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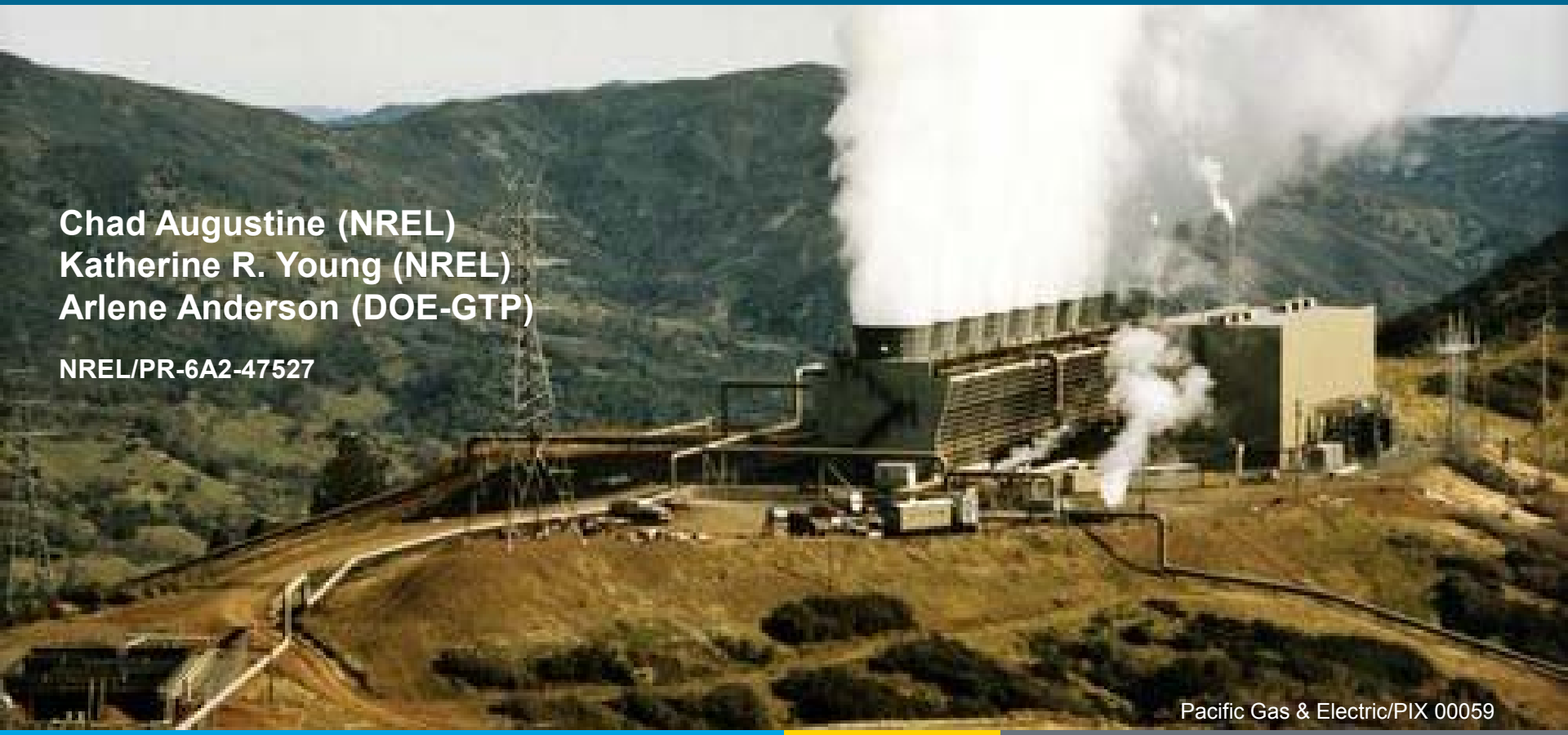

Pacific Gas & Electric/PIX 00059

DOE Updated U.S. Geothermal Supply Curve

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U.S. Geothermal Supply Curve Project

Purpose: To provide input to annual reporting by the U.S. DOE under the Government Performance and Results Act of 1993, the DOE portfolio development support processes, and market penetration models in support of other DOE analyses.

