC ORC & Future of Geothermal Energy
- DOE – GTO Funding Opportunity Announcements
- Assembled team – Energy engineer, electrical power engineer, oil industry partner, developer as partner for 50% cost-share
- **No PPA possible due to exclusive contract CLR & SEC – lost developer**
- Teamed with Calnetix (Access Energy) for ORCs – two problems solved

Project Stages

- **Contract with CLR and UND clause on liability – UND cannot accept**
- Meeting at CLR headquarters – Access Energy became contractor
- **Access Energy frightened by potential liability > $10 million**
- Buy Insurance - Problem solved



Project Stages

- Site preparation and installation estimate $20,000 – budgeted $30,000
- Bakken & Three Forks oil boom (7 bn bbl recoverable oil)
- **Oil field contractor's costs rocketed and only bid was $285,410**
- North Dakota Renewable Energy Council provided $261,000
- Basin Electric Cooperative contributed $50,000

November, 2015
Two AE ORCs delivered to CLR site

March, 2016
Two AE ORCs with cooling systems connected to CLR water supply

Project Stages

- 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

Project Stages

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

Jeff Foxworthy could do a lot with this

Project Stages

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.

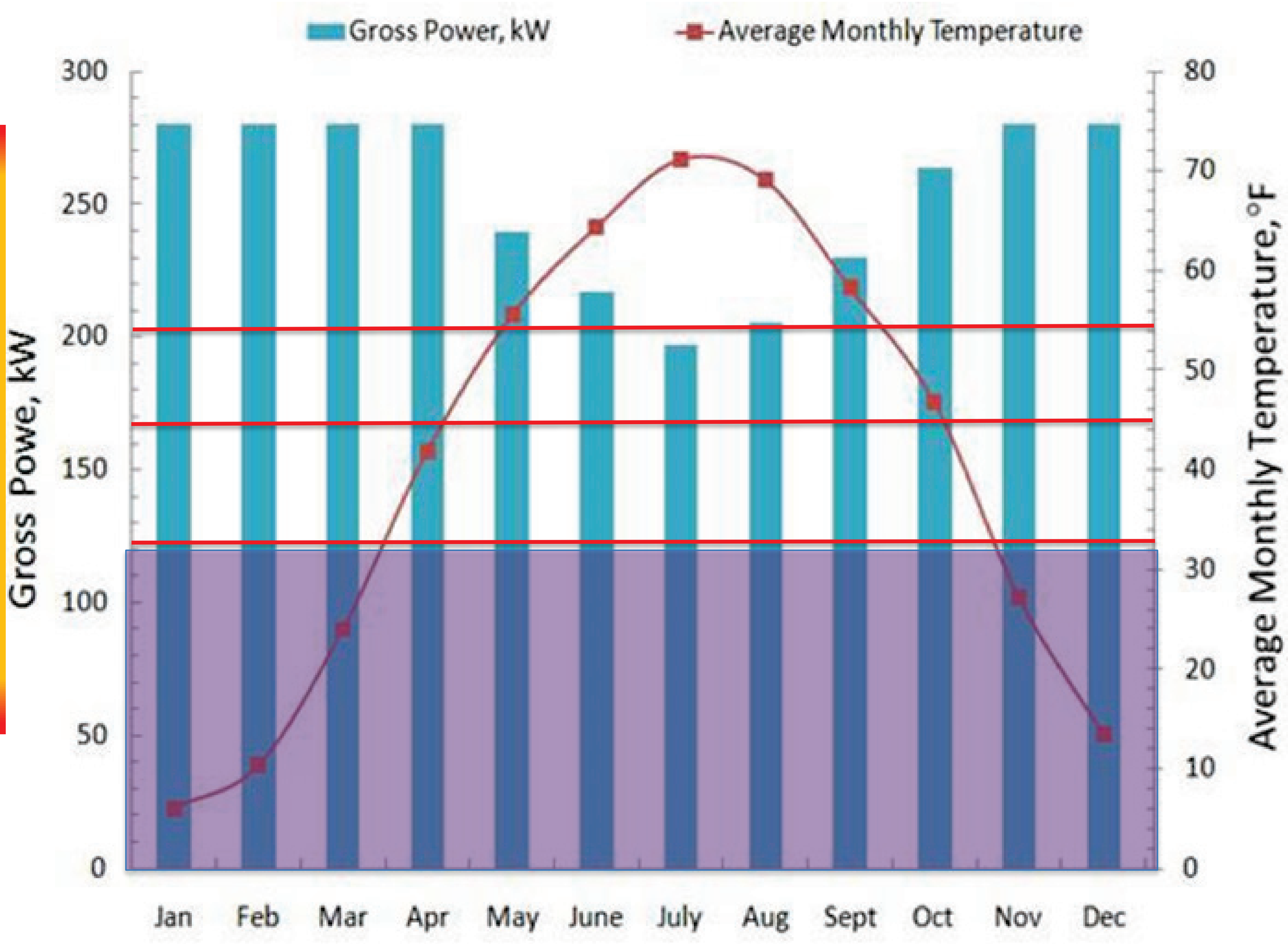
Gary N. Johnson

Injection Superintendent

Seasonal Power estimates for UND-CLR site

Max T 107 °F 7/23/2007
Min T -32 °F 1/30/1996

LDMx T -18 °F 1/10/1997



Company	kW output	Total Cost	Cost per kWh
Ormat	350	$1,610,000	$5,367
Pratt & Whitney	430	$1,175,000	$4,423
Green Machine	235	$1,275,655	$6,679
Recurrent Engineering	750	$2,551,500	$3,076
Deluge	1750	$,4,575,000	$6,679
Calnetix	550	$1,475,000	$3,000

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

CLR water production wells Bowman County, ND

Total water production 1,950 gpm

Name	Bradac	Hegge	Ostrow	Davis	Hegge
ID2	34-27	1-36	14-35	44-32	43-36
Well Type	WSW	WSW	WSW	SWI	WSW
Section	27	36	35	32	36
TWP	T132N	T132N	T132N	T131N	T132N
RANGE	R107W	R106W	R107W	R106W	R107W
gpd	273,000	420,000	273,000	630,000	1,224,000
gpm	190	292	190	438	850
TDS	12,920	2,702	8,618	NA	2,830
pH	5.87	7.78	7.33	NA	7.37
NaCl	11,973	1,137	7,184	NA	1,049
Ca	3,492	270	436	NA	262
Mg	222	18	89	NA	31
Na	705	607	2,600	NA	607
Fe	10.7	0.1	3.1	NA	0.2
Cr	0	0	0	NA	0
Ba	0.6	0	0	NA	0
K	101	91	205	NA	88
Chloride	7,261	19.5	4,356	NA	636
Carbonate	0	0	0	NA	0
Bicarb.	439	220	268	NA	207
Sulfate	688	807	660	NA	999
Nitrate	0	0	0	NA	0

CLR Cooling towers viewed from ORC location

The towers cool the water prior to injection to protect instruments, seals, and equipment in injection line

CLR Injection pumps

Water flood pressurizes the Red River (Ordovician) for oil production

Hot water lines from Davis and Hegge water supply wells entering CLR cooling tower

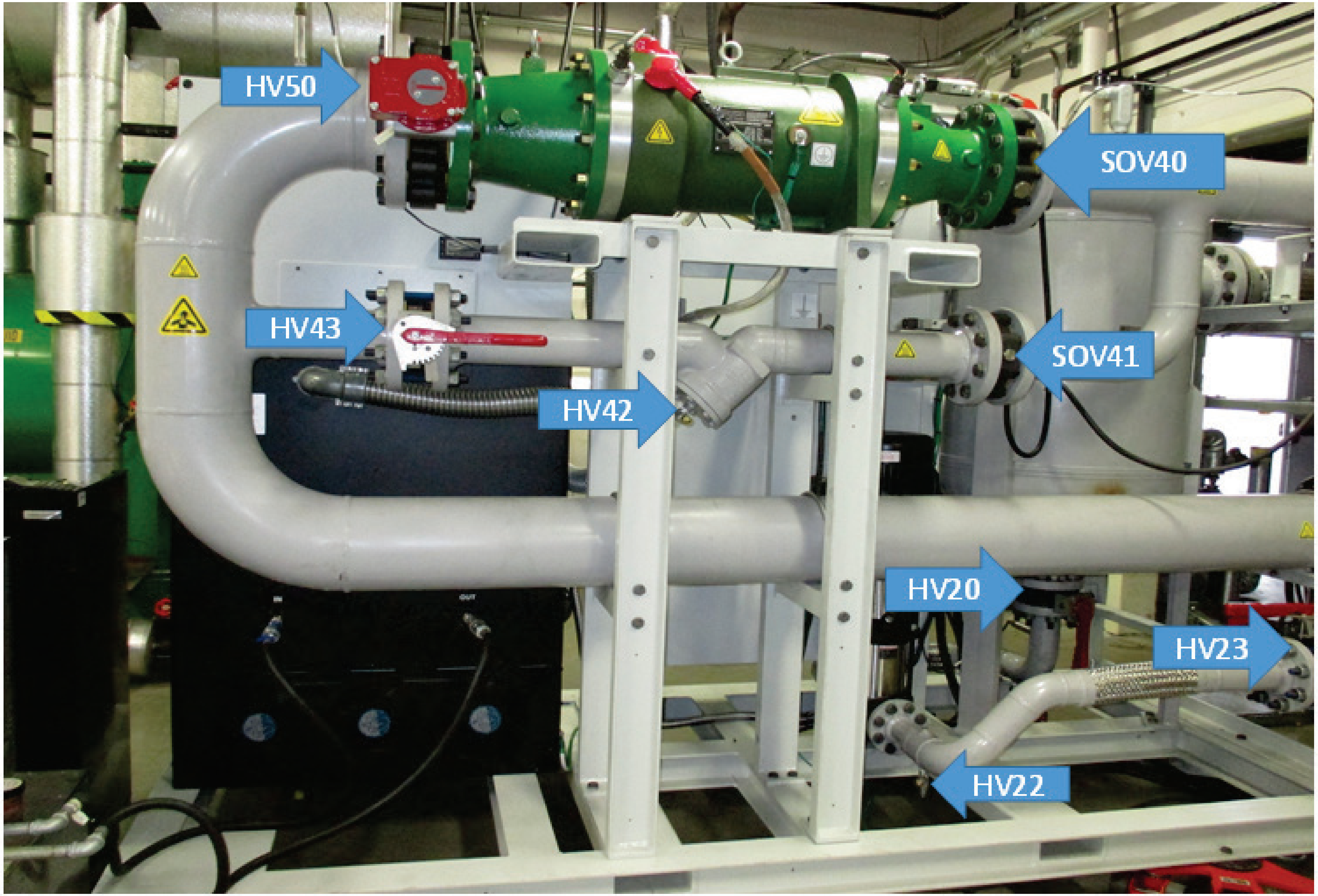
We take the water from this manifold to the AE ORCs

