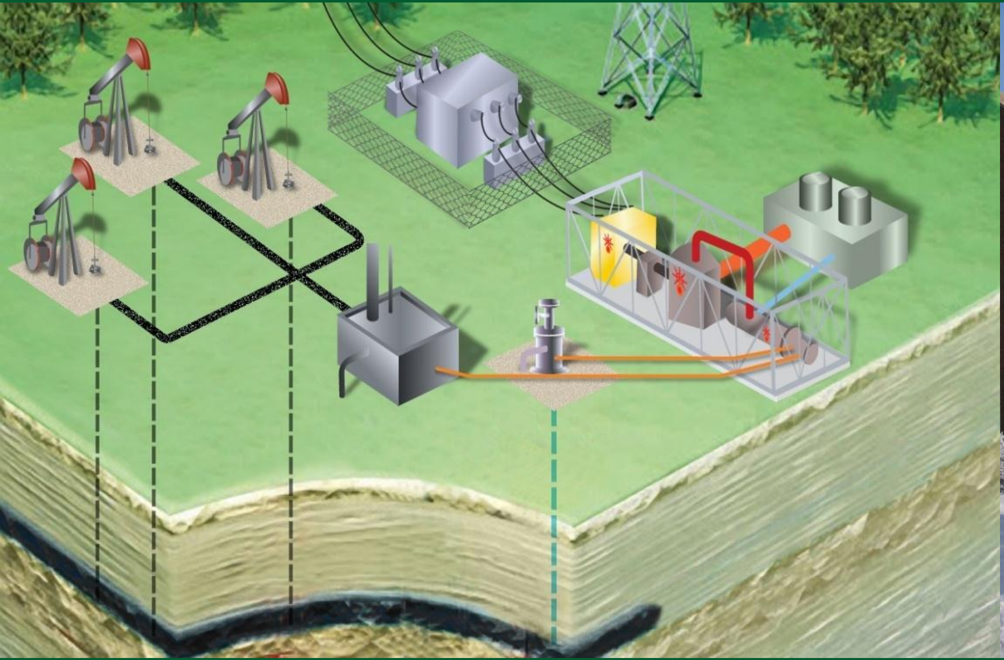
The University of North Dakota

Petroleum Research, Education, and Entrepreneurship Center

NORTH DAKOTA GEOTHERMAL PROJECTS

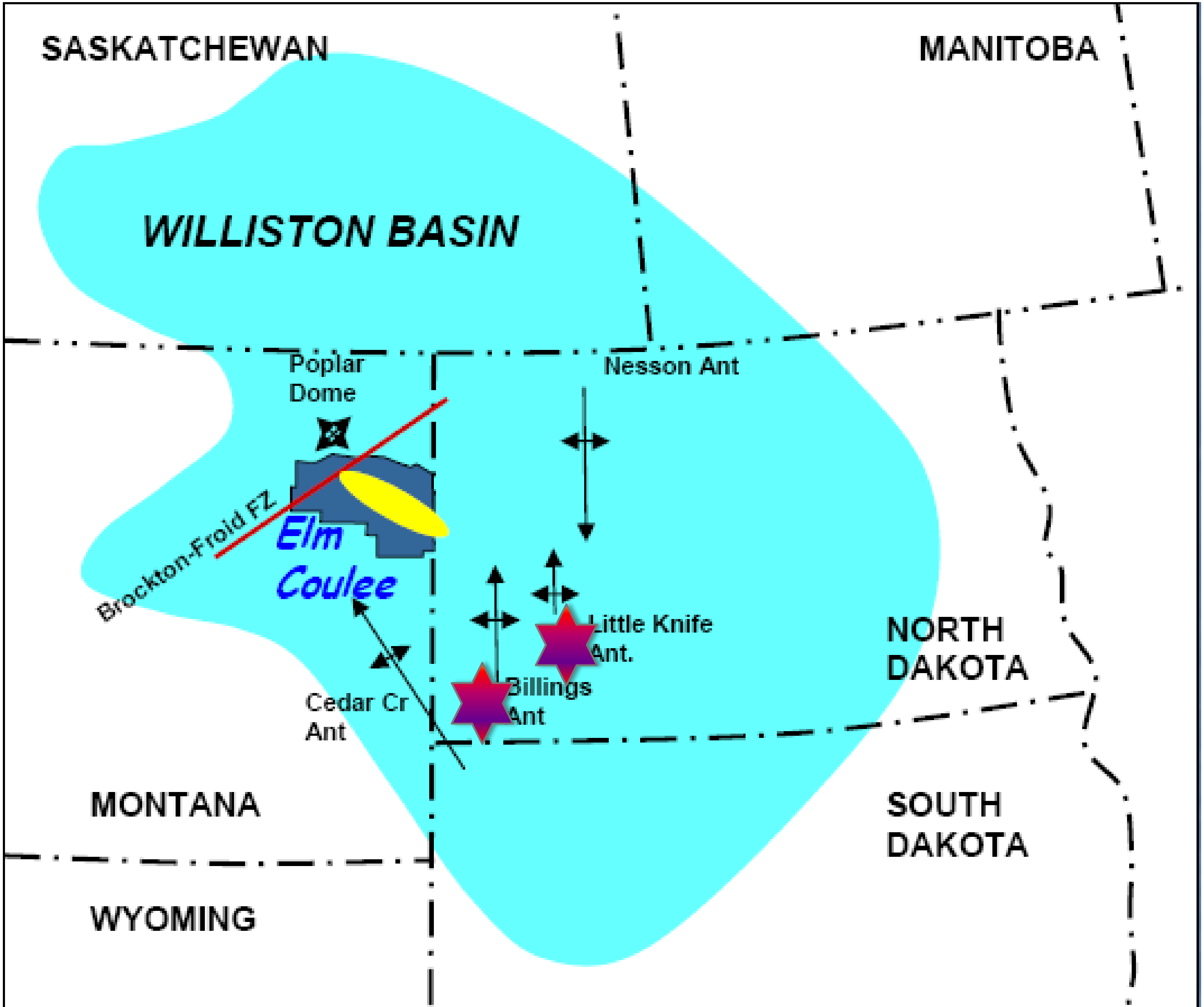
WILL GOSNOLD



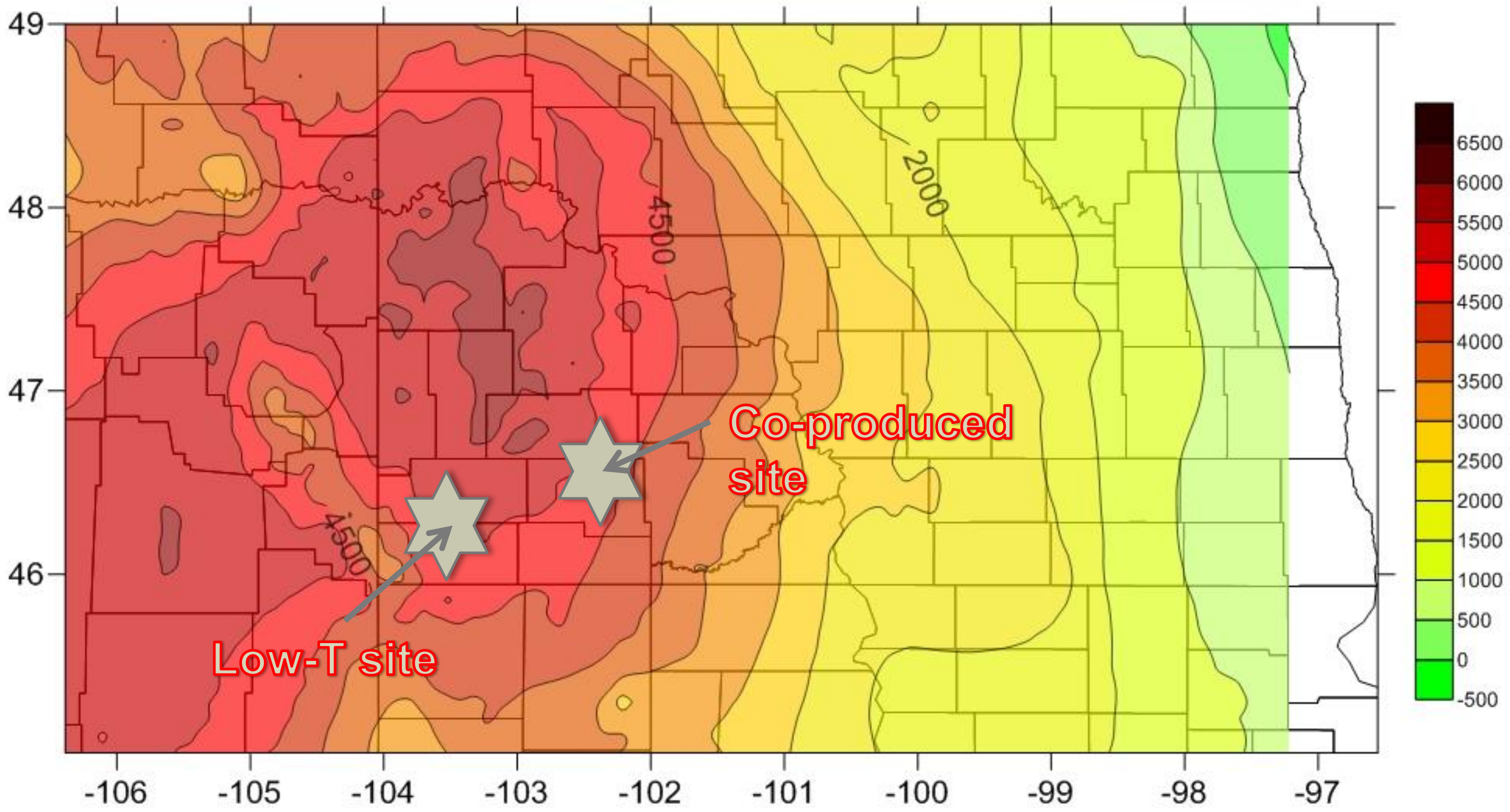
Geothermal Energy Utilization
Associated with Oil and Gas Development
Southern Methodist University, Dallas, Texas
June 13-15, 2011

OUTLINE

- **ND and Williston Basin**
- Project and Partners
- **Phase I tasks**
  - Energy conversion systems
  - Economics, electrical power concepts
- Other prospects in the basin
  - Geology, fields, fluids, temperatures


SASKATCHEWAN
MANITOBA
WILLISTON BASIN
Poplar Dome
Nesson Ant
Brockton-Froid FZ
Elm Coulee
Little Knife Ant.
Billings Ant
Cedar Cr Ant
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
WYOMING