Outline

Geothermal Resource

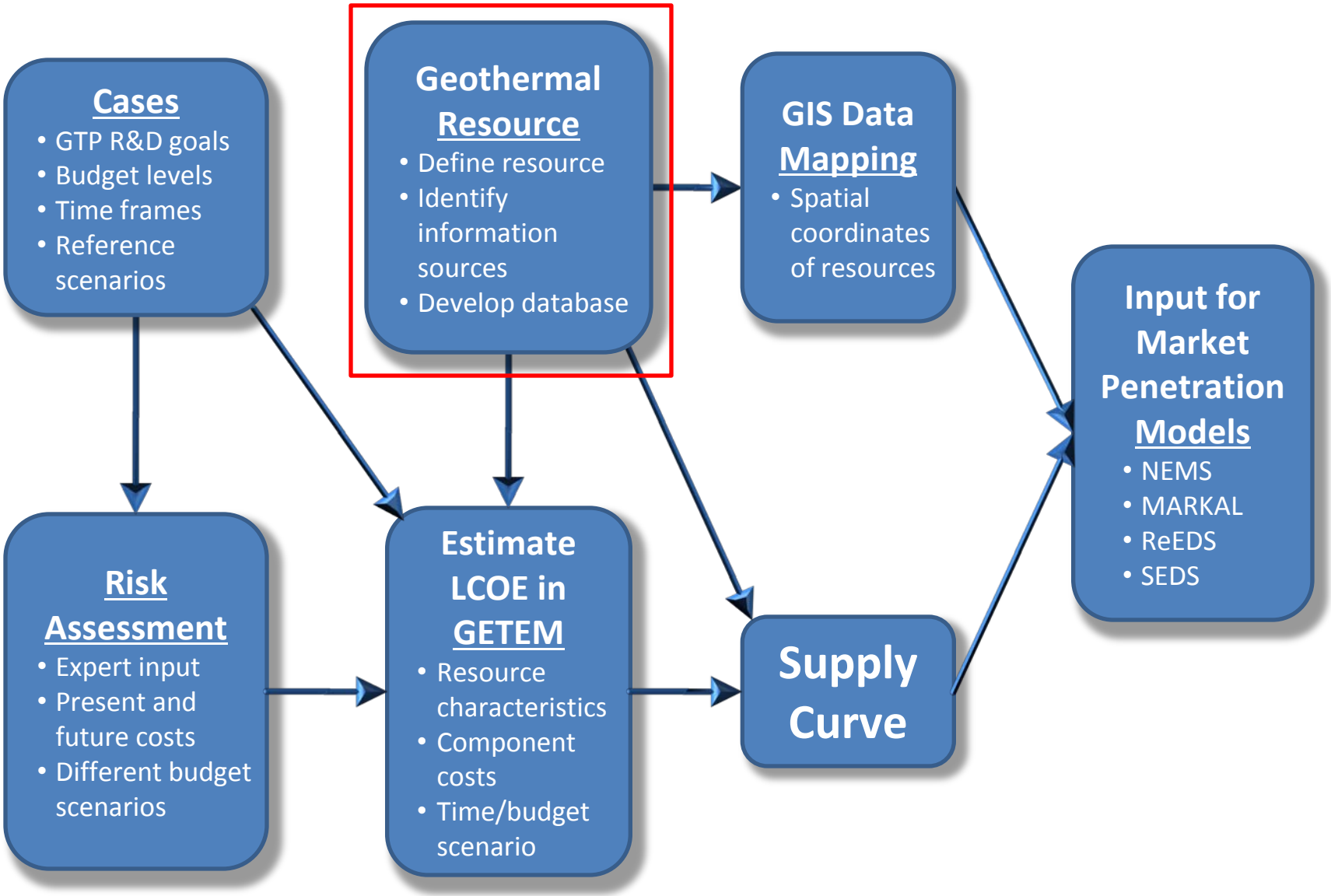
- **Hydrothermal resource**
  - Identified
  - Undiscovered
- **Enhanced Geothermal Systems (EGS) resource**
  - Near-Hydrothermal Field EGS
  - Deep EGS