AE ORCs connected to water supply lines

AE ORCs installed and ready for startup

Annotated photo of inside south unit on site

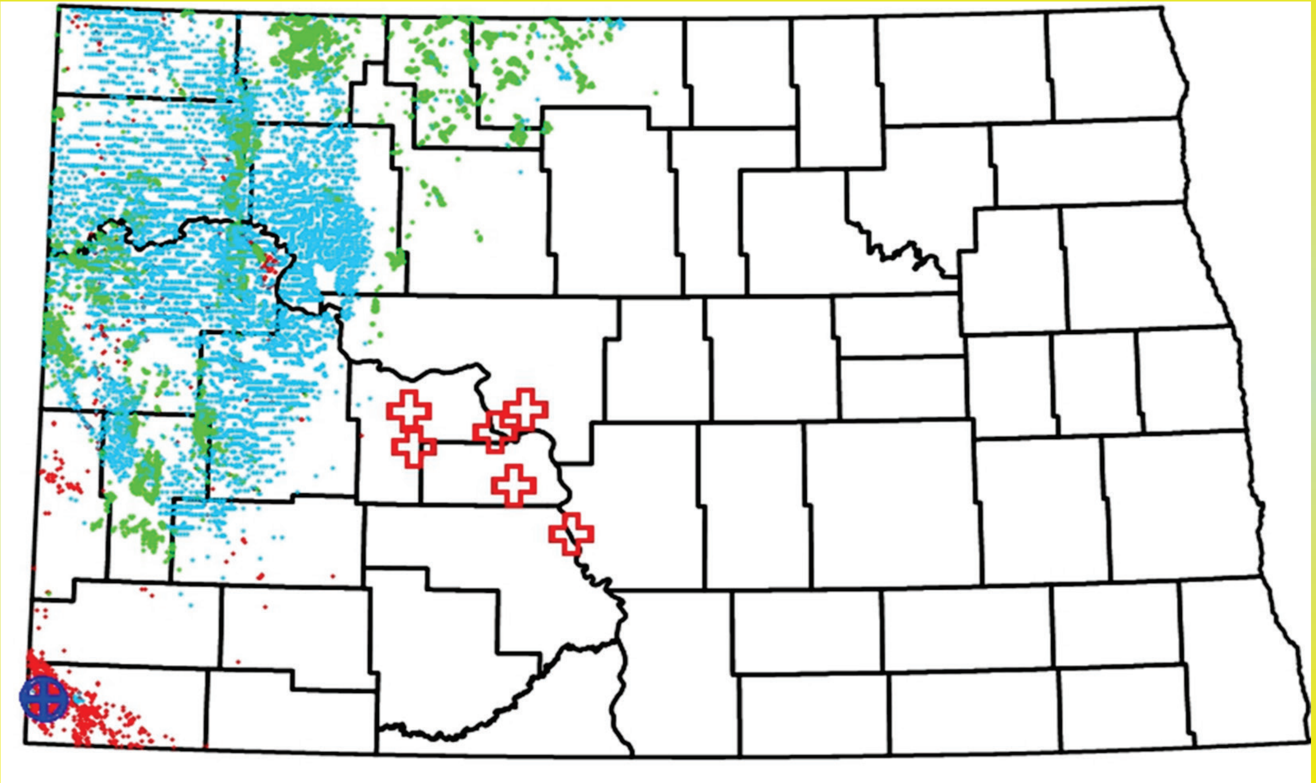
One moving part
Magnetic bearings
Magnets in turbine blades
Efficiency 2X most ORCs

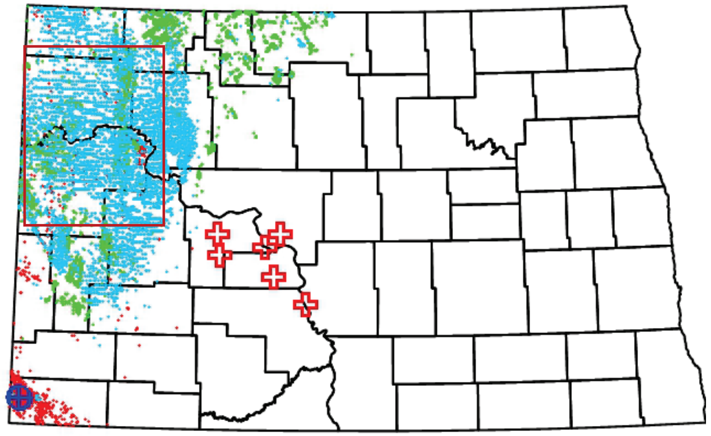


Valve location on XLT skid.

Opportunities for Development

- 2,600 MW additional power needed to produce Bakken and Three Forks by 2032
- Existing power for ND-MT is from 6 coal-fired power plants on Missouri River.
- Current supply for the boom is from diesel, propane & produced gas at 5 X grid power cost



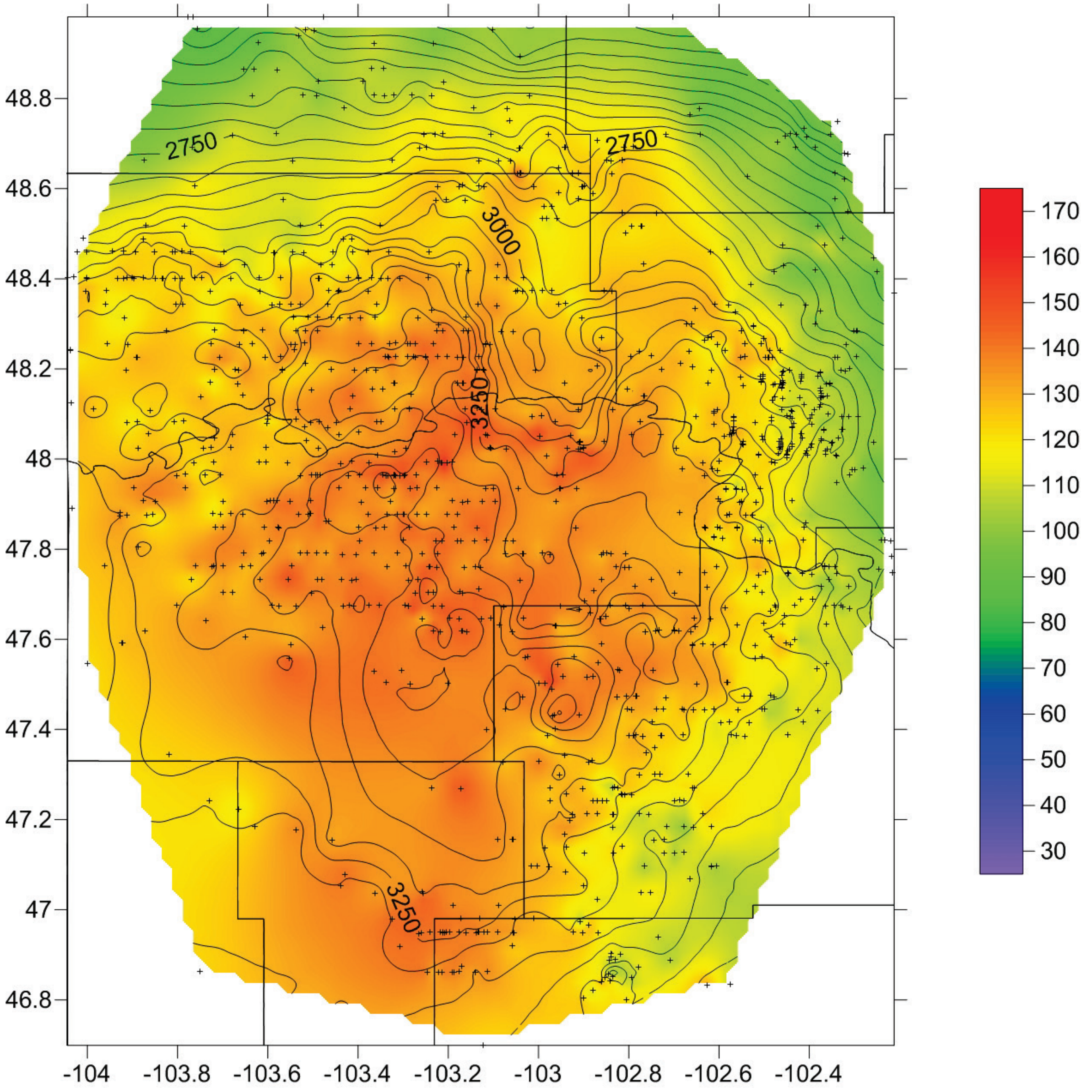


Bakken formation

Devonian-Mississippian Oil & Gas

Contours are depth to top (m)

Colors are temperature (°C)

