Geothermal and Electric Power Analysis of Horizontal Oil Well Fields Williston Basin, North Dakota, USA*

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Search and Discovery Article #80681 (2019)**
Posted June 17, 2019

*Adapted from oral presentation given at 2019 AAPG European Region, 3rd Hydrocarbon Geothermal Cross Over Technology Workshop, Geneva, Switzerland, April 9-10, 2019
 DOI:10.1306/80681Gosnold2019

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Abstract

Economics constraining power generation from producing oil field fluids depend on the amount of energy generated, infrastructure costs, and power grid factors. Key factors in geothermal energy production are temperature and fluid volume and finding the optimal combination of these factors is critical for sedimentary basin geothermal development.

Sedimentary basin temperatures, typically 90 ºC to 150 ºC, require binary power conversion systems, the efficiencies of which are low, typically 6%, but recent advances in technology have led to the development of systems with efficiencies approaching 14%. Concepts for oil-field geothermal development have emphasized the use of existing infrastructure and have focused on water available in co-production or through conversion of marginally economic oil and gas wells to water production. Though technologically feasible, both concepts face limitations in delivering adequate fluid volume and, for that reason, there has been minimal progress. However, two developments, horizontal infill drilling on multi-well pads and the capability of binary systems to use the total oil and water flow, can overcome this limitation. To test the concept, we analyzed the potential for power production from two low-volume and two high-volume Bakken fields in the Williston Basin.

The Bakken is a tight formation with low production rates for water and oil per well. For comparison, we also analyzed two fields in a high-volume carbonate formation. Average total production for 2017-2018 for the low-volume Clear Creek Bakken Field was 7.28e5 liters/day oil and 3.04e5 liters/day water. Production in the Baker Bakken field averaged 5.15e5 liters/day oil and 1.01e6 liters/day water. The high-volume Heart Butte Bakken field averaged 3.16e6 liters/day oil and 3.83e6 liters/day water. The Parshall Bakken Field averaged 6.27e6 liters/day oil and 5.5de6 liters/day water. Bakken temperatures are approximately 120 ºC. We calculated the thermal energy production for each field based on a single pass ORC with a ΔT of 30 ºC and a cascaded ORC system with a total ΔT of 50 ºC using, where ρ is fluid density, cv is heat capacity, and V is volume. The total thermal energy for oil and water combined ranges from 5.18 e9 J for the Clear Creek Field to the 1.0 e11 J for the Parshall Field. Converting the numbers to electrical power with the two different ΔT values gives a range of 100 kWh to 4.11 MWh for the fields. The lower rate is for a ΔT of 30 ºC and an ORC efficiency of 6 percent. The higher rate is for a ΔT of 50 ºC and an ORC efficiency

of 14 percent. A concept for future geothermal development as Bakken production declines would be to repurpose existing infrastructure by re-entering the vertical well and drilling a long lateral into the overlying water-bearing Lodgepole formation.

Water production per well determined from 5 horizontal wells in the Lodgepole formation operated by Continental Resources averages 2e6 liters/day. Average production per well for the fields in our analysis of co-produced fluids averages 0.28 liters/day. Thus, repurposing existing infrastructure in the fields to electrical power could result in a million-fold increase in energy production. Assuming the re-drilling cost in Bakken/Three Forks is $2 million per well and 4.97e5 liters oil production per well in 24 months, a Net Profit Value (NPV) of $1.75 million would be obtained with $50 per barrel at least, if one ignores the other operation costs and production decline. The South Red River B and North Red River B fields produce from mile-long horizontal wells in a dolomite/limestone formation. Well density rarely exceeds 10 per square mile, but the volume of fluid produced in the two fields provides a good comparison with the averages of our Bakken wells. The SRR-B field produces 4.28e3 liters/day total fluid and the NRR-B produces 1.39e3 liters/day. The resulting energy estimates of 1.46 e11 J and 4.62e10 J predict energy production of 6.66 MWh and 1.8 MWh respectively. This encouraging analysis of energy from co- produced fluids raises the question of who will take the lead in development.

The University of North Dakota

UND Geothermal Laboratory
The University of North Dakota

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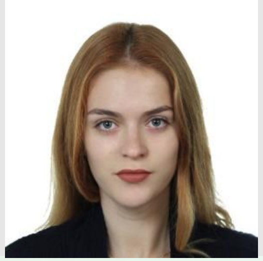
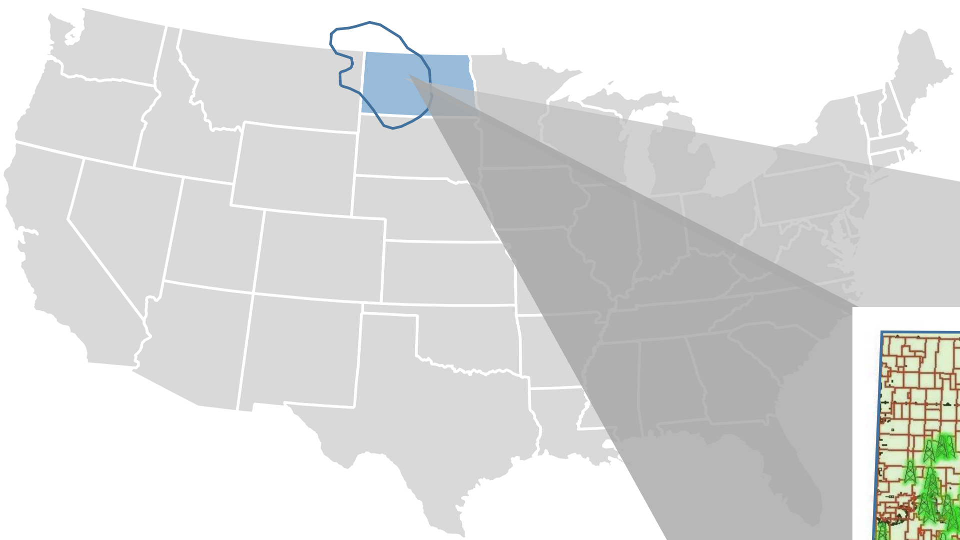


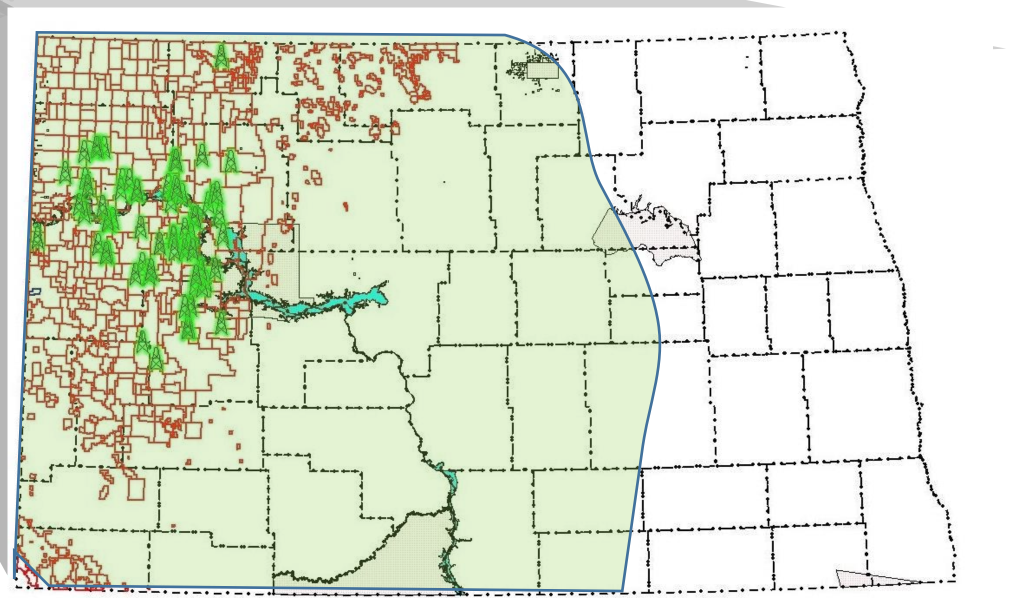
Presented by
Mark Ballesteros
Mid West Geothermal Power

