Low-temperature Geothermal Utilization:

Potential for Direct-Use Applications in West Virginia

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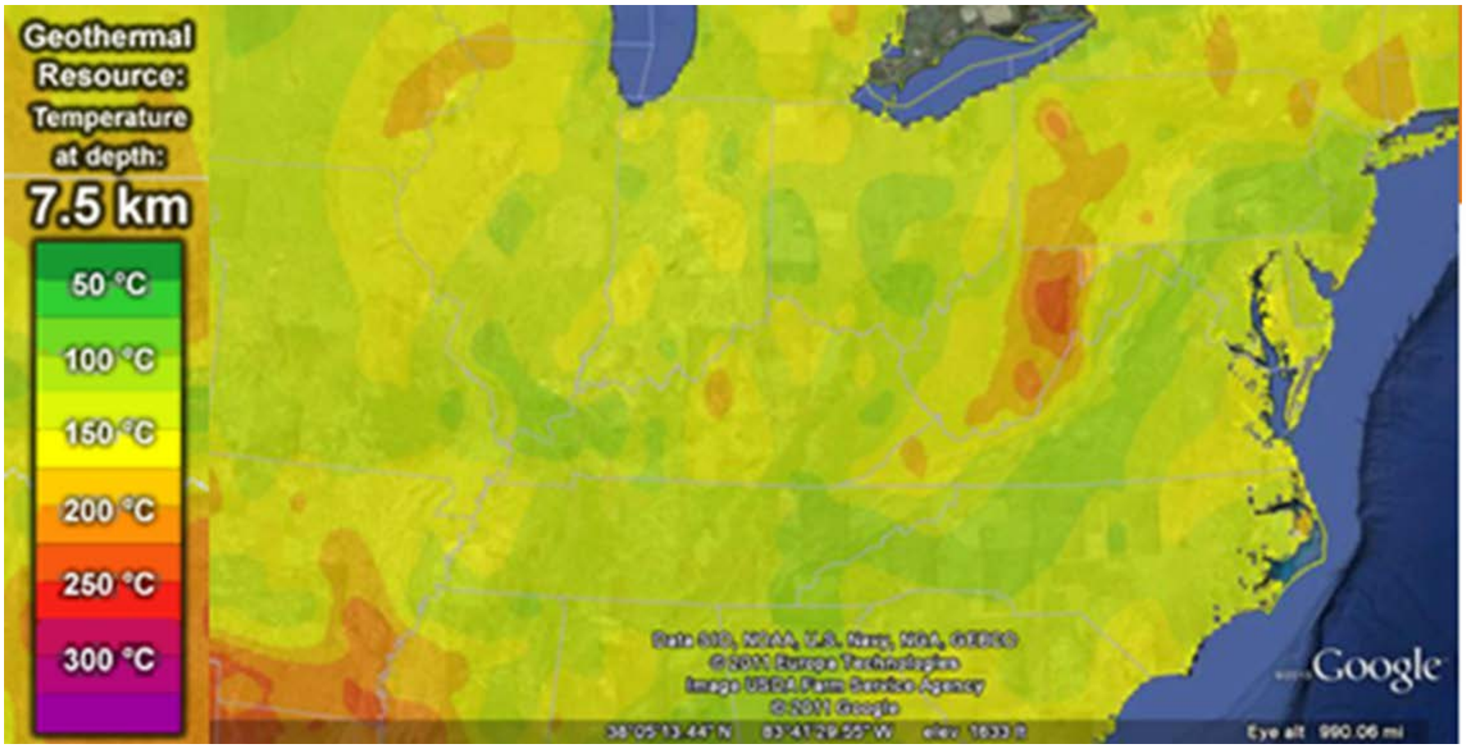
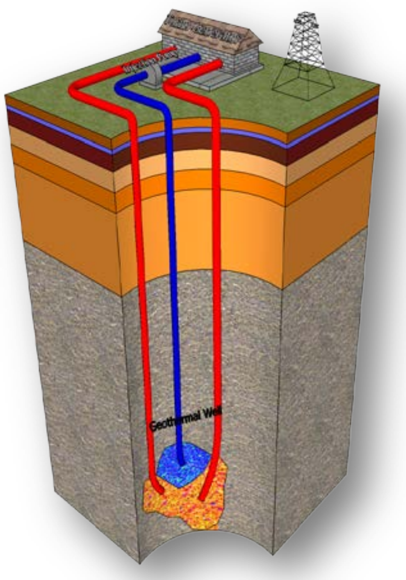




What is Geothermal?

Geothermal Heat Pumps/ Ground Source Heat Pumps	Use relatively constant temperature of the earth as heat sink/source for commercial/residential heating and cooling	• Near ambient temperatures (~40-80°F) • Shallow depths - trenches to wells hundreds of feet deep
Direct Use Geothermal	Use thermal energy (heat) from the earth directly for heating/cooling buildings, greenhouses, aquaculture, pools, spas, etc.	• Moderate temperatures (100-300°F) • Wells hundreds to thousands of feet deep
Geothermal Power (Electricity Generation)	Use thermal energy (heat) from the earth to generate electricity	• High temperatures (>300°F) • Wells hundreds to thousands of feet deep • Baseload generation

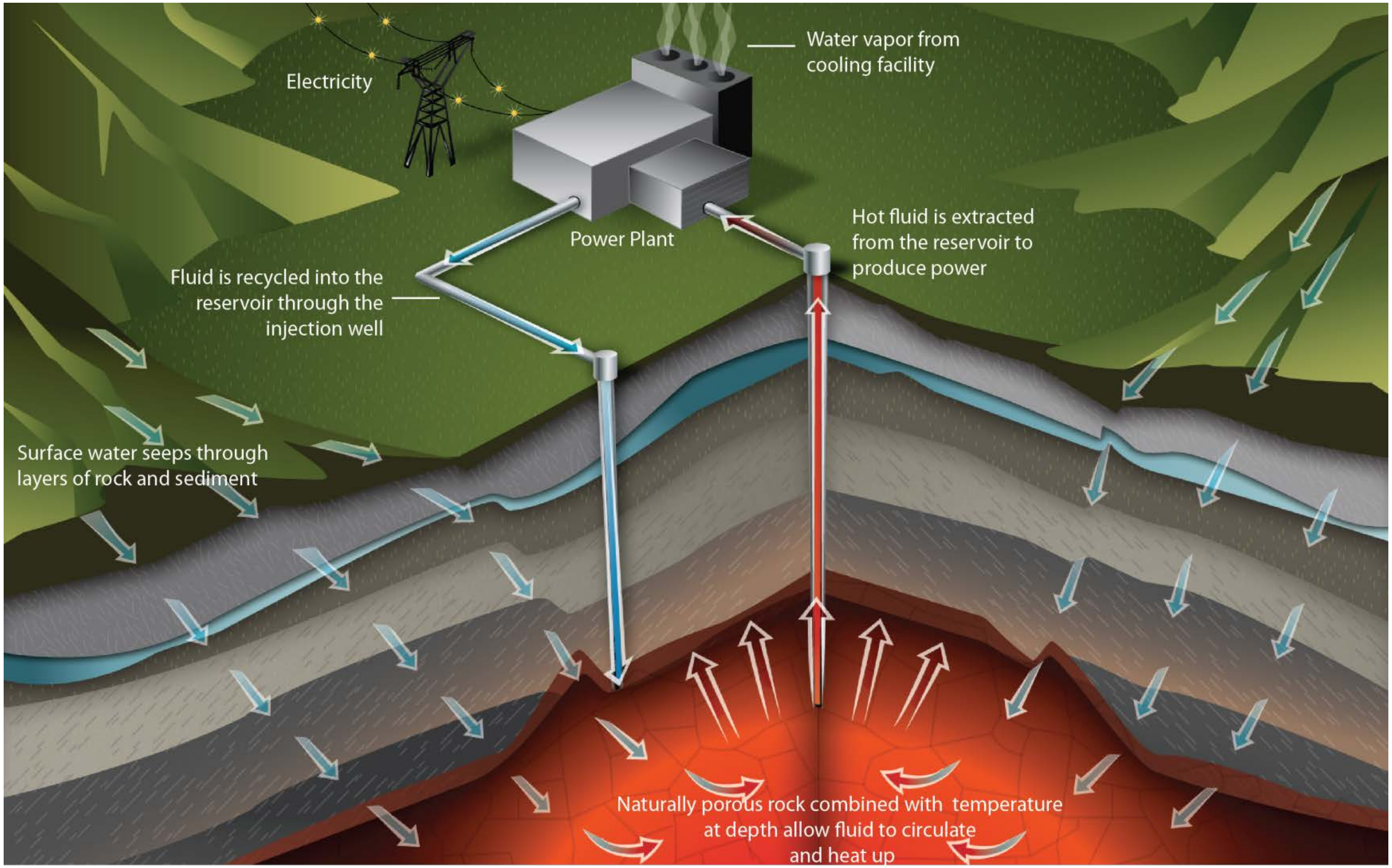
GEOTHERMAL OPPORTUNITIES

Current → **Emerging**

Conventional → **Unconventional**

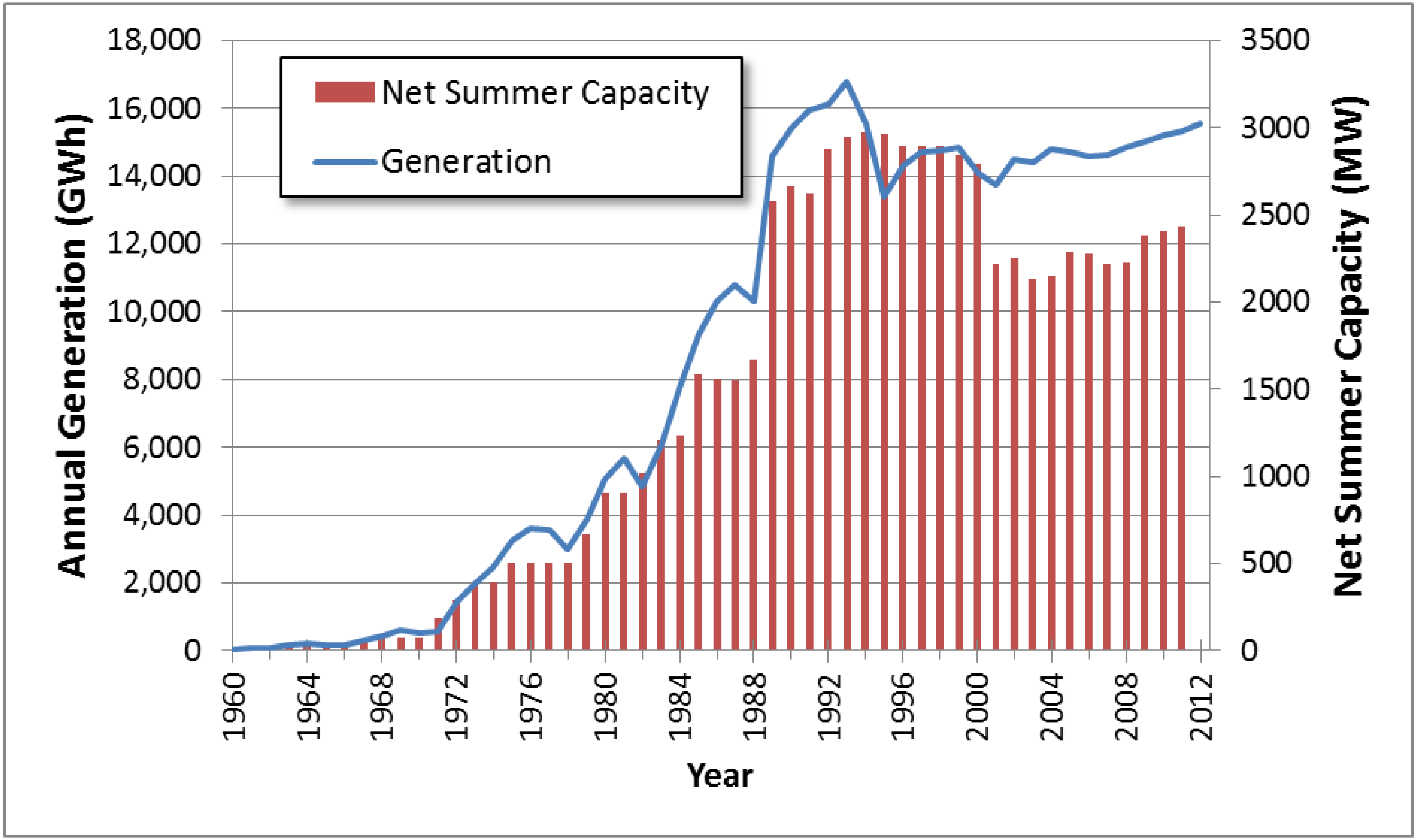
	Hydrothermal Resources	Low-Temperature and Direct Use Resources	Enhanced Geothermal Systems
Potential	10's of GWe (Gigawatt electric)	100's MWe – GWe, Huge (~100's GWt) thermal potential	100's of GWe
Key Challenges	Exploration, Permitting, Financing	Education, Infrastructure, Demonstration and Scale Up	Reservoir Creation, Drilling, Scale Up, Reservoir Management
Strategies	Identify New Sites, Promote Sector Growth	Utilize Waste Heat, Promote Distributed Energy, Engage O&G	Expand Existing Fields, Develop Replicable Site

Typical Geothermal Power Plant



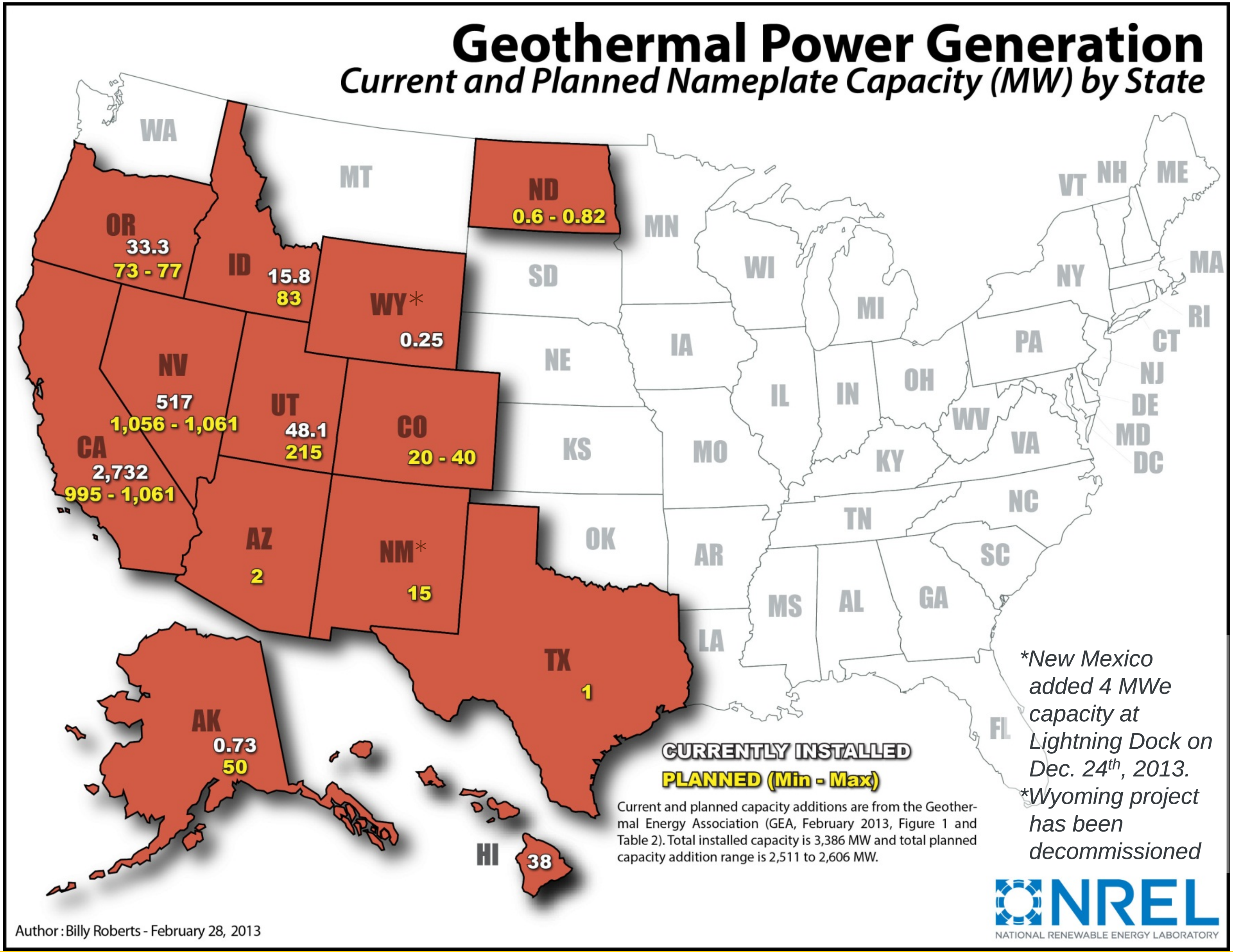
Hot fluid (water, steam, or both) produced from wells drilled into ground → Fluid passed through power plant to generate electricity → Fluid (usually) re-injected back into ground

Historic Generation and Capacity



- U.S. installed capacity: 3,187 MW (4/2013), the largest in world
- Installed US geothermal power capacity grew 5% in 2012, 147 MW in new capacity added and 175 additional projects under development

Current Installed and Planned Capacity



*New Mexico added 4 MWe capacity at Lightning Dock on Dec. 24th, 2013.