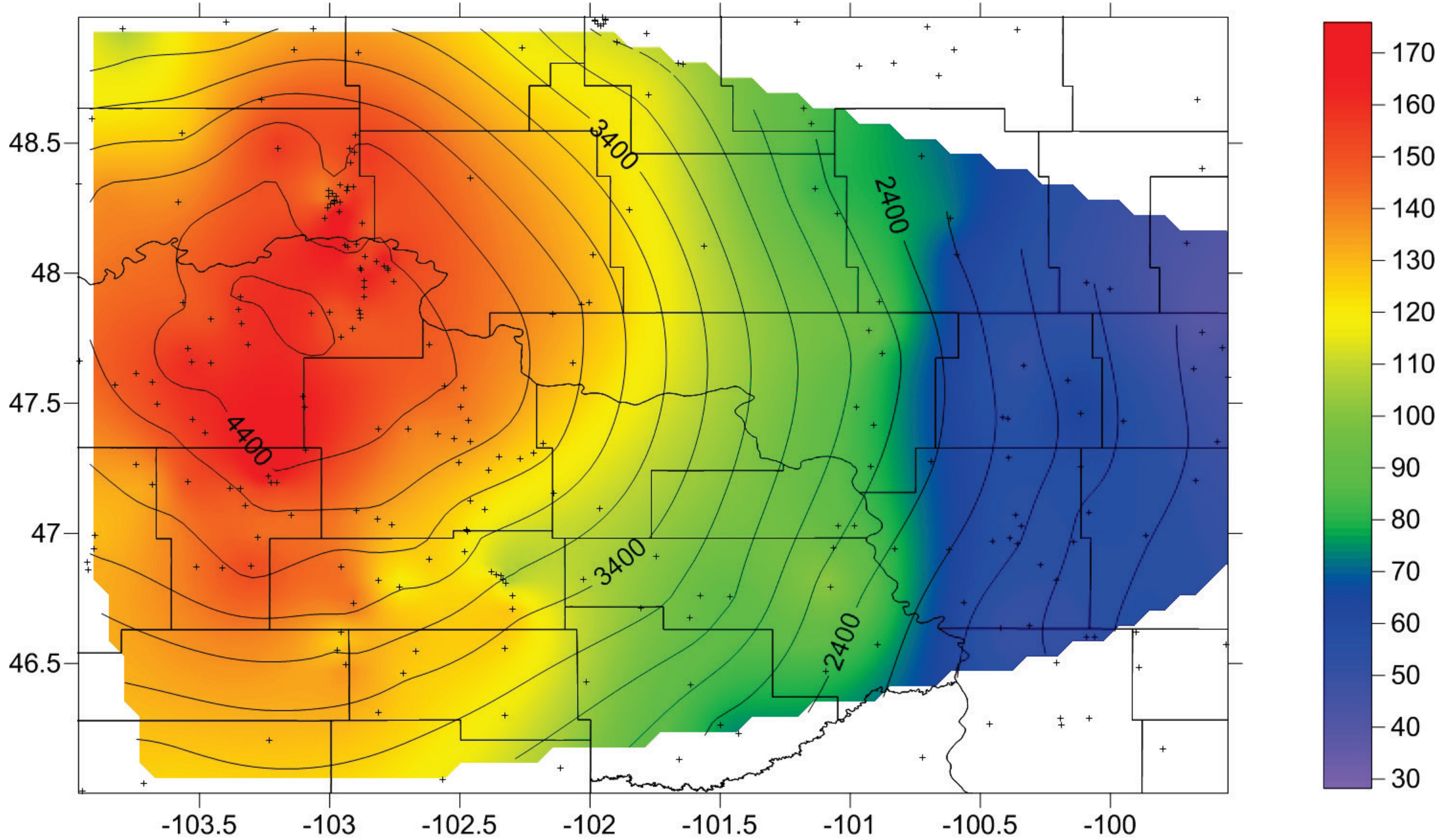


Deadwood formation

Cambrian – limestone, dolomite, shale, sandstone, Oil & gas

Max thickness 305 m

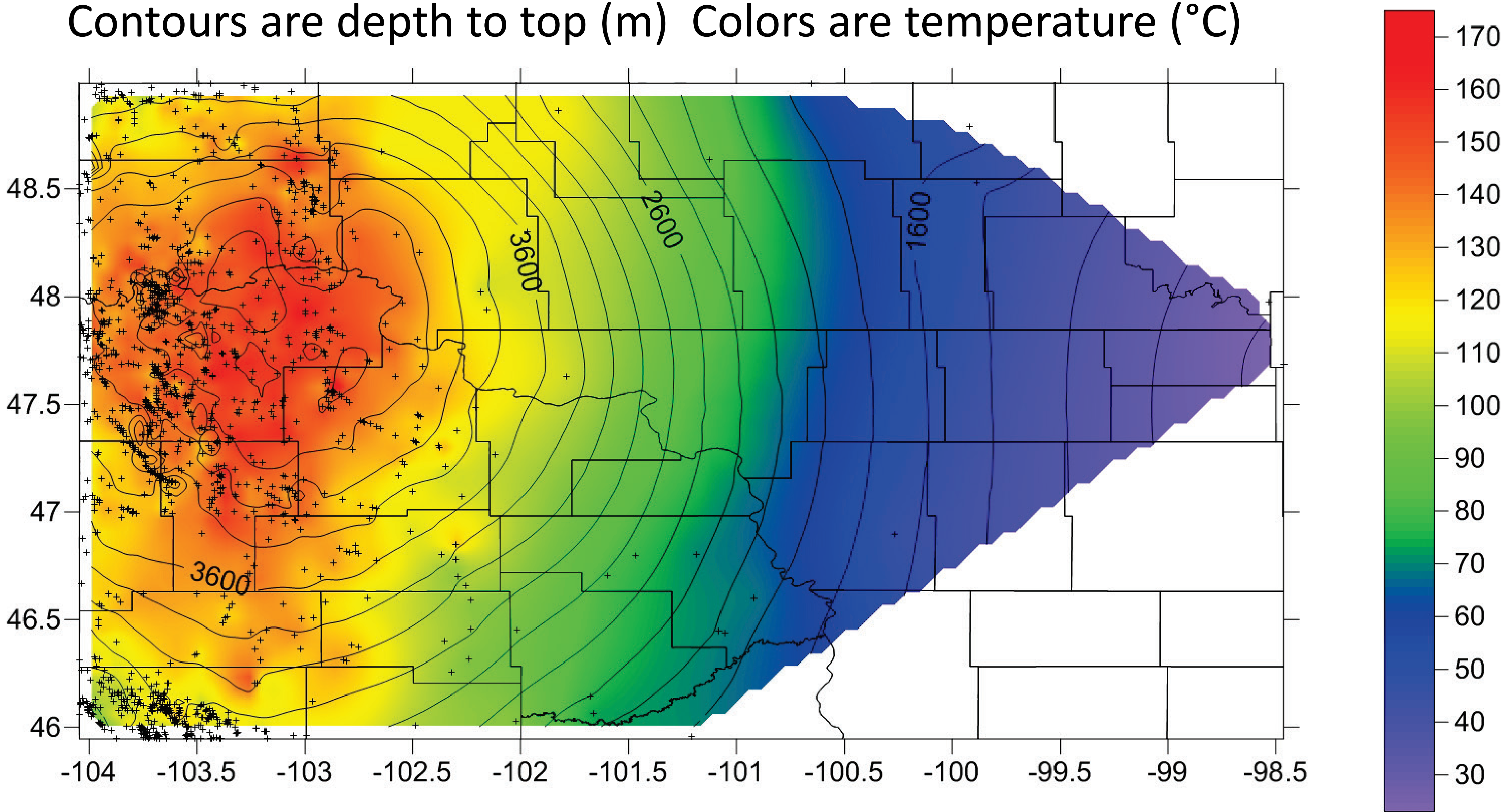
Contours are depth to top (m) Colors are temperature (°C)



Red River formation

Ordovician - limestone Oil & gas Max thickness 213 m

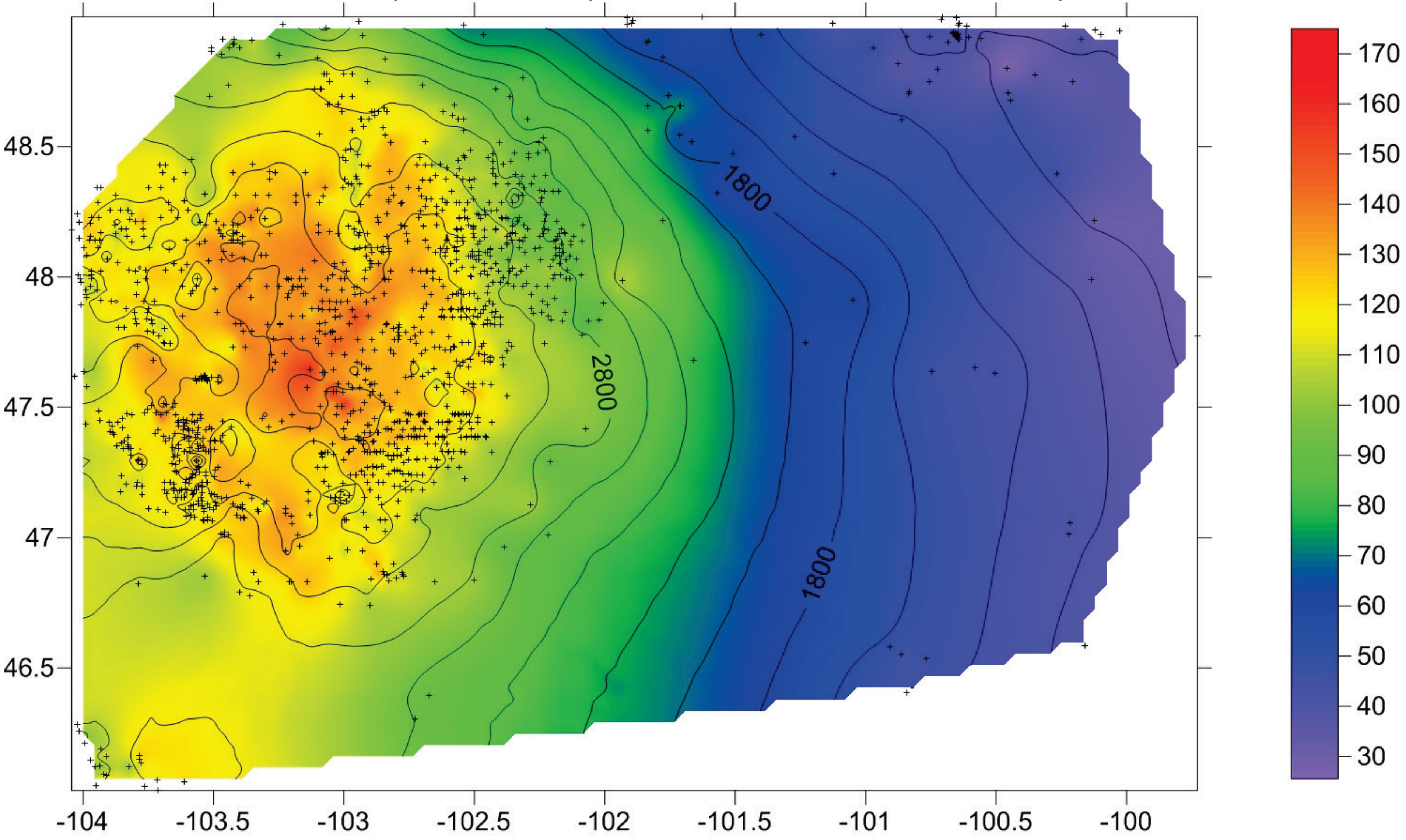
Contours are depth to top (m) Colors are temperature (°C)