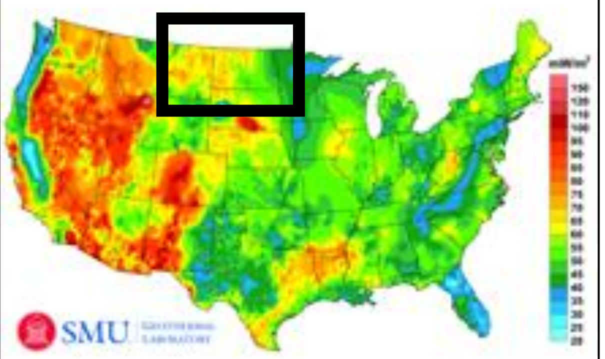
AAPG 3rd Hydrocarbon – Geothermal Crossover Technology Workshop
Geneva, Switzerland 9-10 April, 2019

OUR STUDY AREA

Williston Basin,
North Dakota







Heat Flow

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 20,000 PJ. (Roughly equivalent to 20 Tcf of natural gas (Groningen ~100 Tcf) or 3.3 Billion bbls oil)

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

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

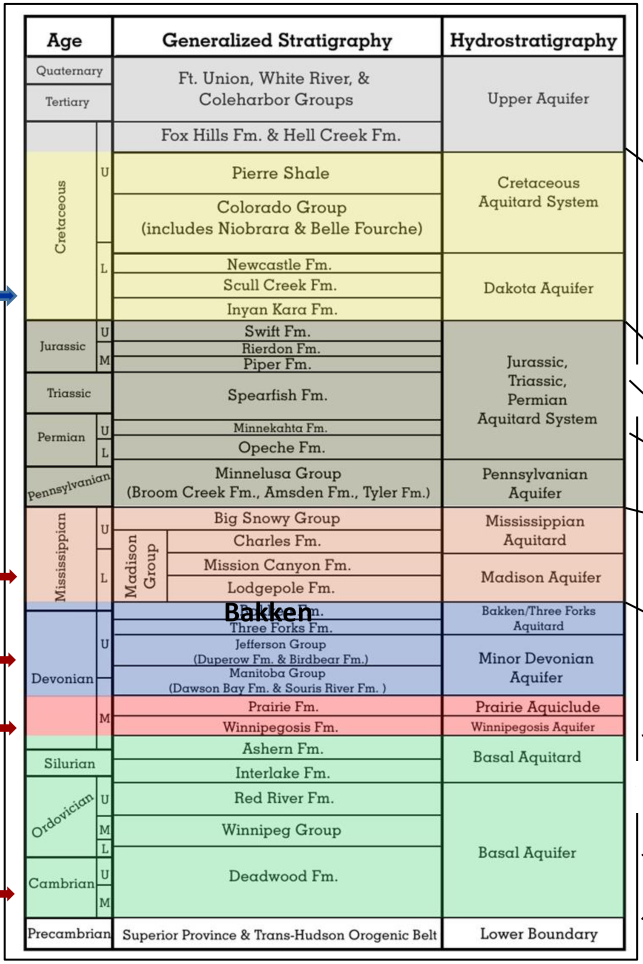
60°C

130°C

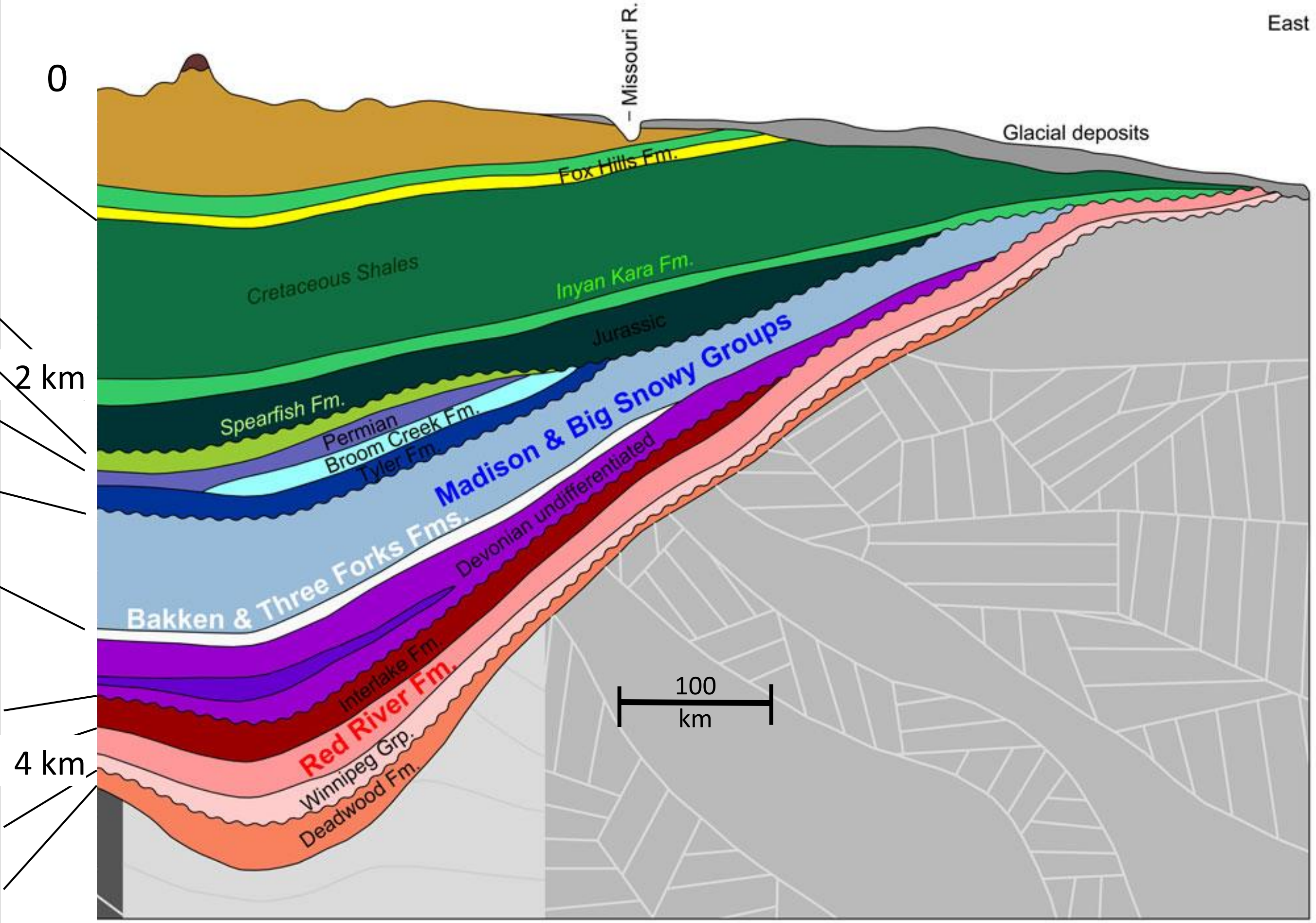
140°C

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
Cretaceous U	Colorado Group (includes Niobrara & Belle Fourche)	
Cretaceous L	Newcastle Fm.	Dakota Aquifer
Cretaceous L	Scull Creek Fm.	
Cretaceous L	Inyan Kara Fm.	
Jurassic U	Swift Fm.	Jurassic, Triassic, Permian Aquitard System
Jurassic U	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.	
Mississippian L	Madison Group: Mission Canyon Fm.	Madison Aquifer
Mississippian L	Madison Group: Lodgepole Fm.	
Devonian U	Bakken Fm.	Bakken/Three Forks Aquitard
Devonian U	Three Forks Fm.	
Devonian U	Jefferson Group (Duperow Fm. & Birdbear Fm.)	Minor Devonian Aquifer
Devonian U	Manitoba Group (Dawson Bay Fm. & Souris River Fm.)	
Devonian M	Prairie Fm.	Prairie Aquiclude
Devonian M	Winnipegosis Fm.	Winnipegosis Aquifer
Silurian	Ashern Fm.	Basal Aquitard
Silurian	Interlake Fm.	
Ordovician U	Red River Fm.	Basal Aquifer
Ordovician M	Winnipeg Group	
Cambrian U, L, M	Deadwood Fm.	
Precambrian	Superior Province & Trans-Hudson Orogenic Belt	Lower Boundary



THREE CRITICAL FACTORS FOR GEOTHERMAL POWER DEVELOPMENT

1

Fluid temperature