WILLISTON BASIN BINARY POWER PROJECT SITES



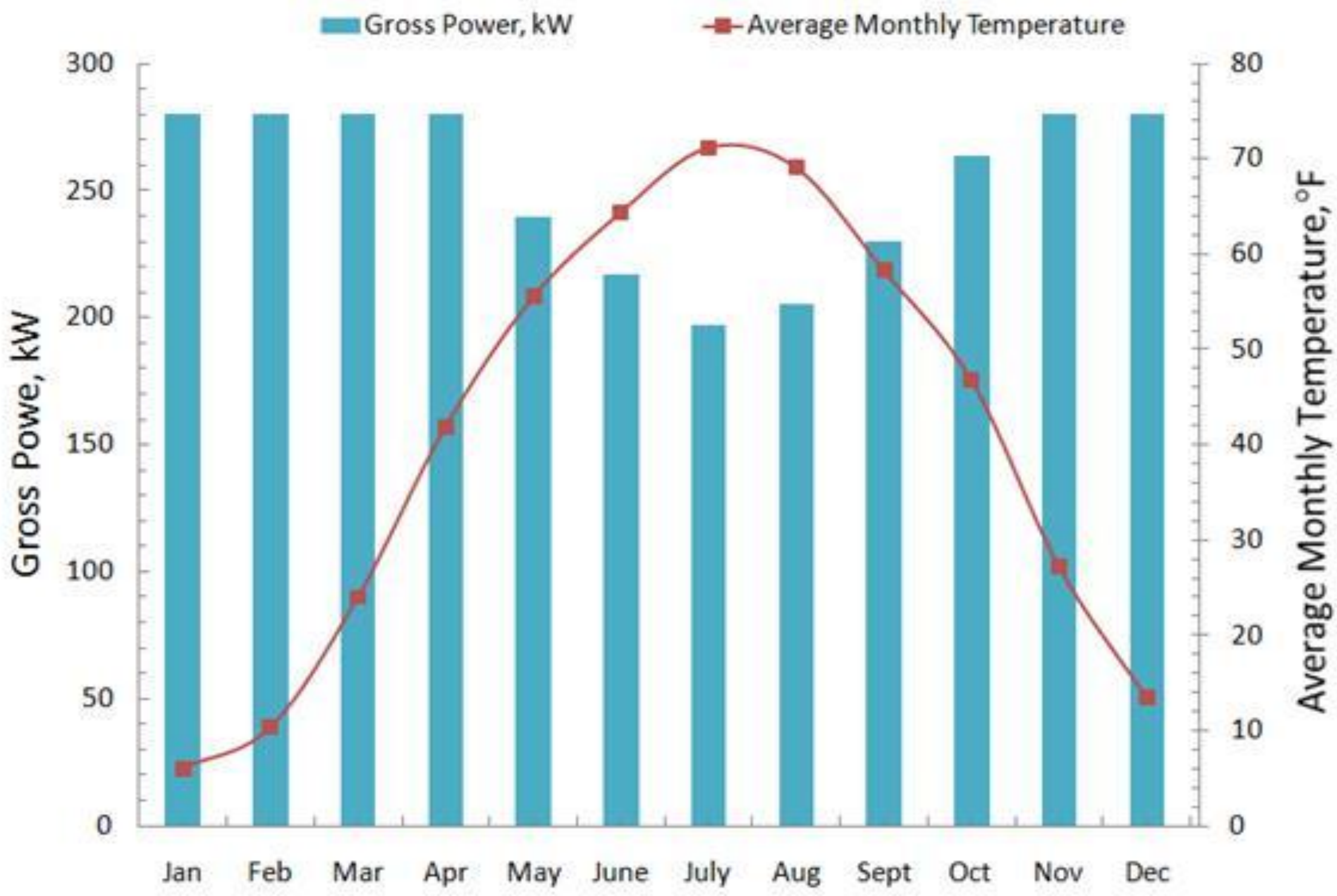
PRO FACTORS FOR BINARY POWER FROM CO-PRODUCED FLUIDS IN WILLISTON BASIN

- **Future need for power**
- **High temperatures in producing formations**
- **Cool climate yields high ΔT for air cooling**
- **Extensive drilling:**
  - 19,711 wells drilled
  - 5,031 TA or shut-in wells
  - 450 multi-well pads

CON FACTORS FOR BINARY POWER FROM CO-PRODUCED FLUIDS IN WILLISTON BASIN

- Lack of water for water cooling
- Low water production (2-5 X oil production)
- High TDS in water east of Cedar Creek Anticline
- Low price of electricity

GROSS POWER OUTPUT AS A FUNCTION OF AVERAGE MONTHLY TEMPERATURE

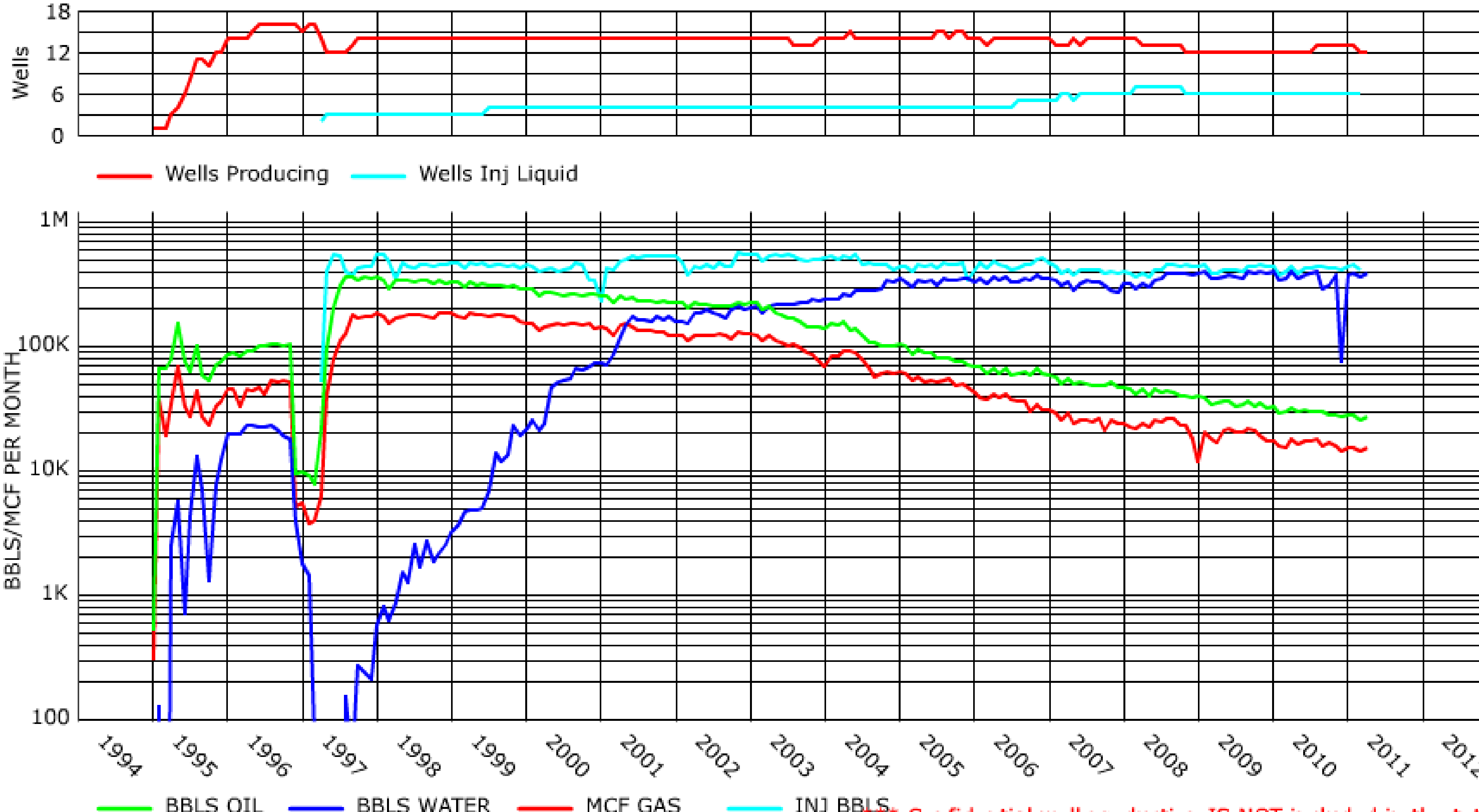


res & Well History

Field Name = **ELAND**

Pool = **LODGEPOLE**

5/2/2011 10:



*** Confidential well production IS NOT included in the tot

WB WATER PRODUCTION

- **Water production in Williston Basin is low compared to other oil producing basins**
- **Formations pumped for water yield 20 to 200 times as much water as those pumped for oil**

FORMATION	BARRELS OF OIL	BARRELS OF WATER	MAX. TEMP C
Spearfish	582,601	320,626	120+
Spearfish/Madison/Charles	52,923,055	81,138,008	120+
Tyler	17,279,723	9,616,114	120+
Madison	1,003,859,751	2,266,631,018	132
Bakken (Sanish)	43,079,616	4,876,685	135+
Birdbear (Nisku)	16,532,269	19,875,577	135+
Duperow	48,360,560	51,290,164	135+
Souris River	58,090	61,886	140+
Dawson Bay	3,985,365	1,191,086	145+
Winnipegosis	8,853,724	6,663,034	145+
Interlake	62,397,829	140,808,361	145+
Stonewall	14,699,878	5,134,309	145+
Winnipegosis	8,853,724	6,663,034	145+
Red River	162,448,927	162,167,866	150+
Winnipeg/Deadwood	168,170	256,474	150+
Total	1,602,219,737	2,927,676,055	

PROJECTS AND PARTNERS

Low Temperature Fluids

- Cedar Creek Field - Water Flood – Bowman, County, ND
  - 210 °F, 875 gpm, low TDS water from the Lodgepole Fm.
  - One of five wells – total available water 1,750 gp

Partners

- Continental Resources, Inc.
- Calnetix, Inc.

MARMARTH, ND LOW-TEMPERATURE SITE

CO-PRODUCED FLUIDS

- Eland Lodgepole Field – Dickinson, ND
  - 210 °F, 470 gpm, high TDS water from Lodgepole Fm.
  - 12 wells in unitized field
  - Patterson Lake potential water cooling source
- Denbury, Inc.

DICKINSON, ND CO-PRODUCED SITE

ENERGY CONVERSION EVALUATION

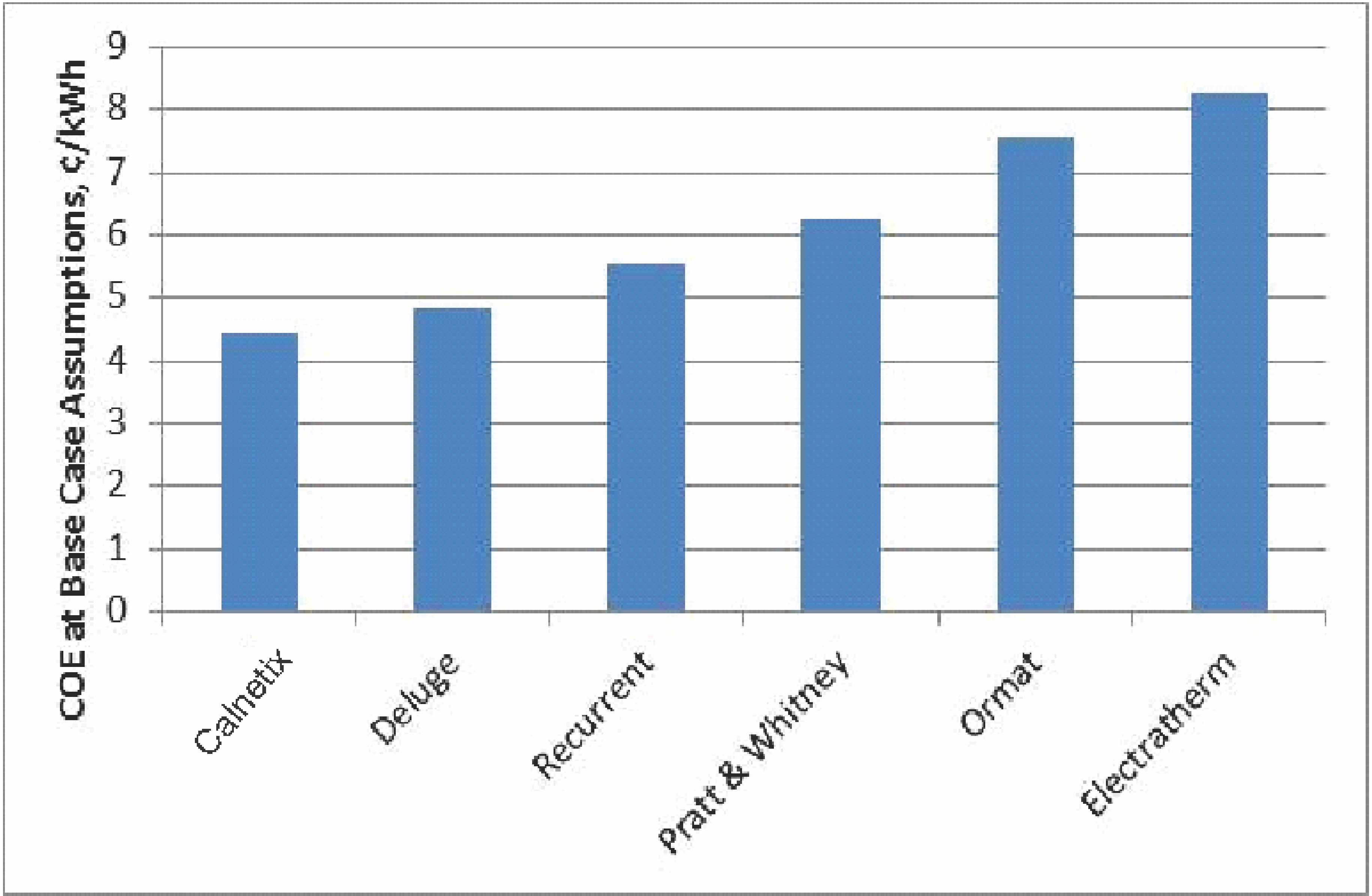
Feature	Ormat	Pratt & Whitney	Deluge	Recurrent	Electratherm	Calnetix
Output (kW)	350	430	1750	845	235	550
Net kW	300	407	1487.5	750	191	495
Footprint (sq. ft.)		420	2800	124	3406	100
Remote operation	yes	yes	yes			yes
Cooling	air	air	not provided	not provided	Forced air	Forced air
No. machines	1	2	7	1	5	2
Working fluid	R245fa	R245fa	liquid $C0_2$	H_2O & NH_3	R245fa	R245fa
Delivery	10 mos	4 mos	4 to 7 mos	10 mos	4 mos	9 mos
Cost	$1,600,000	$1,175,000	$4,165,000	$1,926,500	$965,665	$1,475,000
Extra Infrastructure	none	Building	Building	Building	Building	none
Extra costs for cooling	0	$565,000	$350,000	$565,000	$250,000	0
Warranty	1 yr.	1 yr,	1 yr.	1 yr.	ext 5 y., included	18/12
Outdoor/Indoor	Outdoor	Indoor	Indoor	Indoor	Indoor	Outdoor