Charles, Mission Canyon, Lodgepole =Madison formation

Mississippian – limestone & evaporites (Oil) Max thickness 723 m

Contours are depth to top (m) Colors are temperature (°C)



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.

Anna Crowell, 2011, M.S. thesis

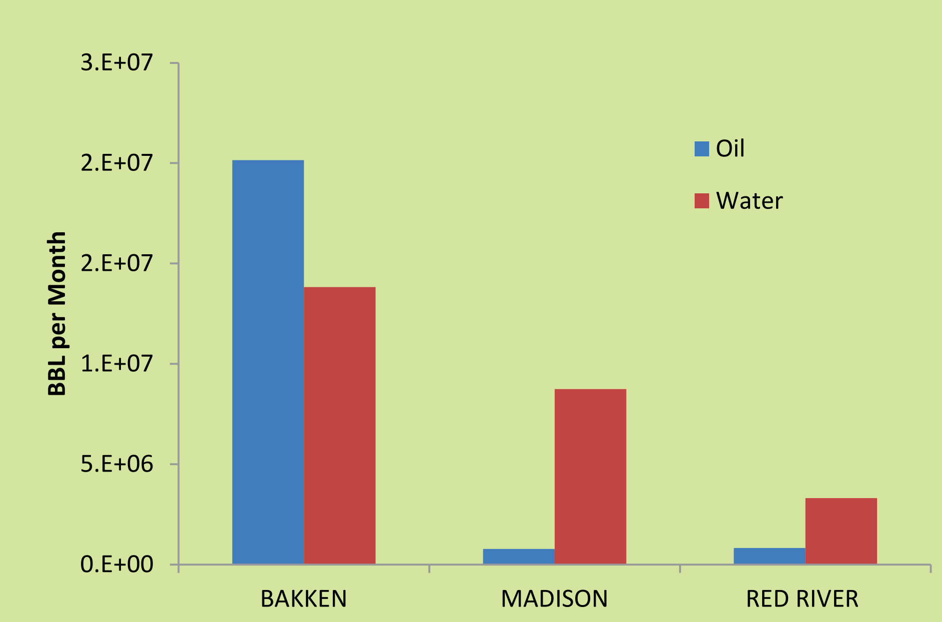
Temp Range	90°-100°C	100°-110°C	110°-120°C	120°-130°C	130°-140°C	140°-150°C	150°C +
Rock Volume	65,167.9 km^3	51,673.1 km^3	48,174.2 km^3	44,626.1 km^3	26,213.4 km^3	11,696.9 km^3	8,825.8 km^3
Water Volume	4,037.2 km^3	3,091.9 km^3	2,891.5 km^3	2,723.3 km^3	1,594.7 km^3	726.3 km^3	530.2 km^3
Thermal Energy	6.88×10^{18} J	6.81×10^{18} J	7.57×10^{18} J	8.17×10^{18} J	5.49×10^{18} J	2.80×10^{18} J	2.36×10^{18} J
Power Availability	2.15×10^{9} MW	1.89×10^{9} MW	2.10×10^{9} MW	2.27×10^{9} MW	1.52×10^{9} MW	7.78×10^{8} MW	6.56×10^{8} MW

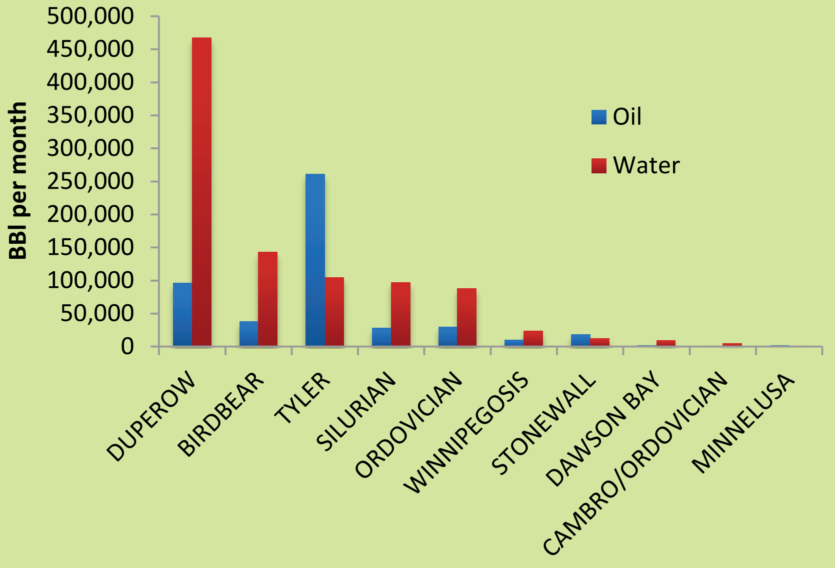
Can co-production yield significant power ?

- The main oil and water producing formations in the Williston Basin

Pool	BBLS Oil	BBLS Water	WOR Ratio	BBl oil/well	BBl water/well
BAKKEN	20,046,962	13,818,929	0.7	4,163	2,869
RED RIVER	829,559	3,305,592	4.0	1,659	6,611
MADISON	699,470	8,119,405	11.6	366	4,253

Numbers are BBLS per month for Oct. 2012





- The average temperatures of the main producing formations were determined from corrected BHTs

Pool	BBLS Oil	BBLS Water	Max T °C at 1 Σ	Min T °C at 1 Σ	Avg T °C
BAKKEN	20,046,962	13,818,929	128	116	122
RED RIVER	829,559	3,305,592	147	113	130
MADISON	768,496	8,691,561	118	92	105

- 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

Pool	T °C	kWe
BAKKEN	122	10,946
RED RIVER	140	2,021
MADISON	105	4,011
Cedar Hills	105	348

The total from the GIS analysis is 656 MWe

Power Production from top Madison and Red River Units in Co-Production Scenario

Unit	Oil bbl	Water bbl	No. Wells	Water gpm	kWe
Cedar Hills S. Red RR B	292,351	2,282,671	117	2,045	1,170
Cedar Hills N. Red RR B	385,634	605,212	115	542	426
Medicine Pole Hills RR	27,908	127,200	22	114	62

Unit	Oil bbl	Water bbl	No. Wells	Water gpm	kWe
Renville Madison	10,009	786,028	18	704	384
T.R. Madison	24,564	416,072	23	373	235
Eland Lodgepole	21,388	318,719	12	286	146