Temperatures in oil and gas formations in the Williston Basin range from 100 ºC to 160 ºC

2

Fluid volume

Open hole 800 m – 1200 m lateral water wells in permeable formations demonstrate that flow rates of 16 l s^{-1} – 50 l s^{-1} per well are possible. 50 l s^{-1} is estimated to be the economic threshold.

Multi-well pads with 8 to 16 wells and closely-spaced pads in fields raise total field flows to > 50 l s^{-1} in many fields.

3

Energy conversion efficiency and cost

Advances in technology keep moving the needle toward achieving good economics.

WHY WAS THERE NO DEVELOPMENT EVEN WITH USE OF EXISTING INFRASTRUCTURE?

1. Temperatures below 150 ºC require binary power systems.
2. ORC efficiencies were 4% to 6% and economics were bad for either co-production or drilling new wells.
3. Fluid volumes for co-production were too small to move the economic needle.
4. No demand

WHAT HAS CHANGED?

1

Binary power technology	Efficiency
Pratt & Whitney 200 kW with 74 ºC water	6%
Calnetix 125 kW with 90 ºC water	7%
Calnetix 125 kW with 140 ºC water	14%
Climeon 150 kW with 90 ºC water	14%

2 Horizontal drilling has increased fluid production volumes to levels that make co-production competitive.

Bakken fluid production increased 14 x

3 Better temperature data

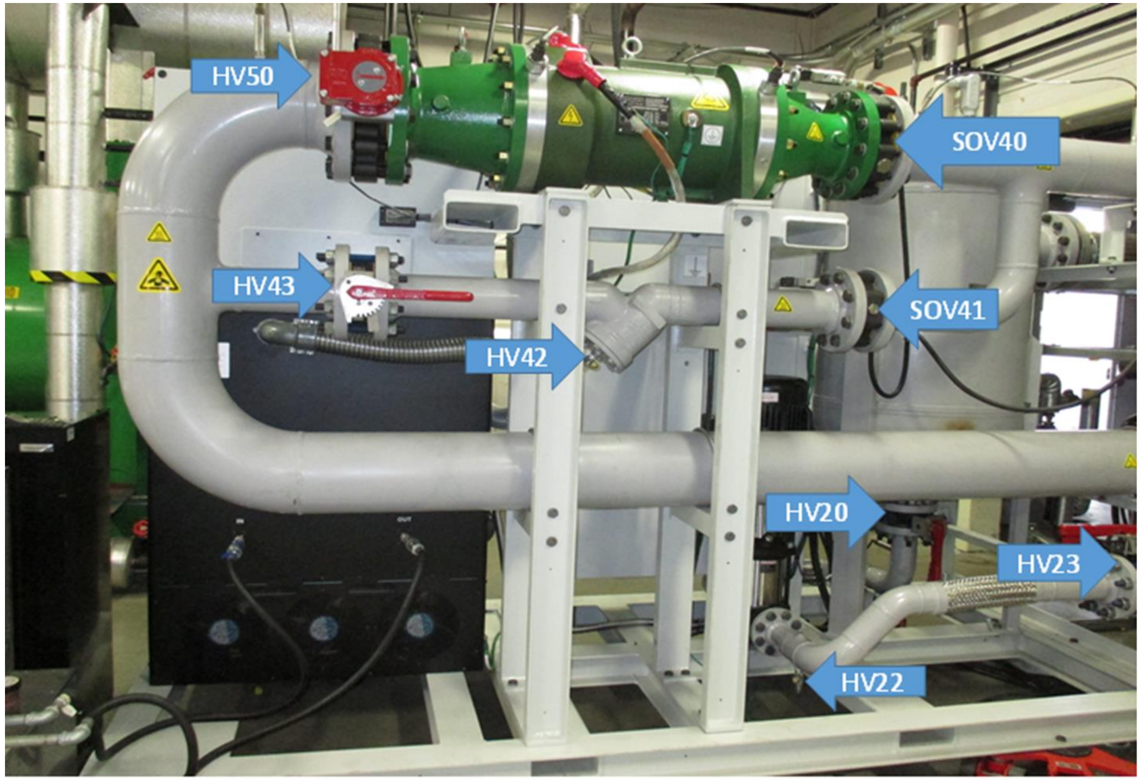
New heat flow and data analysis

4 Incentives

Demand for power and need to develop renewable energy

1. TECHNOLOGY. CALNETIX

AE XLT 125 kW



Valve location on XLT skid.

≥95.6°C full gross power of 125 kW produced

<95.6°C partial power produced

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

1. TECHNOLOGY. CLIMEON C3

>12 patents/applications and counting...