ENERGY CONVERSION EVALUATION

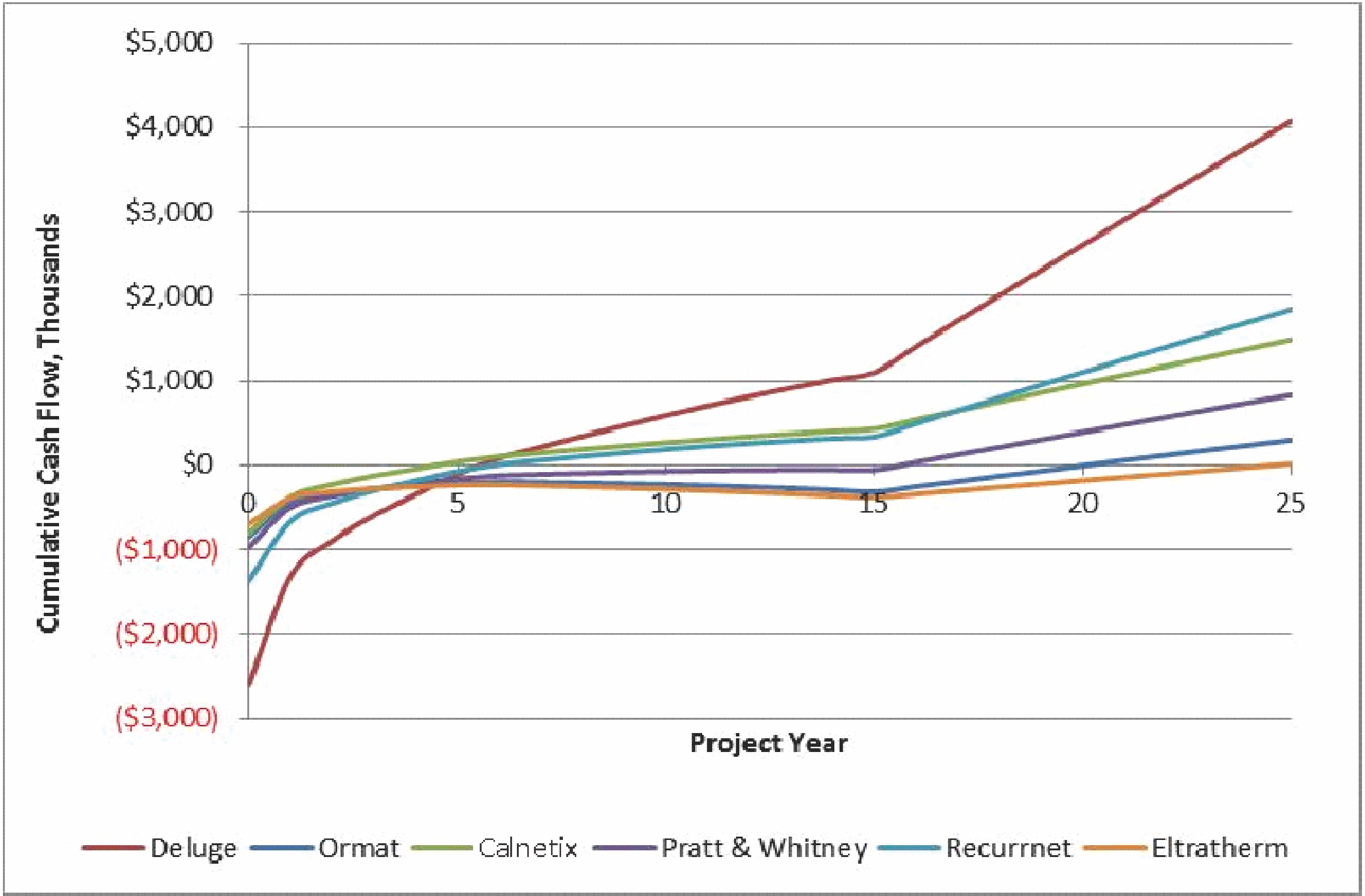
Feature	Ormat	Pratt & Whitney	Deluge	Recurrent	Electratherm	Calnetix
Output voltage	480	480	480	480	480	350 -500
Shipping	we pay	yes				we pay
Performance guarantee	yes			yes		yes
Insulation for HE and Pipe	yes					
Connection to grid	no	yes	no	no	no	yes
Transportation to site	yes	yes	unknown	unknown	yes	no
Special	no pad req.	Turnkey install.	pad req.	no pad req.	pad req.	no pad req.
Infrastructure	$10,000	$60,000	$60,000	$60,000	$60,000	$10,000
Total Cost	**$1,610,000**	**$1,800,000**	**$4,575,000**	**$2,551,500**	**$1,275,665**	**$1,485,000**
Cost per kW	**$5,367**	**$4,423**	**$3,076**	**$3,402**	**$6,679**	**$3,000**
Yearly sales $.05/kWh	**$124,912**	**$169,464**	**$619,356**	**$312,280**	**$79,527**	**$206,105**
Years to cover investment	**12.9**	**10.6**	**7.4**	**8.2**	**16.0**	**7.2**

DOE CREST MODEL RESULTS

Cost of Renewable Energy Spreadsheet Tool

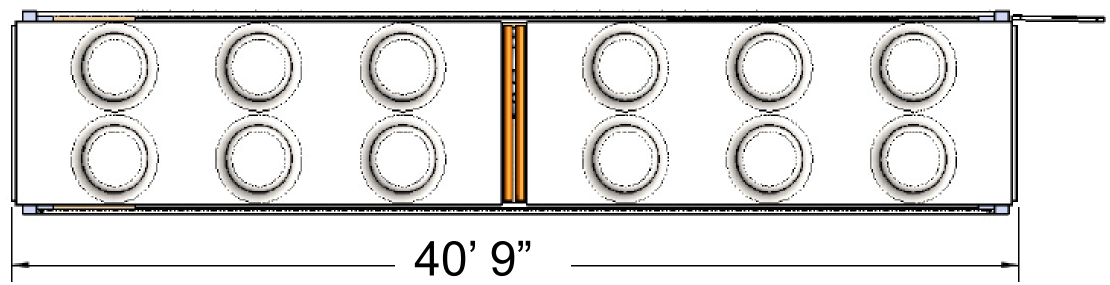


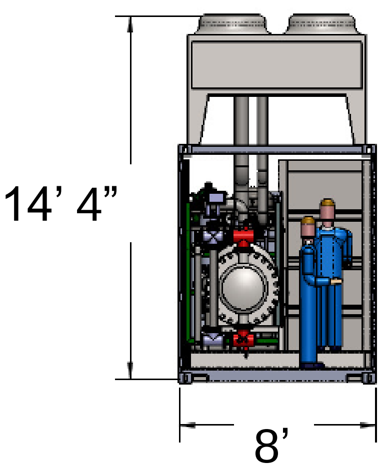
CUMULATIVE CASH FLOW USING $.05 PER KWH LEVELIZED COST OF ELECTRICITY

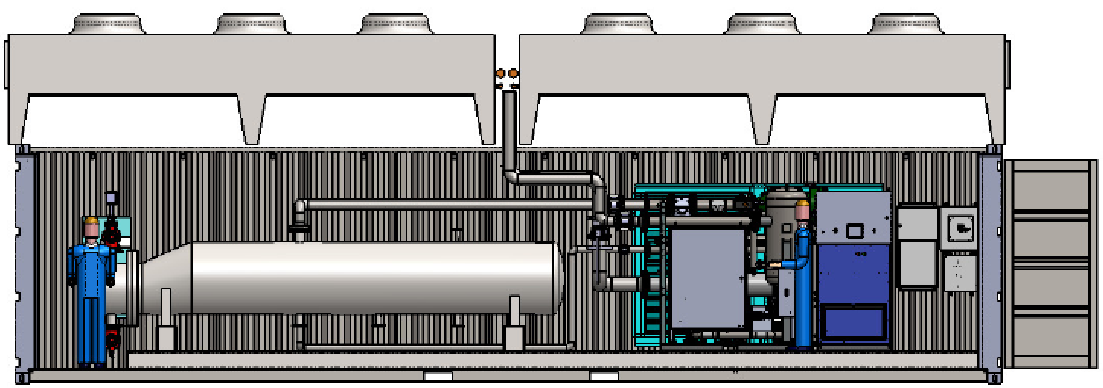


Calnetix ORC System

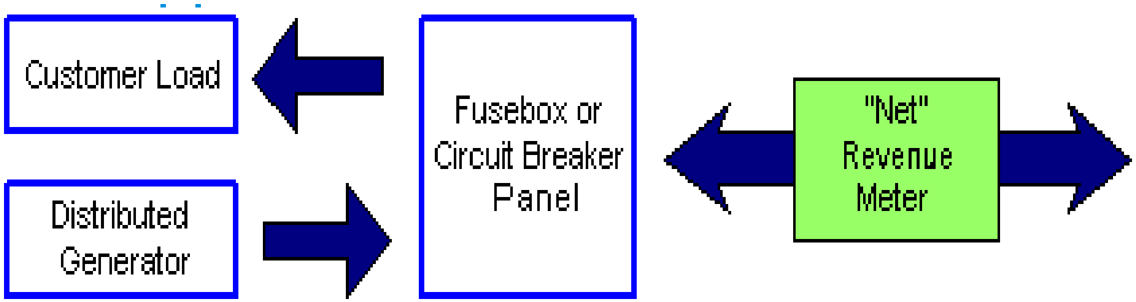
- Minimal on-site engineering
- Skid-mounted
- Direct electrical connect
- Top-mounted air cooling
- High efficiency