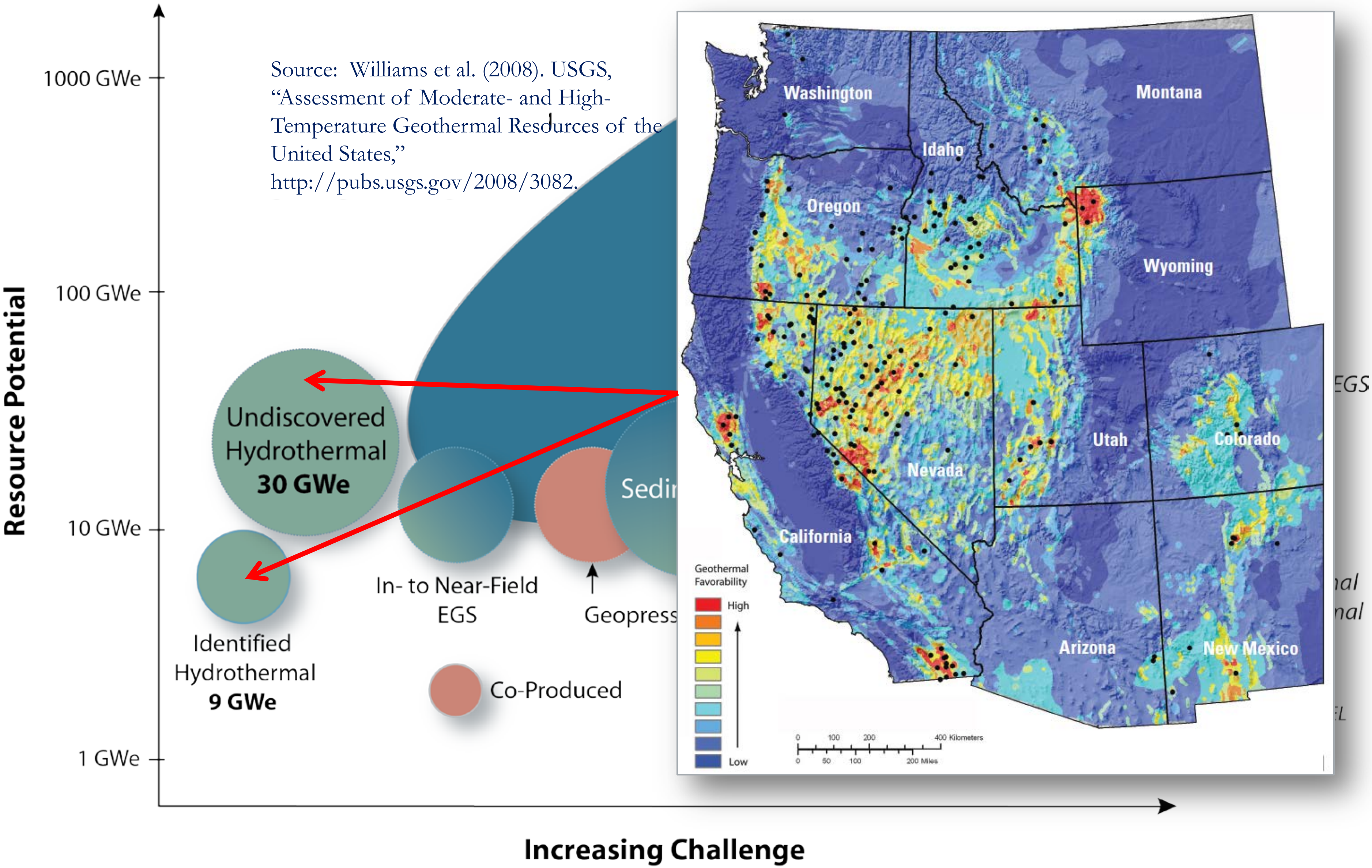
*Wyoming project has been decommissioned

Geothermal Power - Advantages

- Renewable/Low-Carbon Intensity
- Baseload – 24/7 operation

Photos Courtesy James Faulds, NBMG

U.S. Geothermal Resource Potential



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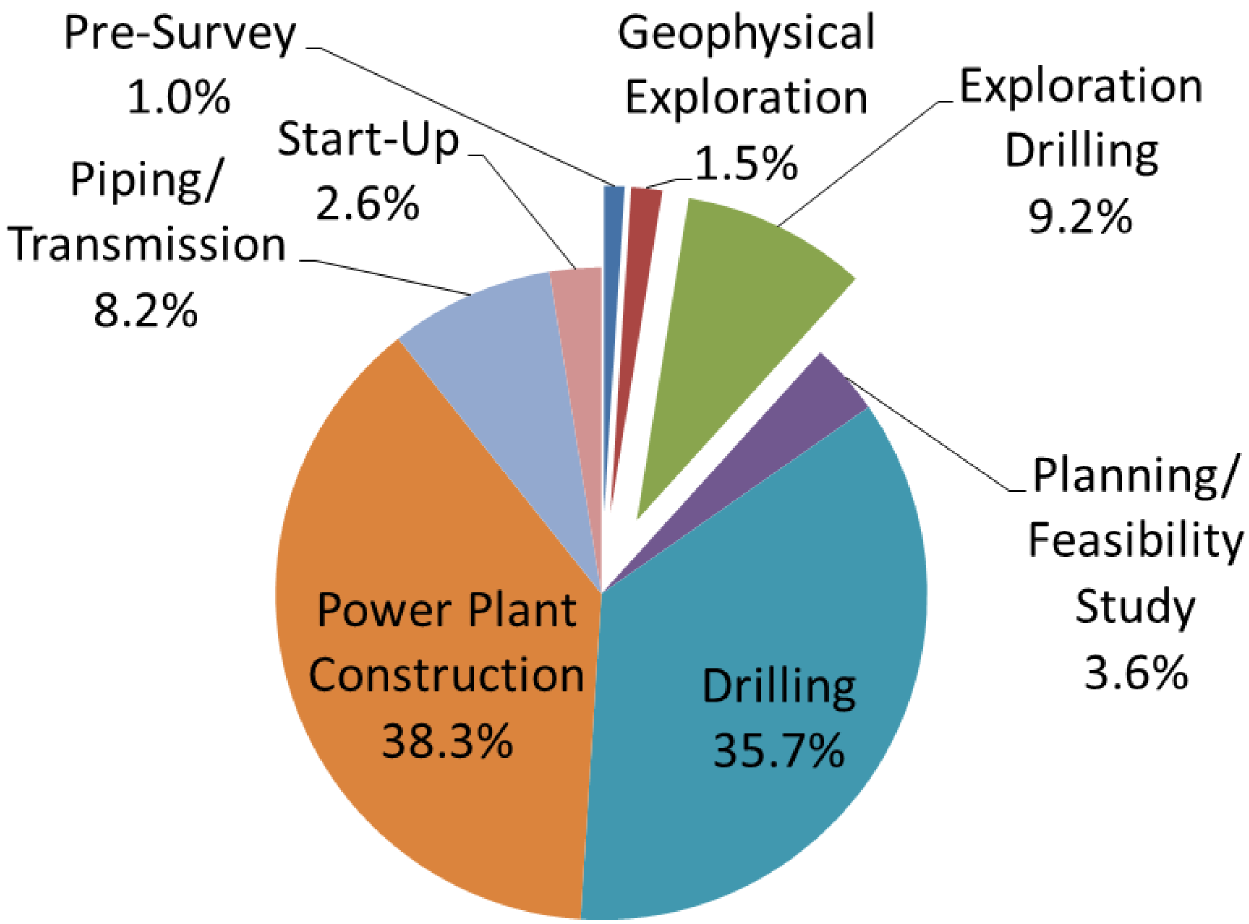
Hydrothermal Plant - "Typical" Cost Breakdown

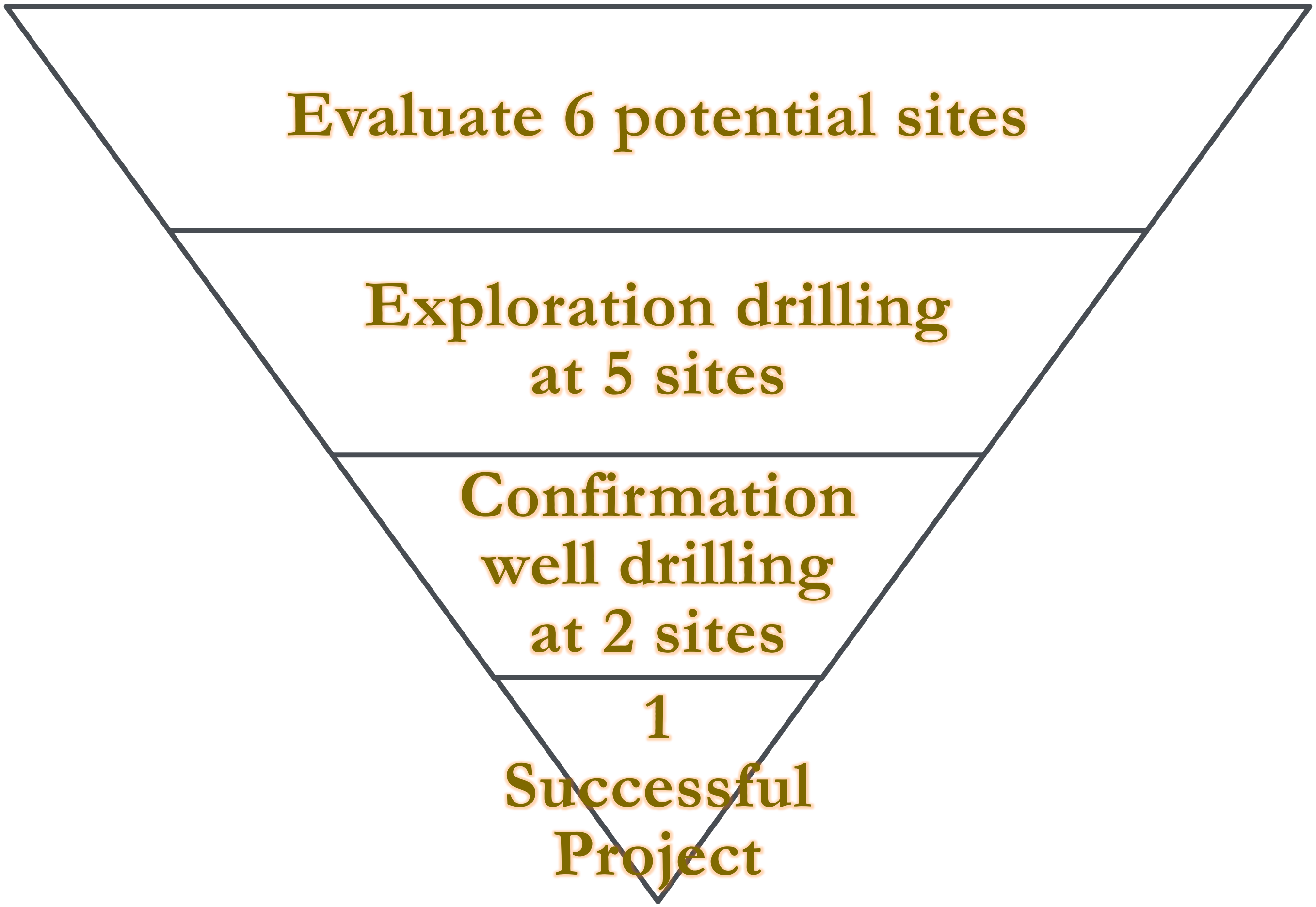
- Installed capital cost: $4,000-$6,000/kW
- LCOE: 6-12 cents/kWh
- Capital costs mostly split between drilling and power plant
- Exploration costs relatively small



Adapted From ESMAP, 2012 Geothermal handbook: Planning and Financing Power Generation