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

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Better temperature data

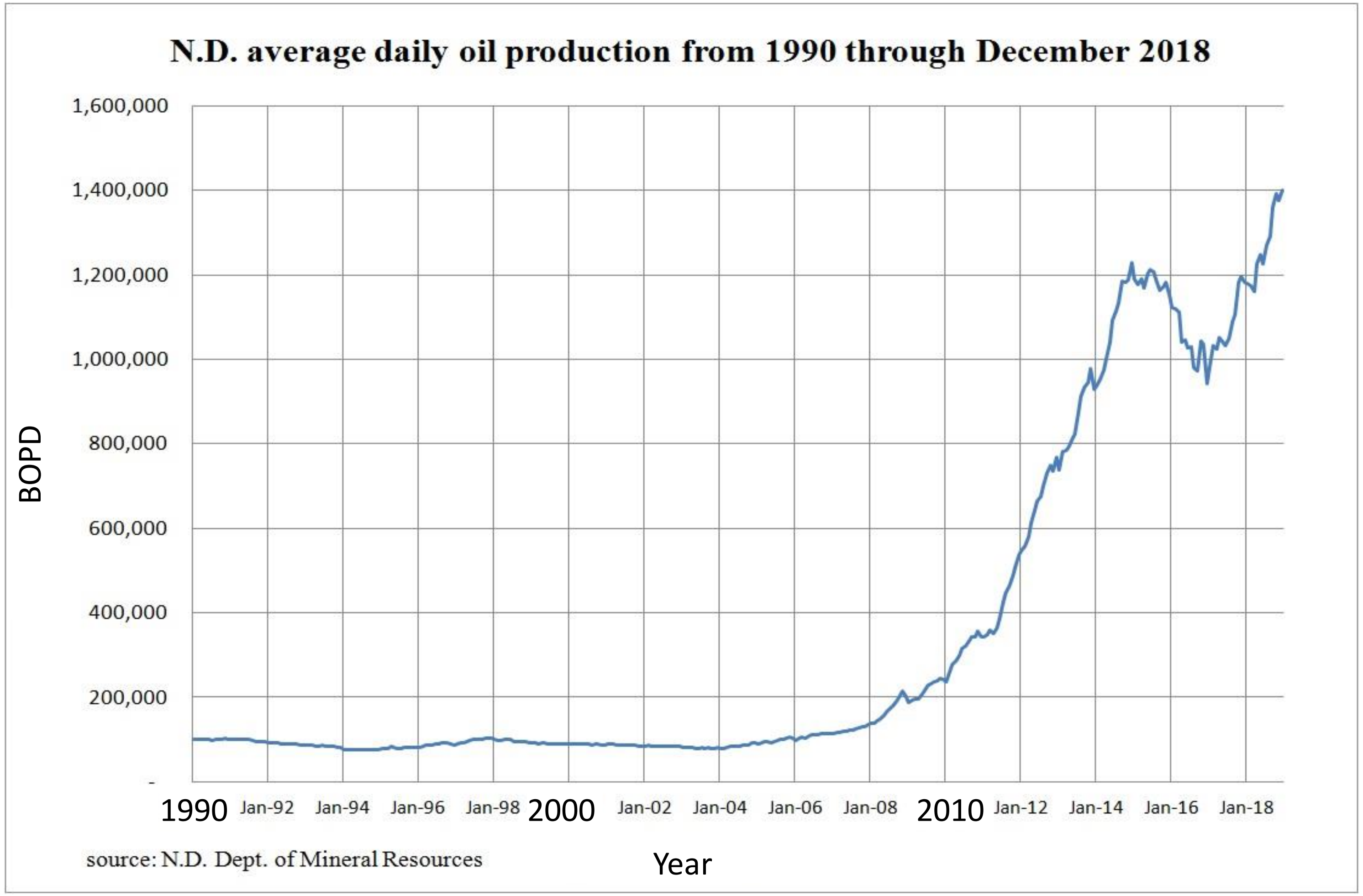
New heat flow and data analysis

4

Incentives

Demand for power and need to develop renewable energy

2. OIL PRODUCTION IN NORTH DAKOTA



The 14X production increase is due to horizontal drilling in the Bakken Formation.
100,000 bbl/day 1990-2006: 1,400,000 bbl/day in 2018

WHAT HAS CHANGED?

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2 Horizontal drilling has increased fluid production volumes to levels that make co-production competitive.

Bakken fluid production increased 14 x

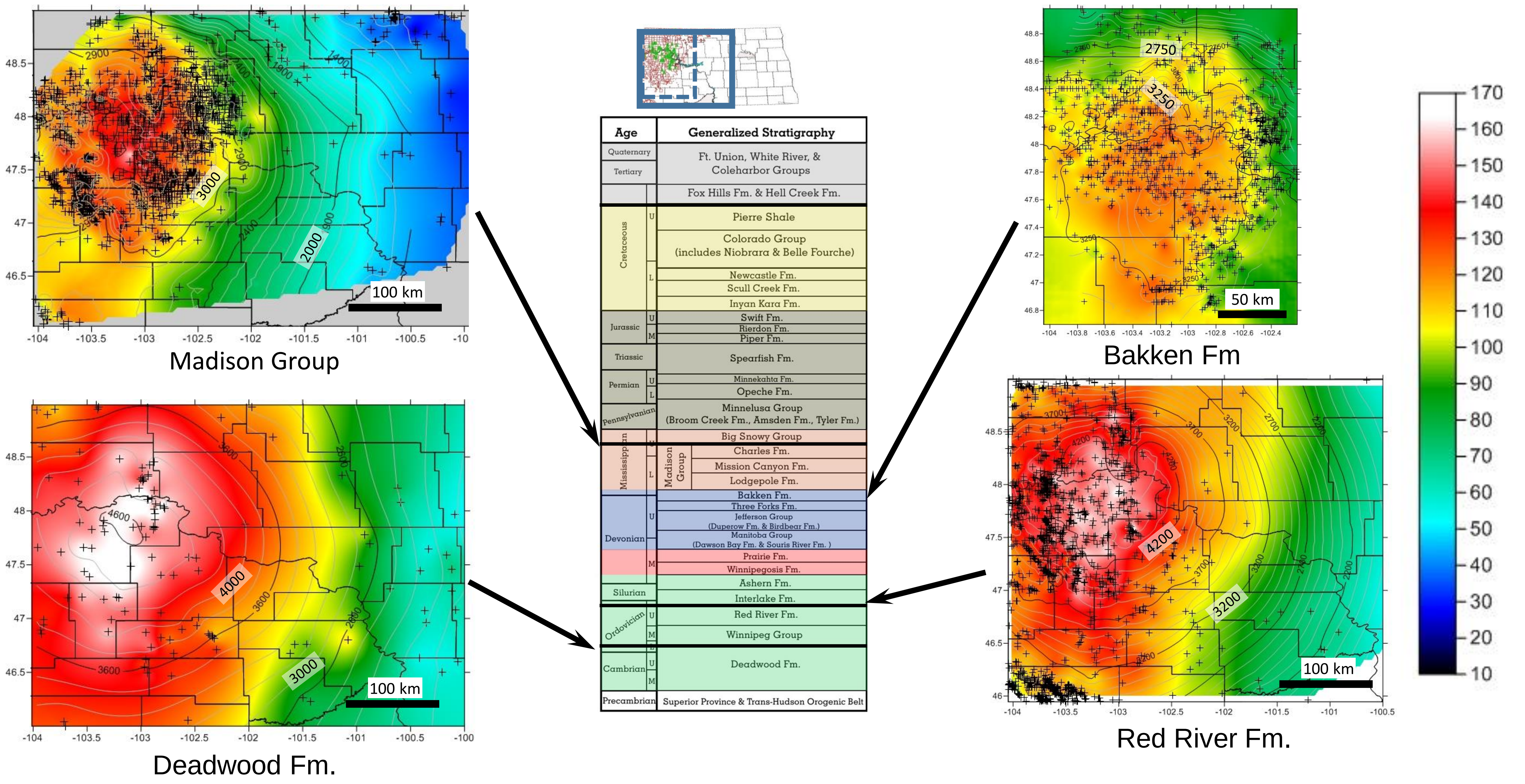
3 Better temperature data

New heat flow and data analysis incorporating over 10,000 wells

4 Incentives

Demand for power and need to develop renewable energy

3. TEMPERATURE AND DEPTH AT KEY STRATIGRAPHIC LEVELS



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New heat flow and data analysis