Supply Curve

- **Based on expert input**
- **Two cases: Base and target**

Results, Conclusions, and Recommendations

General Approach



GEOTHERMAL TECHNOLOGIES

Hydrothermal

- Conventional technology – Steam, dual flash, flash, binary
- Shallow (1-3 km), hot (150+ ^{o}C), naturally occurring, localized
- Examples – The Geysers, Salton Sea, Hatch (NV) Plant

Enhanced Geothermal Systems (EGS)

- **Near-Hydrothermal Field EGS**
  - "Almost" hydrothermal fields – lack permeability and/or in-situ fluids
  - Near-term, lowest cost EGS – likely to be developed first
  - Examples –Geysers (Calpine), Newberry (AltaRock), Raft River (U. Utah)
- **Deep EGS**
  - Deployable "anywhere" – drill until high temperatures found
  - 3+ km deep, no natural permeability and/or in-situ fluid – fracture + flow
  - Long term, higher costs – likely to follow successful near-field tests
  - Examples – Fenton Hills, Soultz, Cooper Basin

Oil and Gas Co-Produced Fluids
Geopressure Fluid

Direct Use
Ground Source Heat Pumps

Resource Characterization

Hydrothermal Resource: Identified

Installed Capacity

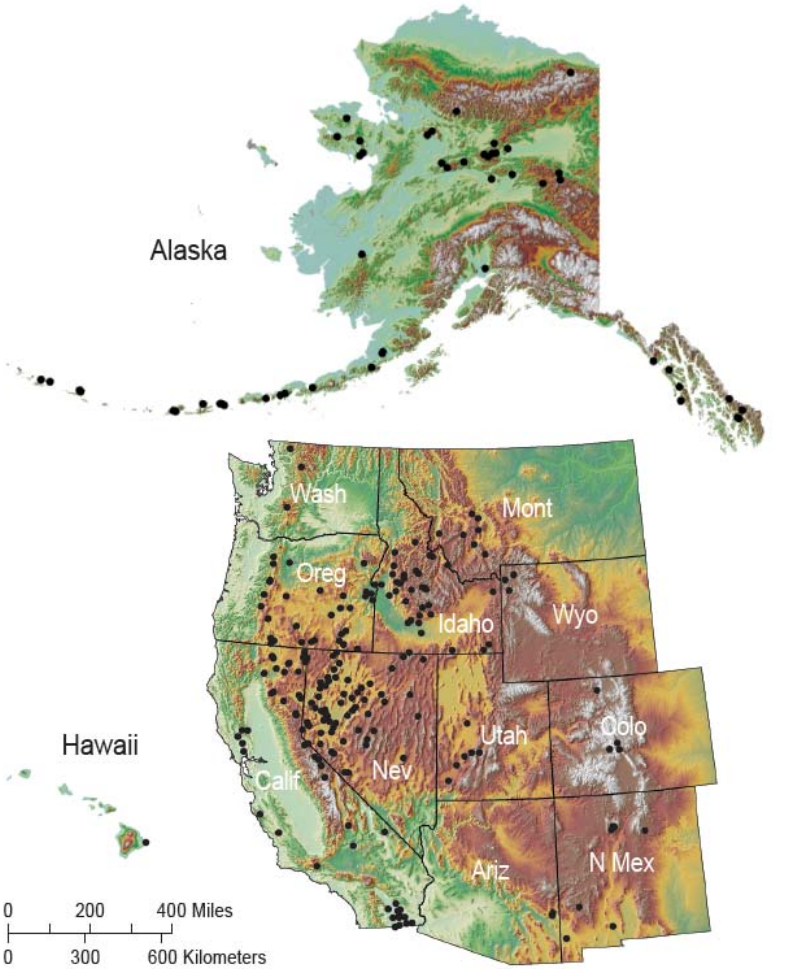
- Geothermal Energy Association: 3,153 MW_e (Sept. 2009)
- Energy Information Administration: 2,480 MW_e (summer capacity, 12/31/07)