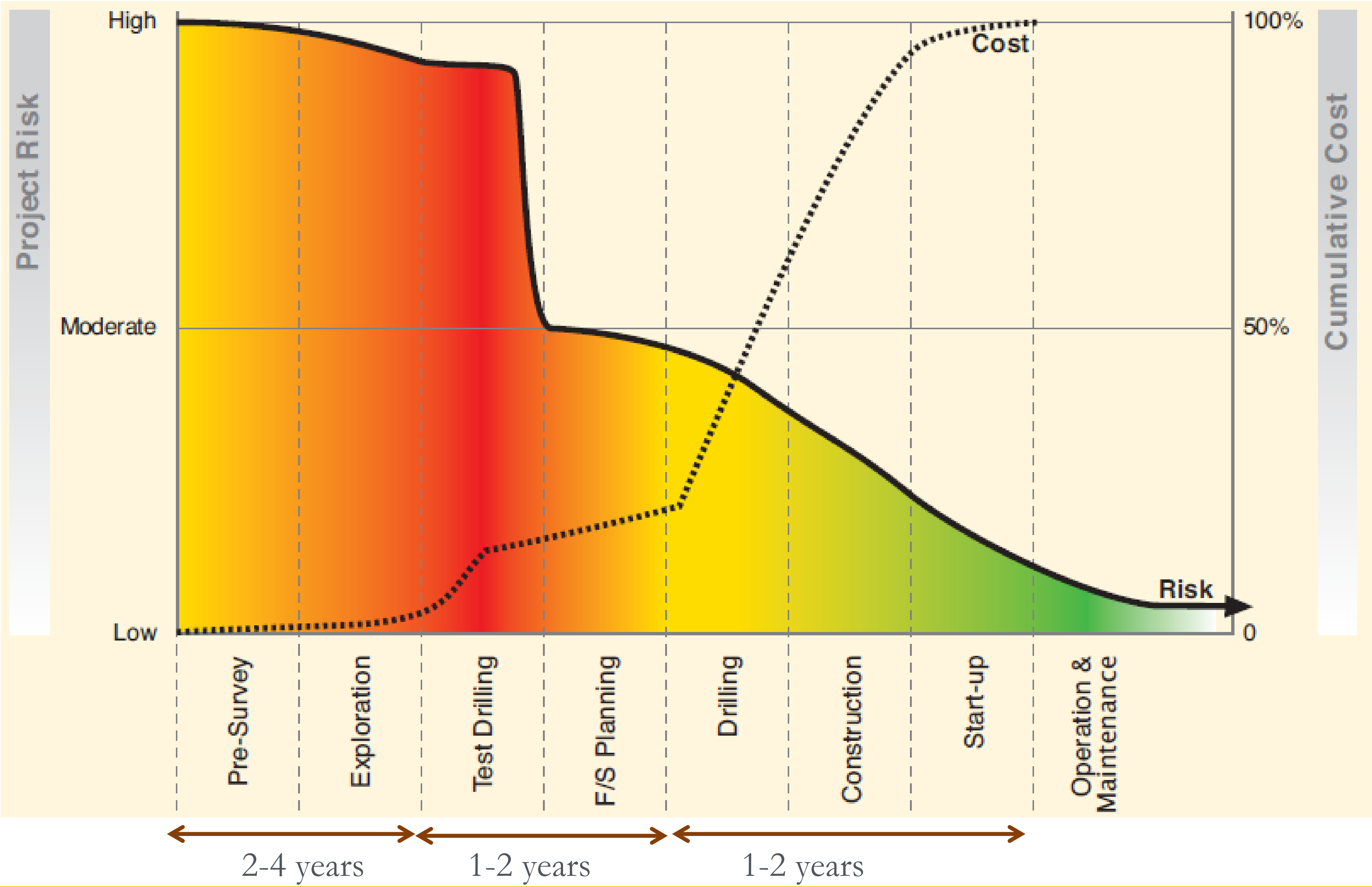
Development Risk

"Typical" exploration phases for one successful hydrothermal project



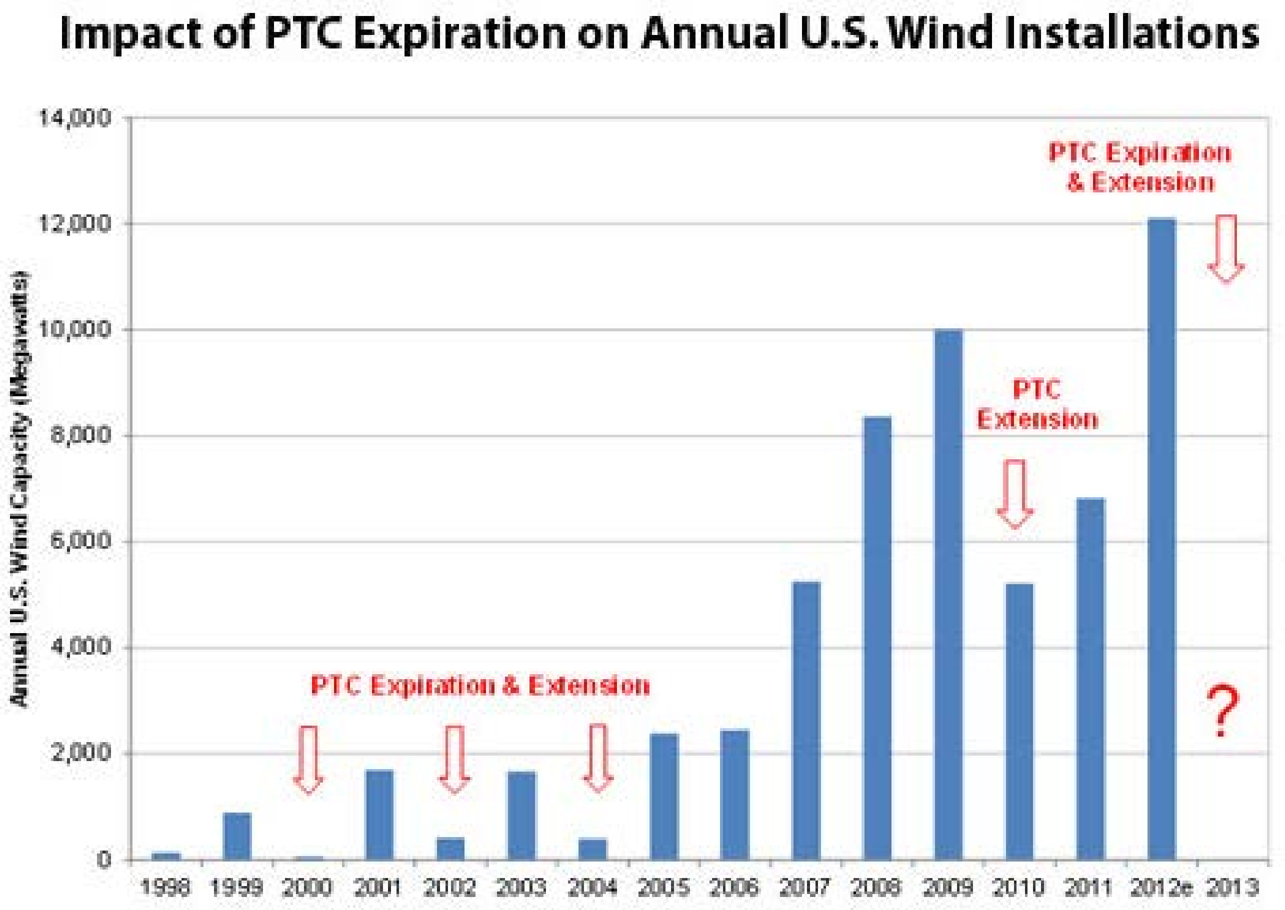
Development Risk

Adapted from ESMAP, 2012 Geothermal Handbook: Planning and Financing Power Generation



Renewable Energy Incentives

- Most incentives (ex., PTC/ITC) have short time frames
- Incentive time frames don't address long development time frames for geothermal (5-7 years)
- Incentives don't address riskiest portion of geothermal development – exploration (including exploration drilling and confirmation drilling)



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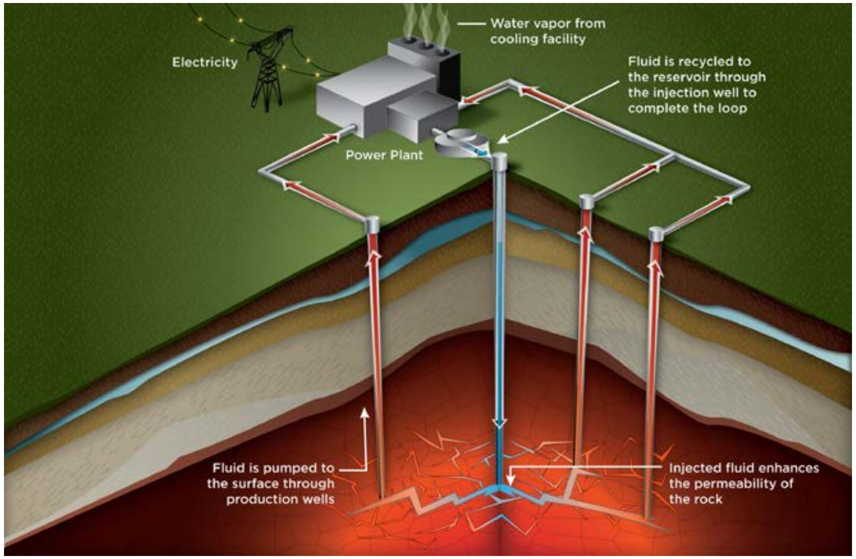
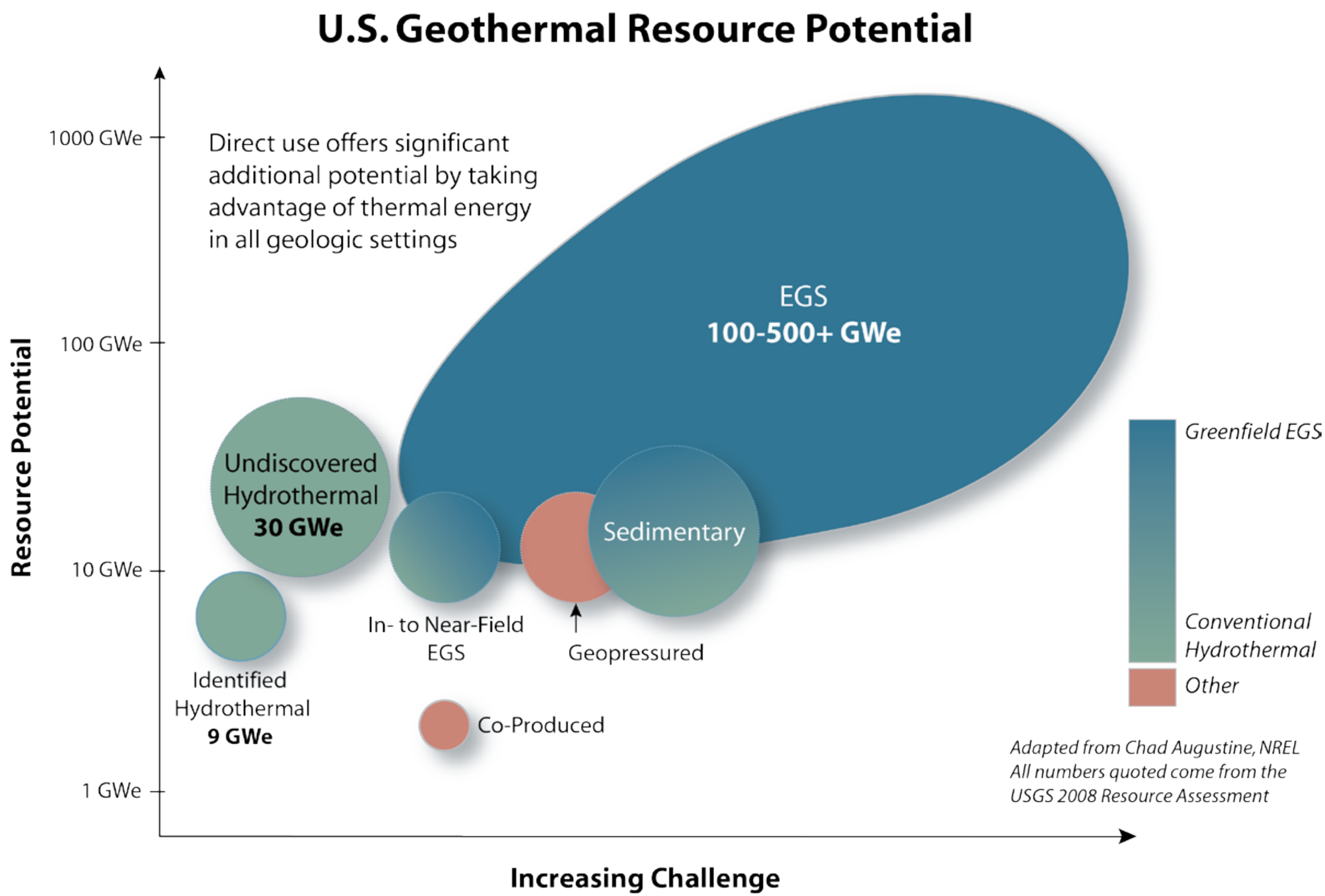
Enhanced Geothermal Systems (EGS)

- Such systems require increasing permeability by stimulating fracturing and shearing of fractures through fluid injection
- Fluid circulated between injection and production wells to capture and extract heat



High Potential Impact of EGS



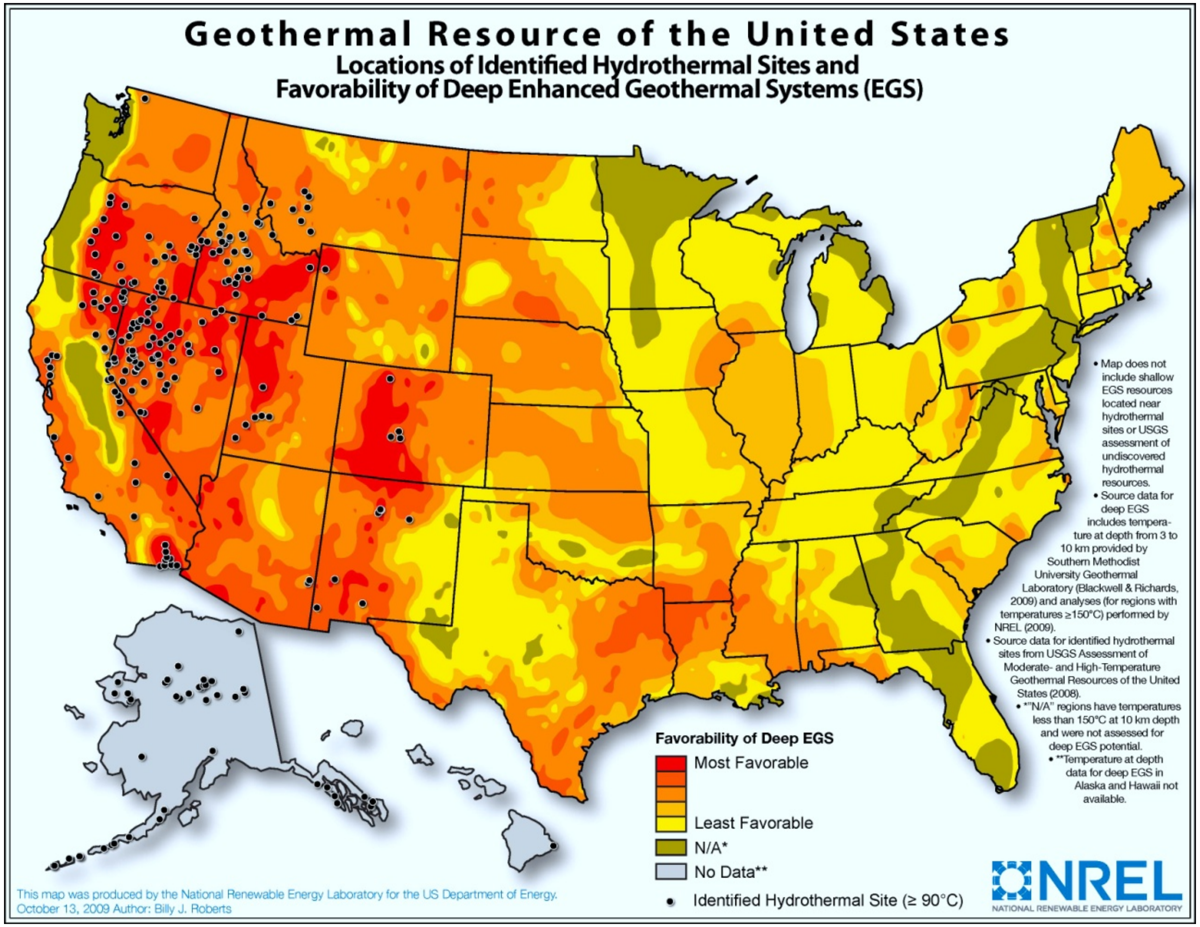
EGS Resources – Where can they be developed?

