NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Innovation for Our Energy Future

National Co-Produced Fluids Resource Estimate

Geothermal in the Oil Field Symposium

RMOTC
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Outline

1. Introduction
2. Approach and Methodology
    a. Well Information
    b. Well Temperature
    c. Co-Produced Water
    d. Power Production
3. Next Steps

Introduction

Goal: Estimate size of electricity generation from water co-produced during oil and gas production

- Focus on active wells already used for oil and gas production
- Targets:
  - High Temperature (≥ 80°C minimum)
  - High co-produced water flow rate
  - "Just add a binary power plant"
- Estimate order-of-magnitude size of resource
- Use to screen potential sites
- Estimate not final

Approach and Methodology

Build a database of information

- Input as much available data as possible
- Update as new information becomes available
- Estimate data where necessary

Screen, Identify, and Estimate Potential

- Power generation based on temperature and produced water flow rates in database

Approach and Methodology

RESOURCE ESTIMATE NEEDS AND CHALLENGES

Needs	Challenges
Well Information – API number – Location (Lat/Long) – Depth – Production Data (O, G, W) – Status (Active/Inactive/Plugged/Abandoned)	Volume of Data – Millions of wells – Spread across multiple sources (state-by-state)
Temperature – Produced fluid temperature – Well bottom-hole temperature (BHT)	Availability/Reliability of Data – Not reported by industry – Difficult to obtain/estimate
Co-Produced Water Flow Rate – Amount of water produced from each well	Availability/Reliability of Data – Reporting standards vary state to state – Reliability of reported data questionable

Approach and Methodology

DATA SOURCE SUMMARY

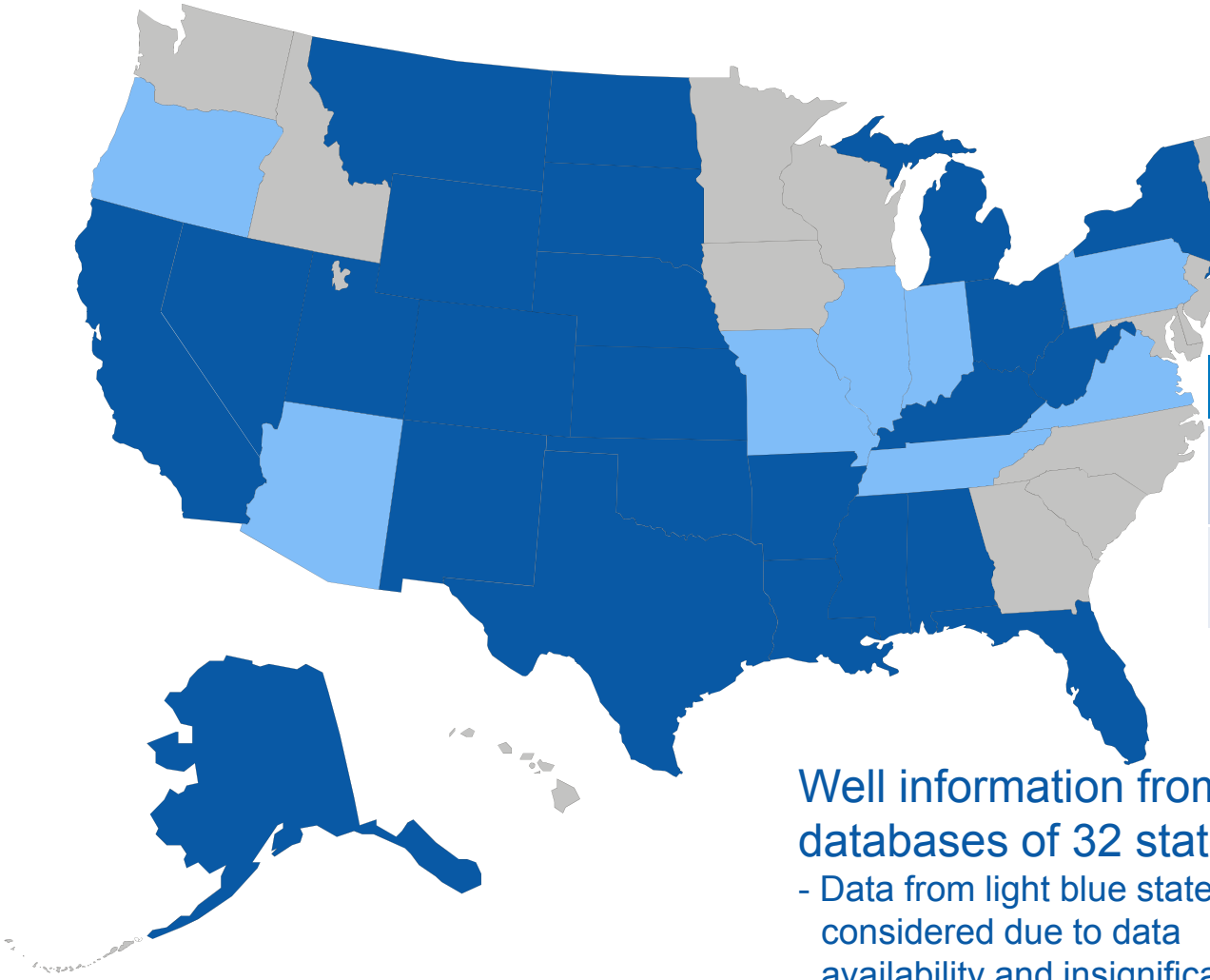
Well Information	• State Databases (32)
Well Temperature	• < 11,500 ft (3.5 km): Estimated using AAPG BHT database • >11,500 ft (3.5 km): SMU Temp vs. Depth Maps
Co-Produced Water	• State Databases (when available) • Argonne National Laboratory Report (Veil (2009) ~ using 2007 data)

Co-Produced Fluid Resource Estimate Approach and Methodology

Well Information

Well Information

STATES INCLUDED



	All	Active[1]
# Wells in Database	2,475,520	444,034
# With Depth	1,782,706	364,451

[1]Active Well = record of oil, gas or water production in any combination:

Well information from databases of 32 states

- Data from light blue states not considered due to data availability and insignificant resource