Potential Capacity

- USGS Circular 790 (1979): 23,000 ± 3,400 MW_e
- USGS 2008 Geothermal Resource Assessment:
  - Mean: 9,057 MW_e
  - 95%ile: 3,675 MW_e
  - 5%ile: 16,457 MW_e

For NREL study…

6,394 MW_e remaining capacity



Source: Williams et al. (2008), USGS, "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States" http:/pubs.usgs.gov/2008/3082

Figure 1. *Map showing the location of identified moderate-temperature and high-temperature geothermal systems in the United States. Each system is represented by a black dot.*

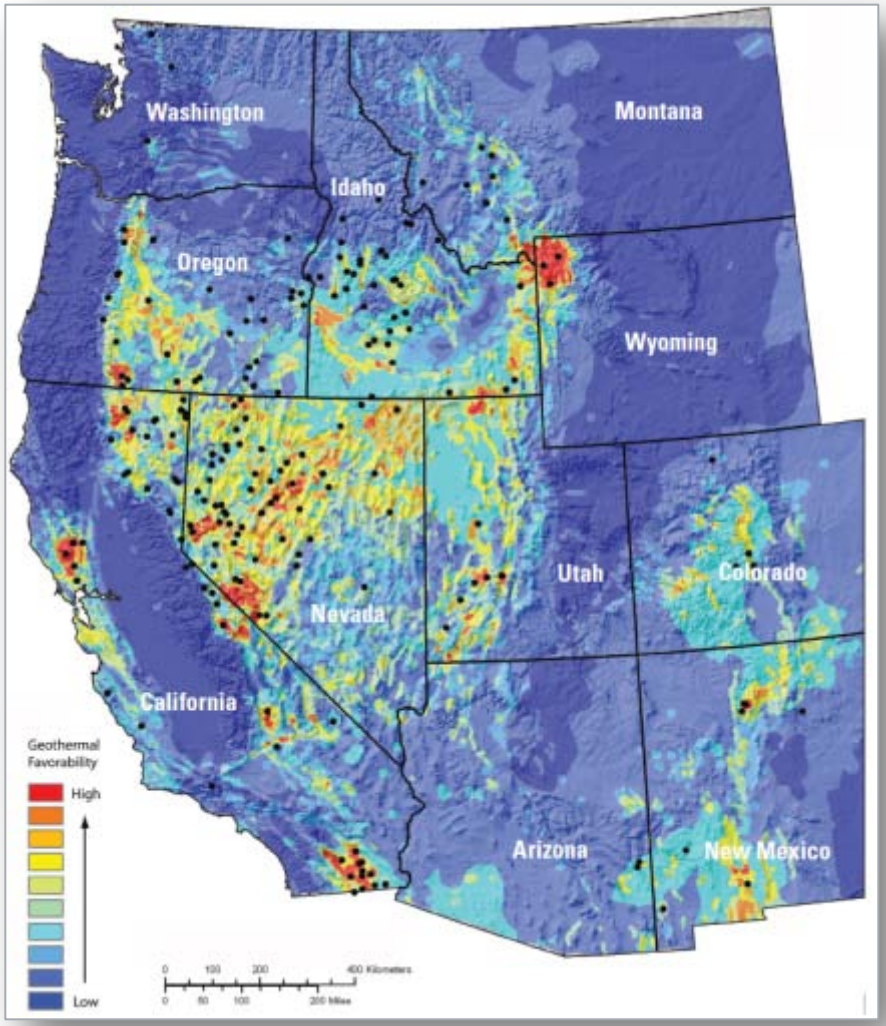
Hydrothermal Resource: Undiscovered

USGS 2008 Geothermal Assessment

- Based on GIS mapping tools and statistical model of spatial correlation of geological factors
- Estimated undiscovered hydrothermal resource potential:
  - Mean: 30,030 MW_e
  - 95%ile: 7,917 MW_e
  - 5%ile: 73,286 MW_e

For NREL Study…

30,030 MW_e potential capacity



Geothermal Resource

Near-Hydrothermal Field EGS

Near-hydrothermal field EGS resource is “halo” around hydrothermal fields.