Co-produced vs. Water Only

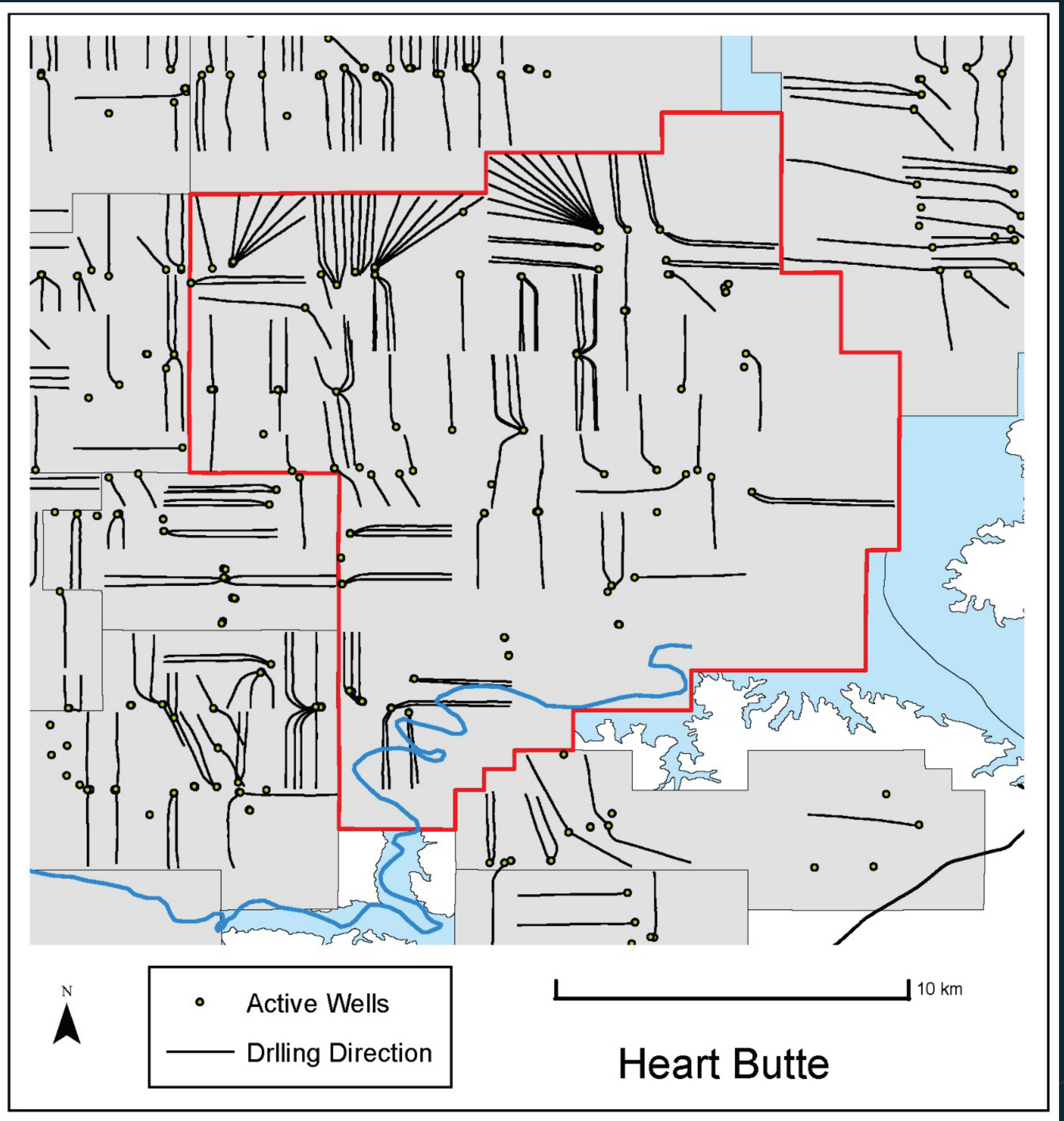
The top producing individual oil wells in the Madison, Red River and Bakken formations do not yield sufficient water to be economic as a co-production electrical power system.

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

Madison Oil bbl/day	100 °C H_2O bbl/day	Fluid bbl/day	H_2O gpm	lb/hr	Co-produced power (kW)	Moderate Rate (kW)	High Rate (kW)
28	3511	3539	98	46809	**110**	**2,200**	**22,000**
92	3006	3099	84	40084	**80**	**1,600**	**16,000**
36	2722	2758	76	36287	**73**	**1,460**	**14,600**

New Developments

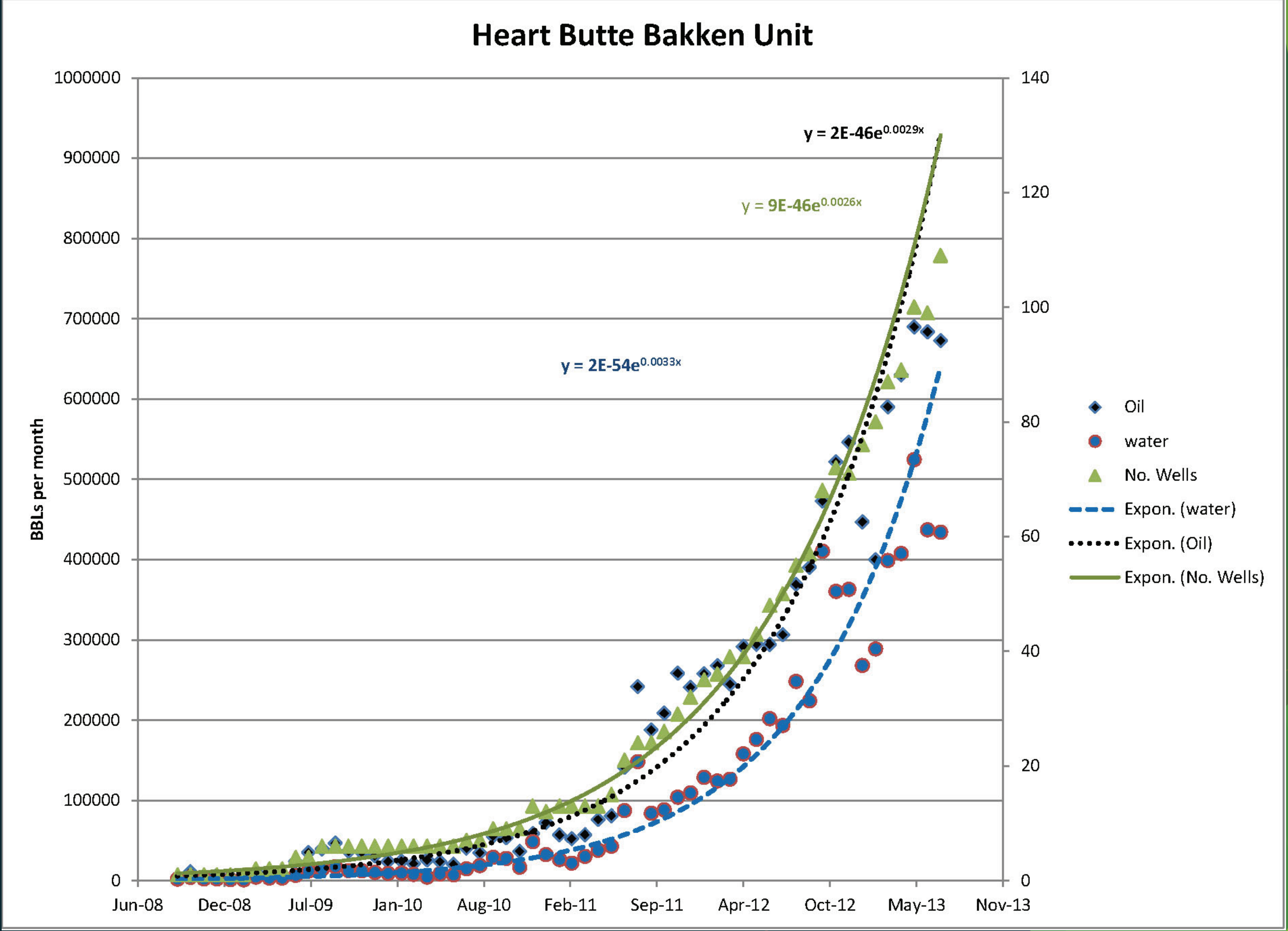
multi-well pads and high density infill drilling

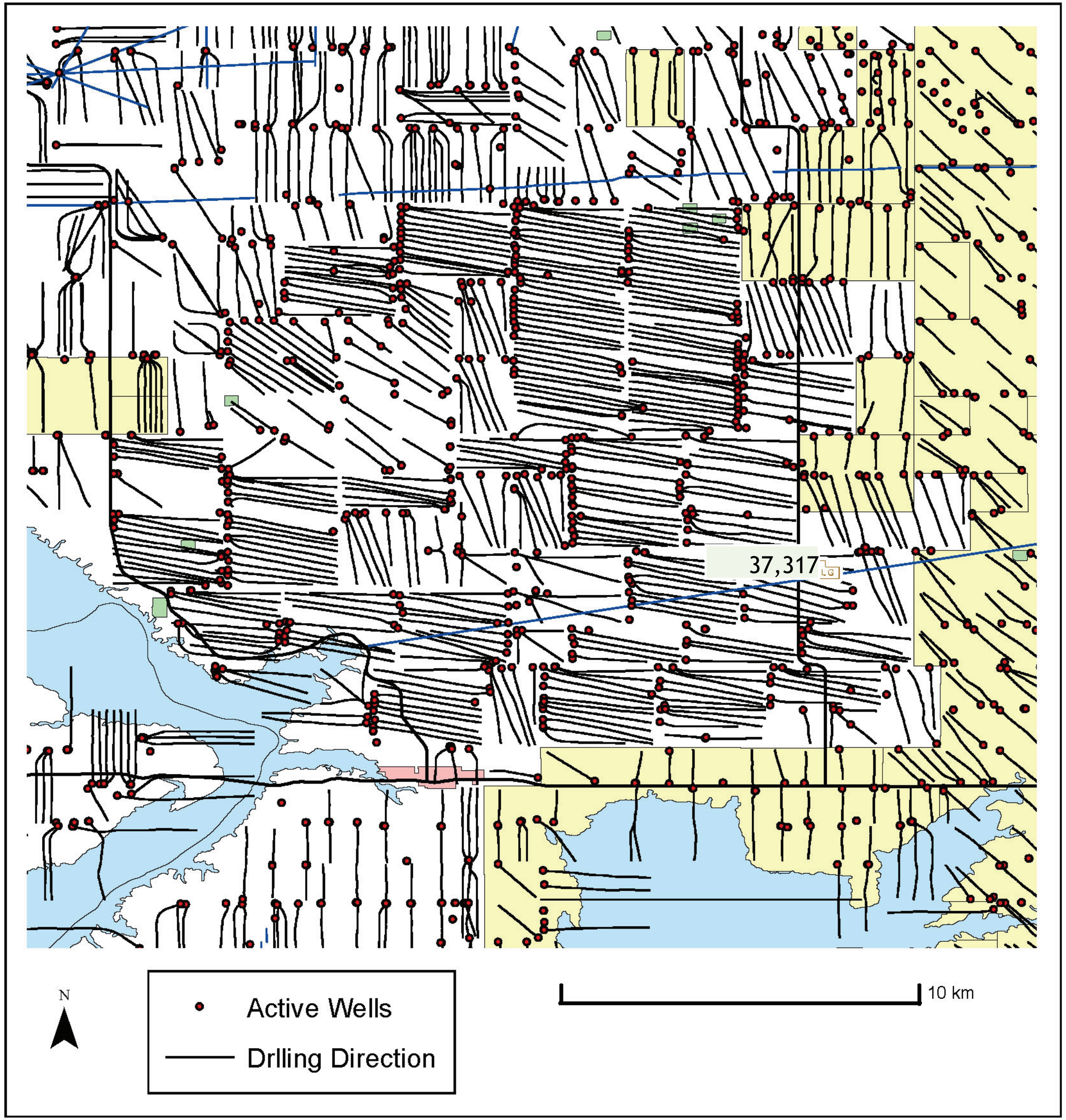


Horizontal drilling and fluid production in the Heart Butte Bakken field have increased exponentially since February 2011.