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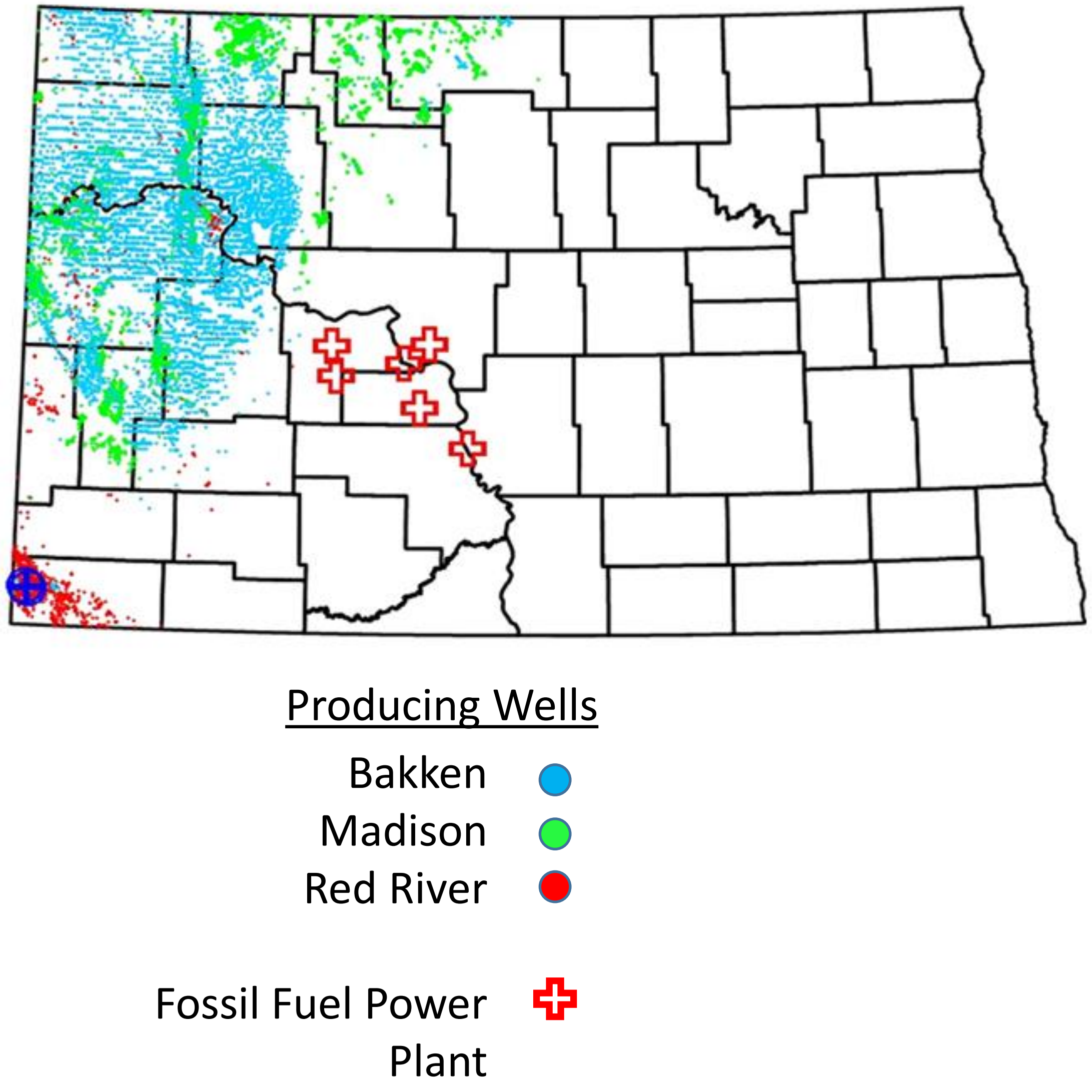
Incentives