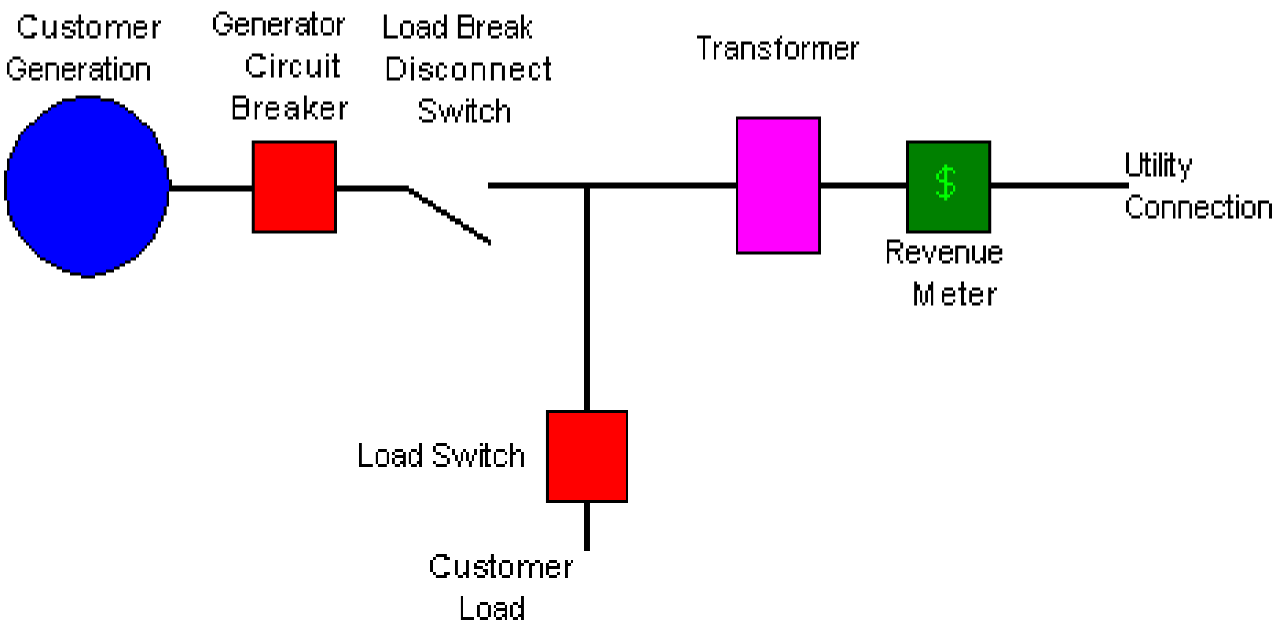




Net Metering Schematic



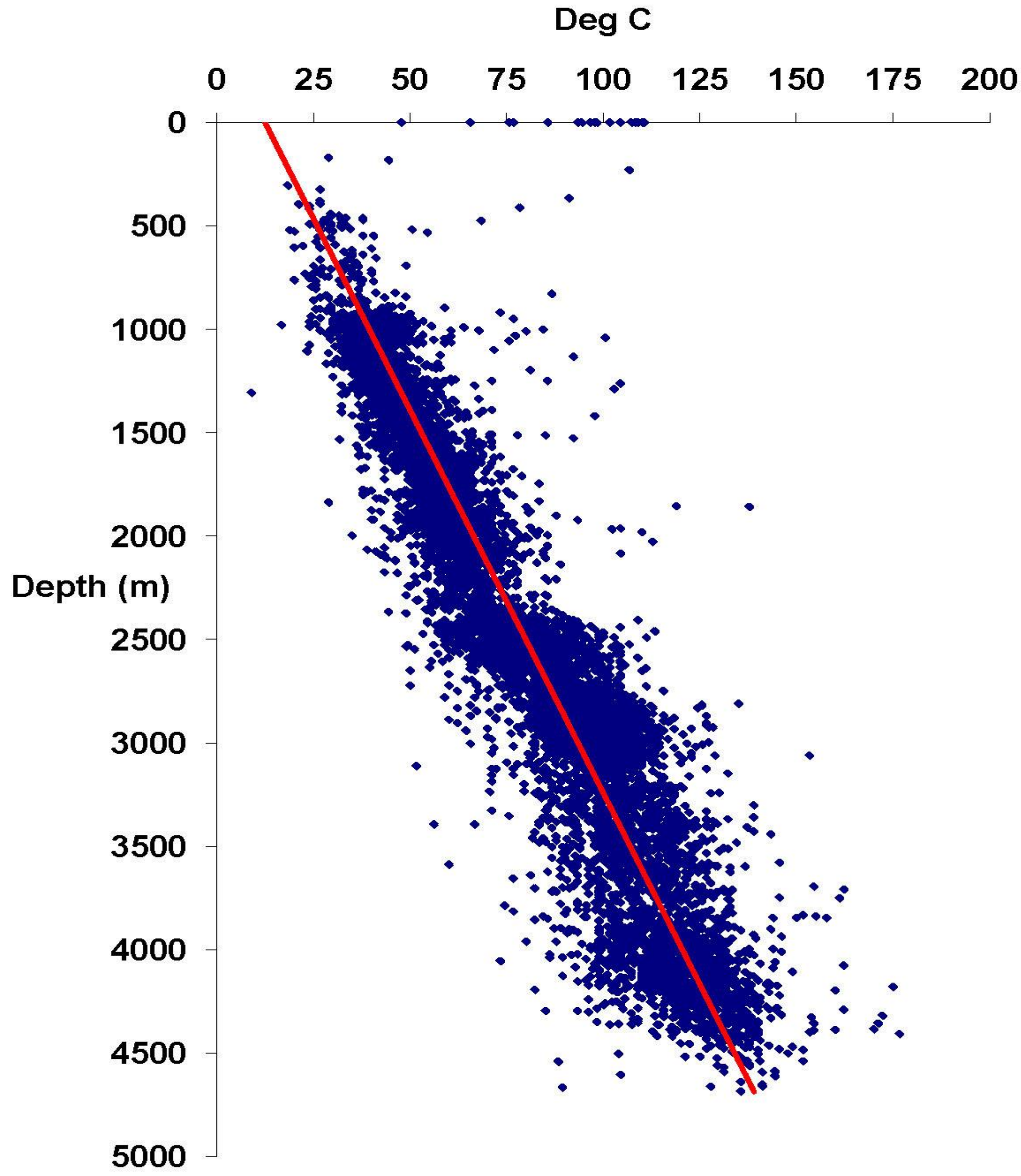
Standby Schematic



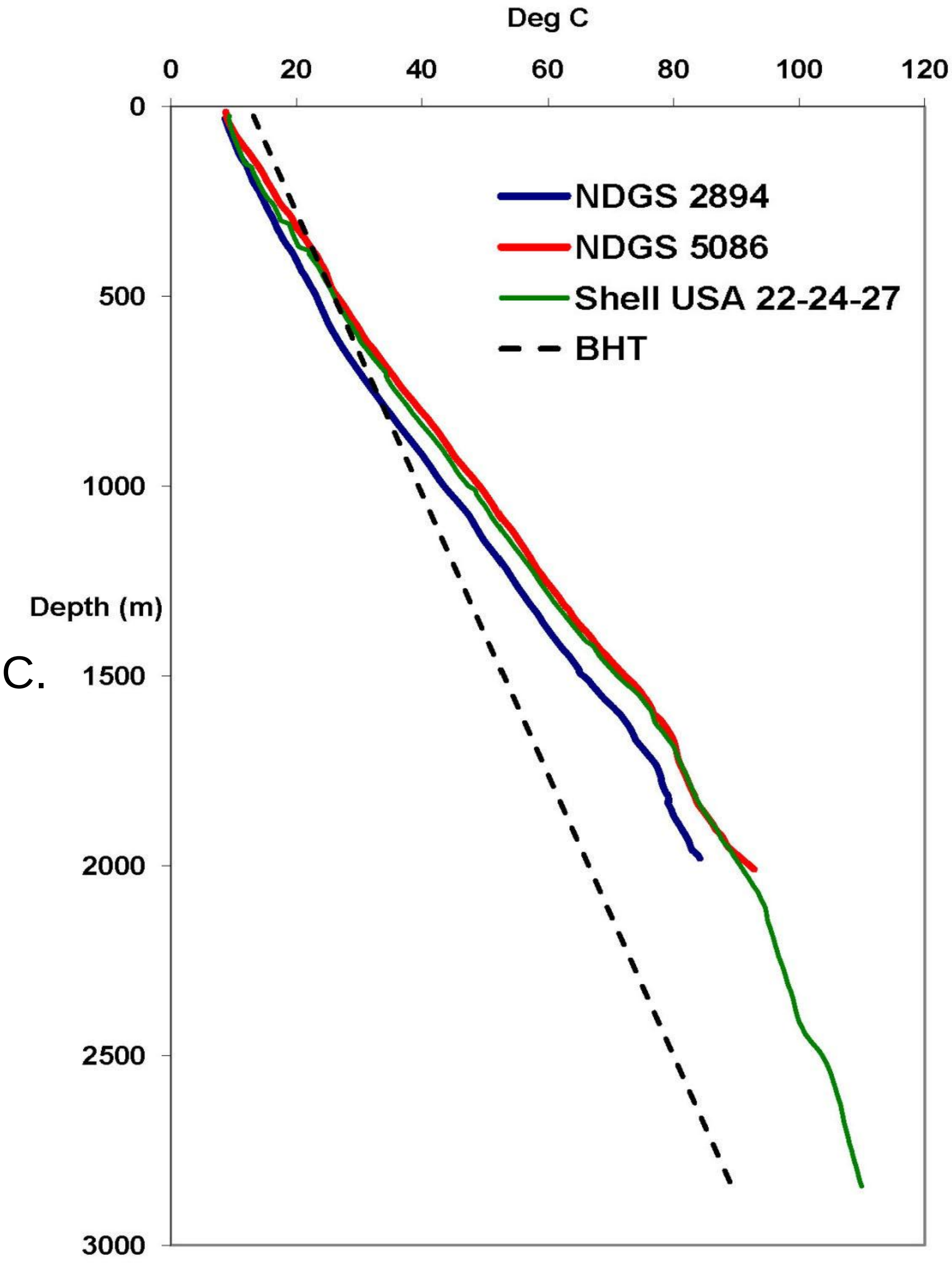
WILLISTON BASIN RESOURCE EVALUATION

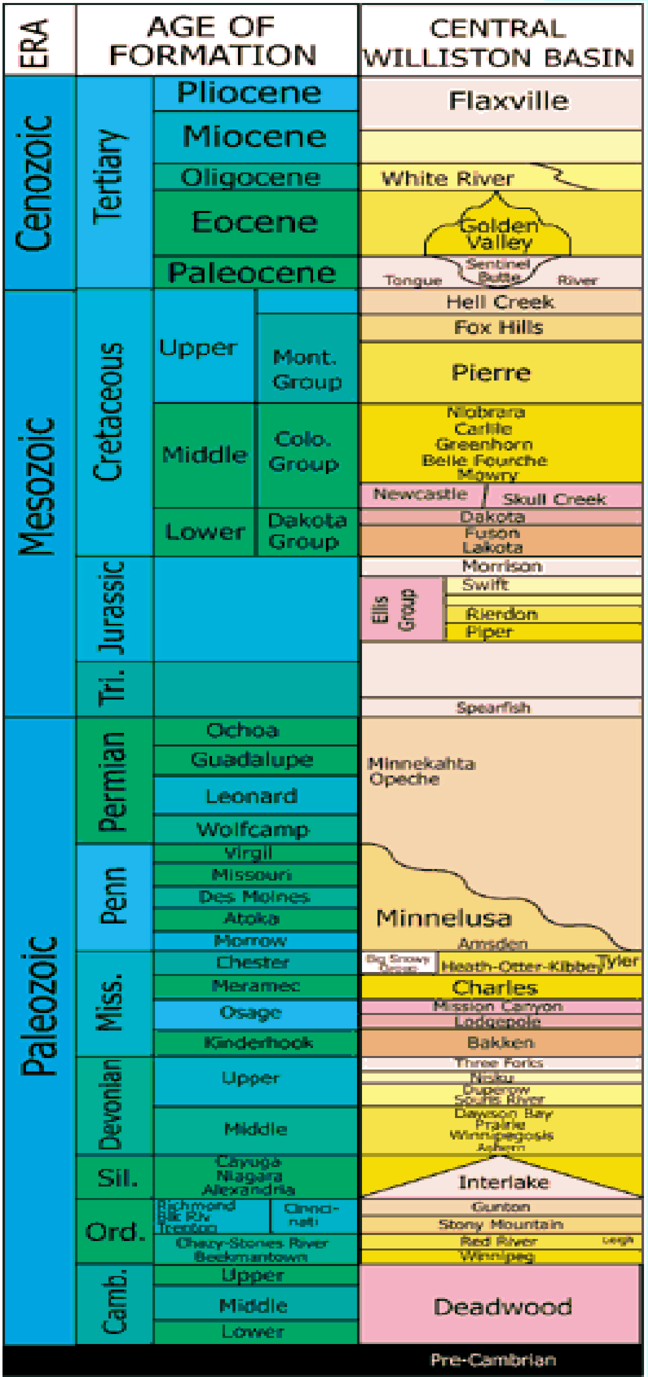
- **10,989 BHTs**
- **Formation temperatures and depths for 5,031 abandoned or shut in wells**
- **Formation temperatures and depths for 5,922 active wells**
- **Water and oil production volumes and rates for 6,115 active wells**
- **33 conventional heat flow measurements**
- **303 heat flow estimates from bottom-hole temperatures**
- **368 thermal conductivity measurements on core samples**