Key aspects of geothermal systems

- Elevated temperature
- Permeable flow pathways
- Benign fluid to extract heat

Key EGS challenges

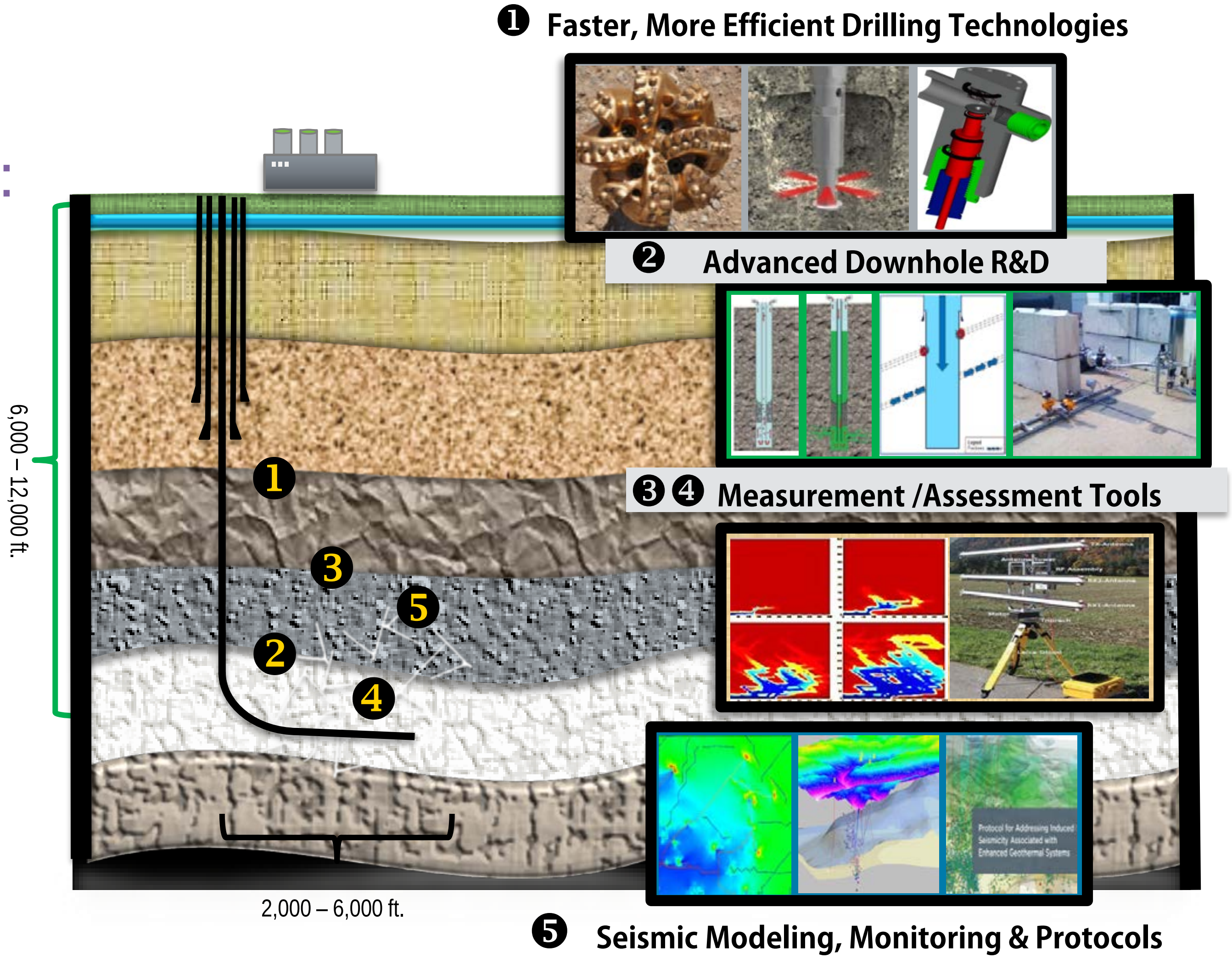
- Reservoir access (drilling)
- Reservoir characterization (subsurface imaging)
- Reservoir creation (stimulation)



EGS Field Observatory
Creating and Optimizing Reservoirs

Addressing Barriers:

- High Cost of Drilling
- Subsurface Characterization
- Creating a Reservoir
- Sustained Reservoir Production
- Risk Management & Mitigation



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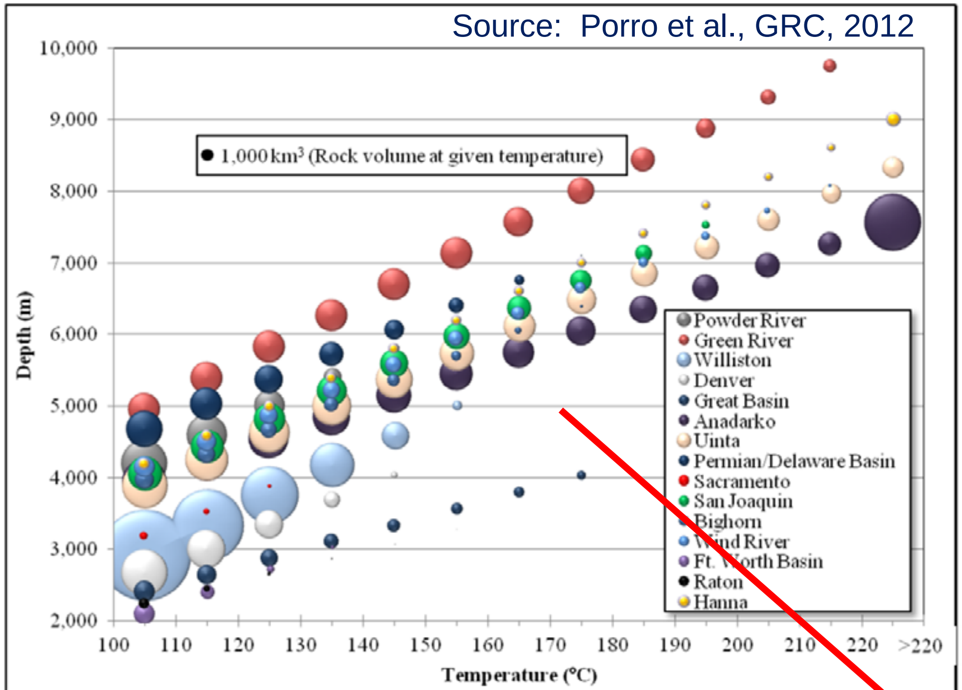
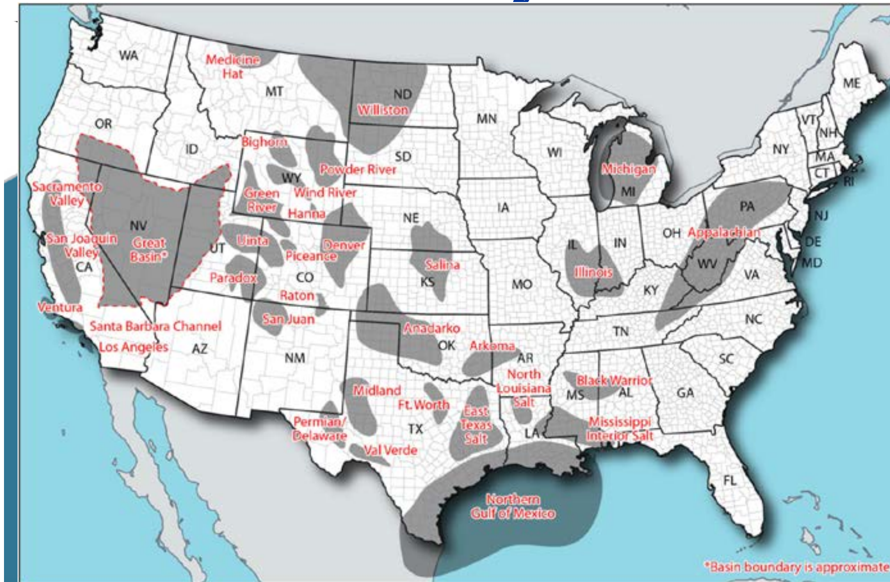
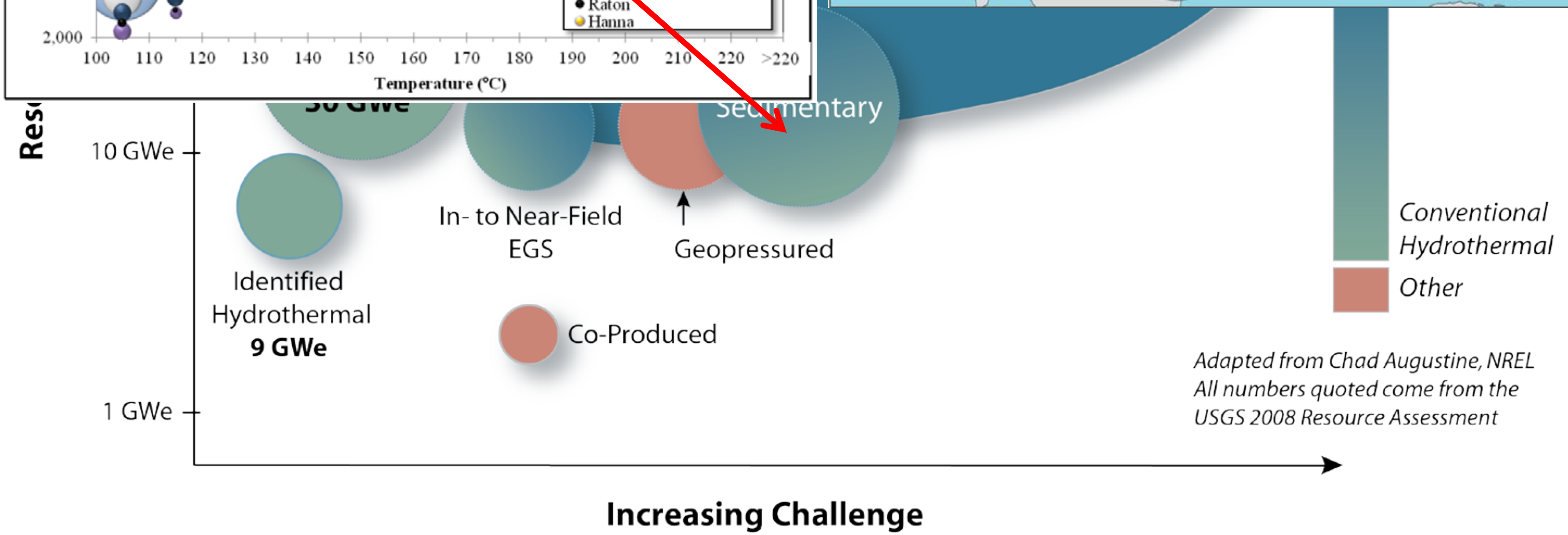
Resource Potential - Summary



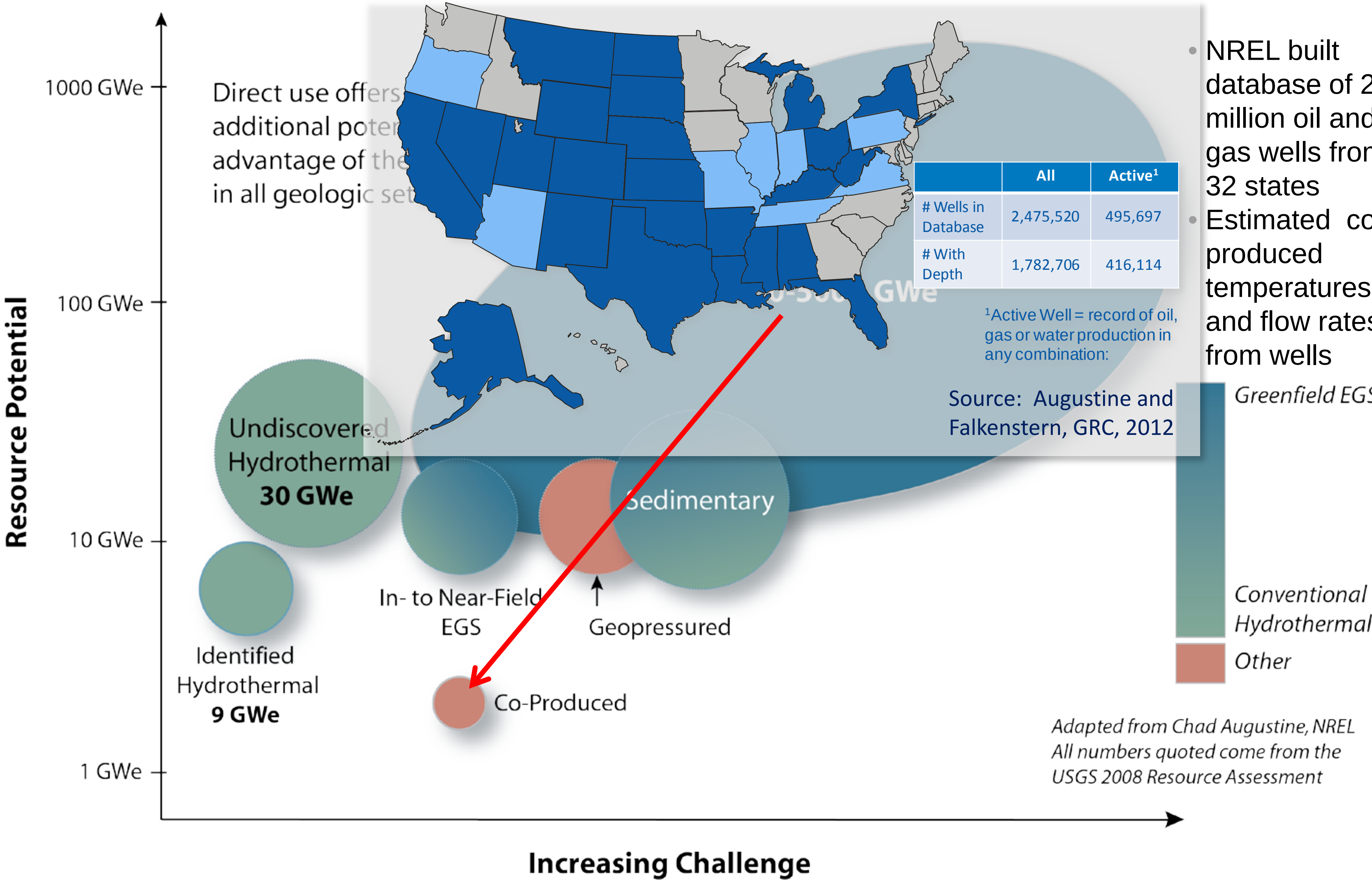




Adapted from Chad Augustine, NREL
All numbers quoted come from the USGS 2008 Resource Assessment

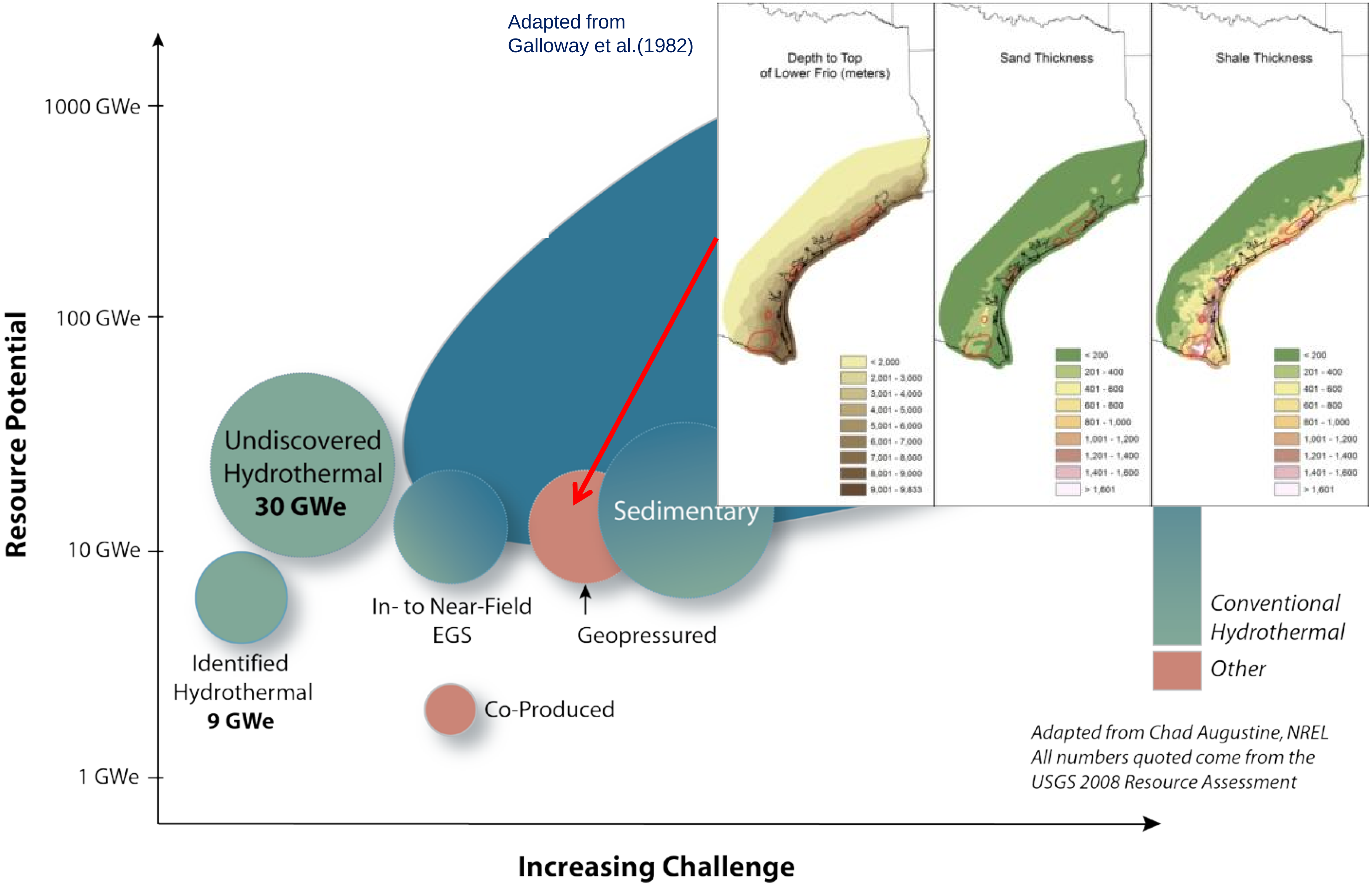
Resource Potential – Co-Produced

- NREL built database of 2.5 million oil and gas wells from 32 states
- Estimated co-produced temperatures and flow rates from wells