Formal assessment not performed yet

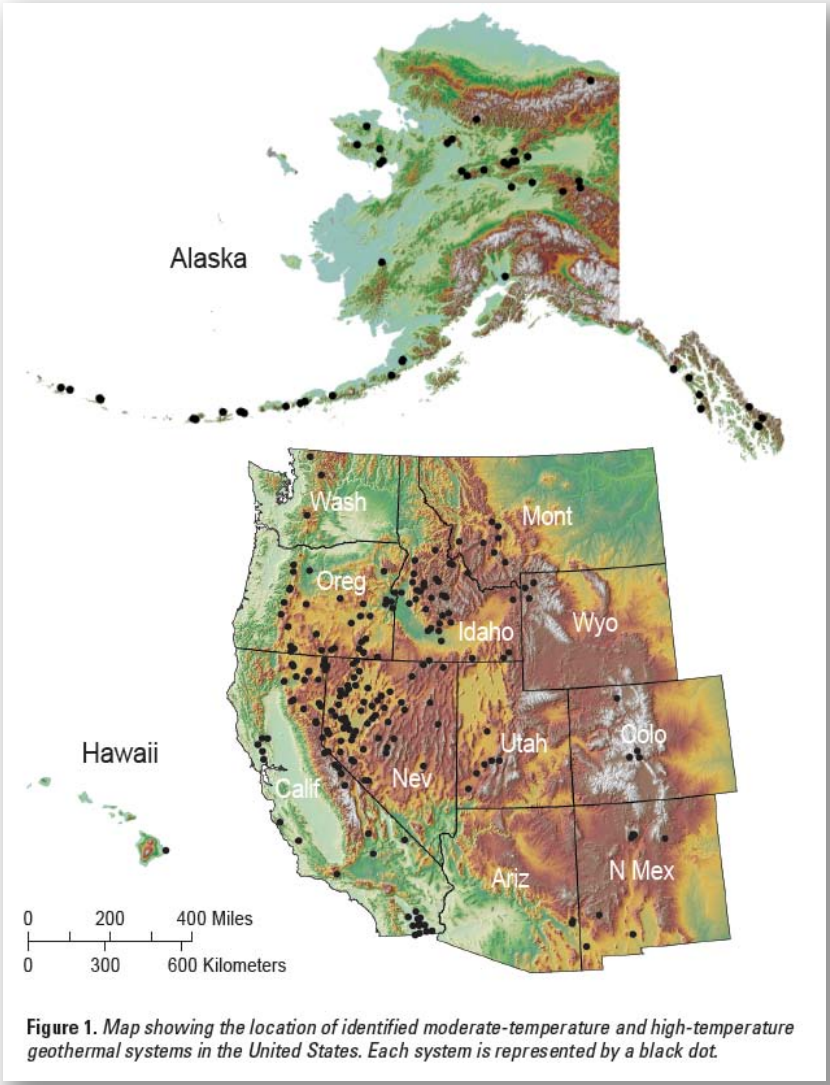
- Use current identified hydrothermal sites
- Assume resource is difference between USGS hydrothermal high (5% probability) and mean values for each site represents near-hydrothermal field EGS opportunity

For NREL Study…

7,031 MW_e potential capacity

Caveats

- First-order estimate of resource
- Does not consider near-hydrothermal field EGS resource associated with undiscovered hydrothermal sites