Demand for power and need to develop renewable energy

4. POWER DEMAND



1 Existing power for ND-MT is from 6 coal or gas-fired power plants on Missouri River.

2 Current supply for the boom is from diesel, propane & produced gas at 5X grid power cost

3 2,600 MW additional power needed to produce Bakken and Three Forks by 2032

ENERGY ANALYSIS

Identify and select fields – download data

Calculate average production oil, gas, no. wells for past two years

Determine field temperature

Calculate energy in fluids using formula

$$\text{Joules} = \rho c_v V \Delta T$$

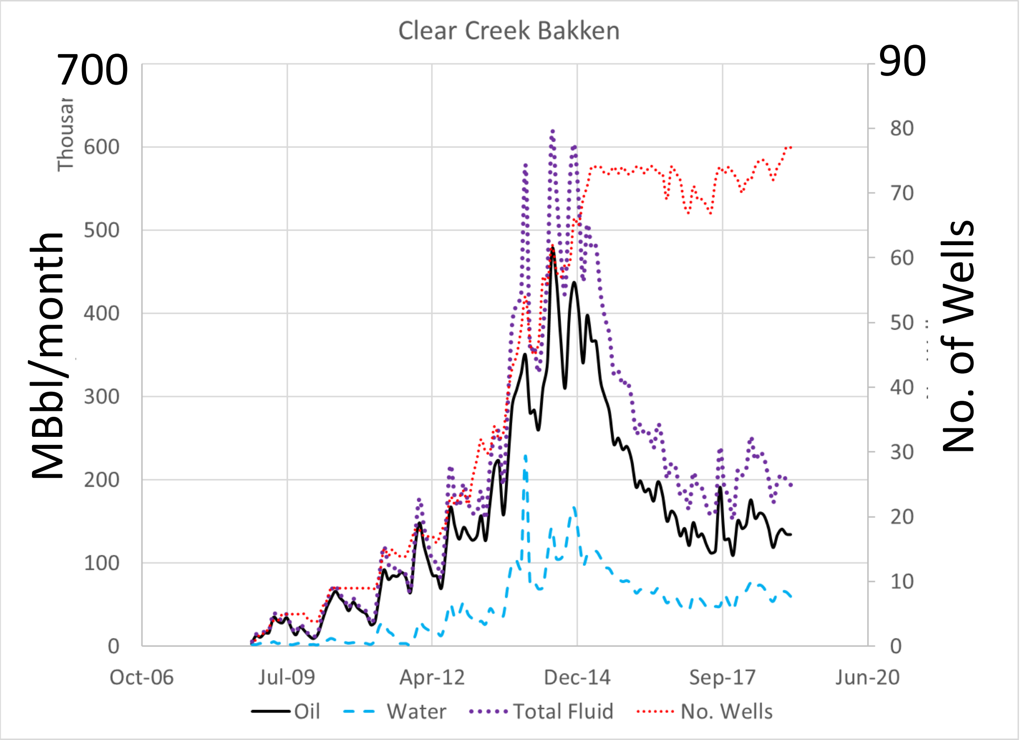
kWh

Calculate energy in kWh for Calnetix and Climeon systems

CLEAR CREEK BAKKEN

Low volume: High temperature

3,245 m, 72 Wells, T = 143 ºC



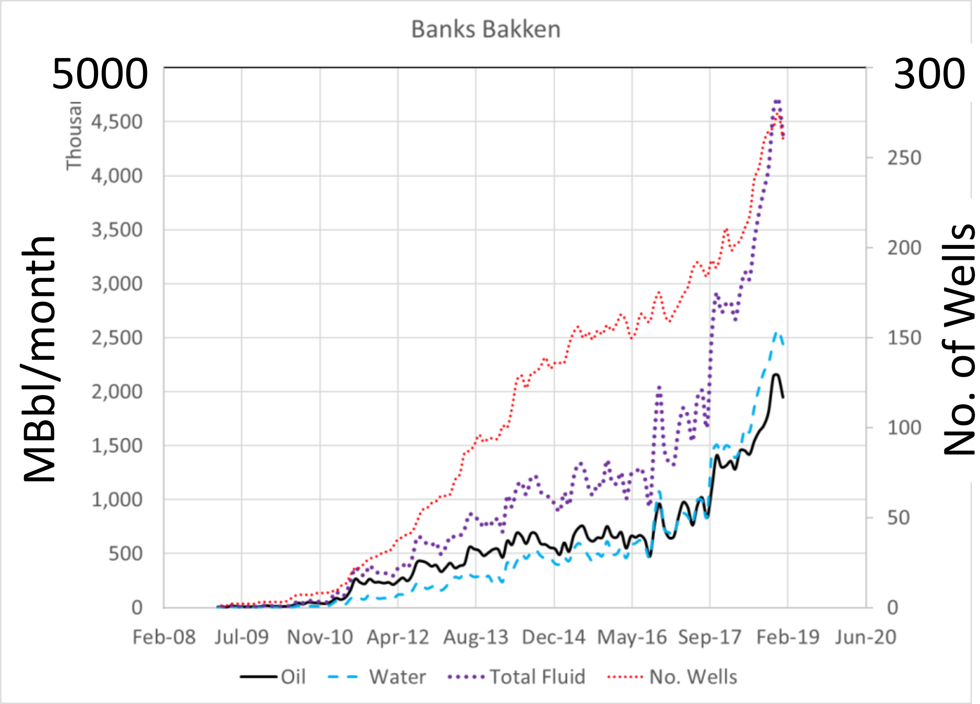
Calculations

Fluid	ρ (kg m^{-3})	c_V (J kg^{-1} K^{-1})	m^3 h^{-1}	ΔT	J h^{-1}	Energy	
Oil	870	1830	30	73	3.52E+09	978	kWt
Water	1030	4181	13	73	4.01E+09	1,114	kWt
				ORC effic.	**14.14%**	**296**	**kWe**

BANKS BAKKEN

High volume: High temperature

3,395 m, 197 Wells, T = 144 ºC



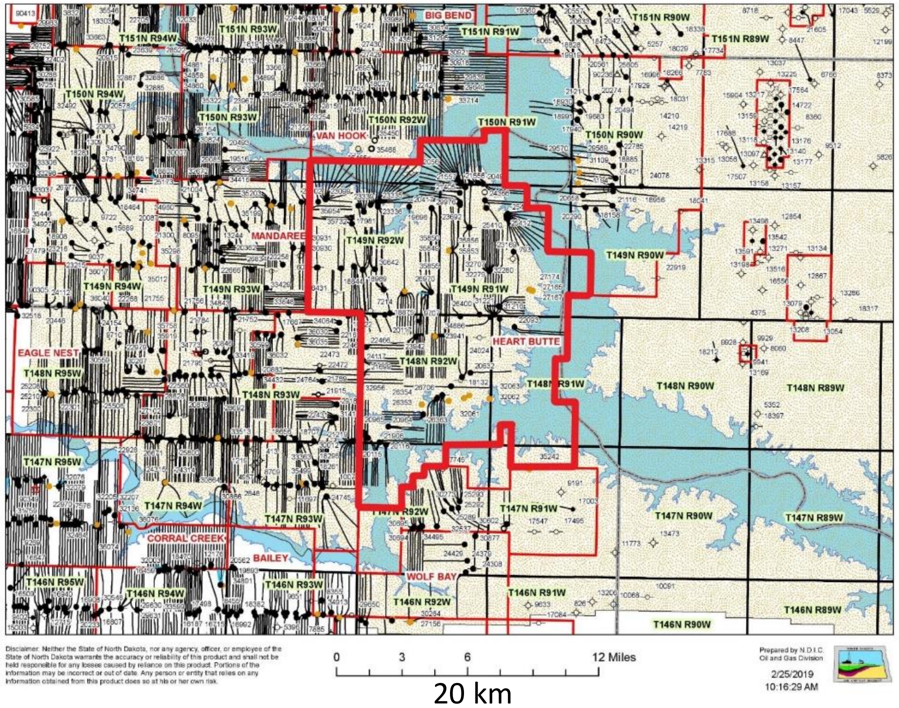
Calculations

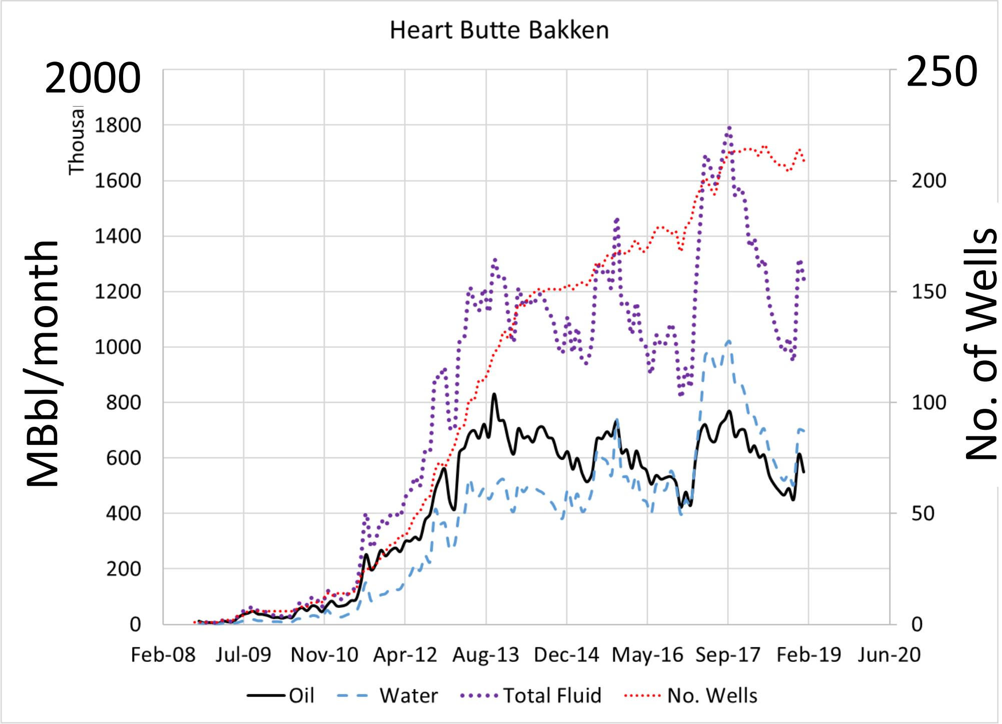
Fluid	ρ (kg m^{-3})	c_V (J kg^{-1} K^{-1})	m^3 h^{-1}	ΔT	J h^{-1}	Energy	
Oil	870	1830	284	74	3.34E+10	9,281	kWt
Water	1030	4181	321	74	1.02E+11	28,379	kWt
				ORC effic.	**14.24%**	**5,363**	**kWe**