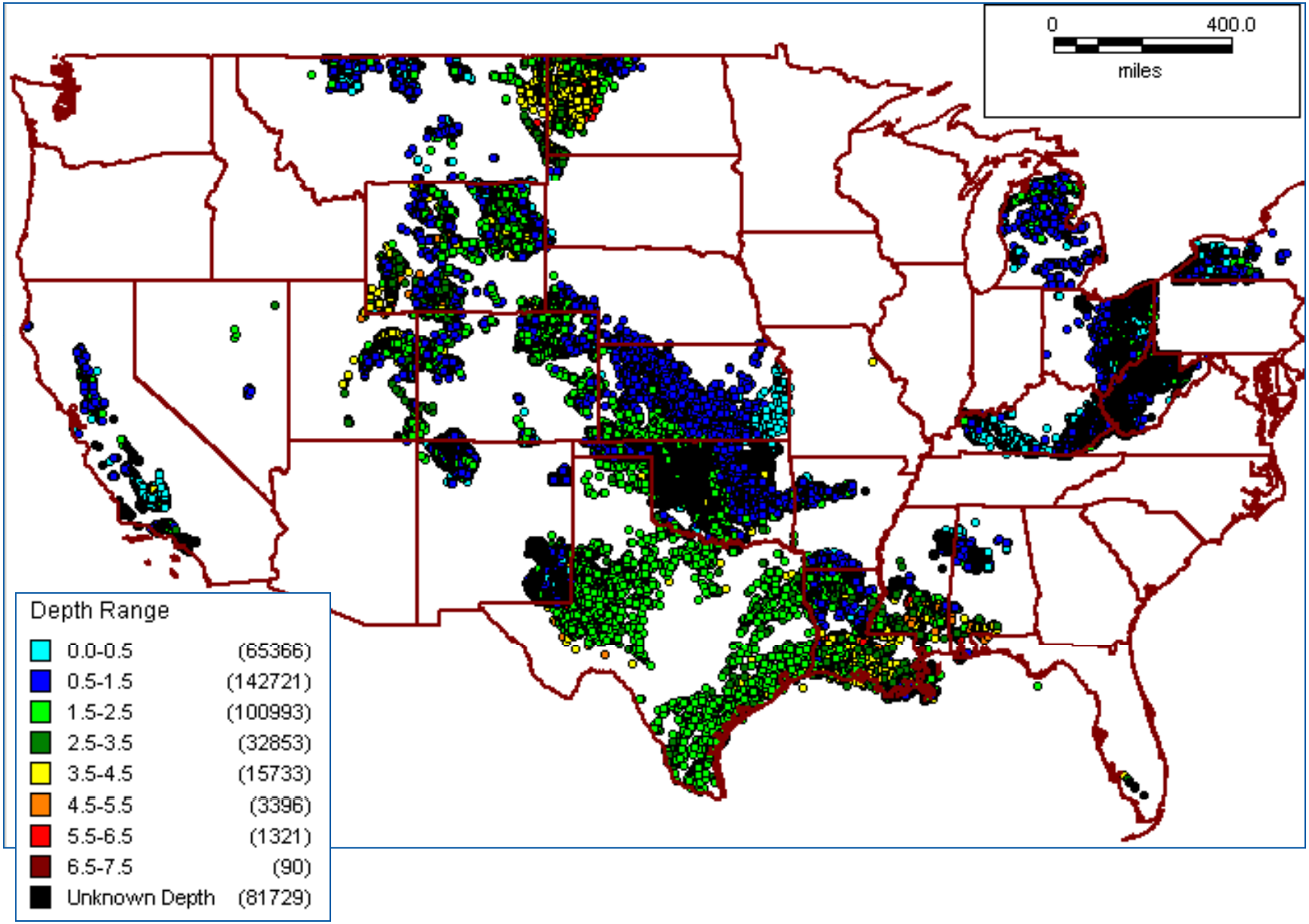
Well Information – State-by-State Summary

State		All Wells in Database			Active Wells in Database		
		Count	Number with Depth	% Compliance	Count	Number with Depth	% Compliance
Alaska	AK	7,635	7,101	93.0%	2,309	2,309	100.0%
Alabama	AL	17,304	15,262	88.2%	6,367	6,327	99.4%
Arkansas	AR	20,979	18,203	86.8%	4,182	3,832	91.6%
California	CA	200,885	72,607	36.1%	52,055	25,574	49.1%
Colorado	CO	89,467	72,404	80.9%	35,114	34,441	98.1%
Florida	FL	1,268	1,073	84.6%	55	47	85.5%
Kansas	KS	407,499	332,712	81.6%	4,041	3,982	98.5%
Kentucky	KY	114,621	89,178	77.8%	11,998	11,782	98.2%
Louisiana	LA	191,411	191,056	99.8%	10,669	10,571	99.1%
Michigan	MI	62,870	50,286	80.0%	3,879	3,795	97.8%
Mississippi	MS	32,464	12,780	39.4%	3,723	2,529	67.9%
Montana	MT	42,930	39,950	93.1%	10,187	10,140	99.5%
North Dakata	ND	19,197	16,001	83.4%	4,769	4,764	99.9%
Nebraska	NE	21,056	20,460	97.2%	693	693	100.0%
New Mexico	NM	95,556	78,670	82.3%	49,417	46,806	94.7%
Nevada	NV	999	757	75.8%	87	86	98.9%
New York	NY	38,475	29,653	77.1%	10,277	9,812	95.5%
Ohio	OH	261,804	178,494	68.2%	41,639	40,155	96.4%
Oklahoma	OK	336,186	99,921	29.7%	75,228	39,435	52.4%
South Dakota	SD	1,859	1,746	93.9%	222	220	99.1%
Texas	TX	241,543	241,543	100.0%	11,879	11,879	100.0%
Utah	UT	27,131	18,105	66.7%	9,692	9,338	96.3%
West Virginia	WV	130,496	83,976	64.4%	53,055	43,668	82.3%
Wyoming	WY	111,885	110,768	99.0%	42,497	42,266	99.5%
Totals		**2,475,520**	**1,782,706**	**72.0%**	**444,034**	**364,451**	**82.1%**