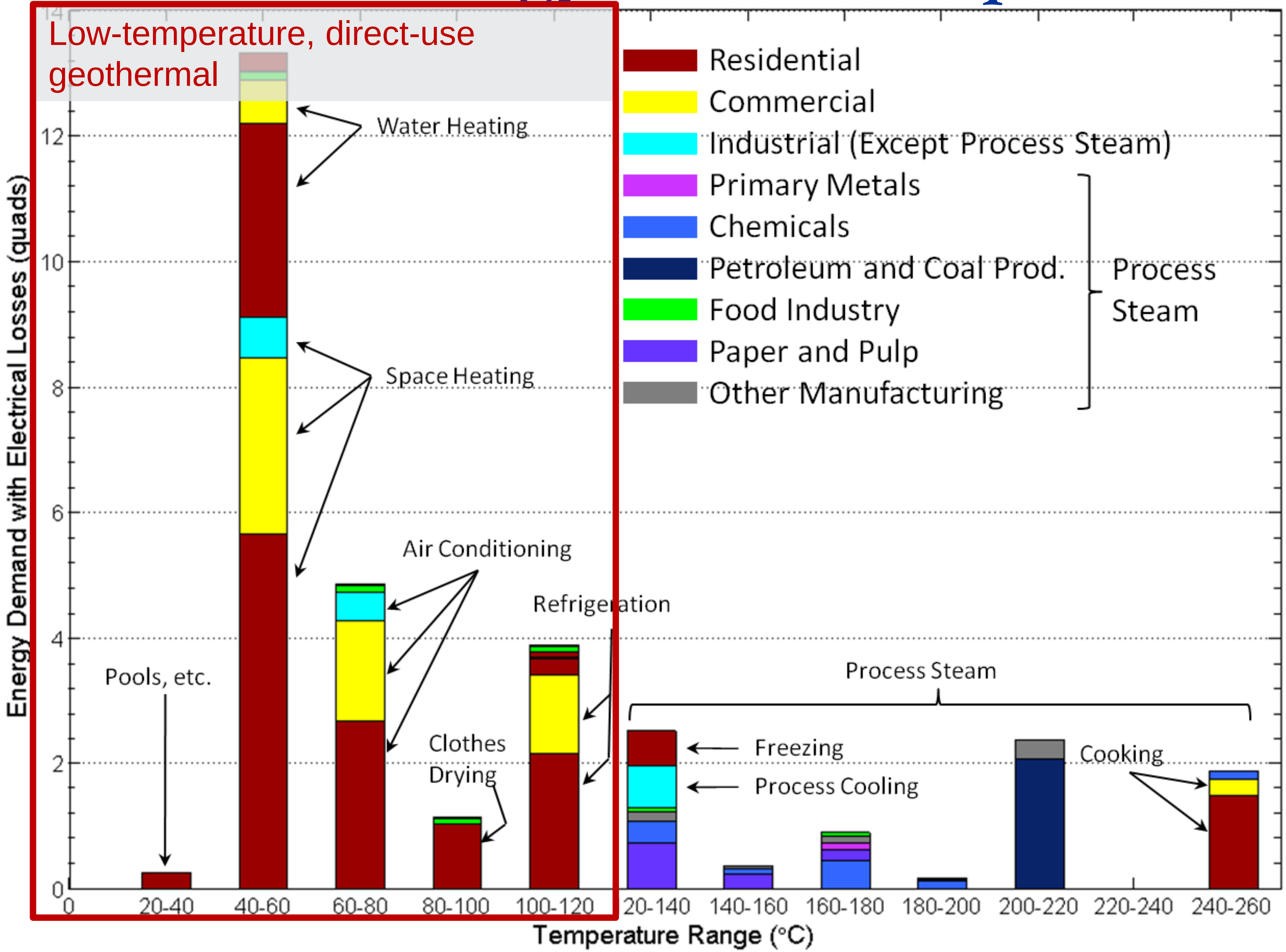


	All	Active[1]
# Wells in Database	2,475,520	495,697
# With Depth	1,782,706	416,114

Resource Potential - Geopressured



Need for Energy at Low Temperature

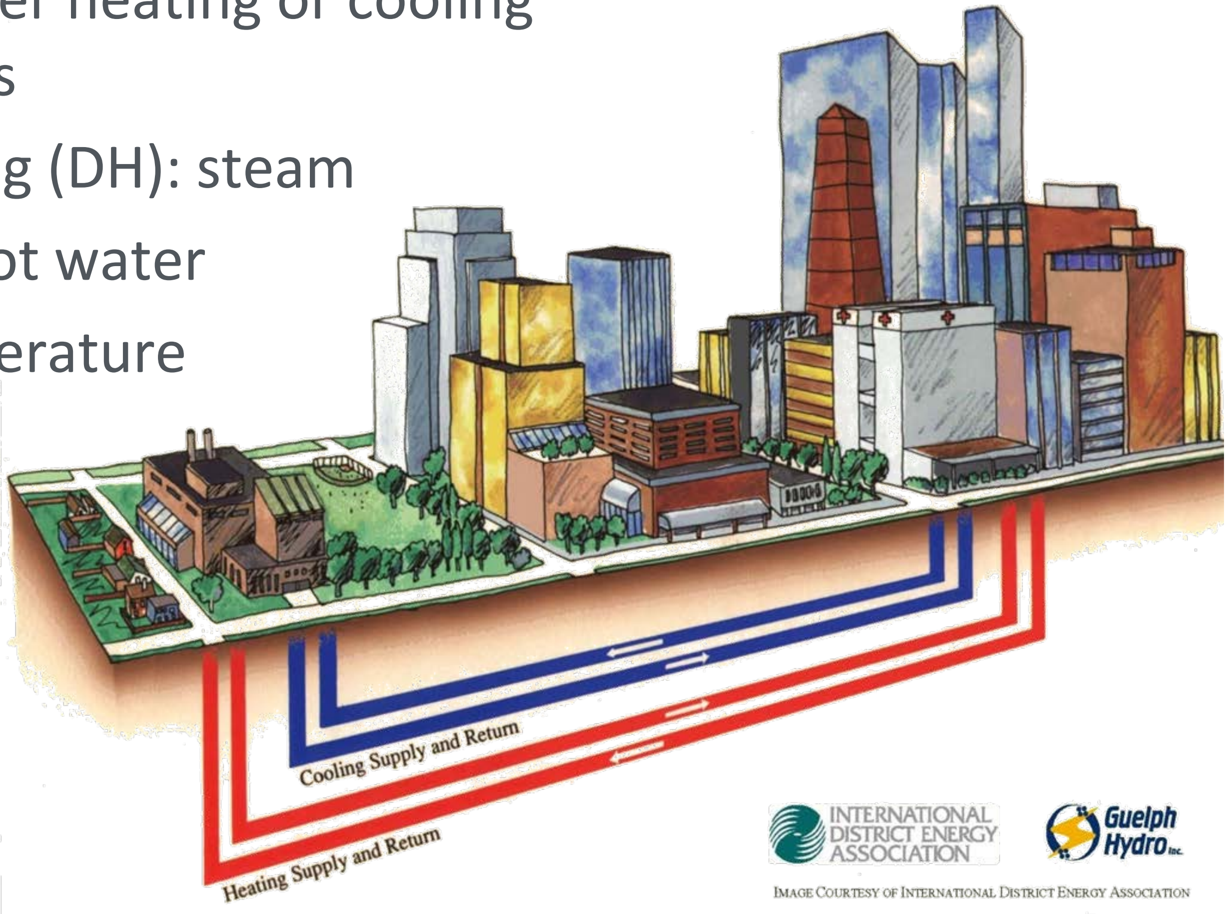


U.S. thermal energy demand from 0-260°C (with electrical system losses)

The thermal spectrum of low-temperature energy use in the United States, Fox et al., *Energy and Environmental Science*, 2011

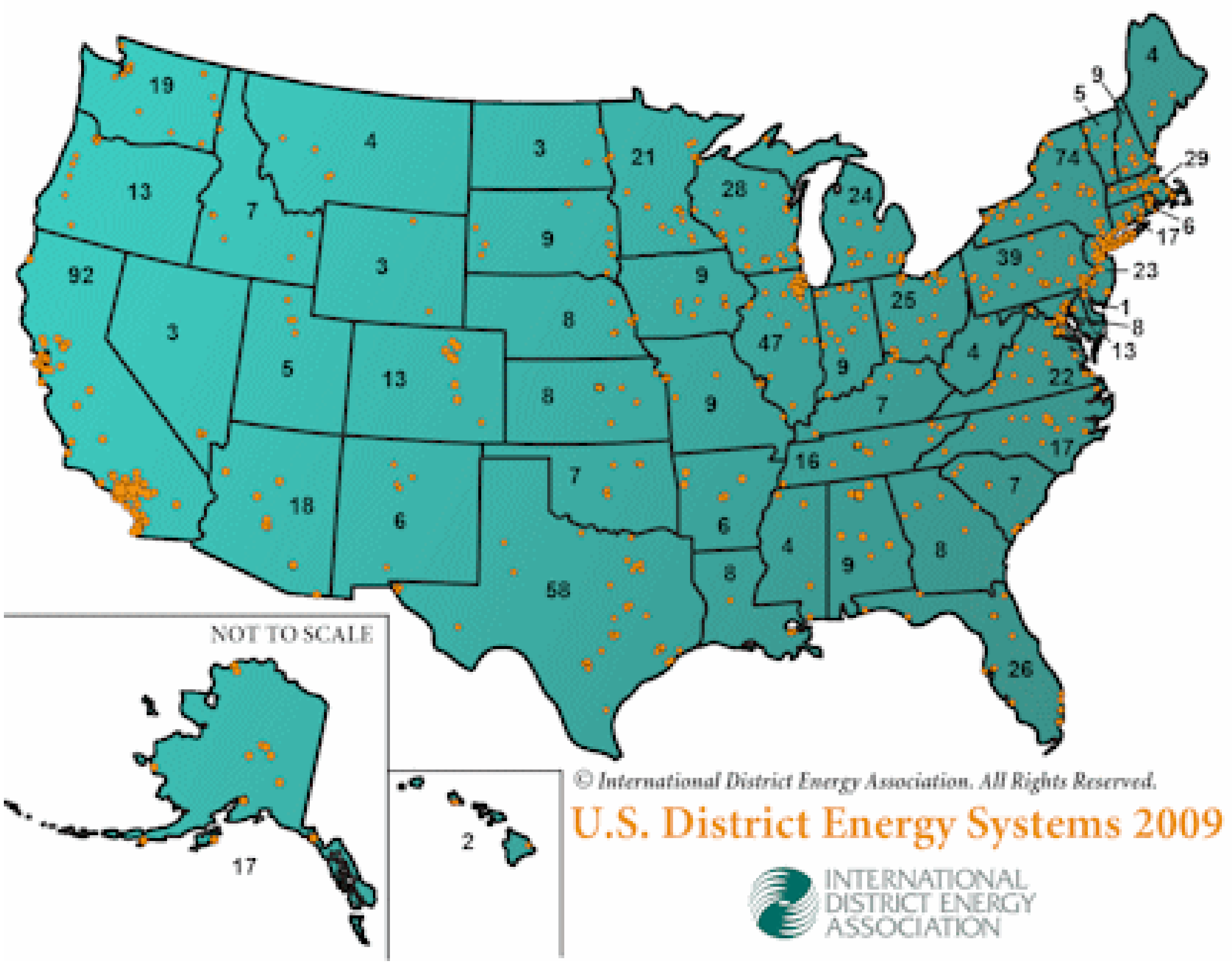
Direct-Use Energy Brief

- Piping networks deliver heating or cooling streams to consumers
- 1st gen District Heating (DH): steam
- 2nd and 3rd gen DH: hot water
- 4th gen DH: low temperature fluid, ~55°C
- 4th gen DH enable penetration of renewable sources
- Higher utilization efficiencies than electricity production

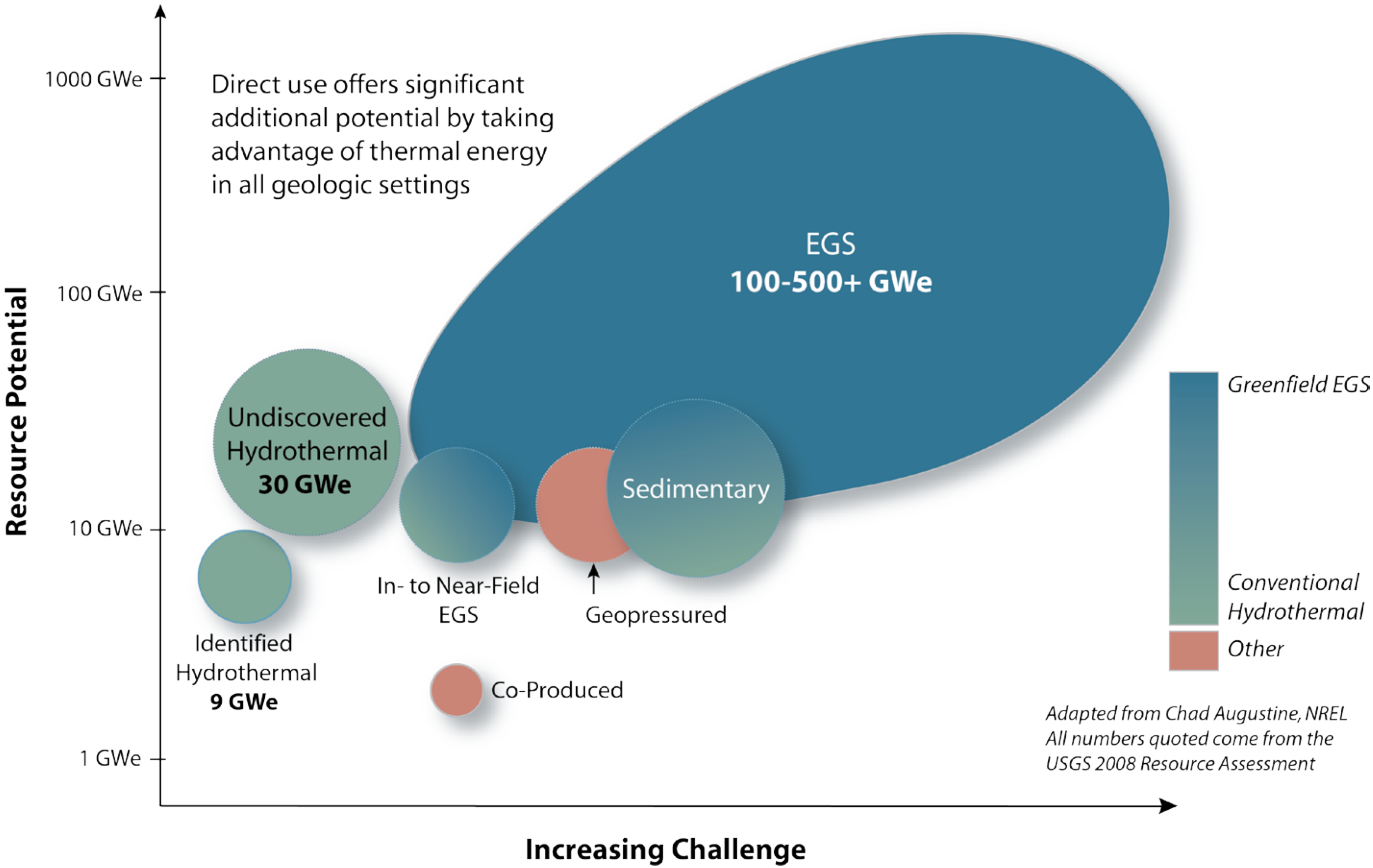


District Energy Systems in the US

- Over 800 district energy systems in the United States
- Operating in the US for over 100 years
- Serving more than 4.3 billion ft^2 of building space