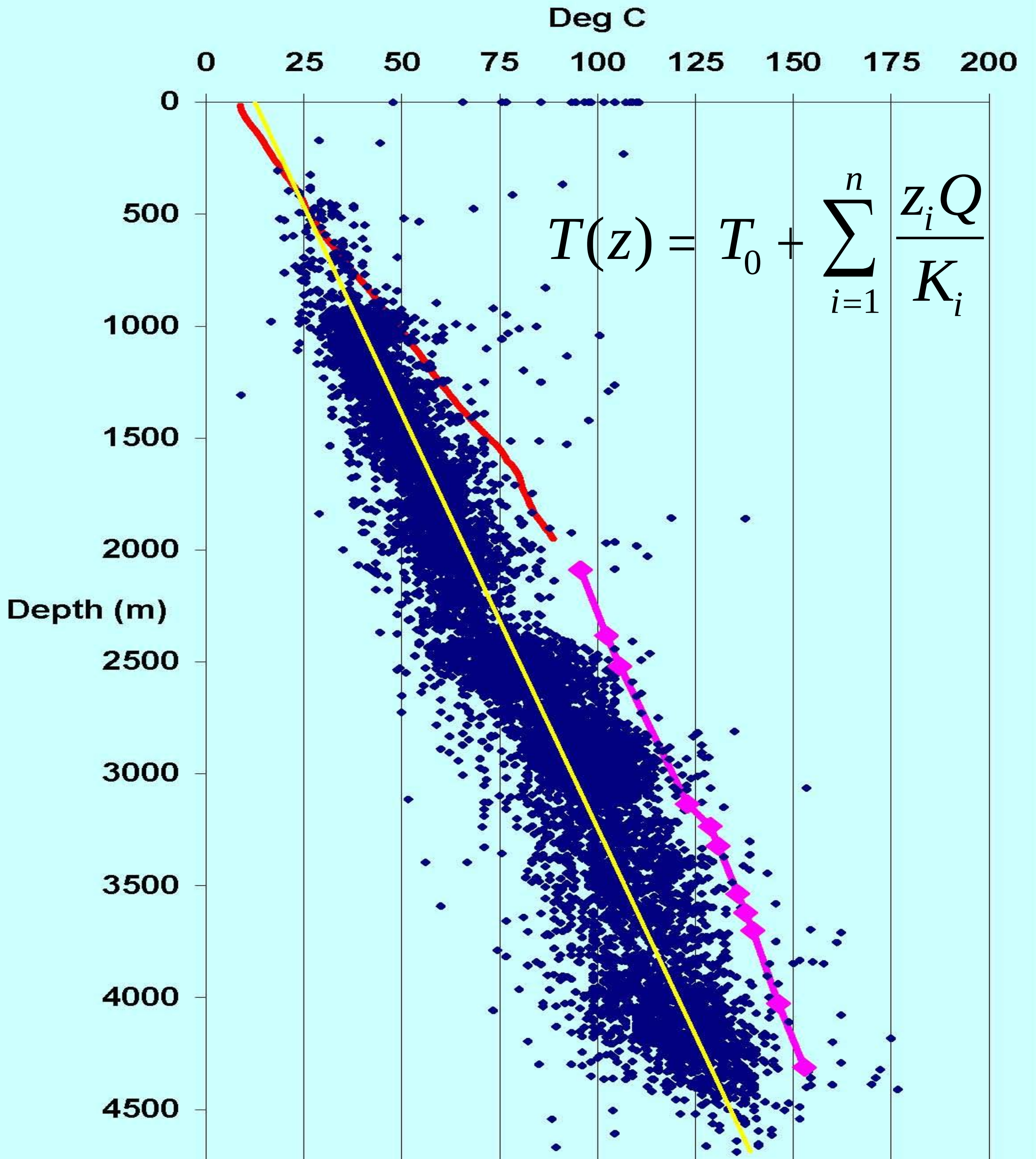
Williston Basin
BHTs



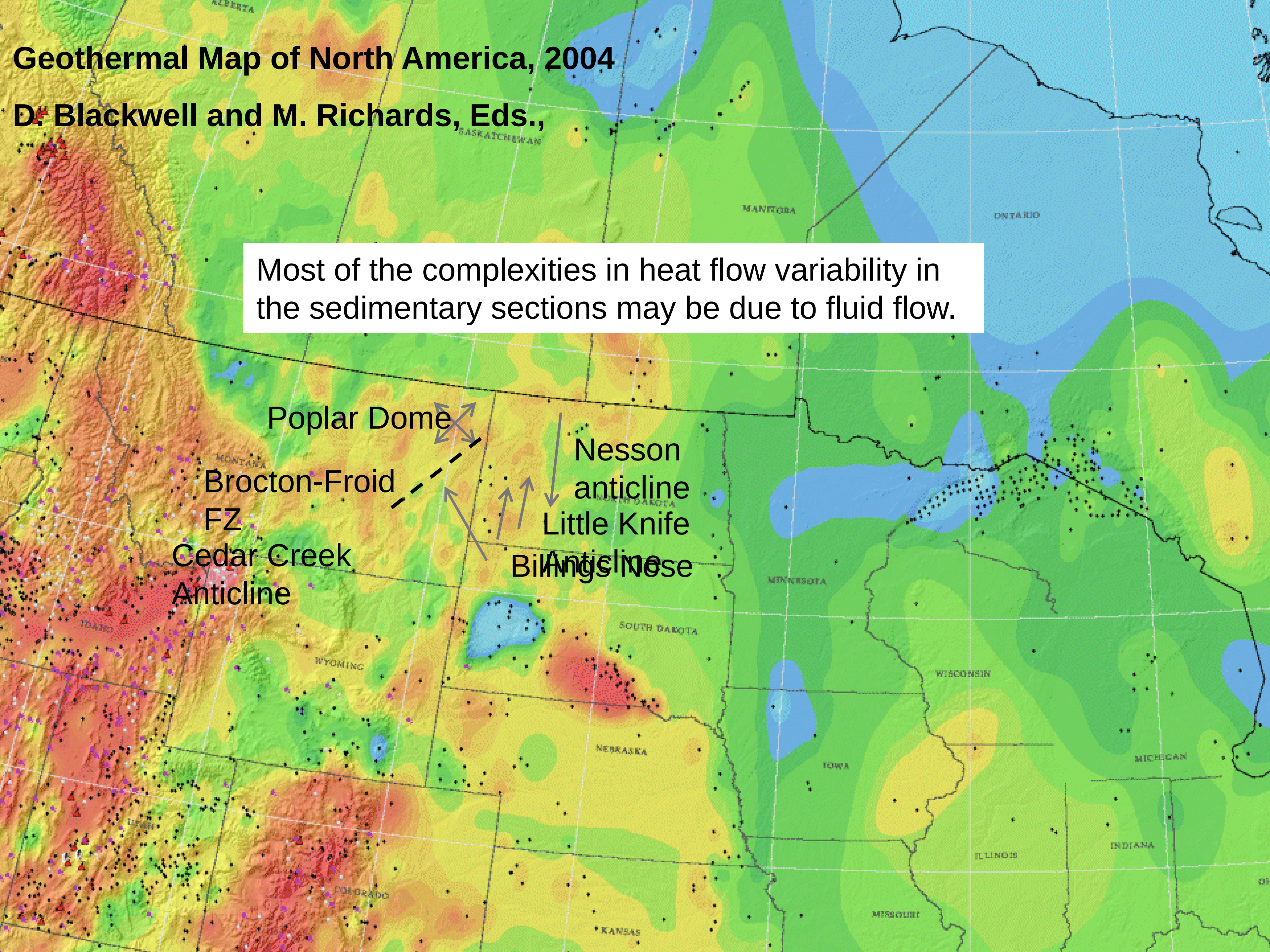
The linear fit to the BHT data under estimates the temperatures at depth by 25 °C.