20,000+ wells pre-1984, most <4,000 feet

Old, shallow oil wells

Wells in Database by Depth



Co-Produced Fluid Resource Estimate Approach and Methodology

Well Temperature

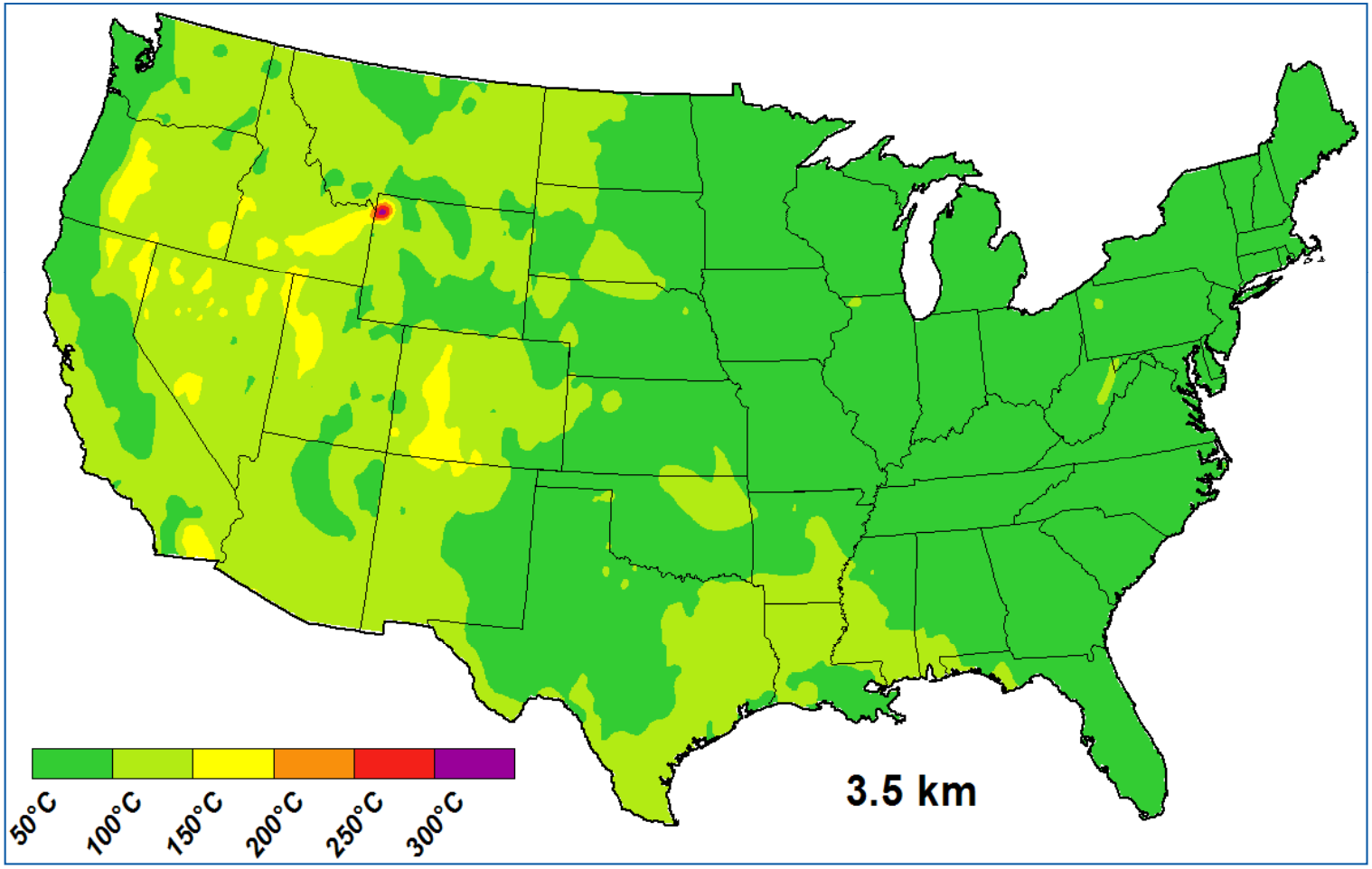
Well Temperature

Most important data, but also hardest to estimate (not collected by state agencies or industry…)

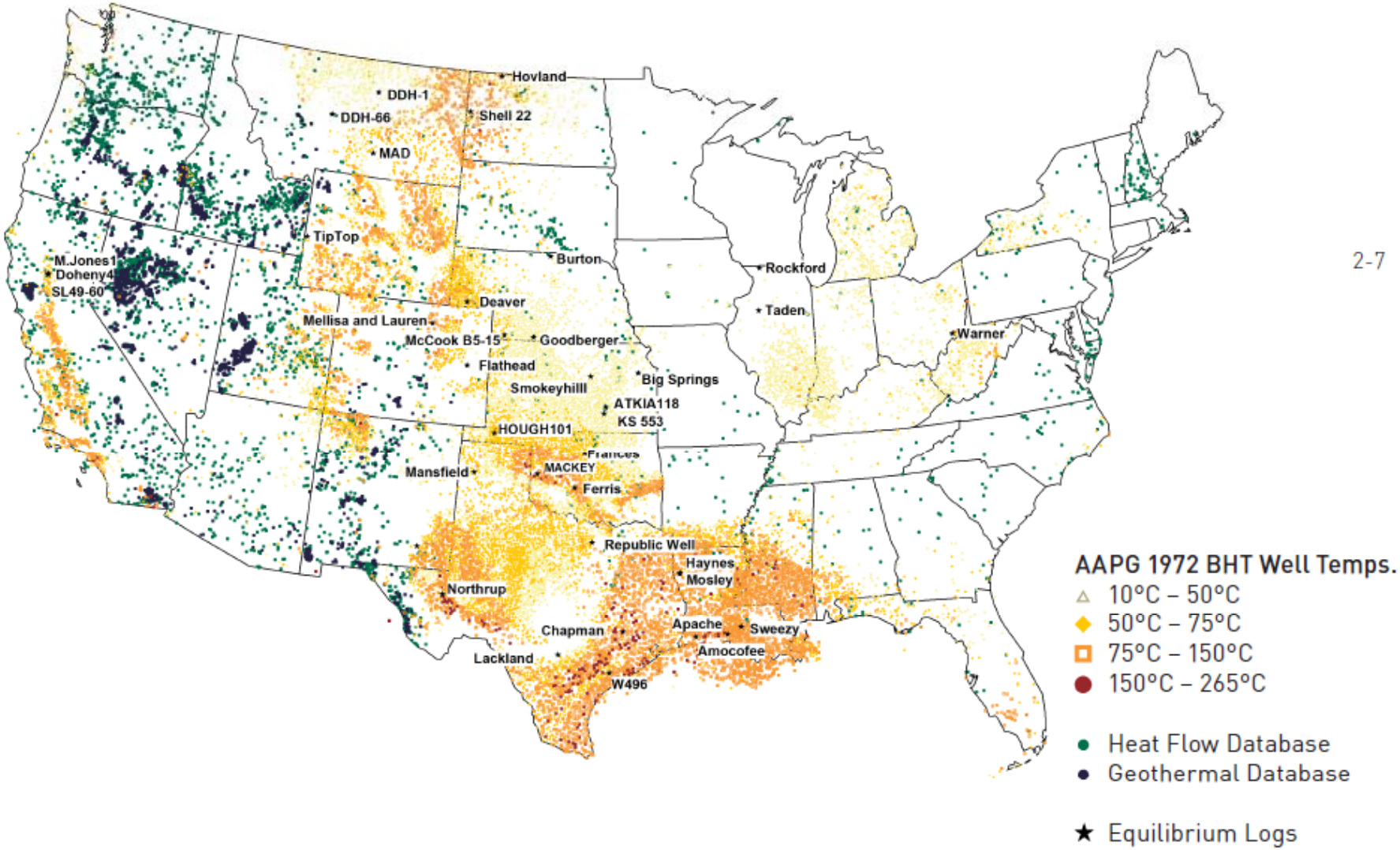
Methodology:

- Wells > 11,500 ft (3.5 km): SMU temp vs. depth maps
  - Temp as a function of depth at 1-km slices (3.5 km – 9.5 km)
  - Interpolate O&G BHT based on depth
- Wells < 11,500 ft (3.5 km): AAPG BHT database
  - 27,500+ BHT in database
  - 23,000+ at <11,500 ft, with BHT corrected
  - Group in 0.5 km increments, create temp map
  - 10 mile buffer zone around wells
- Wells <11,500 ft outside of AAPG buffer zones
  - If SMU temp at 3.5 km < 175°F (< 80°C), then assume well temp is also < 175°F (< 80°C)
  - Estimated 80°C Temp Depth based on SMU and AAPG data

Well Temperature – SMU data



Well Temperature – AAPG Data



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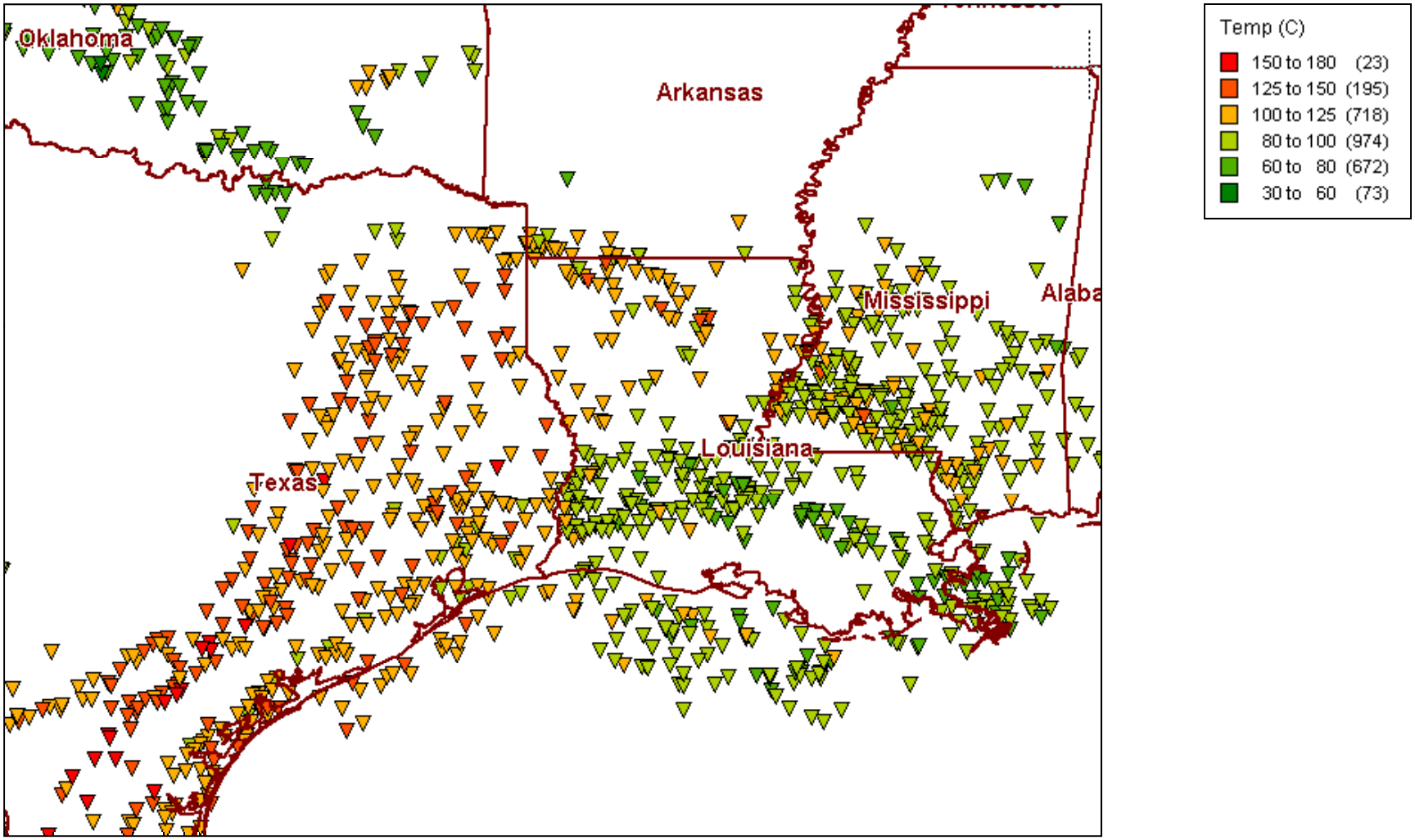
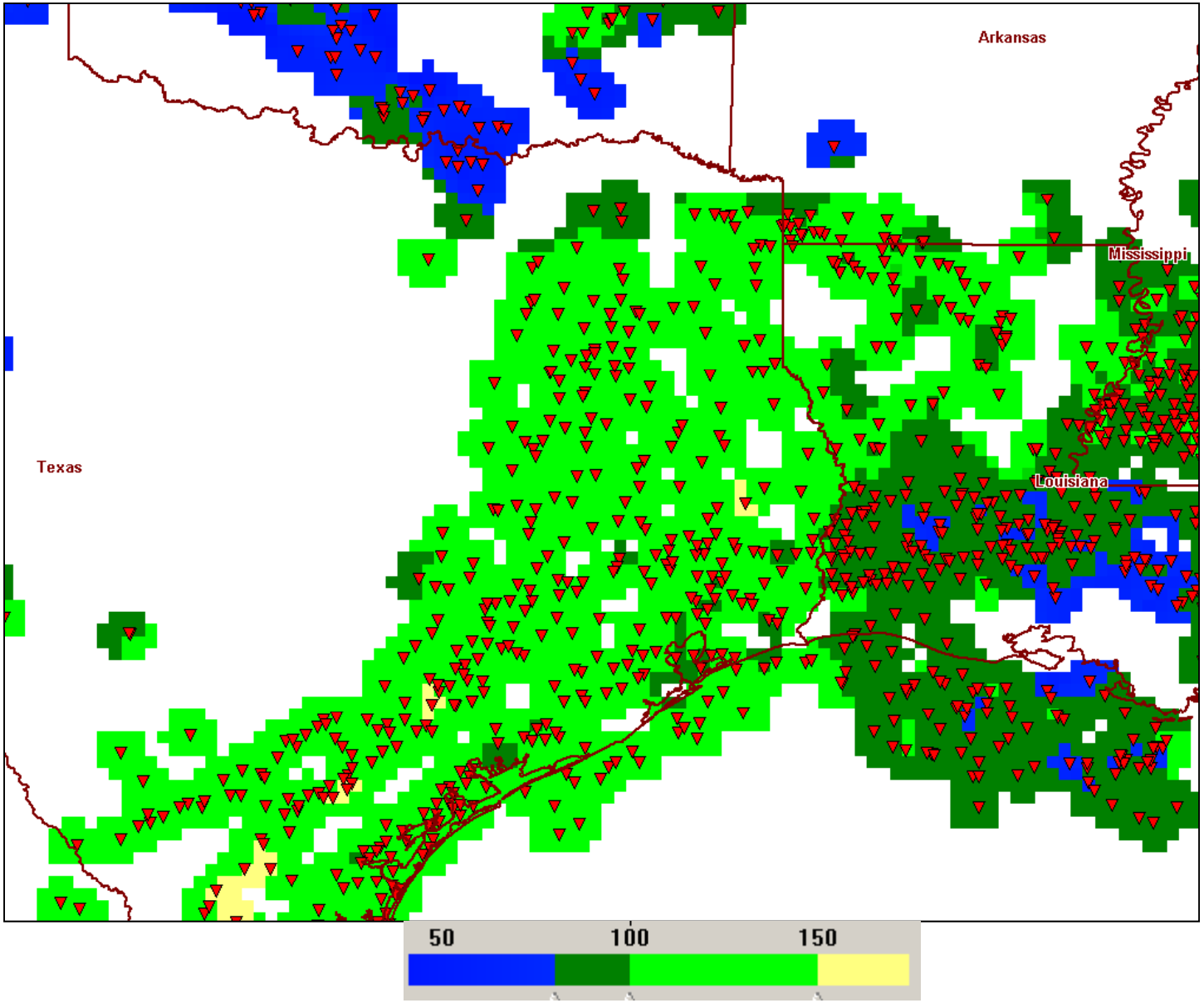
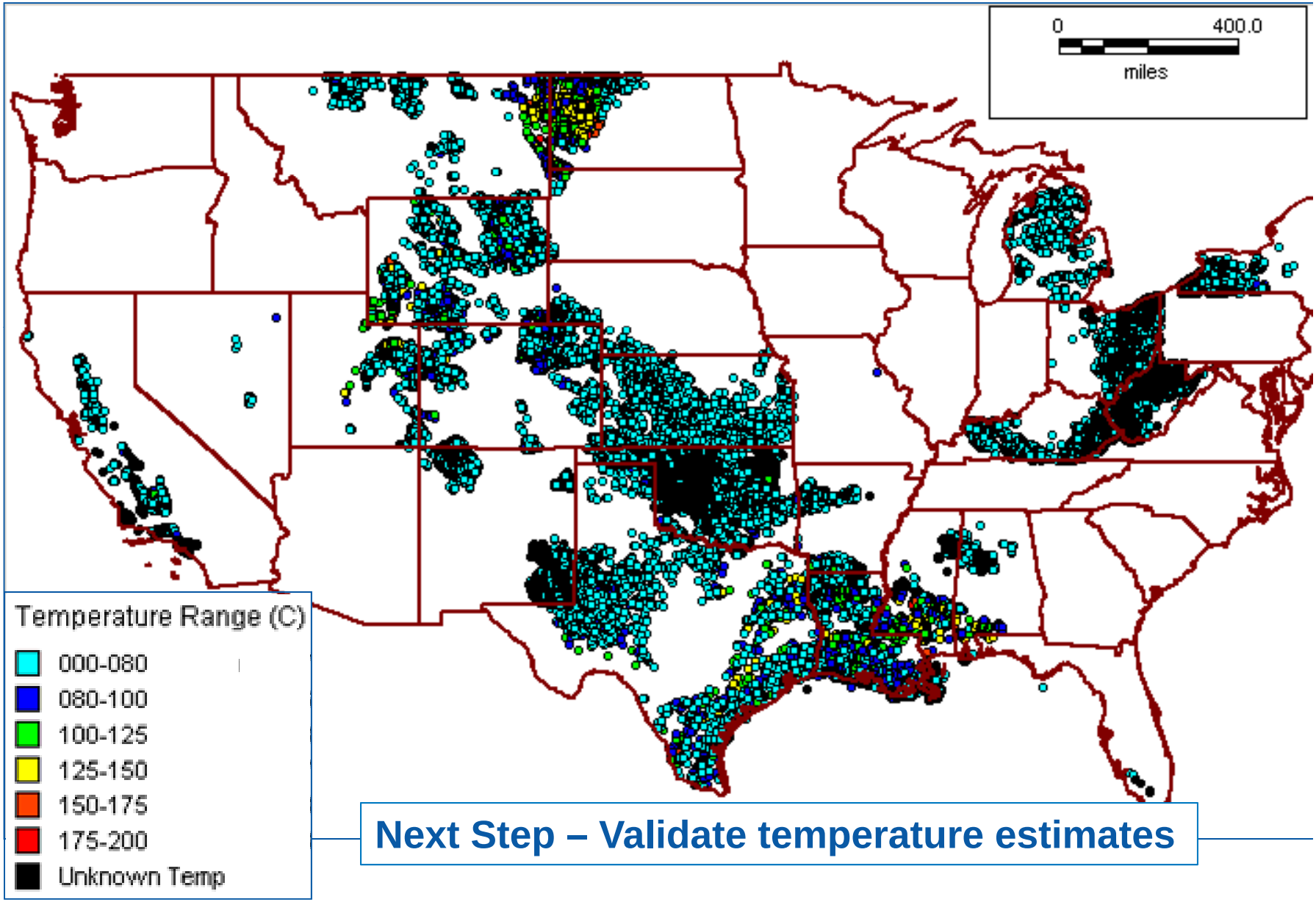
Well Temperature – AAPG data (3.0-3.5 km)