Resource Potential – Low-T



Adapted from Chad Augustine, NREL
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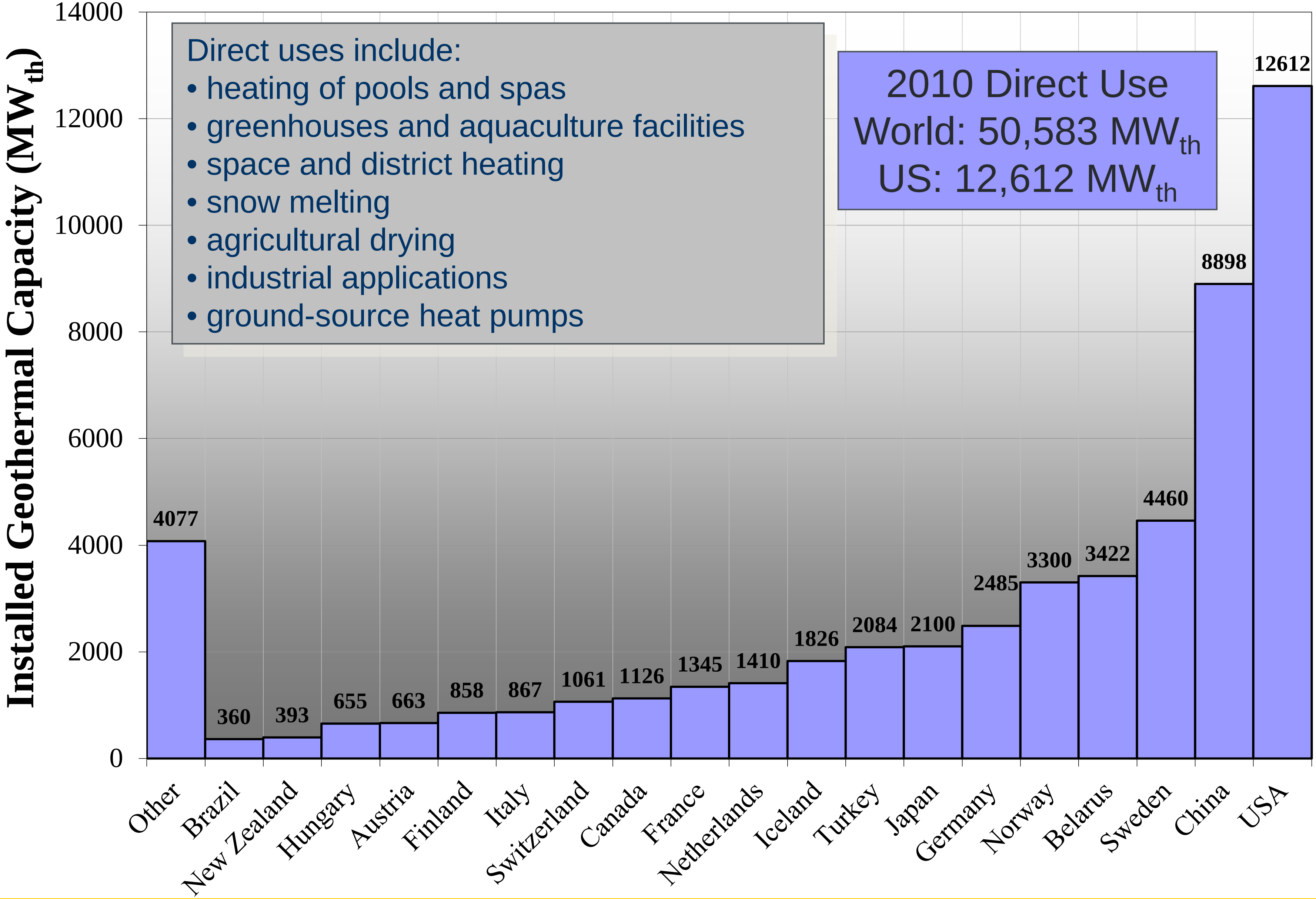
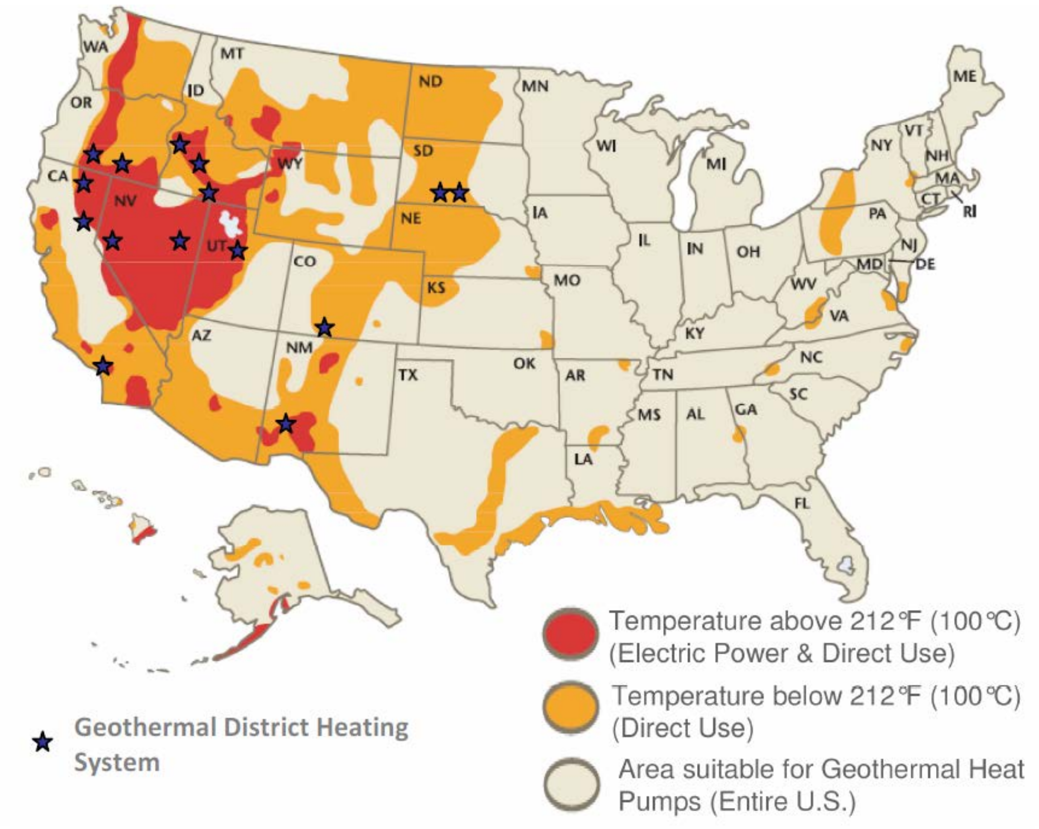
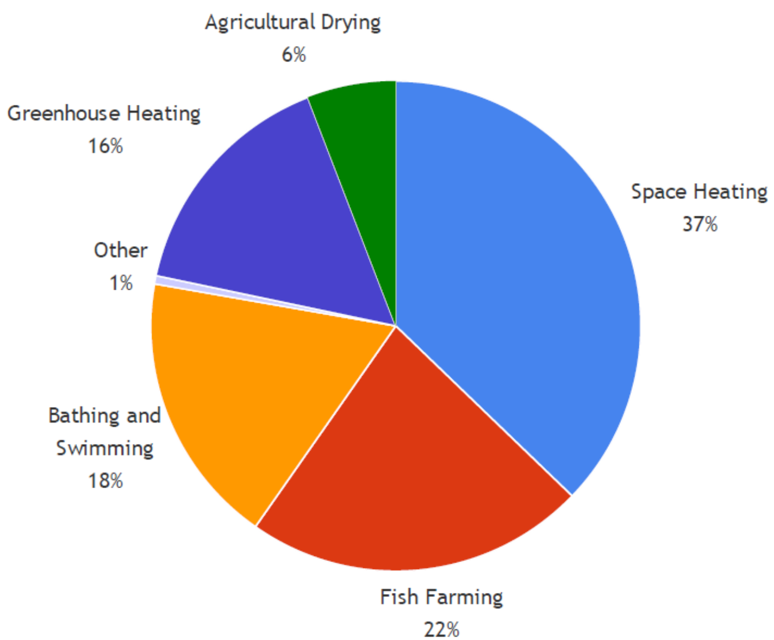
Direct Use Geothermal Worldwide



Direct-Use Geothermal Usage in the US



U.S. Geothermal district heating systems (from Richter, 2007)



Geothermal direct-use in the U.S. 2004 (data from Lund, 2005)

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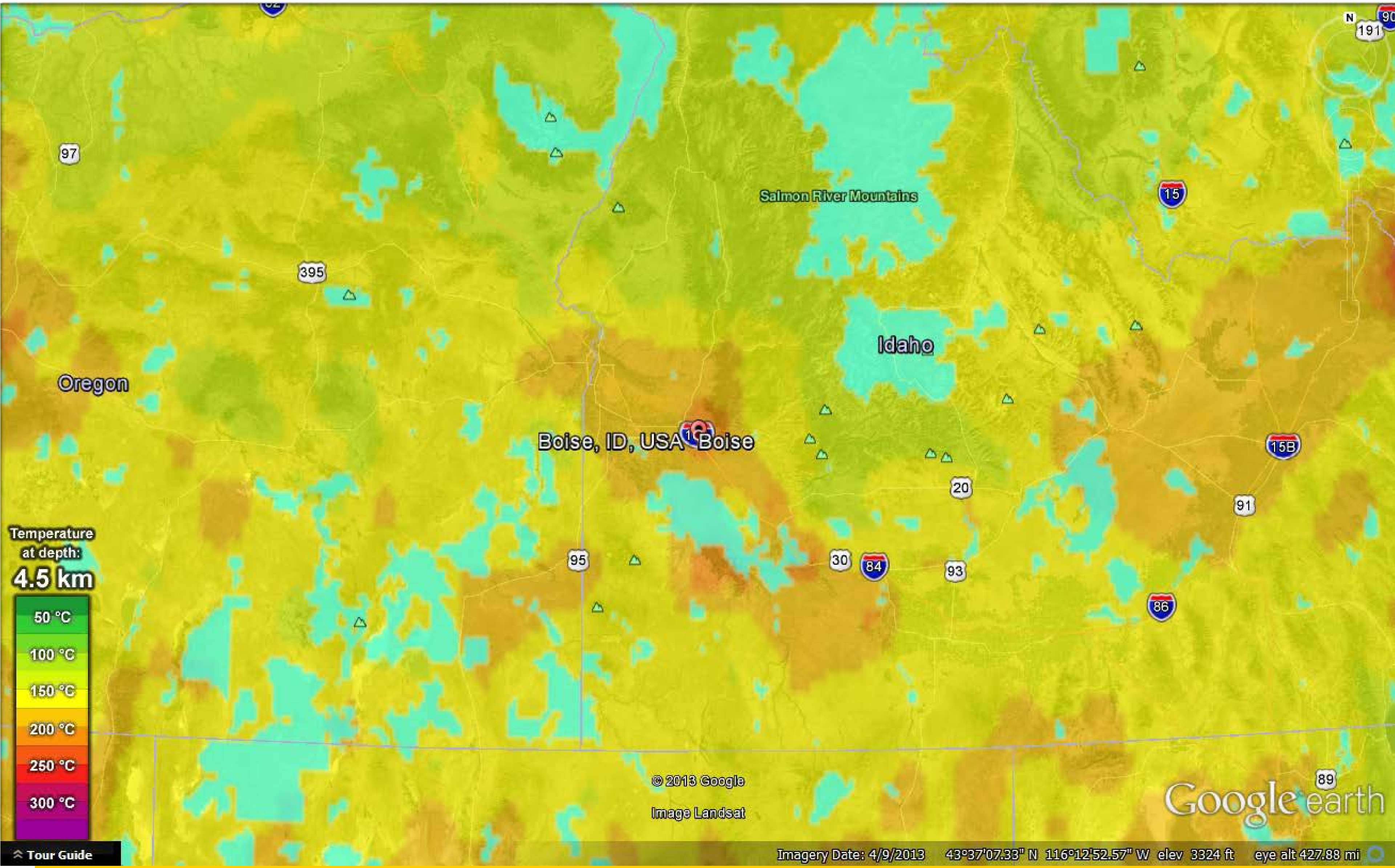
Boise, ID

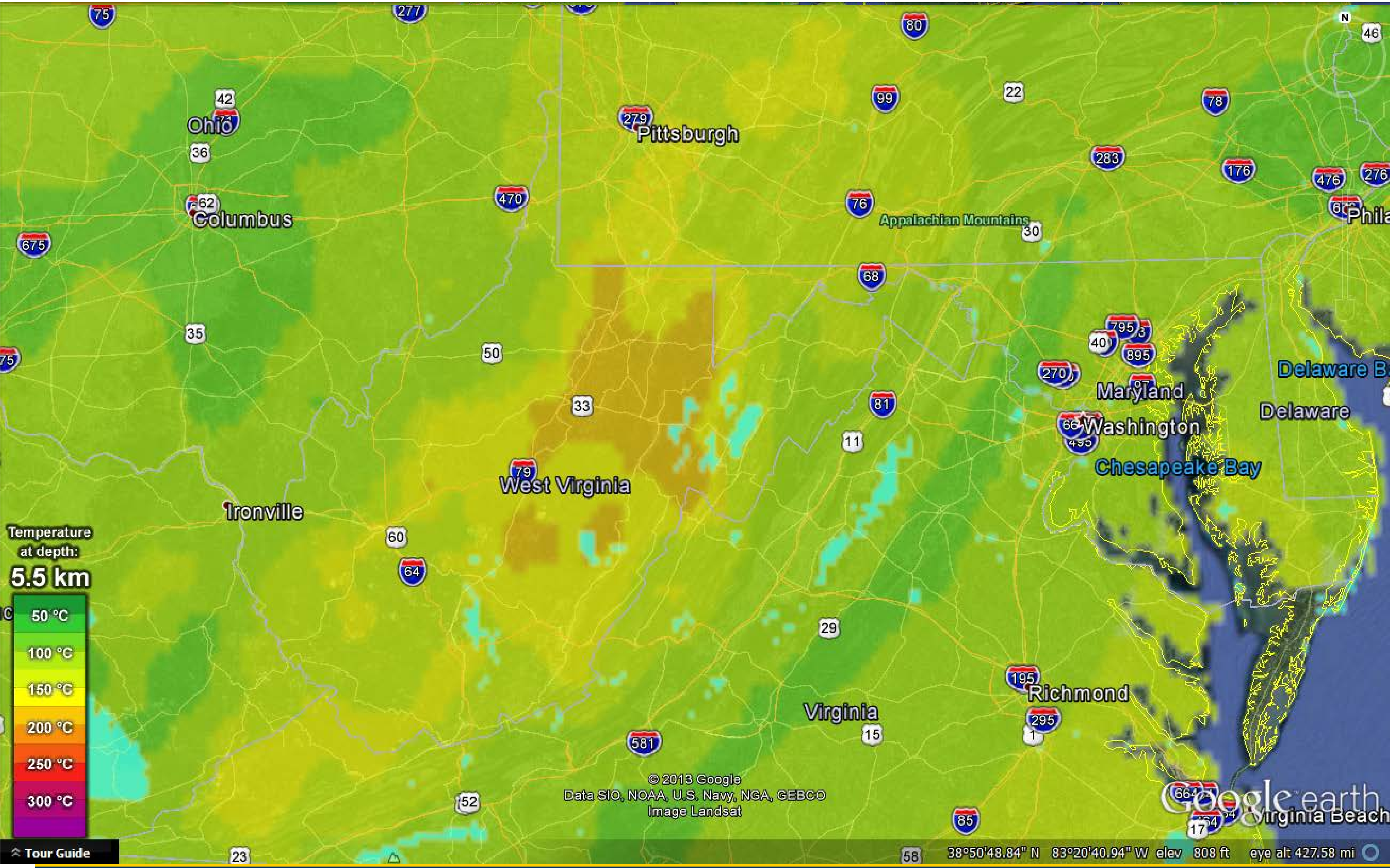
- **Largest of 17 US geothermal district heating systems**
- **First system installed in 1892**
- **Four systems currently operating**
  - Boise Public Works – downtown core area
    - 170°F (77°C), 65 customers, 1.8 million ft^2 including: City Hall, Ada County Courthouse, Idaho Water Center, Boise High School and YMCA
  - State of Idaho – State Capital and Capital Mall complex
    - 165°F (74°C), 9 buildings in the Capitol Mall complex, including the State Capitol (Neely, 1994). Currently, the system is used to heat about 1.5 million ft^2
  - Veterans Administration – VA campus
    - 400,000 ft^2 in 22 buildings on the VA grounds
  - Boise Warm Springs Water District – residential hot water
    - 176°F (80°C), Original system installed in 1892