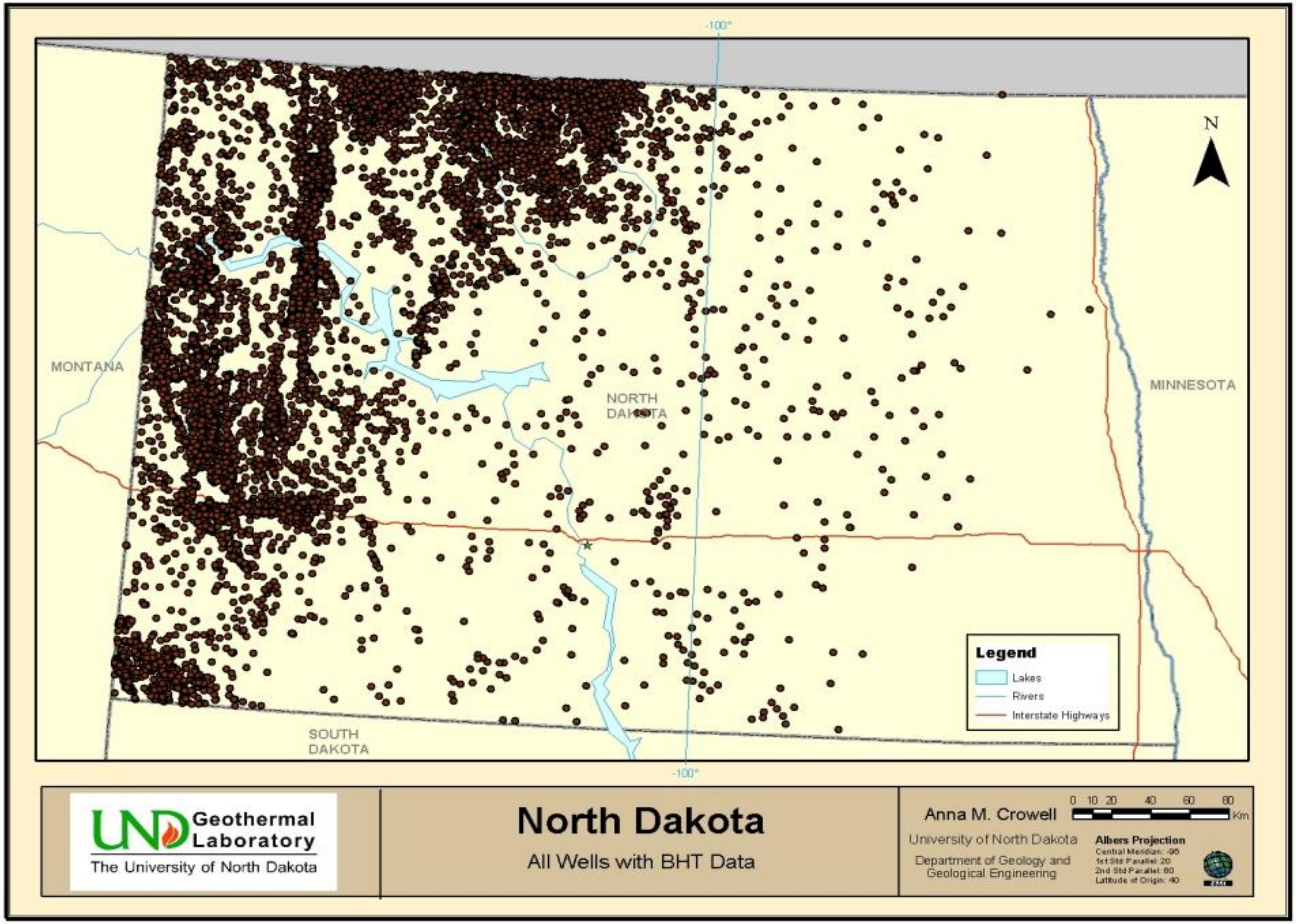


$$T(z) = T_0 + \sum_{i=1}^{n} \frac{z_i Q}{K_i}$$



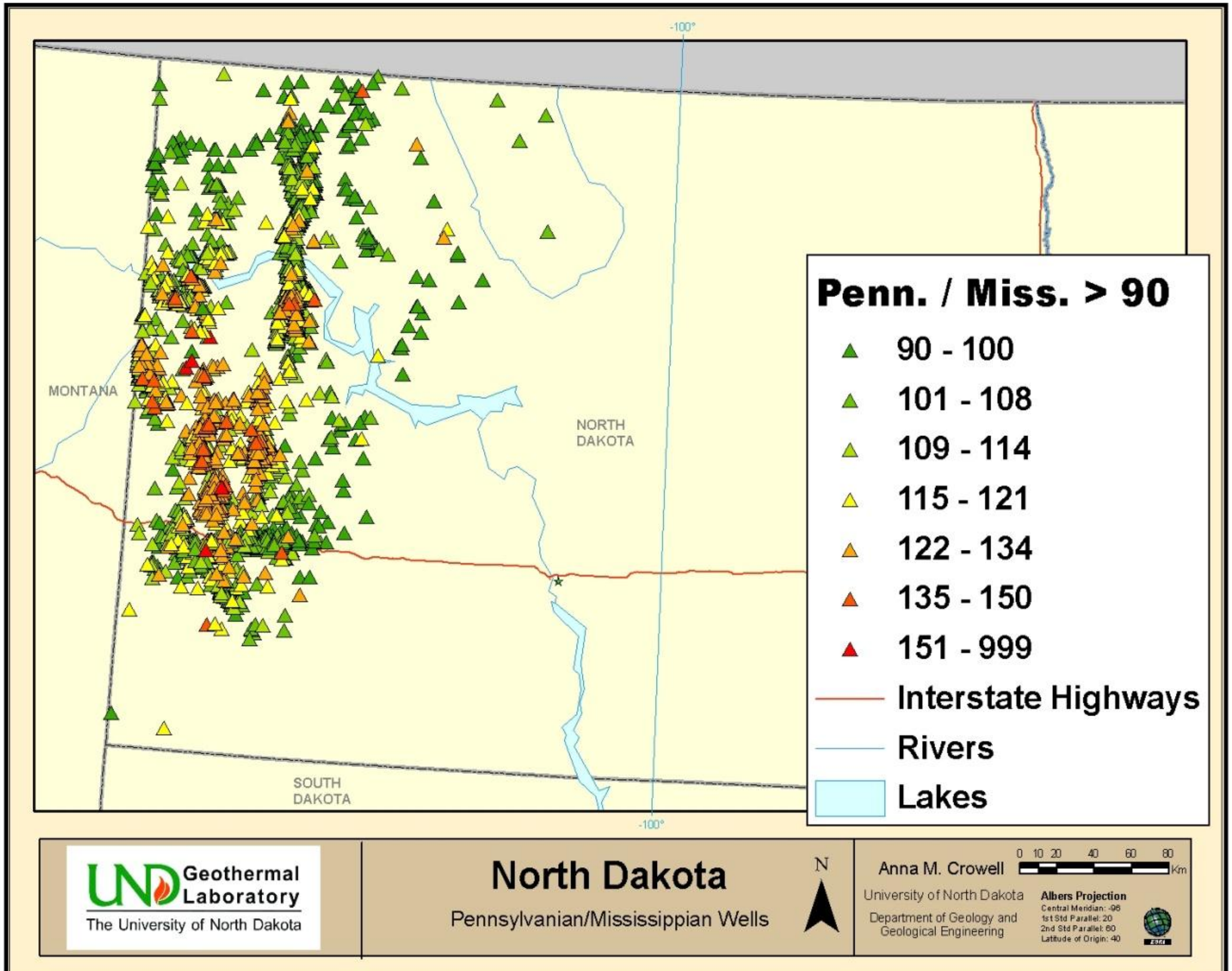
Geothermal Map of North America, 2004
D. Blackwell and M. Richards, Eds.,
Most of the complexities in heat flow variability in the sedimentary sections may be due to fluid flow.
Poplar Dome
Brocton-Froid FZ
Cedar Creek Anticline
Nesson anticline
Little Knife Anticline
Billings Nose
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
IDAHO
WYOMING
NEBRASKA
IOWA
MICHIGAN
COLORADO
KANSAS
ILLINOIS
INDIANA
MISSOURI

19,711 WELLS

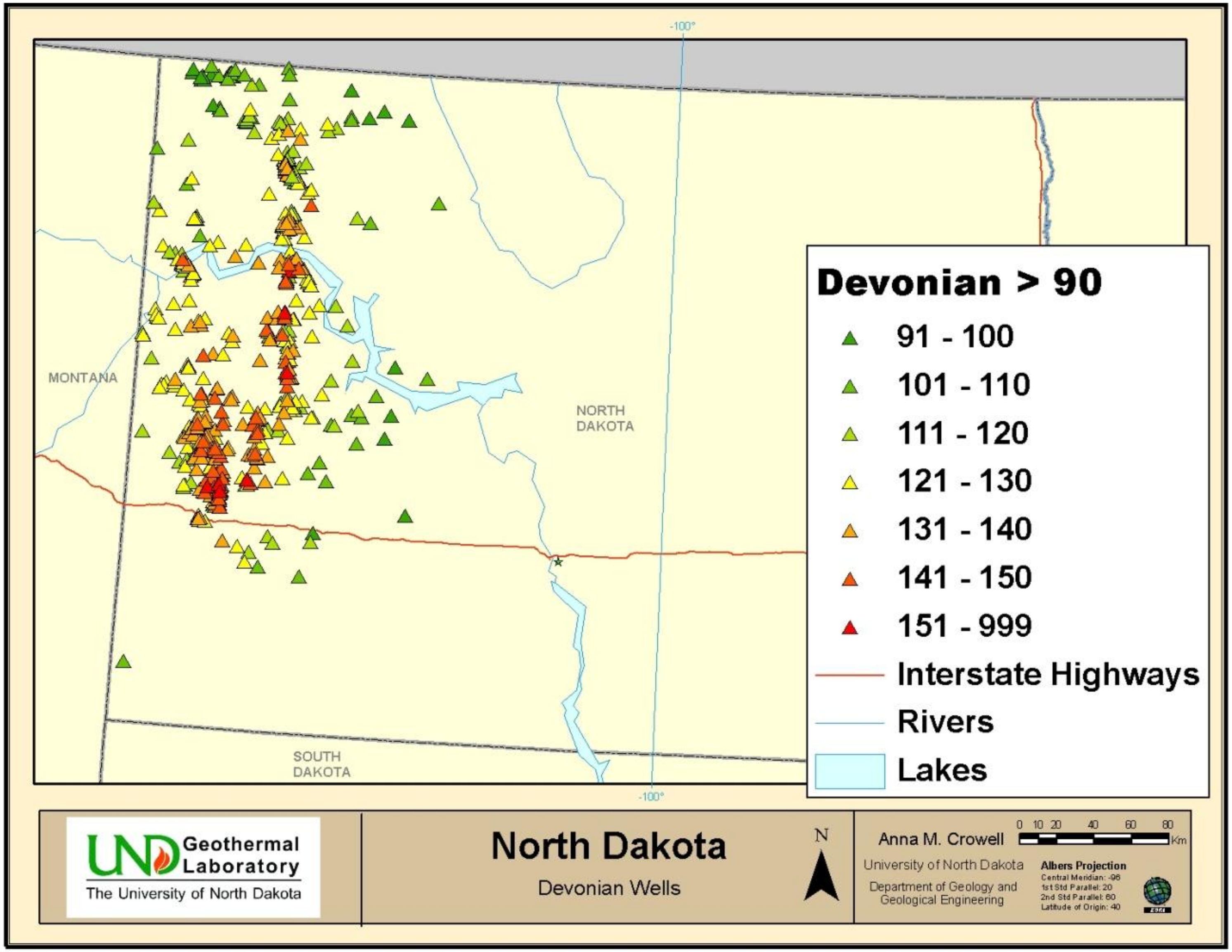


-100°
MONTANA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
N
Legend
Lakes
Rivers
Interstate Highways
UND Geothermal Laboratory
The University of North Dakota
North Dakota
All Wells with BHT Data
Anna M. Crowell
University of North Dakota
Department of Geology and Geological Engineering
0 10 20 40 60 80 Km
Albers Projection