Well Temperature – AAPG Buffer Zones (3.0-3.5 km)



Wells in Database by Temperature



Next Step – Validate temperature estimates

Co-Produced Fluid Resource Estimate Approach and Methodology

Co-Produced Water

Co-Produce Water - Summary

Data Sources:

- Reported by state on per-well basis

- Oil and Gas reported by well
- Water calculated from WOR/WGR (Veil, 2009)
- Validated against Veil 2007 total co-produced water by state

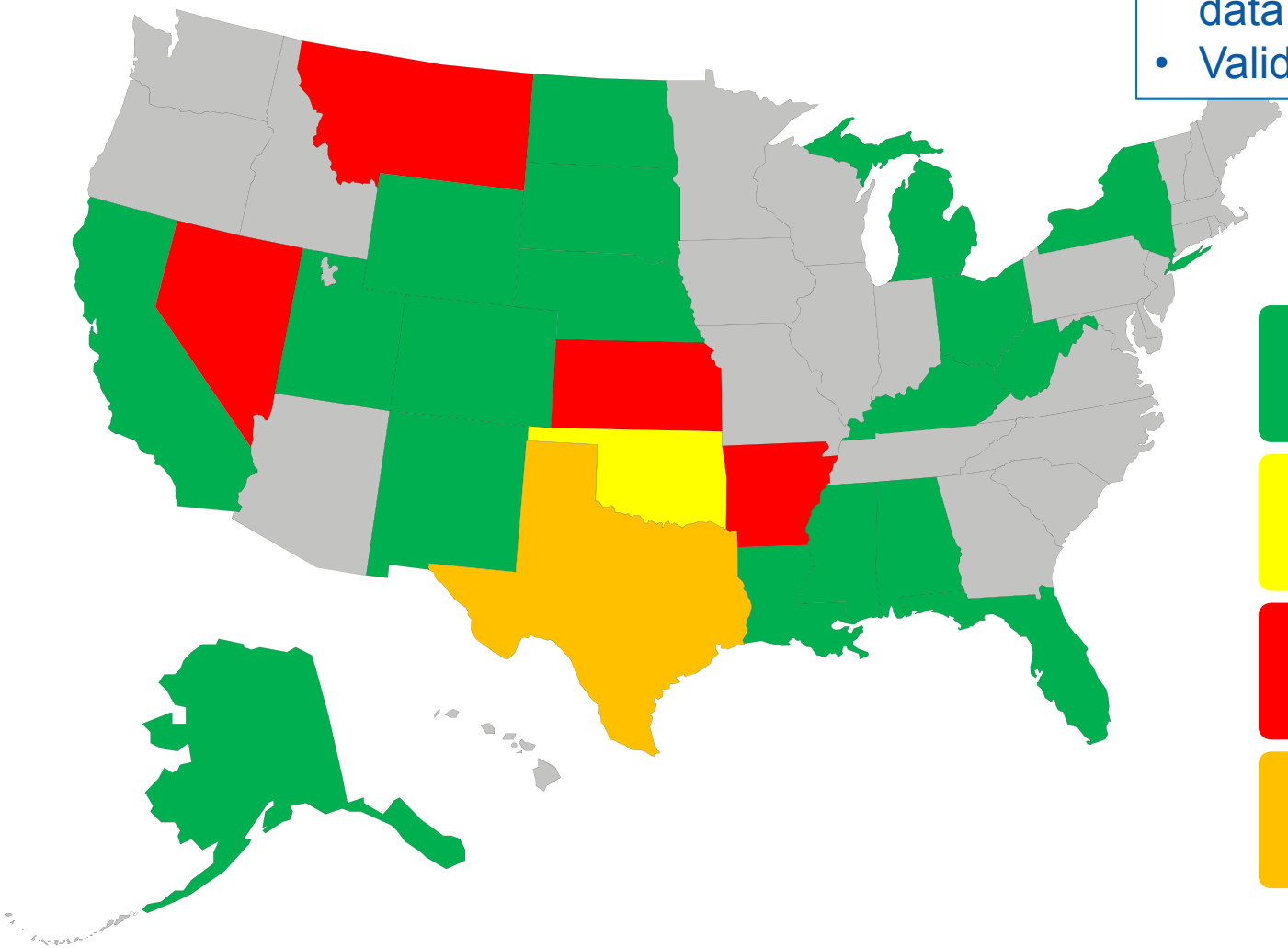
- Oil and gas reported by field or county, averaged per well
- Water calculated from WOR/WGR (Veil,2009
- Validated against Veil 2007 total co-produced water by state

- Reported by state on injection-well basis

Co-Produced Water – Summary

Next Steps

- Incorporate remaining data (esp. Texas)
- Validate flow estimates



- Actual reported per-well values
- Calculated from per-well oil and gas data
- Calculate from per-field oil and gas data
- Injection-well basis

Co-Produced Fluid Resource Estimate Approach and Methodology

Power Production Estimate

Estimated Power Production

Methodology

- Potential power output based on well temperature and well flow rate
  - Evaluate on per-well basis for each active well in database
- Use two power production correlations
  - MIT “Future of Geothermal Energy” correlation (Chapter 6)
  - PureCycle plant efficiency correlation (brochure)
- Pro-rate power output to per-kW basis (plant can be of any size)

Power Potential Correlations

MIT "Future of Geothermal Energy" Correlation

- Based on charts and equations in MIT report, plant thermal efficiency
- Assumed 95°F (35°C) co-produced fluid power plant outlet temperature
  - same assumption used to estimate co-pro resource in MIT report