HEART BUTTE BAKKEN

High volume: Low temperature

3,215 m, 200 Wells, T = 112 ºC



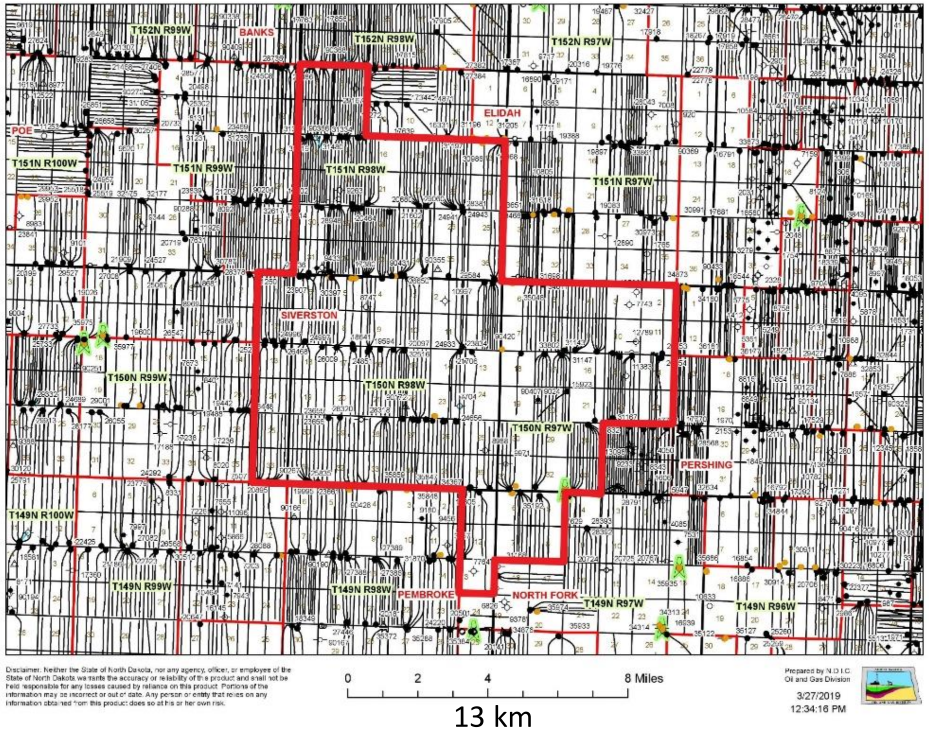


Calculations

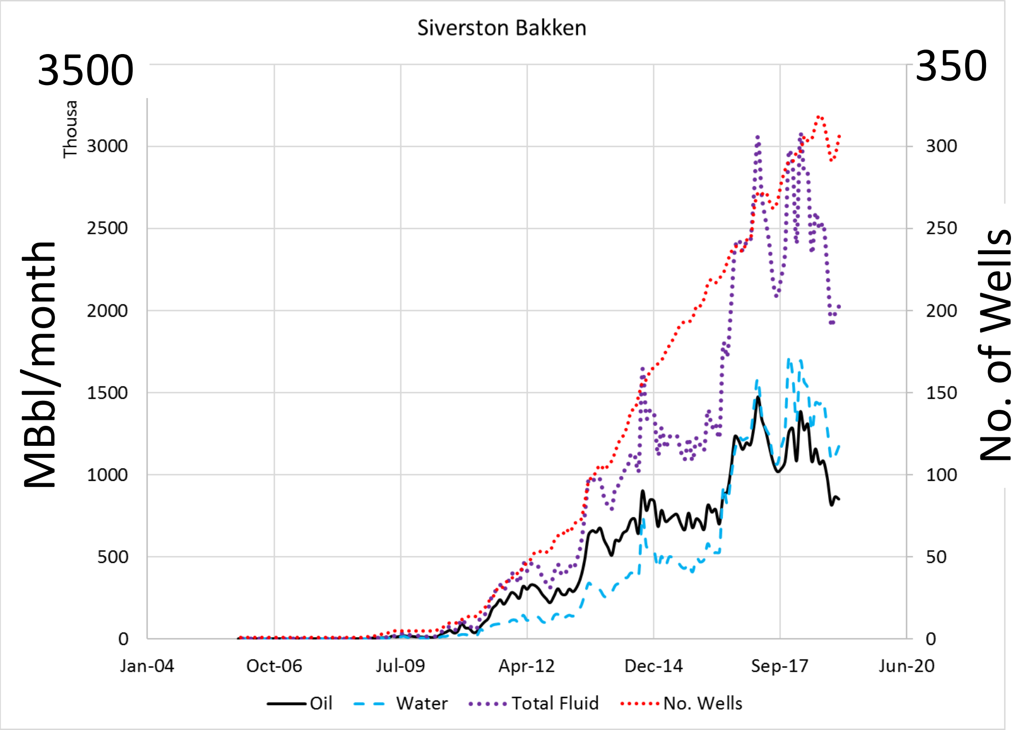
Fluid	ρ (kg m^{-3})	c_V (J kg^{-1} K^{-1})	m^3 h^{-1}	ΔT	J h^{-1}	Energy	
Oil	870	1830	132	42	8.8E+09	2,443	kWt
Water	1030	4181	159	42	2.88E+10	7,995	kWt
				ORC effic.	**10.78%**	**1,126**	**kWe**

SIVERSTON BAKKEN

High volume: High temperature
3,375 m, 286 Wells, T = 141 ºC



13 km



Calculations

Fluid	ρ (kg m^{-3})	c_V (J kg^{-1} K^{-1})	m^3 h^{-1}	ΔT	J h^{-1}	Energy	
Oil	870	1830	249	71	2.82E+10	7,823	kWt
Water	1030	4181	293	71	8.96E+11	24,894	kWt
				ORC effic.	**13.93%**	**4,559**	**kWe**

PRELIMINARY ECONOMICS

Based on Calnetix estimated efficiencies and costs.