Photo credits: Idaho Capital Commission (top), Idaho Governor's Office of Energy Resources (middle), and Idaho State Historical Society (bottom)

Geothermal Potential near Boise, ID



Geothermal Potential in the East



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by Eli Kintisch on 4 October 2010, 5:02 PM | Permanent Link | 5 Comments

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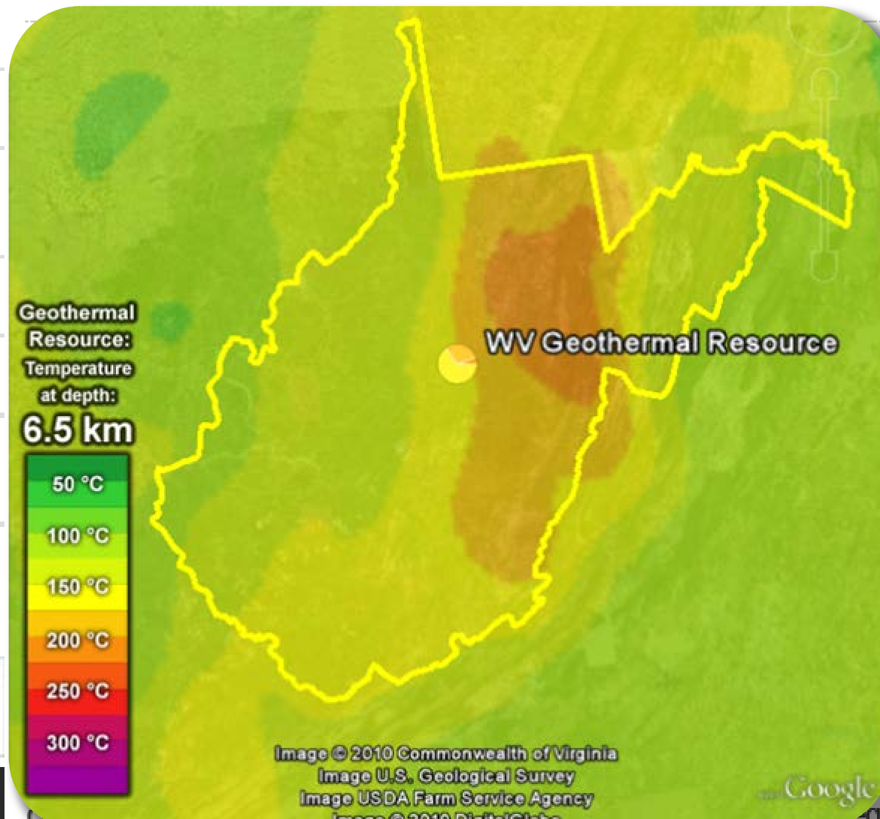

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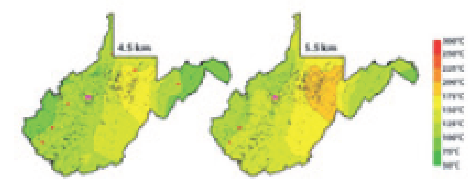

Hot or not? A new map of underground temperatures suggests that West Virginia has great potential for geothermal energy.

Credit: Source: Southern Methodist University and Google.org

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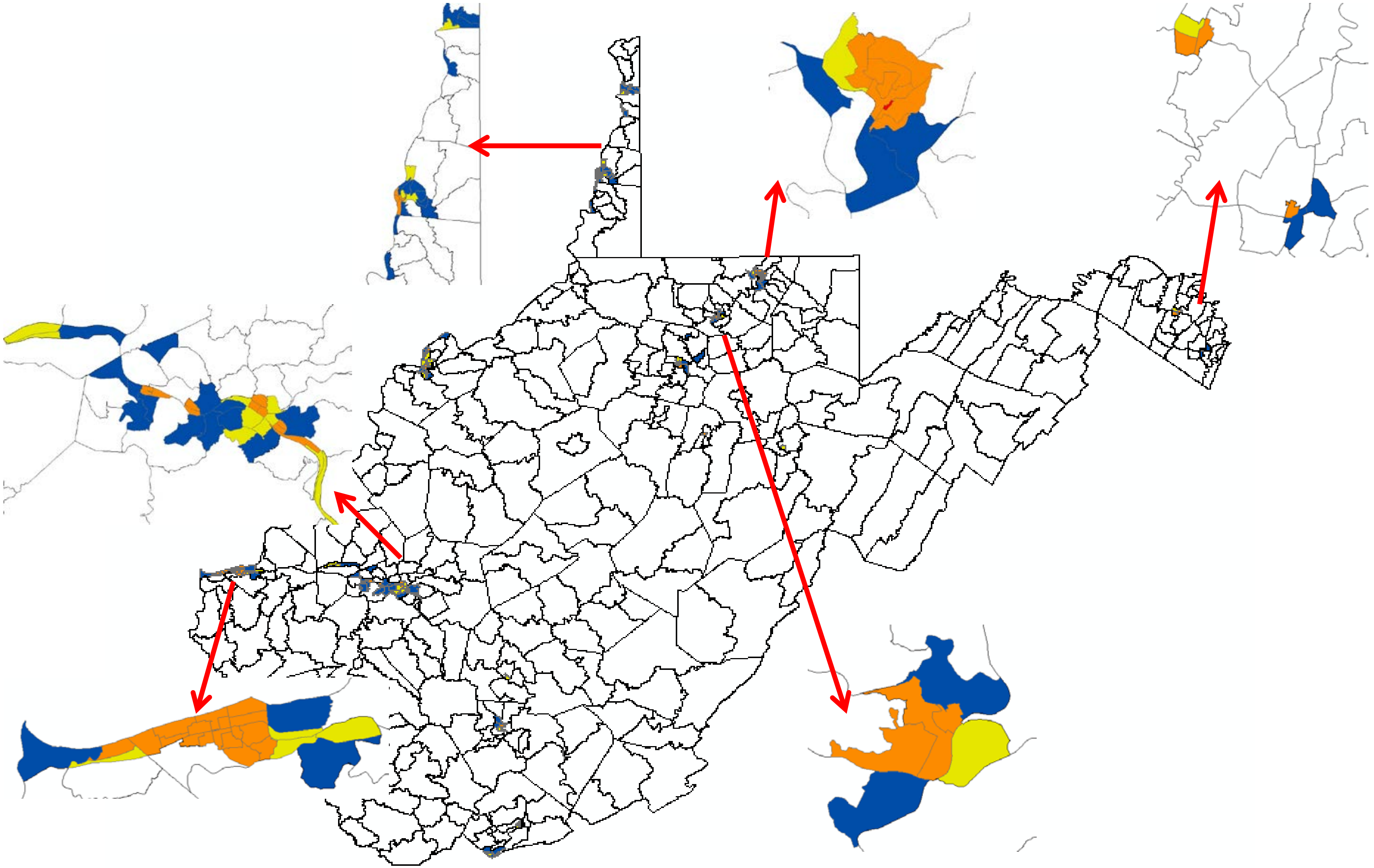
Targets of Opportunity for Direct Use in West Virginia



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WVU Case Study

- AspenPlus models of the heating distribution system and absorption chilling system constructed and analyzed.

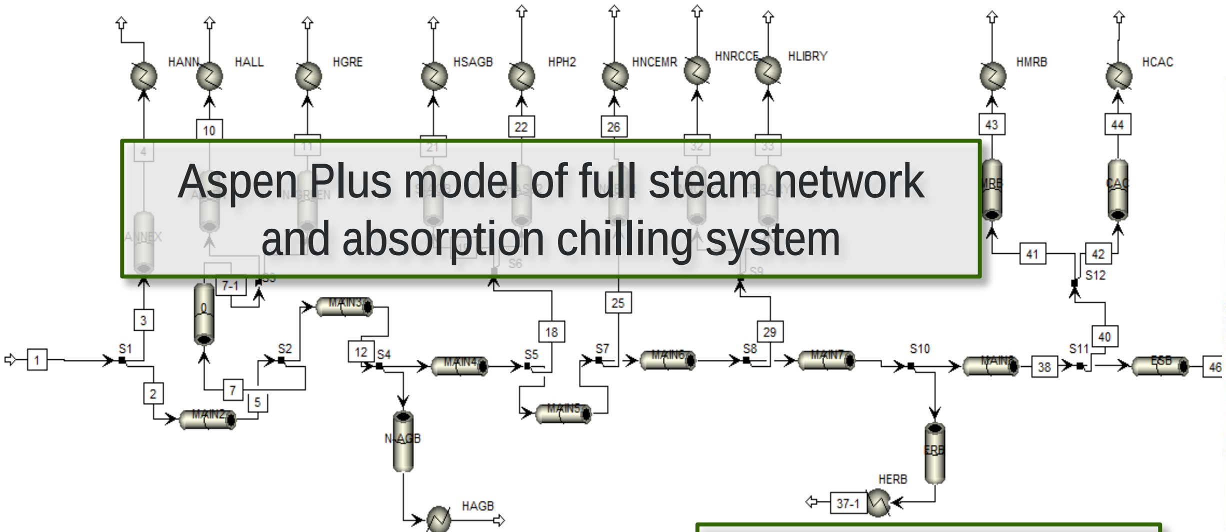
He, X., Anderson, B.J., "Low-Temperature Geothermal Resources for District Heating: An Energy-Economic Model of West Virginia University Case Study," SGW, 2012, SGP-TR-194

Case	Heating (MW_{th})	Cooling (MW_{th})	Levelized Energy Cost ($/MMBtu$_{th}$)
1	16.24	9.93	11.70~12.72
2	16.24	9.93	8.46~9.50
3	16.08	9.93	5.30~6.37

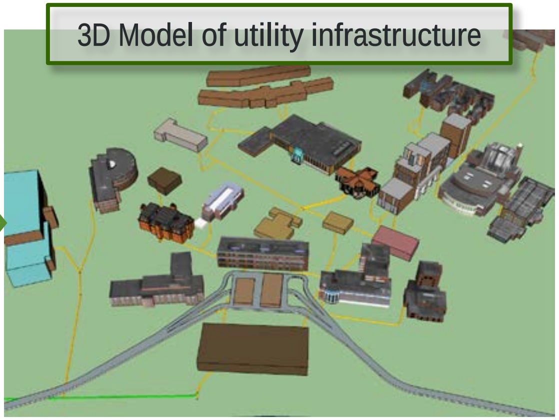
Case 1: Full costs, complete retrofit, no tax breaks

Case 2: Public entity bond rates, tax incentives

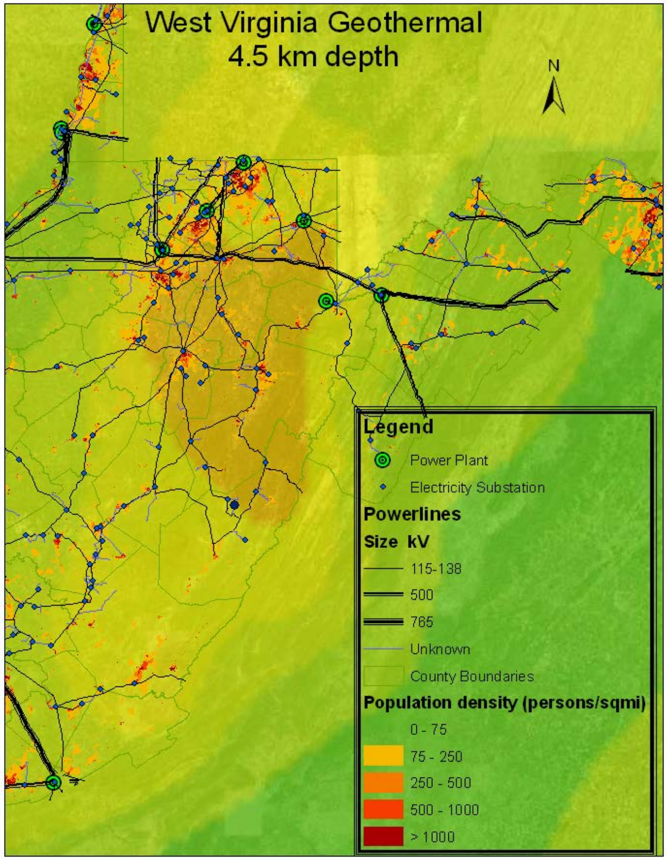
Case 3: Lower retrofit costs, using hot water not steam



Aspen Plus model of full steam network and absorption chilling system



3D Model of utility infrastructure



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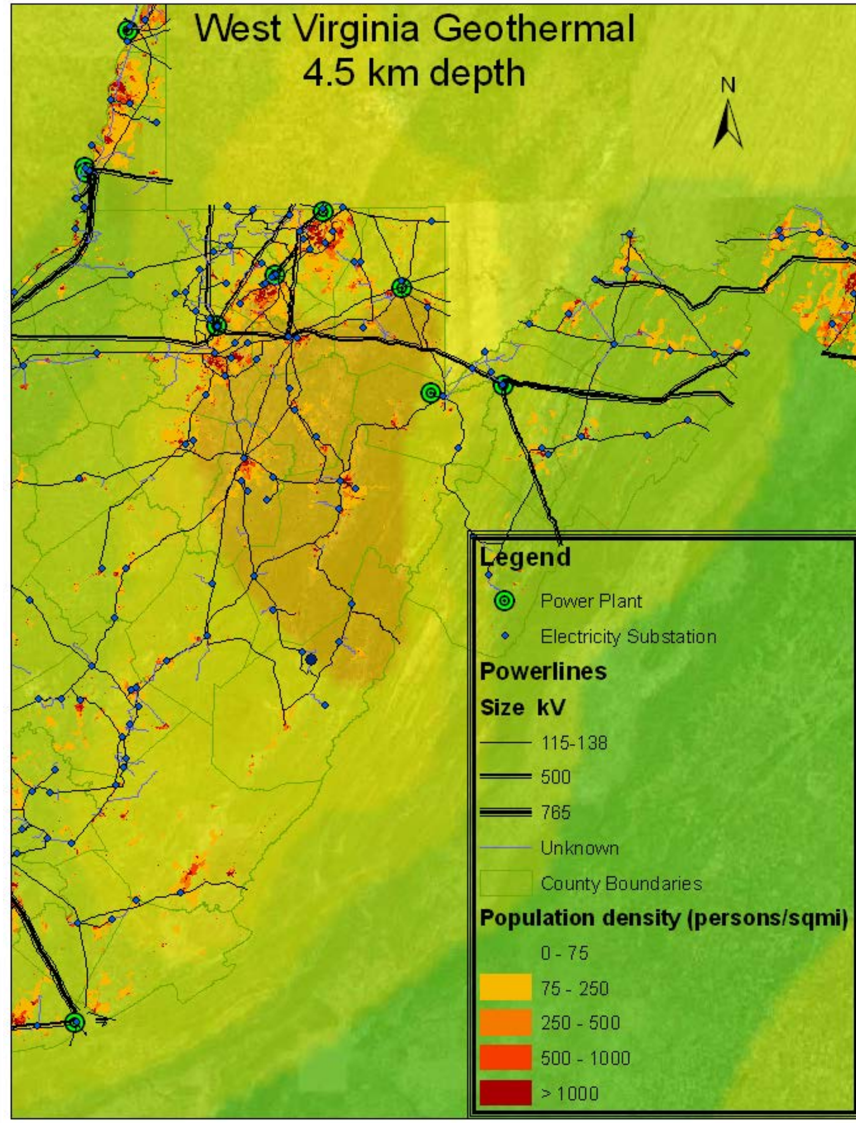
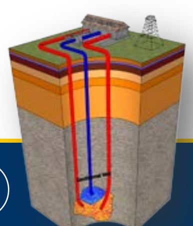
CO_2 Geothermal Overview