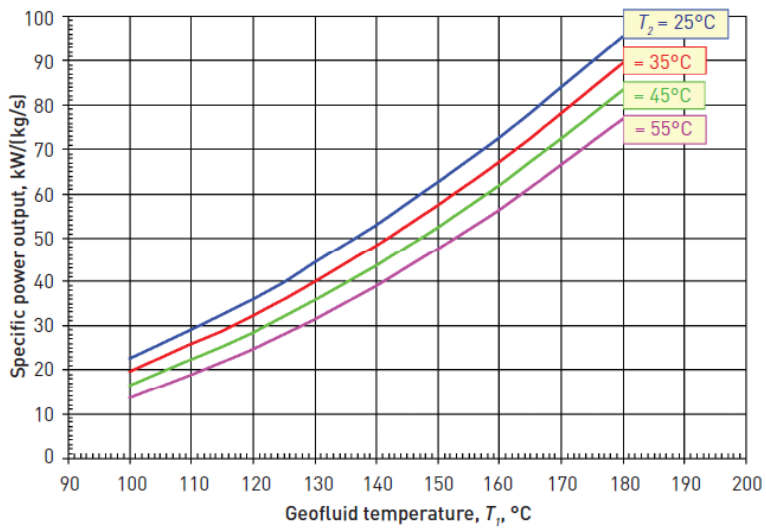
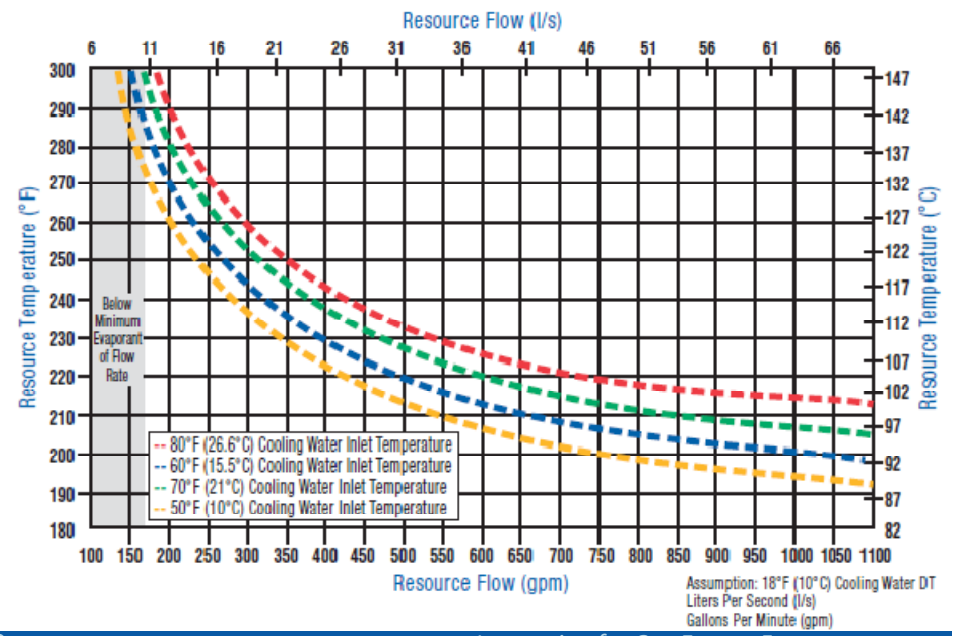


Figure 7.3 Specific power output (in kW/(kg/s)) for low- to moderate-temperature geofluids as a function of inlet (T_1) and outlet temperatures (T_2) shown in degrees Celsius (°C).

UTC PureCycle Correlation

- Based on brochure data
- Assume 50°F cooling water available
- Corresponds to MIT correlation with 170 °F (77°C) co-produced fluid power plant outlet temp.



Power Plant Correlations

MIT correlation assumptions result in much higher plant output due to lower co-produced fluid outlet temperature

- Results in greater amount of thermal energy being used to generate power
- Effect is amplified as potential resource temperature drops
- Optimistic assumption – actual plant performance limited by ambient temperature, size of heat exchangers

Resource Temp		Power Output (kW) as a function of Temperature for 10,000 bbl/day flow		
(°C)	(°F)	MIT	Purecycle	Ratio
93	200	286	106	2.7
100	212	339	138	2.5
125	257	634	345	1.8
150	300	1023	607	1.7