Simple payback of Capex = 3.4 years

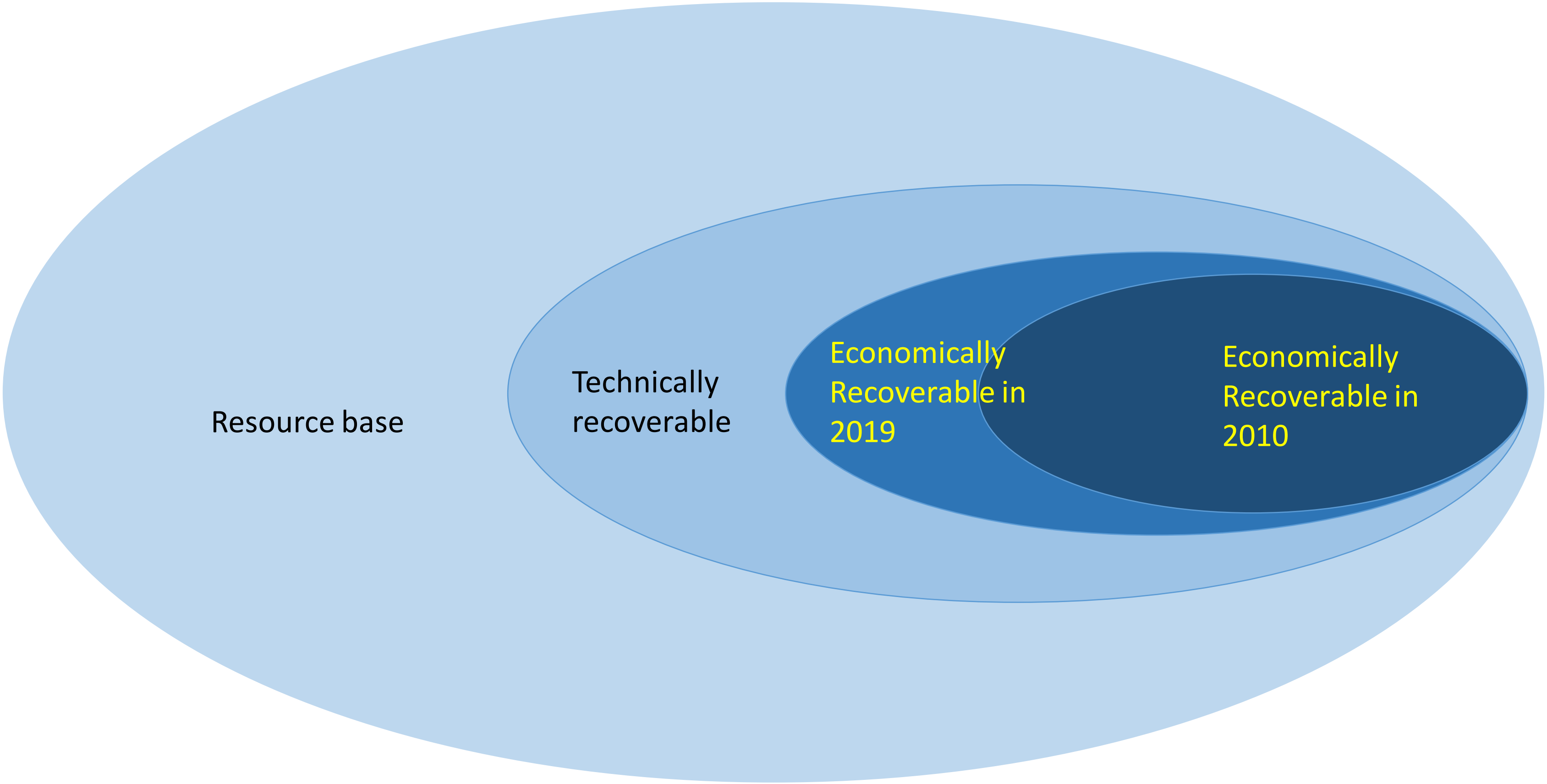
Field	Depth (m)	Temp (°C)	Flow (l/s)	Efficiency (%)	MWe	Revenue (annual)	No XLTs (125 kW)	Capex (@$2600/kW)
Banks Bakken	3395	144	168	14.2	5.4	$ 4,151,015	44	$14,040,000
Siverston Bakken	3375	141	151	13.9	4.6	$ 3,536,050	38	$11,960,000
Sanish Bakken	3220	114	145	11	2.0	$ 1,537,413	17	$5,200,000
Elm Tree Bakken	3250	136	75	13.4	1.8	$ 1,383,672	15	$4,680,000
Heart Butte Bakken	3215	112	81	10.8	1.1	$ 845,577	10	$2,860,000
Parshall Bakken	2930	100	135	9.4	1.1	$ 845,577	10	$2,860,000
Baker Bakken	3280	126	17	12.4	0.4	$ 307,483	4	$1,040,000
Clear Creek Bakken	3245	143	12	14.1	0.3	$ 230,612	3	$780,000

Assumptions:

- 100% capacity factor
- Revenue for 1 year of production
- Electricity price =US$0.0878 / kWh
- Capex costs assume US$2600/kW (from Calnetix)
- No Opex or other costs considered

LOOKING TOWARDS THE FUTURE…..

Advances in technology are improving economics –
And the trend is set to continue!

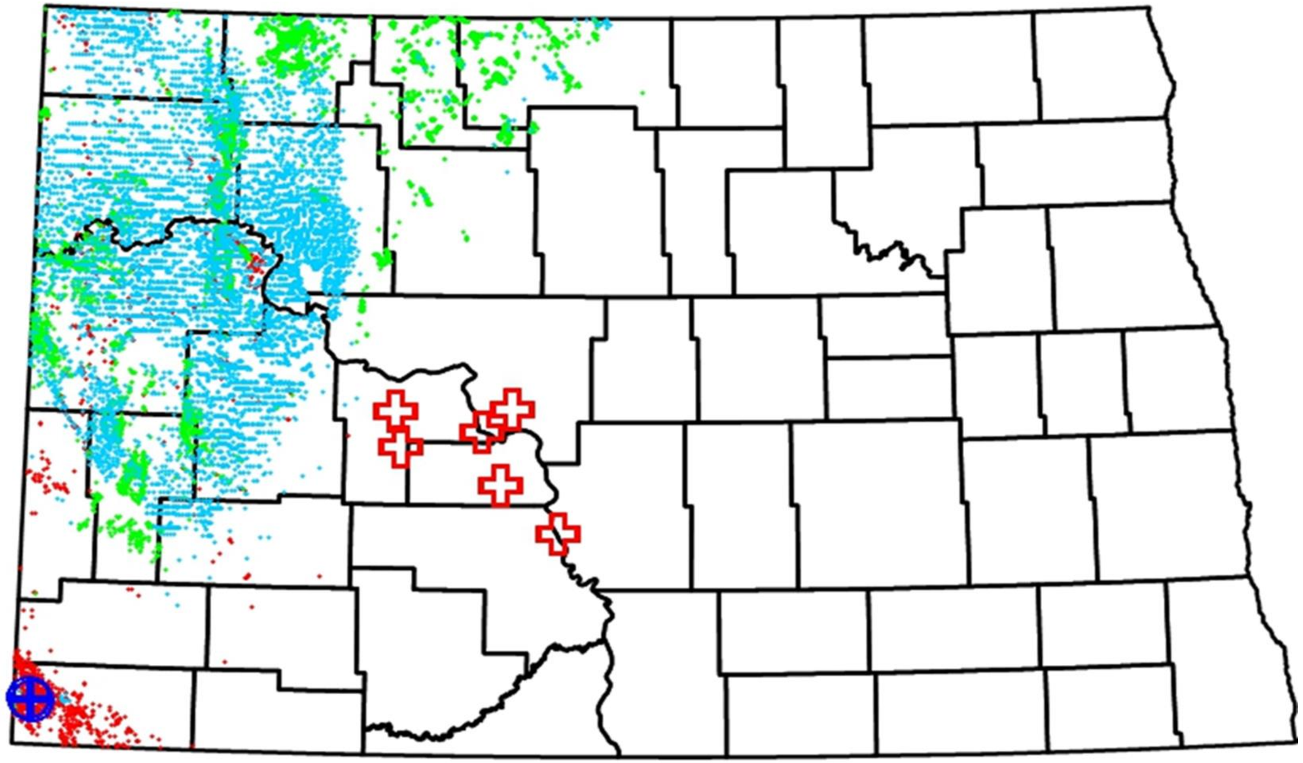


CONCLUSIONS

- Preliminary analysis shows co-production looks economic now - and will get better
- Efficiency of low temperature ORCs has improved dramatically
- Multiple horizontal wells drilled from common pad generate substantial fluid volumes – commercially adequate
- Large number of wells in Williston Basin creates big power demand
- Existing power grid inadequate and local generation is expensive

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



Discussion – Caveats and Key Points

- This analysis assumes that geothermal fluid flow can be concentrated at distributed collection points for ORC operations.
- All wells will not produce equally – detailed analysis required to select best locations for project.
- Integration with existing infrastructure (production/injection well locations) required
- Must work closely with oil company to minimize operational disruptions
- Potential to significantly reduce oil field Opex (each ESP uses 16-25 kW)
- Specific heat of water>oil – as water cut increases, extractable heat should also increase
- Impact on abandonment decisions? Fluid production rates?

FUTURE CONSIDERATIONS

- Repurpose depleted wells for optimal water production
- Drill down to Red River or other deeper formation
- Sedimentary EGS associated with naturally fractured Deadwood?