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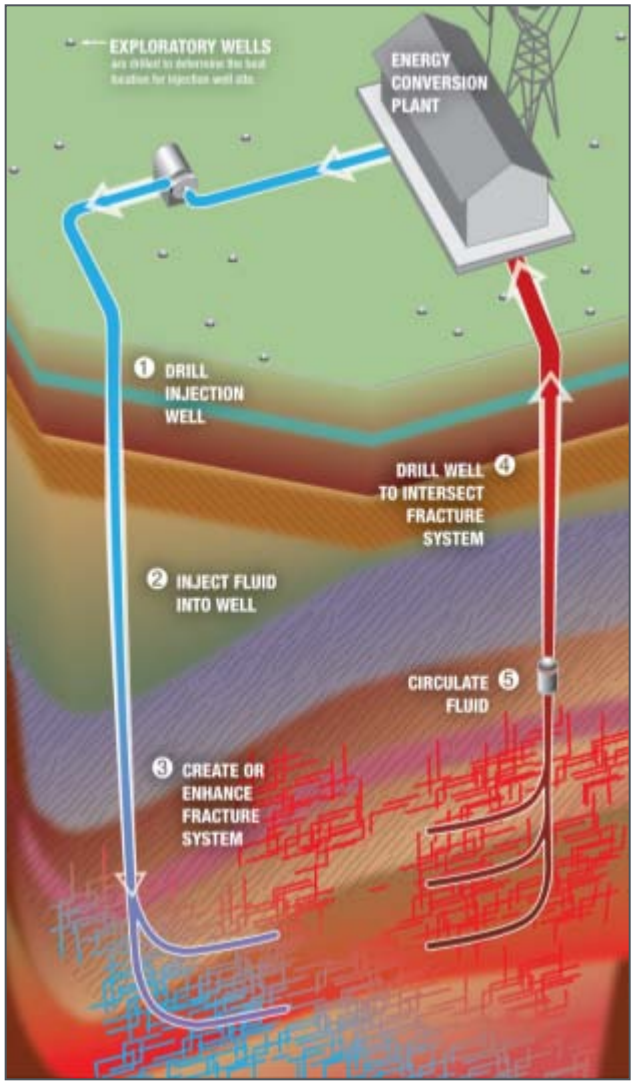
Deep EGS Resource

Previous Assessments

- MIT "Future of Geothermal Energy" report (2006) concluded 100 GW_e of EGS capacity by 2050 possible with reasonable R&D investment
- USGS 2008 Geothermal Resource Assessment estimated mean value of 517,800 MW_e deep EGS potential
  - Limited to 11 Western states
  - Only considers 3-6 km depth range
  - Federally-protected and DOD lands excluded