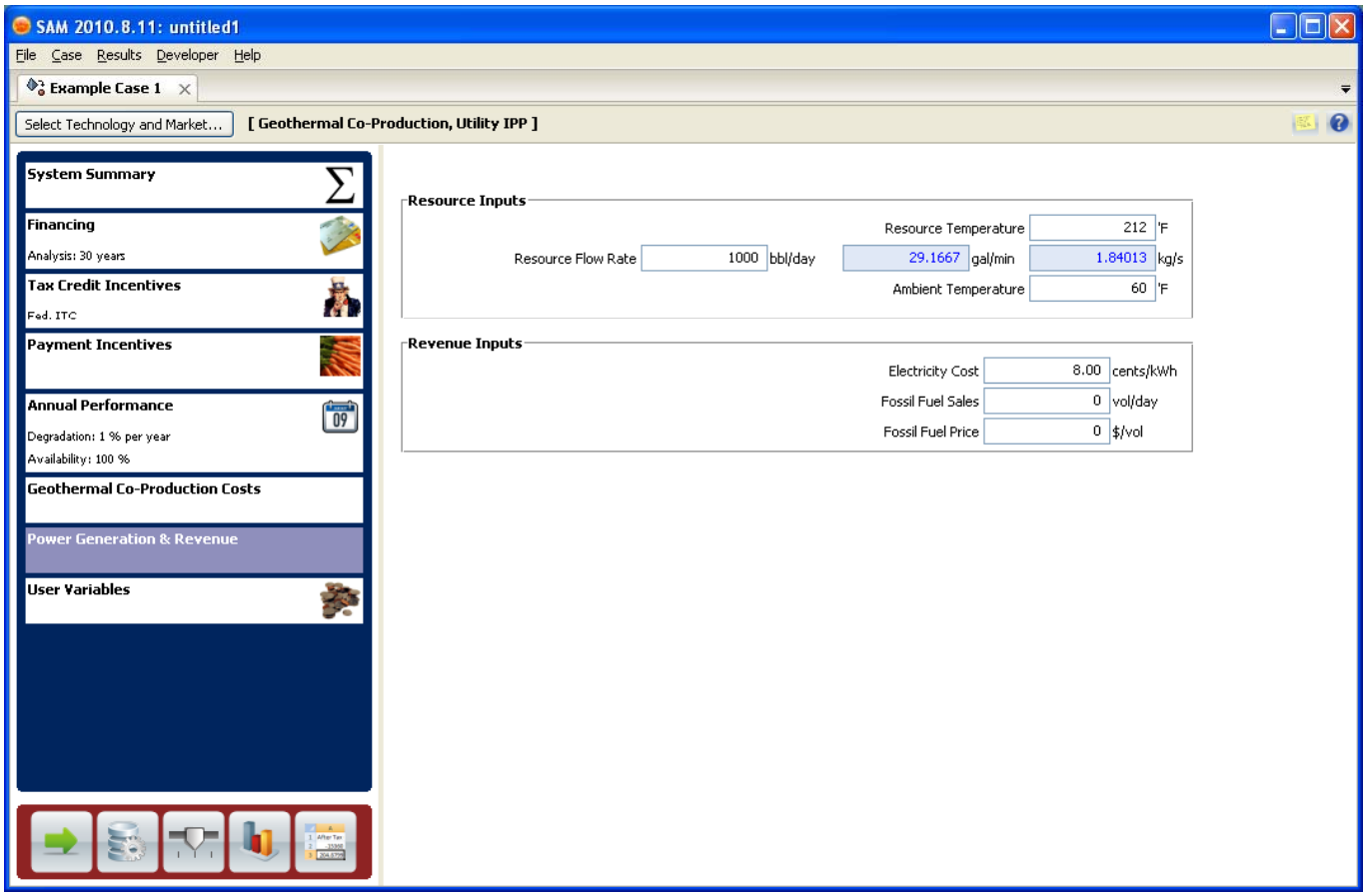
Next Steps

- Validate temperature estimates
- Finish Co-Produced Water estimates
  - Incorporate data (esp. Texas)
  - Validate estimates
- Incorporate potential power production correlations into database
  - Well-by-well basis
  - Identify promising wells and fields
  - Estimate of national co-produced power potential

Next Steps

Also working on co-produced power economic model

- Based in NREL's **S**olar **A**dvisor **M**odel (SAM)
- In process of being coded
- Key to good output is good input
  - Accurate costs
  - Financial assumptions



Next Steps

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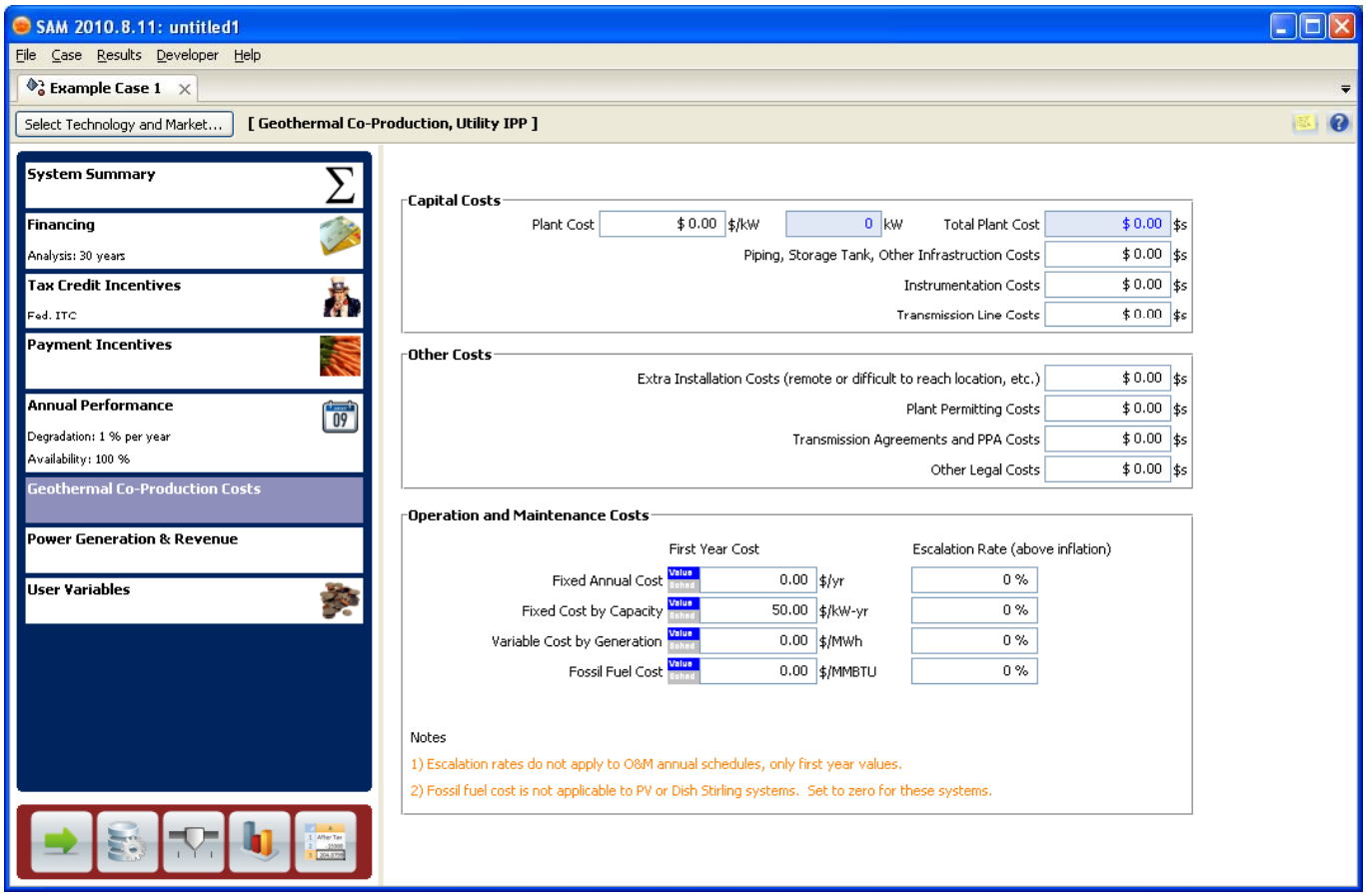
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