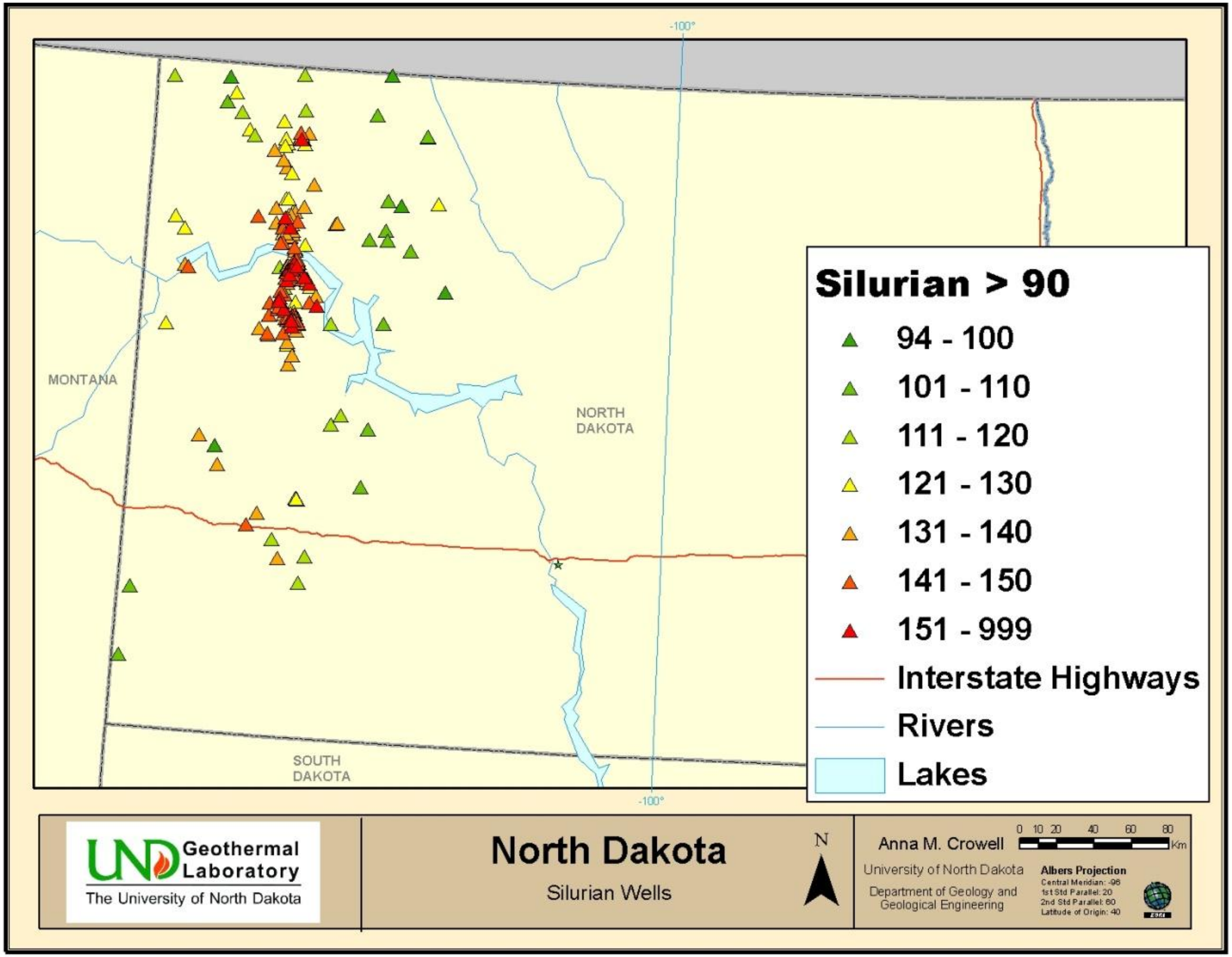
PENNSYLVANIAN& MISSISSIPPIAN BHTS



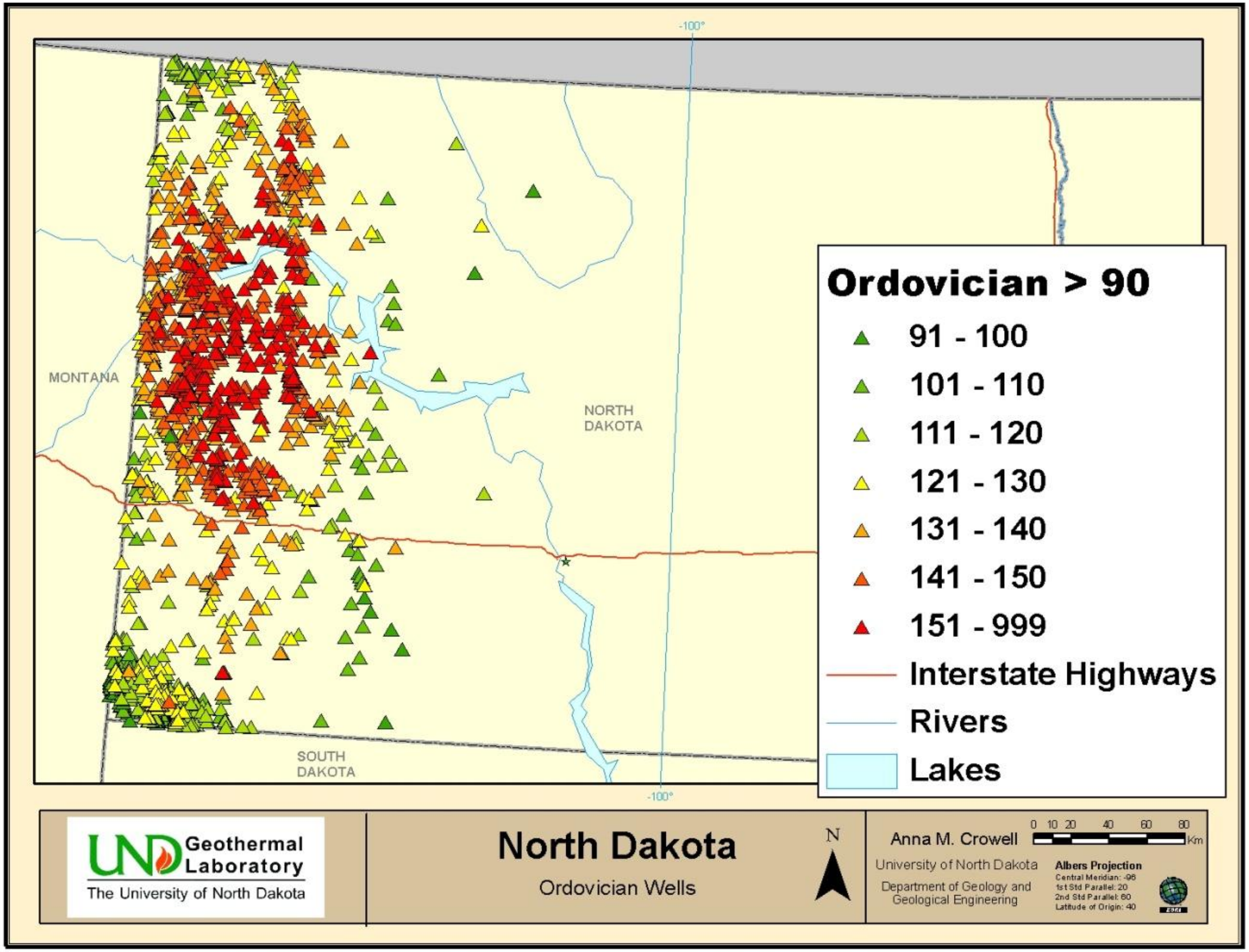
DEVONIAN BHTS



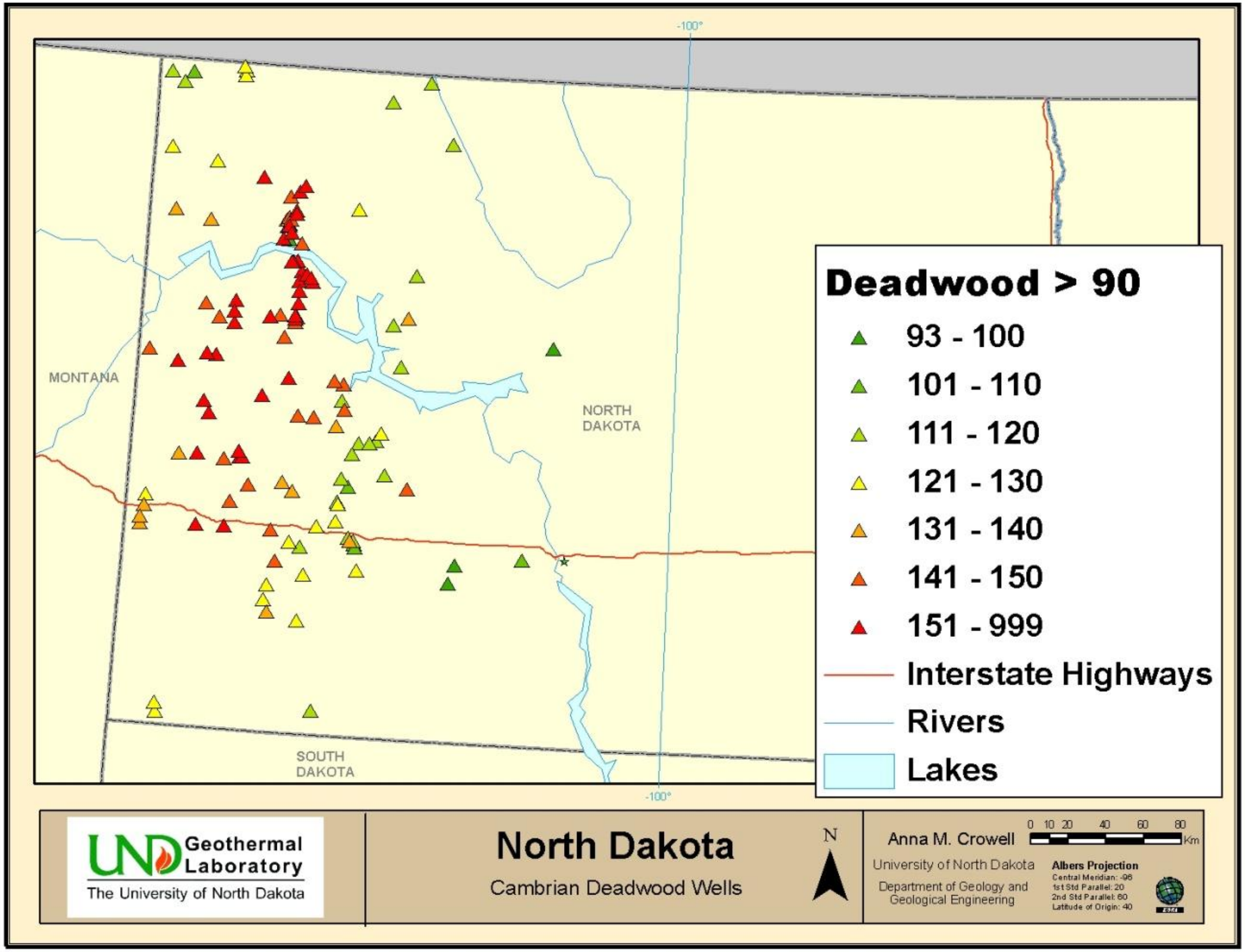
SILURIAN BHTS



ORDOVICIAN BHTS



CAMBRIAN BHTS



$$q_R = \rho c a d(T - T_{ref})$$

$\mathbf{q_R}$ is the resource base (J), $\boldsymbol{\rho}$**c** is volumetric specific heat of rock plus water (J m^{-3} K^{-1}), **a** is formation area (km^2), and **d** is formation thickness (km)

90° -100°		Avg Thick	Area	Rock Volume	H_2O Volume	Energy R.	Energy W.
Fm or Sys	**Porosity**	**km**	**km^2**	**km^3**	**km^3**	**Joules**	**Joules**
Mississippian	0.15	2.61	54,400.34	95,313.53	14,297.03	1.59E+19	2.39E+18
Devonian	0.18	1.50	23,071.55	34,538.10	6,216.86	5.78E+18	1.04E+18
Silurian	0.04	0.80	20,728.59	16,679.01	729.57	2.79E+18	1.22E+17
Ordovician	0.08	1.13	34,281.26	38,864.32	3,225.74	6.50E+18	5.40E+17
Deadwood	0.07	0.51	13,741.71	7,072.38	495.07	1.18E+18	8.28E+16

90° -100° Fm or Sys	Energy Fluid Joules
Mississippian	2.39E+18
Devonian	1.04E+18
Silurian	1.22E+17
Ordovician	5.40E+17
Cambrian	8.28E+16

110° - 120° Fm or Sys	Energy Fluid Joules
Mississippian	3.16E+18
Devonian	1.82E+18
Silurian	1.53E+17
Ordovician	1.44E+18
Cambrian	2.76E+17

100° -110° Fm or Sys	Energy Fluid Joules
Mississippian	2.98E+18
Devonian	2.47E+18
Silurian	2.48E+17
Ordovician	9.78E+17
Cambrian	1.21E+17

120° - 130° Fm or Sys	Energy Fluid Joules
Mississippian	1.17E+17
Devonian	1.63E+18
Silurian	2.17E+17
Ordovician	1.37E+18
Cambrian	3.51E+17

130° - 140°	Energy Fluid
Fm or Sys	Joules
Mississippian	1.71E+18
Devonian	1.08E+18
Silurian	1.39E+17
Ordovician	1.30E+18
Cambrian	2.82E+17

T ≥ 150°	Energy Fluid
Fm or Sys	Joules
Devonian	1.15E+18
Silurian	3.60E+16
Ordovician	7.73E+17
Cambrian	1.57E+17

140° - 150°	Energy Fluid
Fm or Sys	Joules
Mississippian	1.53E+16
Devonian	1.08E+18
Silurian	1.33E+17
Ordovician	8.81E+17
Cambrian	2.04E+17