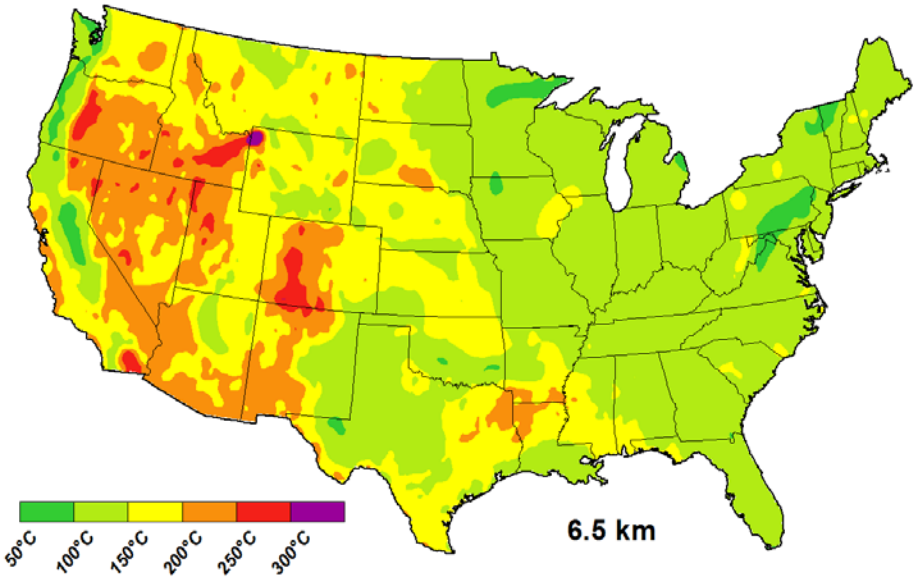
Geothermal Resource

Deep EGS Resource - NREL

- Same method used in MIT report (2006)
- Thermal resource based on SMU maps of temp vs. depth (3-10 km) used in previous assessment
  - Exclude federally-protected lands (e.g. DOD, federal parks)
- Potential electric capacity calculation methodology:
  - Calculate heat in place for 1-km thick slices of rock
  - Apply recovery factor (20%), heat recovery rate (30 years), and assumed plant efficiency (DiPippo 2004) for resource temperature
  - Multiply potential electric capacity of each resource temperature range by area covered on map

For NREL Study…

15,908 GW_e potential capacity



Resource Temp Range	Average Reservoir Temp Decline	Recovery Factor	Plant Life	Recoverable Heat Rate	Plant Efficiency	Potential Electric Capacity
(°C)	(°C)	%	(years)	(MW/km^3)	%	(MW/km^3)
T	$T_{decline}$	R_g	life	$Q_{th,dot}$	η_{th}	W_e
150-200	10	20%	30	5.39	11%	0.593
200-250	10	20%	30	5.39	14%	0.755
250-300	10	20%	30	5.39	16%	0.863
300-350	10	20%	30	5.39	18%	0.970
>350	10	20%	30	5.39	22%	1.186

Geothermal Resource

Deep EGS Resource - NREL

Potential Electric Capacity (MW_e)						
		Resource Temperature (°C)				
		150-200	*200-250*	*250-300*	*300-350*	*350+*
Reservoir Depth (km)	*4*	91,516	117	0	0	
	5	590,763	26,526	134	0	0
	6	1,139,749	227,969	7,680	50	0
	7	1,337,049	723,692	86,057	631	0
	8	1,539,597	1,129,434	345,285	32,964	320
	9	1,881,116	1,159,750	761,653	138,204	9,922
	10	1,907,066	1,251,474	1,015,937	433,749	69,298

Excluded areas: DOD land, federally-protected land (e.g. - Yellowstone)