- CO_2 stored in deep geothermal reservoirs may have many advantages over other alternatives for CO_2 sequestration, such as
  - shallow saline aquifers
  - coal seams
  - depleted oil and gas reservoirs
- The energy produced from the geothermal system will help offset the parasitic losses associated with CO_2 capture, separation, and pressurization requirements for both power generation and fuel processing operations

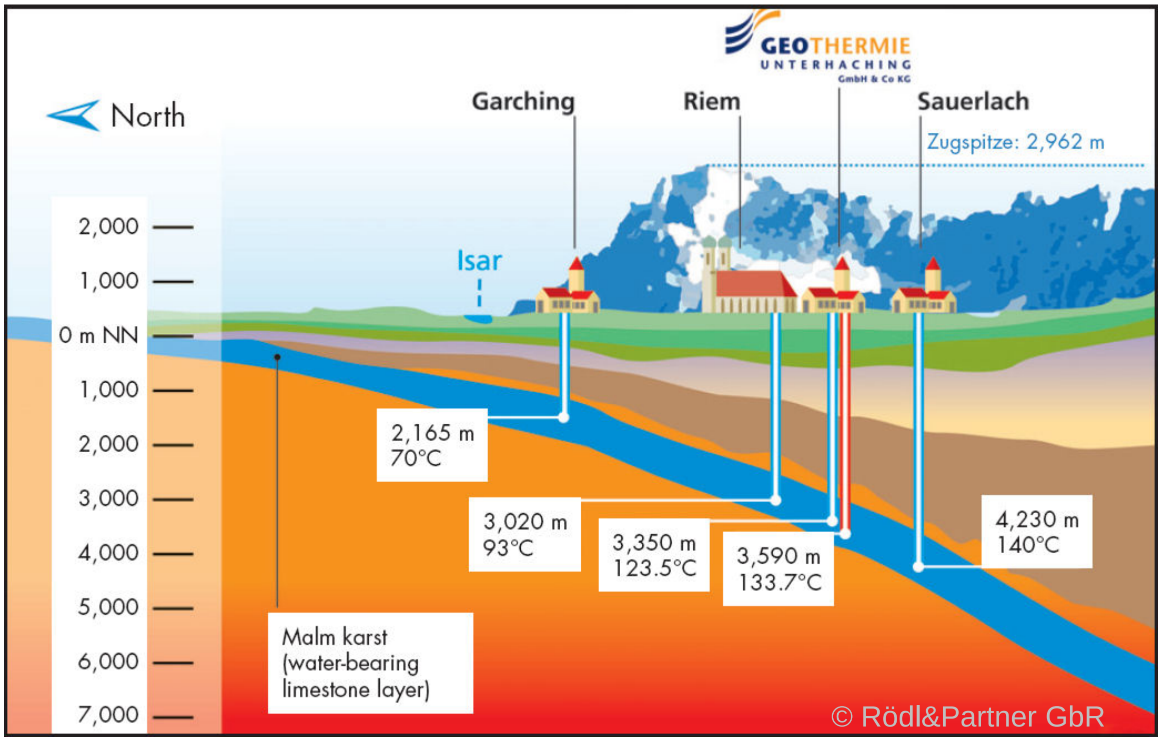


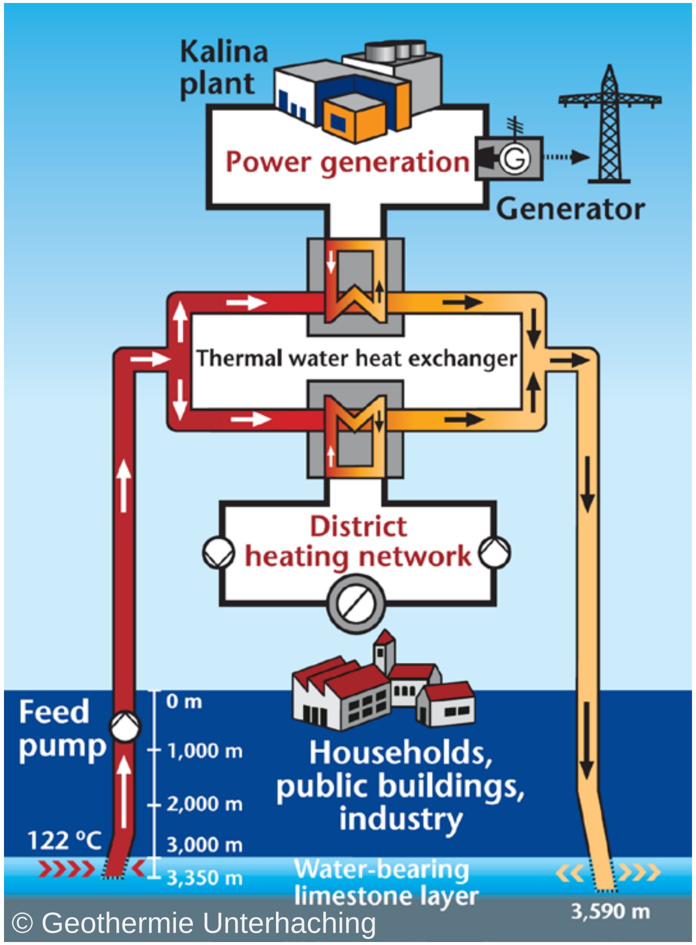
However, there are many fundamental science issues to be overcome



Geothermal Combined Heat and Power

- **Unterhaching geothermal plant near Munich, Germany**
  - Located in the Bavarian Molasse Basin (similar geologic setting as the Eastern US)
  - Low-temperature (122°C) production of heat and electricity
  - Heating 5,000 households
  - 2 wells (3.3 and 3.4 km) resulting in 38 MW_{th}





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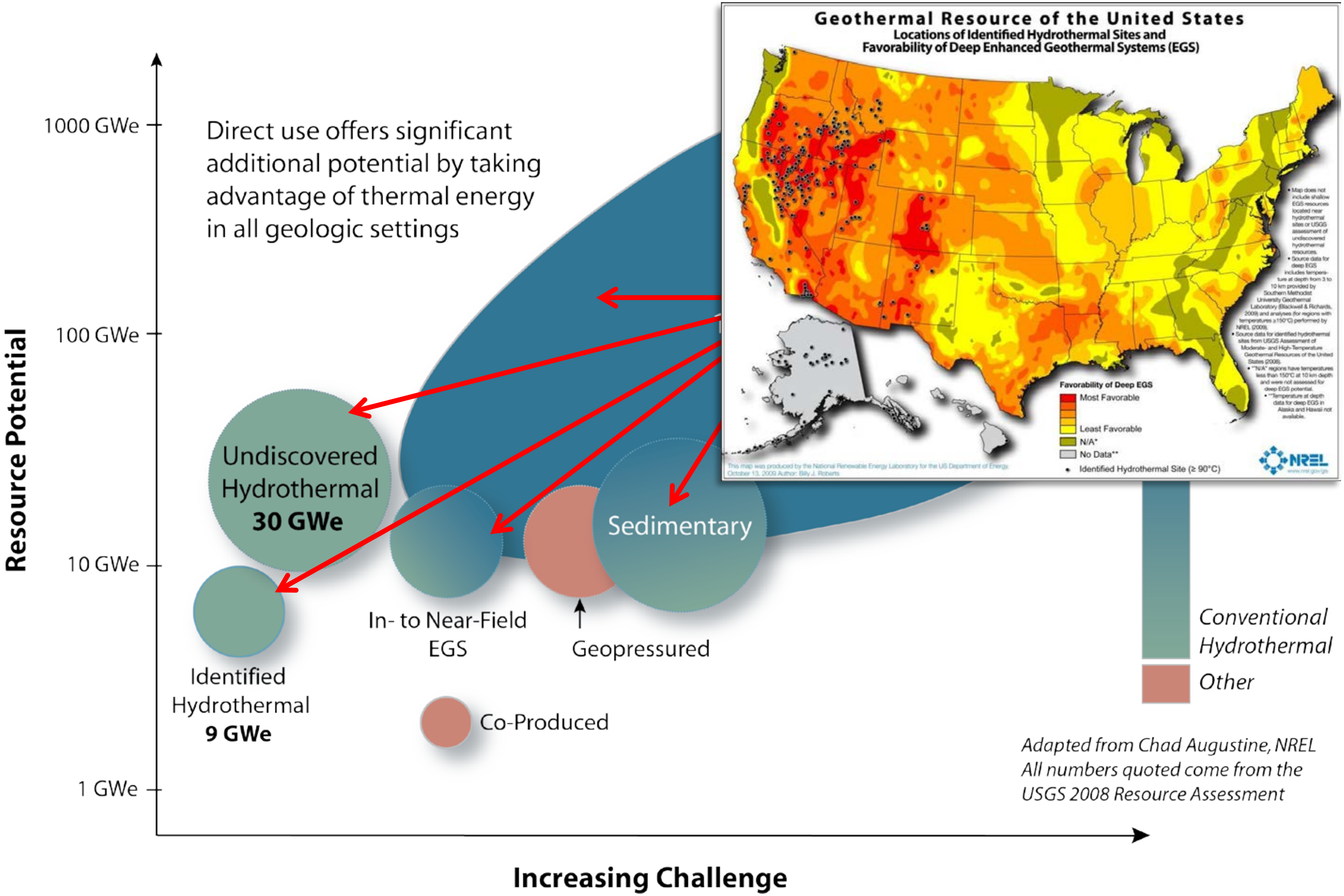
Resource Potential – Direct-Use



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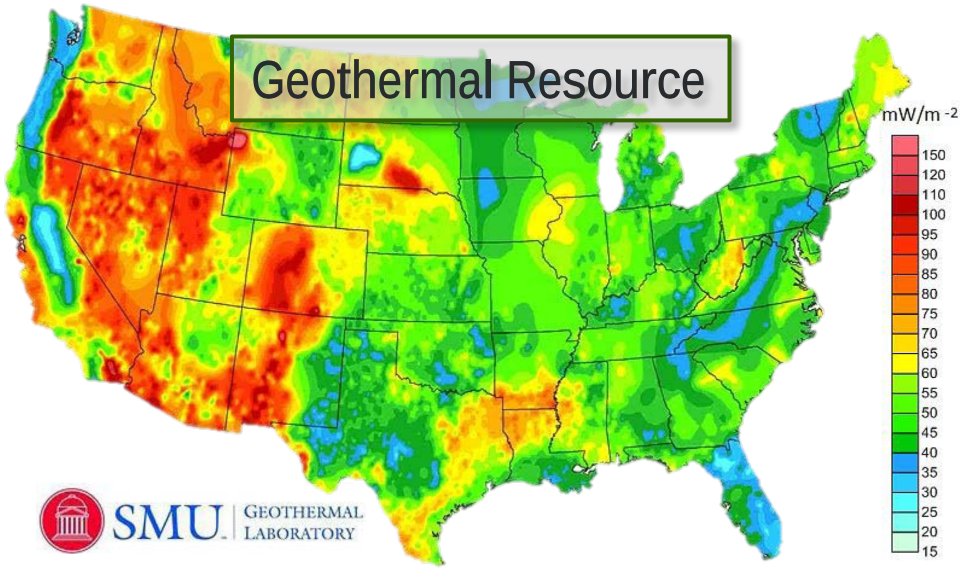
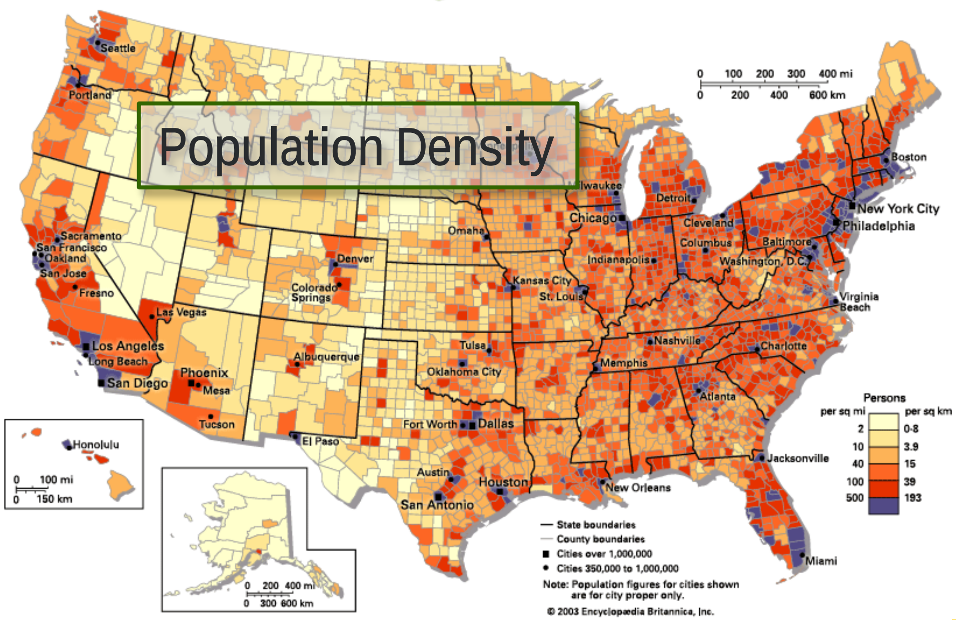
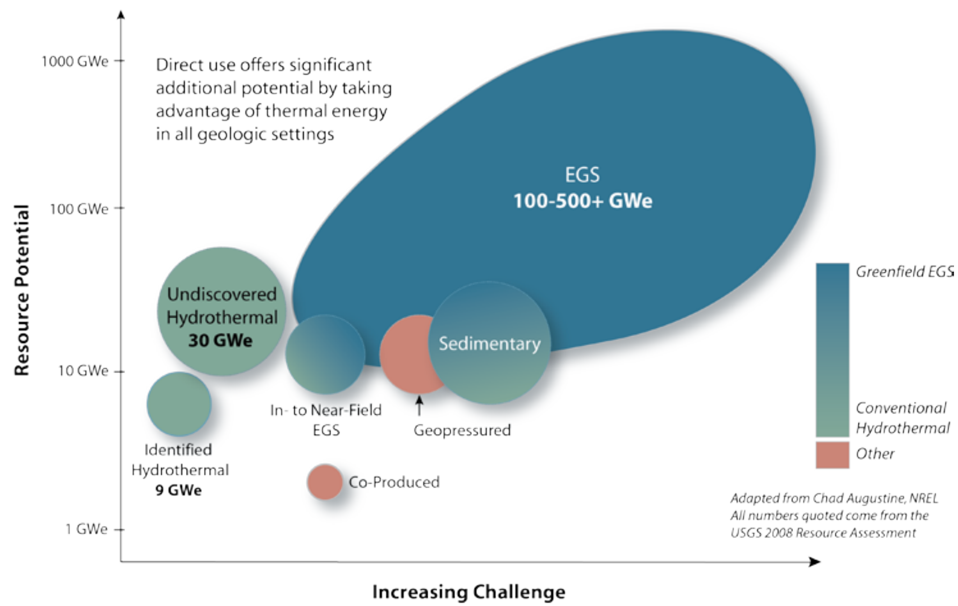
Low-Temperature, Co-Produced, and Geopressured Geothermal are National Resources





- Temperature sufficient in many parts of the country to supply direct-use heating and cooling
- Direct-use geothermal extends the economically recoverable envelope by allowing for lower-temperature utilization



SUMMARY

- Geothermal resources could supply 5-10% of U.S. demand
  - Geographically diverse
- EGS and direct use of geothermal energy can expand geothermal development throughout the country
- Improved ability to find new resources is critical to lowering risk
- Long development timelines are a reality, but so is long and reliable baseload energy production
- Opportunities in leveraging oil and gas technologies and infrastructure
- Geoscience has a pivotal role to play in finding, developing, and responsibly using these resources

Thank you