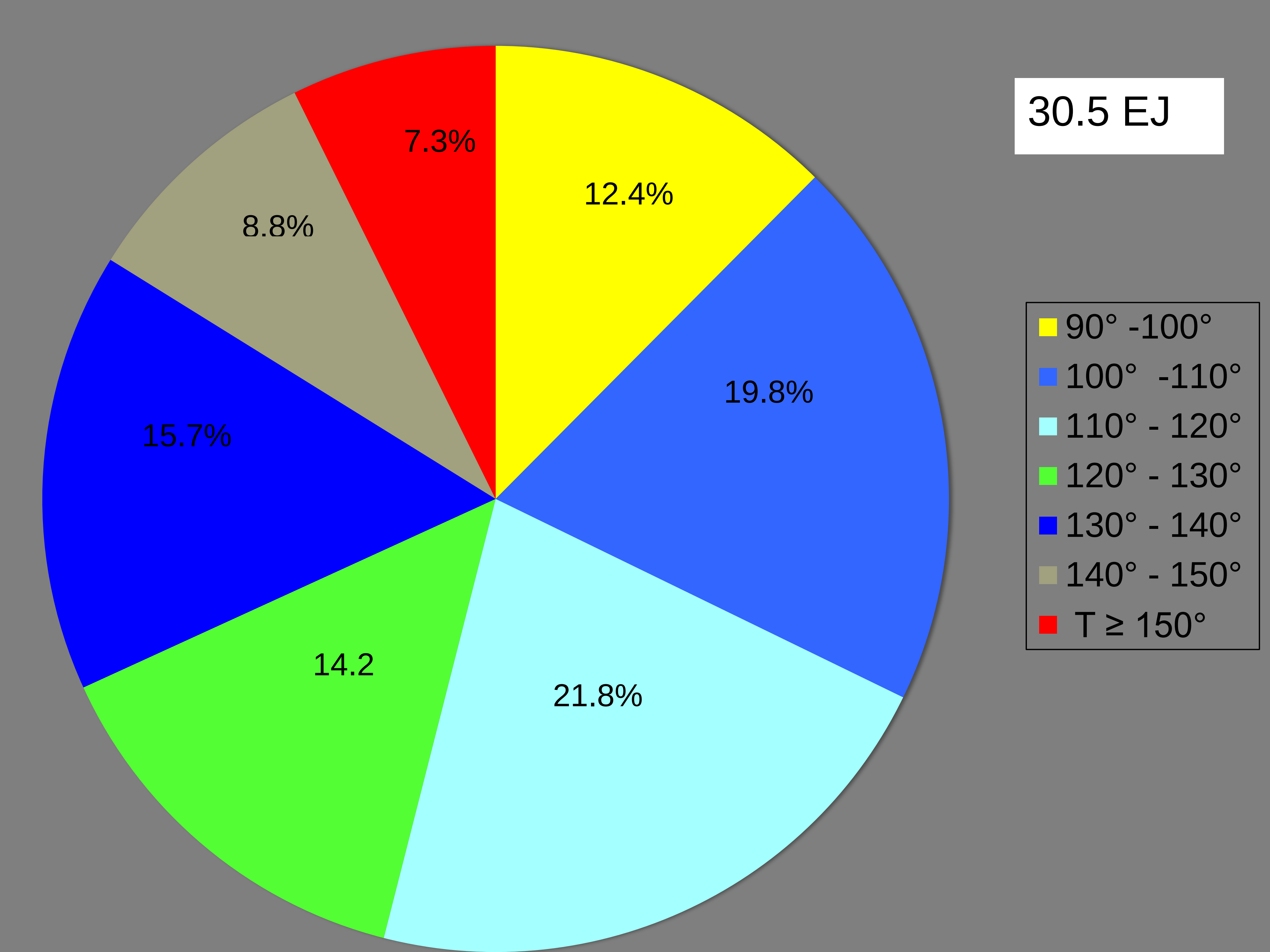
Total Energy

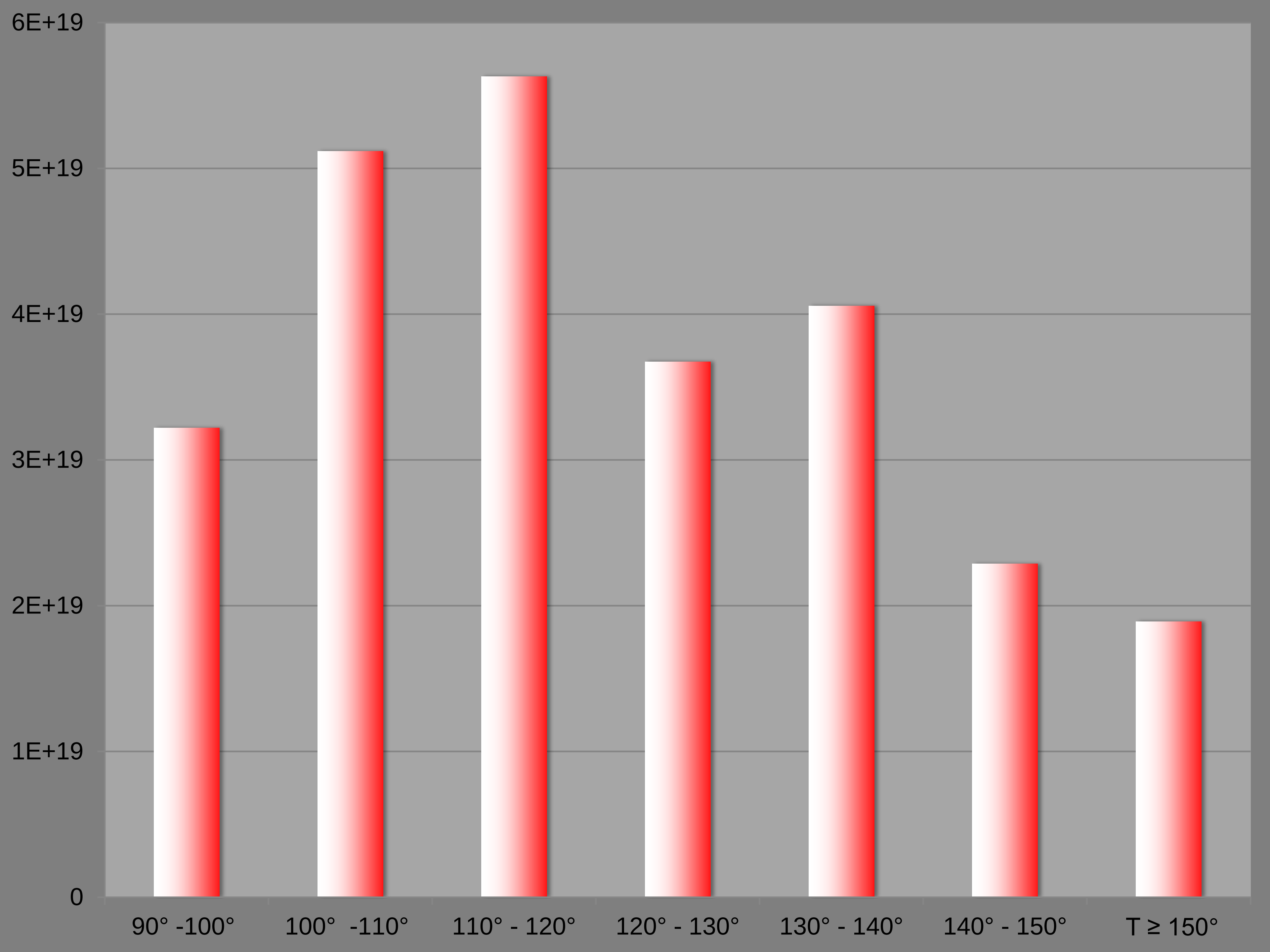
1 EJ= 10^{18} J

Rock 259 EJ

Fluid 30.5 EJ

7.19×10^{13} kWh


30.5 EJ
7.3%
12.4%
8.8%
19.8%
15.7%
14.2
21.8%
90° -100°
100° -110°
110° - 120°
120° - 130°
130° - 140°
140° - 150°
T ≥ 150°


6E+19
5E+19
4E+19
3E+19
2E+19
1E+19
0
90° -100°
100° -110°
110° - 120°
120° - 130°
130° - 140°
140° - 150°
T ≥ 150°

ORC ON A SINGLE WELL

E=((Q*C*L)+(EEUR*P))*A)-I

EEUR in (bbls)

P=Oil Price ($/bbl)

E=Net profit

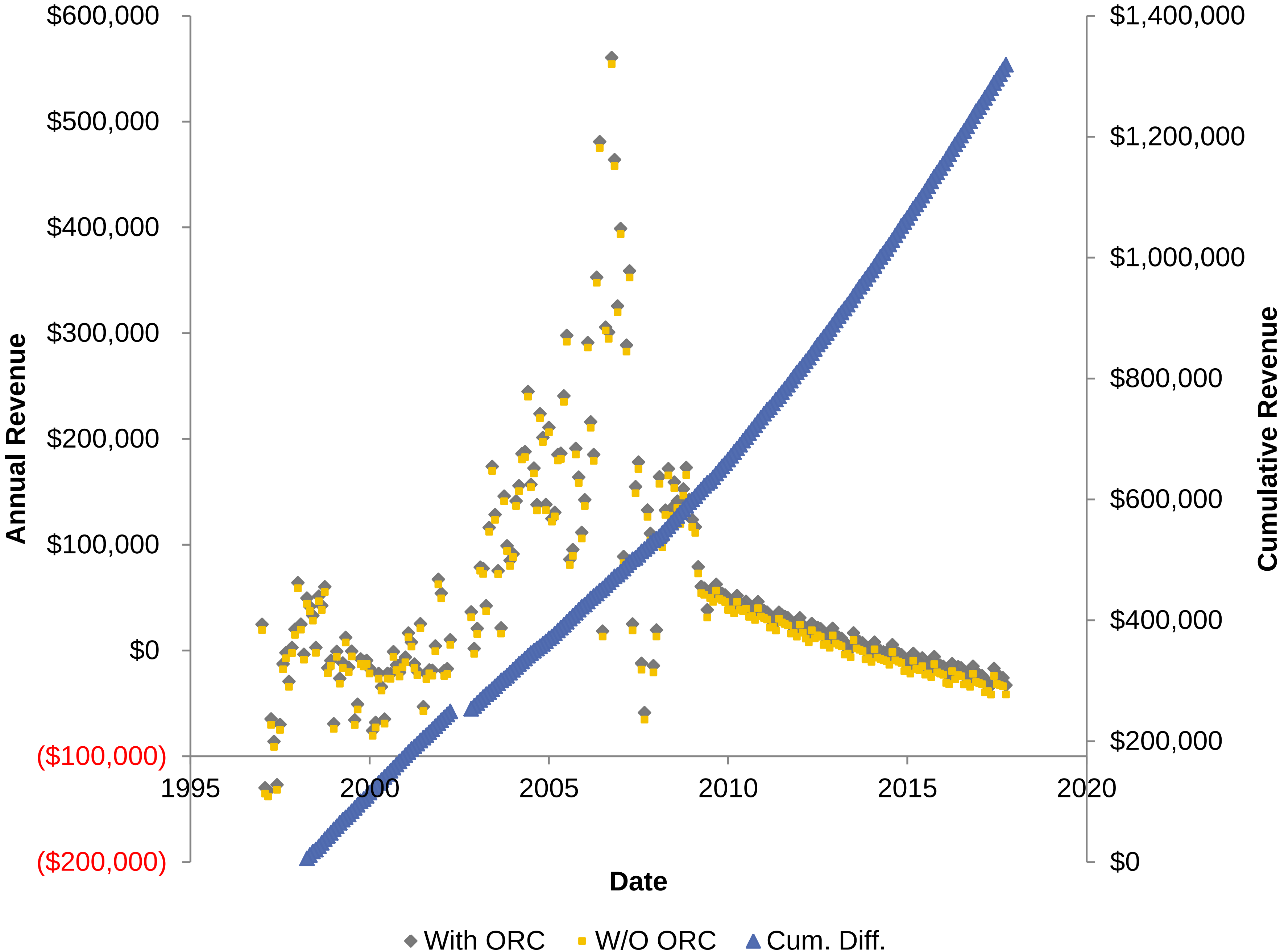
Q=plant capacity (kW)

L=Lifetime of plant (hrs)

C=Wholesale Price of Electricity

A=Plant availability (%)

I=O&M costs



$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$0
($100,000)
($200,000)
Annual Revenue
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
Cumulative Revenue
1995
2000
2005
2010
2015
2020
Date
With ORC
W/O ORC
Cum. Diff.

Binary Power System Selection

Basin Evaluation

Economics of Binary Power