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

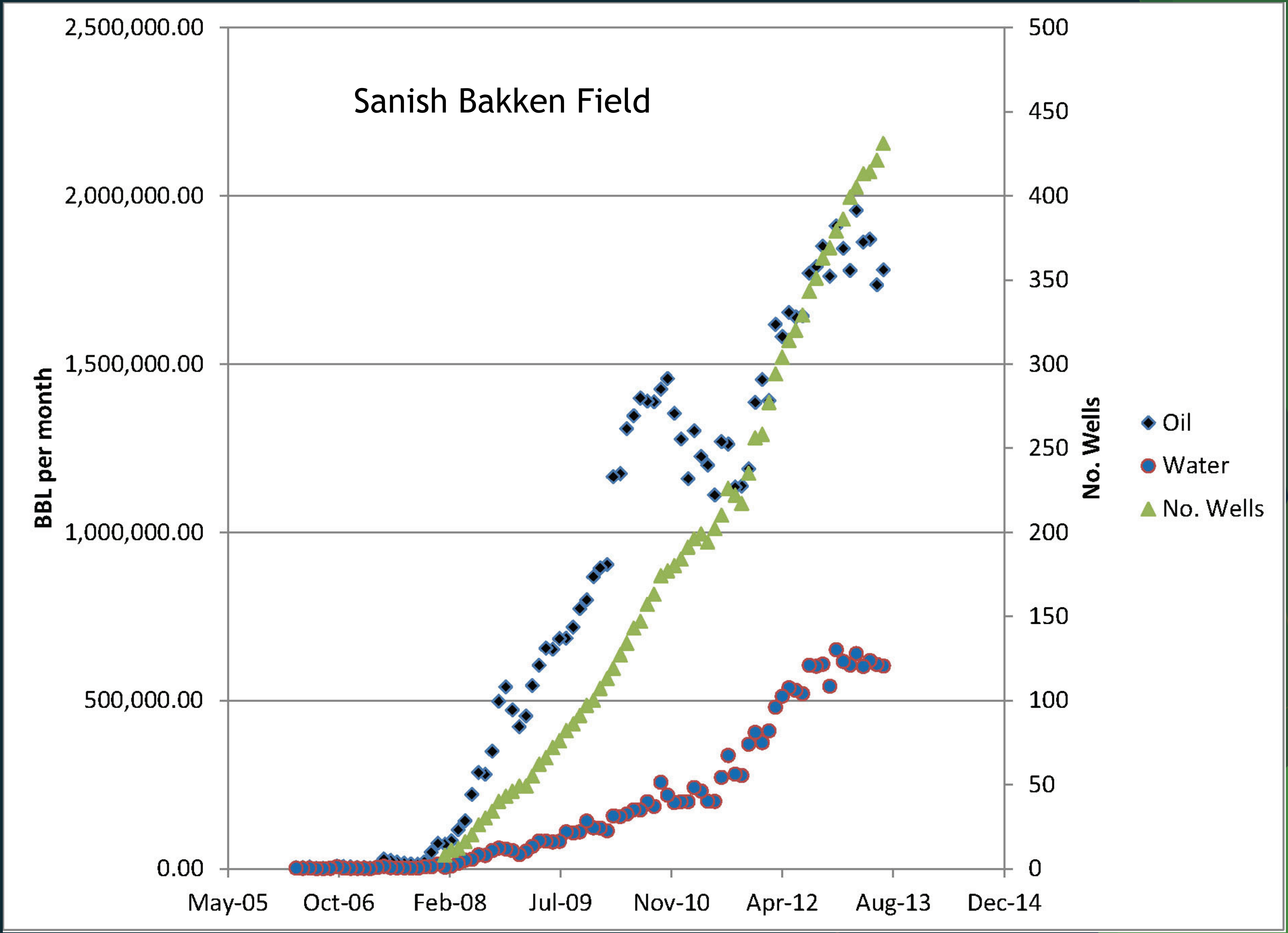
Estimate of power using oil water mix before separation: > 2 MWe


Heart Butte Bakken Unit
BBLs per month
y = 2E-46e^0.0029x
y = 9E-46e^0.0026x
y = 2E-54e^0.0033x
Oil
water
No. Wells
Expon. (water)
Expon. (Oil)
Expon. (No. Wells)
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
140
120
100
80
60
40
20
0
Jun-08
Dec-08
Jul-09
Jan-10
Aug-10
Feb-11
Sep-11
Apr-12
Oct-12
May-13
Nov-13



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


Sanish Bakken Field
BBL per month
2,500,000.00
2,000,000.00
1,500,000.00
1,000,000.00
500,000.00
0.00
No. Wells
500
450
400
350
300
250
200
150
100
50
0
May-05
Oct-06
Feb-08
Jul-09
Nov-10
Apr-12
Aug-13
Dec-14
Oil
Water
No. Wells

Current data show that the unitized Madison, Red River and Bakken formations do yield sufficient water to be economic for co-produced electrical power.

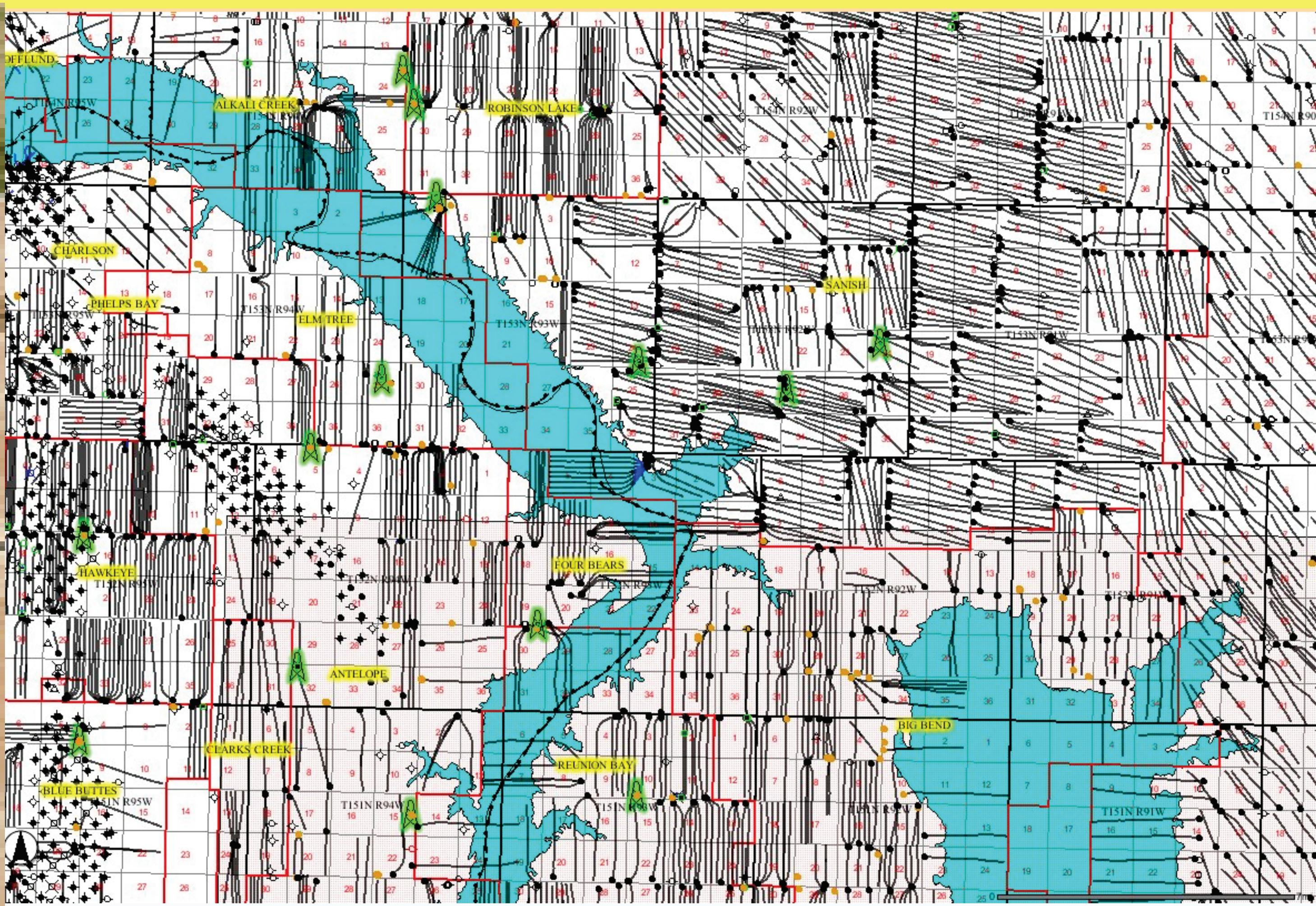
The table shows power that could be produced by using the water-oil mix prior to separation.

Pool	Oil bbl/day	H_2O bbl/day	gpm	Total MW	MWe
Red River 130°	1,534,083	12,016,573	350,483	1,569	210
Madison 100°	710,216	8,212,515	239,532	1,052	114
Bakken 122°	23,028,598	15,240,015	444,500	3,222	380
Total	25,272,897	35,469,103	1,034,516	**5,843**	**704**

The total from the GIS analysis is 656 MWe

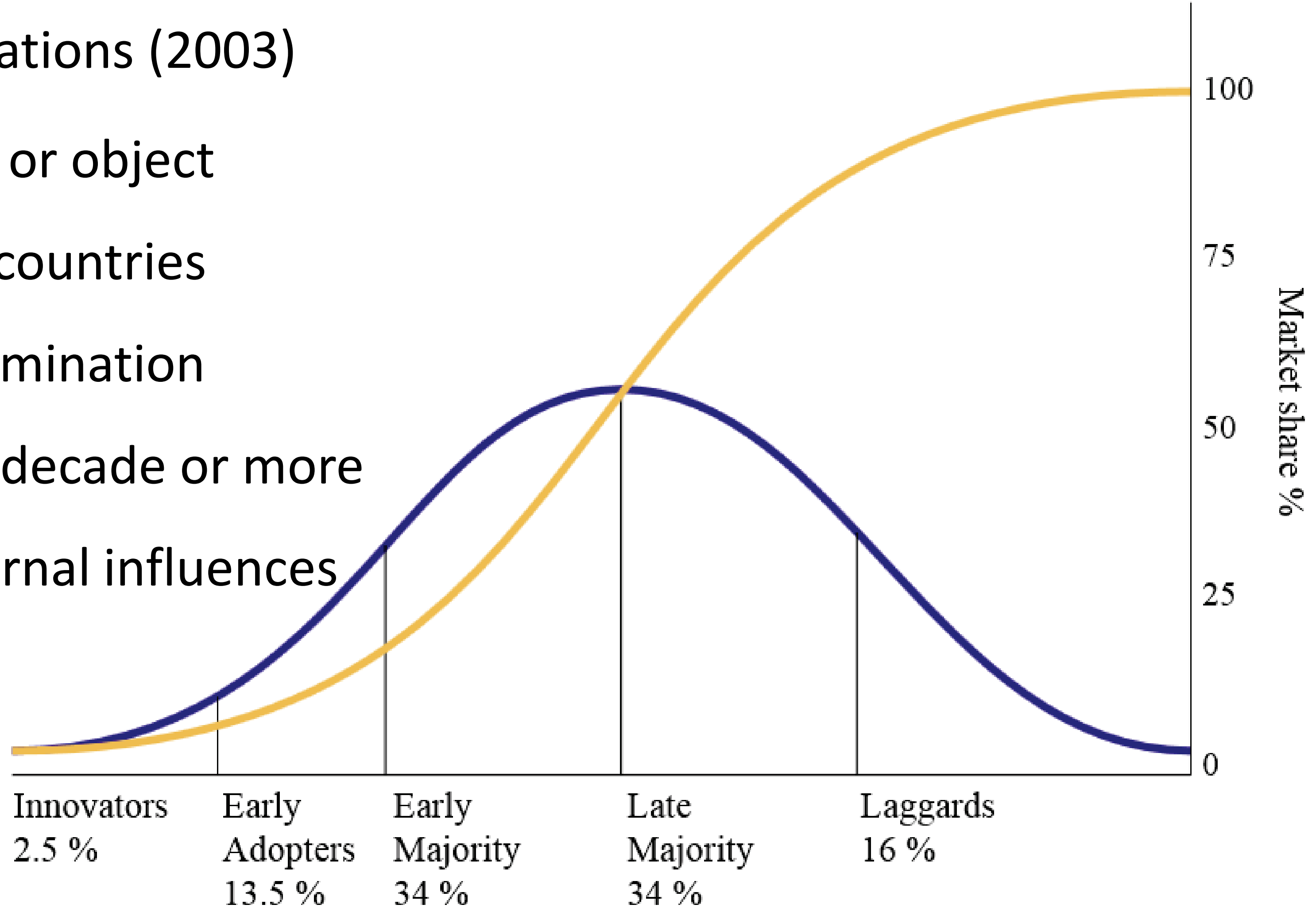
How to Advance this Concept?

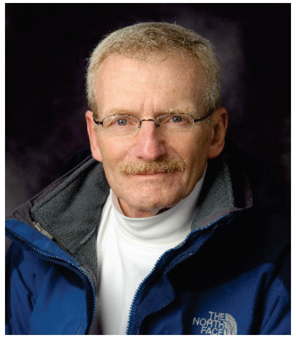
1. Get the electric power industry involved
2. Get entrepreneurs involved
3. Move now while electrical costs are a factor



Everett Rogers – Diffusion of Innovations (2003)

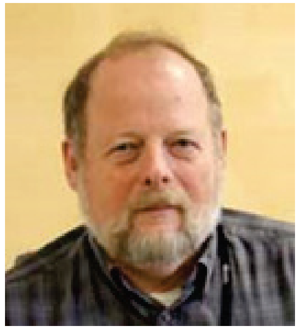
- Innovation – any new idea, practice or object
- Adopters – individuals, businesses, countries
- Communication – information dissemination
- Time – many influences, could be a decade or more
- Social system – combination of external influences




Will Gosnold


Michael Mann

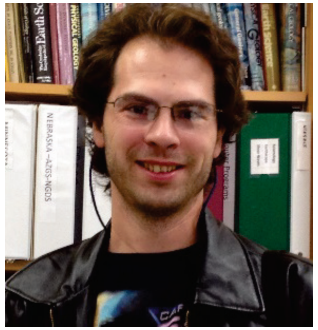

Hossein Salehfar


Rich LeFever


Steve Nordeng


Deb Hanson


Anna Crowell PhD

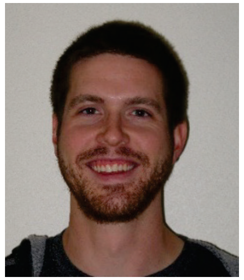

Josh Crowell PhD


Kirtipal Barse PhD

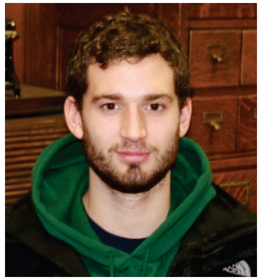

Samir Dahal PhD


Mark McDonald PhD


Rob Klenner MS


Aaron Ochsner MS


Nick Low


Preston Wahl BS


Angel Von Oploo BS

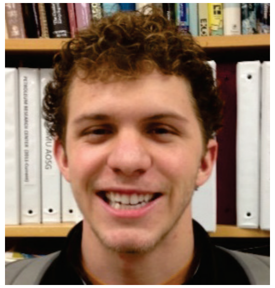

Eric Zimny MS


Bailey Bubach BS


Godswill Njoku MS

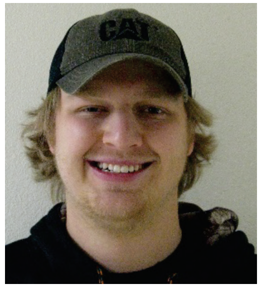

Faye Ricker MS


Caitlin Hartig MS


Dylan Young


Burke Brunson


John Sandven


Chris Colby


Caleb Rust

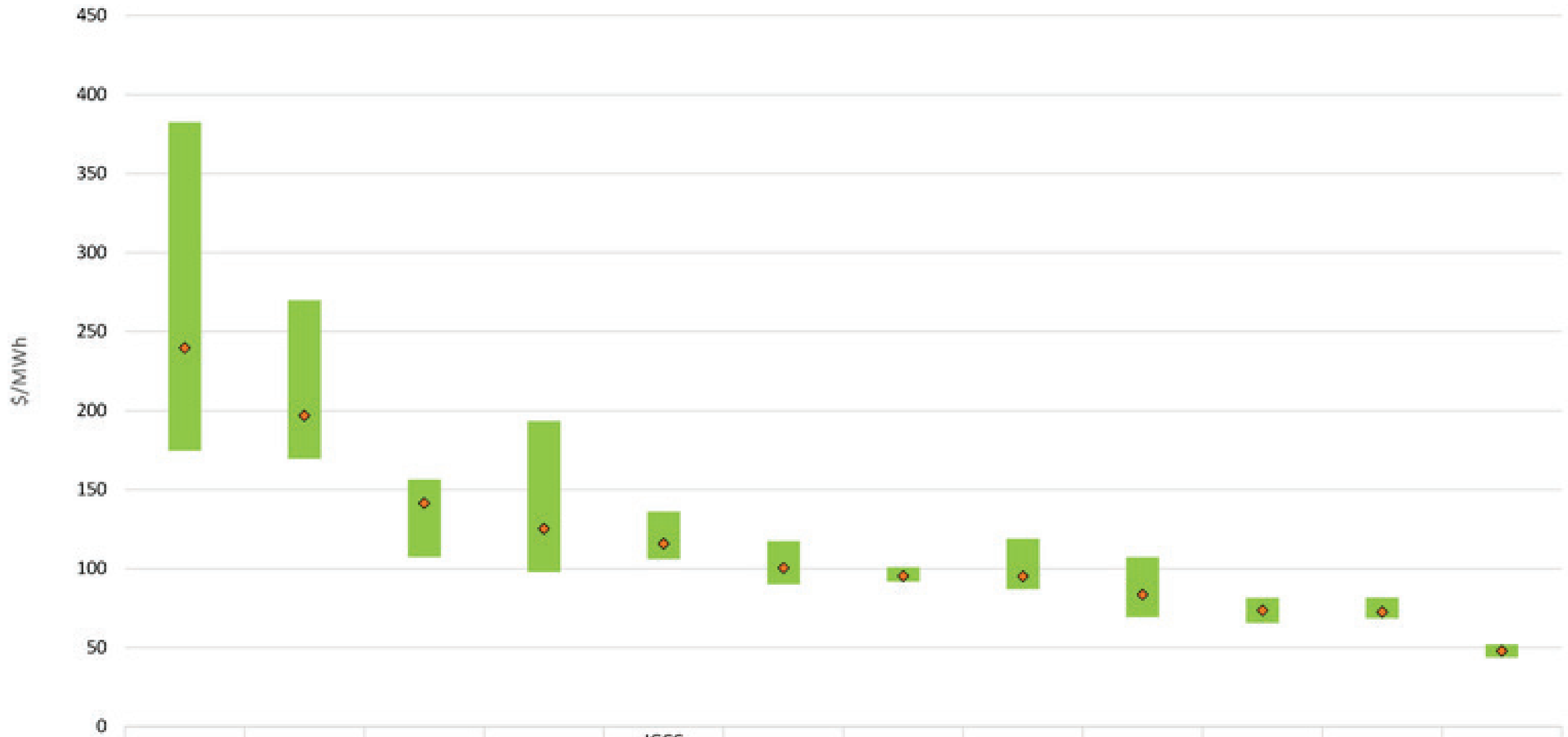

Samantha McLaughlin


Jason Myrvold

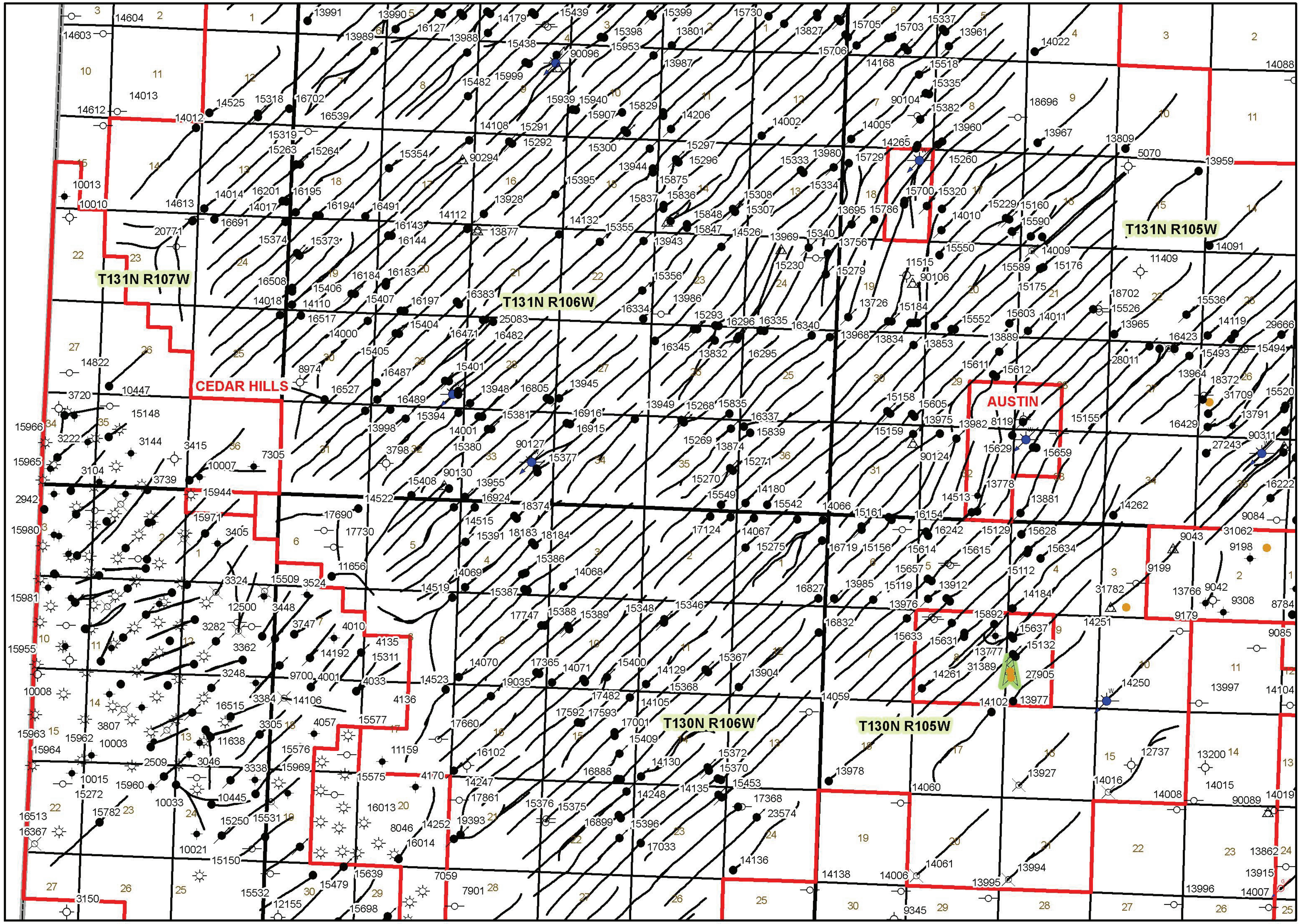

Michael Farzaneh

UND Geothermal Energy Team 2009-2016

Projected LCOE in the U.S. by 2020 (as of 2015)



	Solar Thermal	Wind offshore	Natural Gas: Conventional Combustion Turbine	Solar PV	IGCC (Integrated Coal-Gasification Combined Cycle)	Biomass	Advanced Nuclear	Conventional Coal	Hydro	Wind onshore	Natural Gas: Advanced Combined Cycle	Geothermal
Minimum	174	170	107	98	106	90	92	87	69	66	69	44
◆ Average	240	197	142	125	116	101	95	95	84	74	73	48
Maximum	383	270	156	193	136	117	101	119	107	82	82	52



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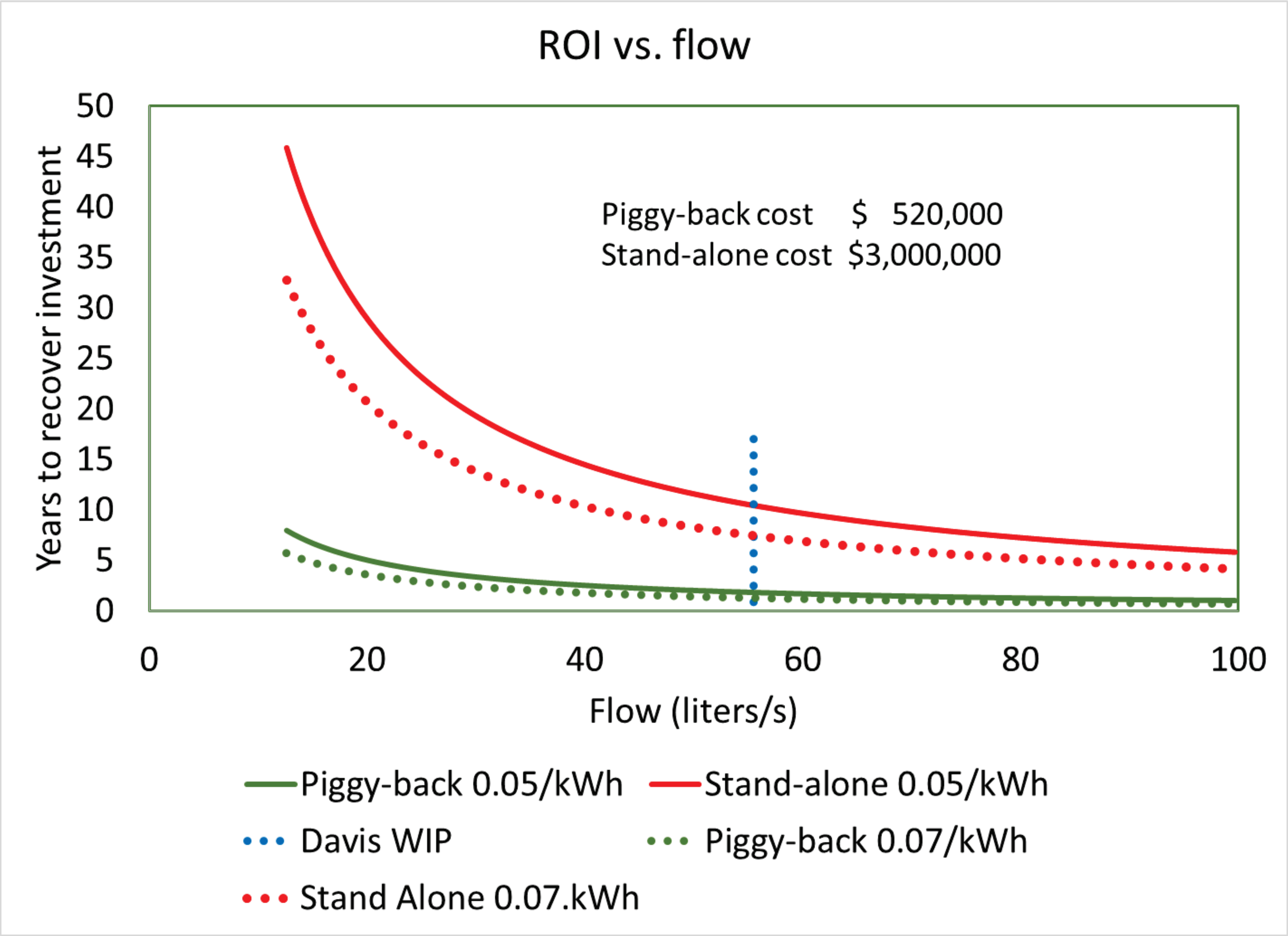
0 1 2 4 Miles

Prepared by N.D.I.C.
Oil and Gas Division

8/21/2015
9:58:33 AM


ROI vs. flow
Years to recover investment
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
Flow (liters/s)
Piggy-back cost $ 520,000
Stand-alone cost $3,000,000
Piggy-back 0.05/kWh
Stand-alone 0.05/kWh
Davis WIP
Piggy-back 0.07/kWh
Stand Alone 0.07.kWh

A lesson about temperature

- 60 F People in LA shiver uncontrollably
- 40 F Italian and British cars will not start
- 20 F Floridians don thermal underwear
- 0 F   People in Miami FL all die
- -20 F Californians escape to Mexico
- -40 Las Vegas disintegrates

- North Dakotans sunbathe
- North Dakotans plant gardens
- North Dakotans drive with windows down
- North Dakotans wear flannel shirts buttons open
- Last barbeque before it gets cold
- North Dakota school buses run 2 hours late