Geothermal Resource

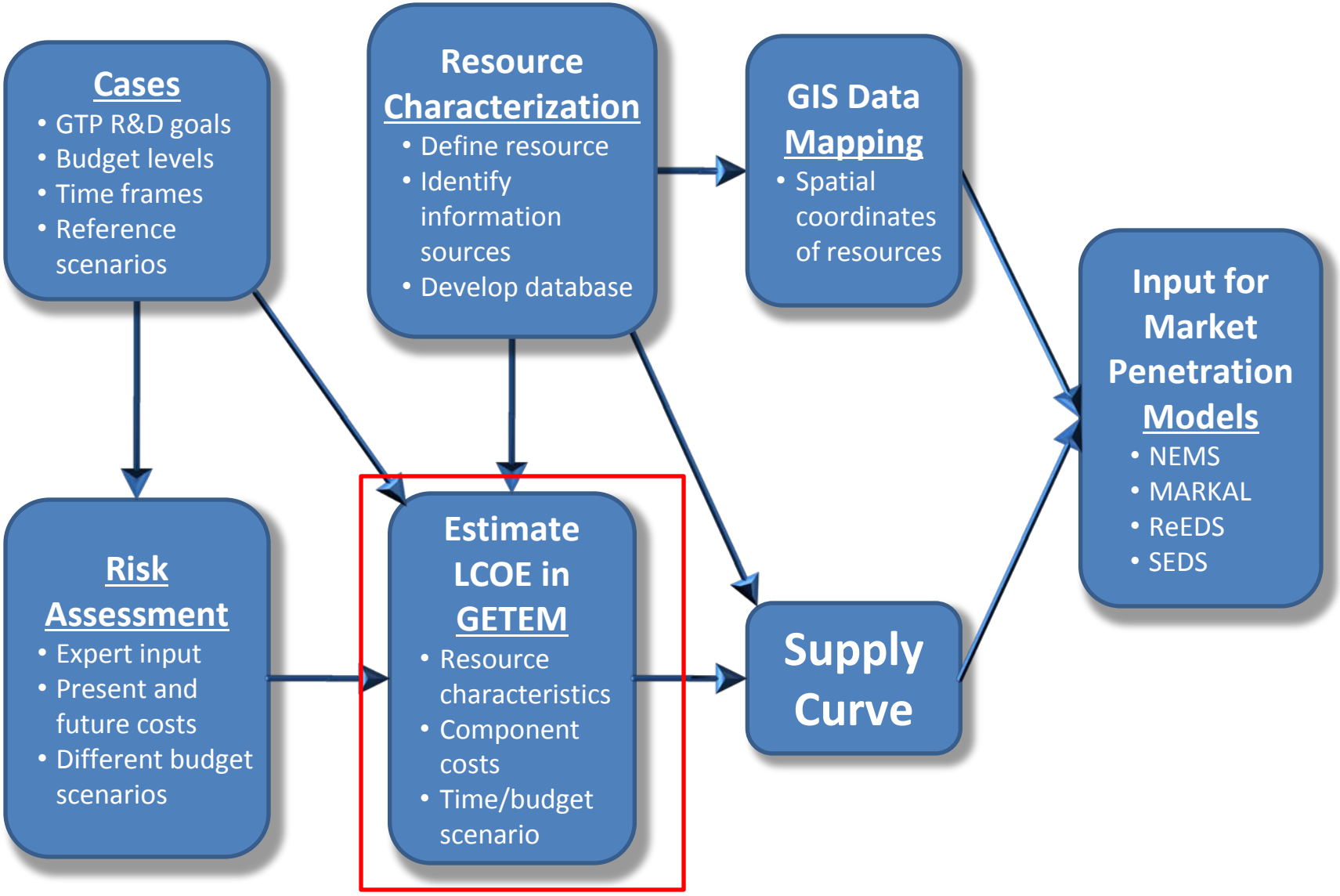
Results – NREL study

Resource		Resource Potential Capacity	
		Capacity (GW_e)	Source(s) and Description
Hydrothermal	Identified Hydrothermal Sites	6.39	USGS 2008 Geothermal Resource Assessment[1] - Identified hydrothermal sites - Sites ≥110 °C included - Currently installed capacity excluded
	Undiscovered Hydrothermal	30.03	USGS 2008 Geothermal Resource Assessment[1]
Enhanced Geothermal Systems (EGS)	Near-Hydrothermal Field EGS	7.03	Assumptions based on USGS 2008 assessment[1] - Regions near identified hydrothermal sites - Sites ≥110 °C included - Difference between mean and 95th%ile hydrothermal resource estimate
	Deep EGS	15,908	NREL 2006 Assessment[2], MIT Report[3], SMU Data[4] - Based on volume method of thermal energy in rock 3-10 km depth and ≥150 °C - Did not consider economic or technical feasibility

[1] (Williams, Reed et al. 2008b)
[2] (Petty and Porro 2007)
[3] (Tester et al. 2006)
[4] (SMU 2009)

*Technologies such as co-produced fluids, geopressured not assessed

General Approach



Estimate LCOE in GETEM

Technology Component Cost and Performance Data

- Apply expert input distributions from 2009 risk assessment to GETEM
- Use @Risk risk analysis software to run Monte Carlo simulations
- *Drilling Costs updated to value 30% lower than 2008 BLS PPI index value based on conversations with leading geothermal drilling contractors*

Hydrothermal

- Estimate LCOE for each identified site using GETEM
- Undiscovered hydrothermal resource characteristics based on average of existing identified hydrothermal sites in each state

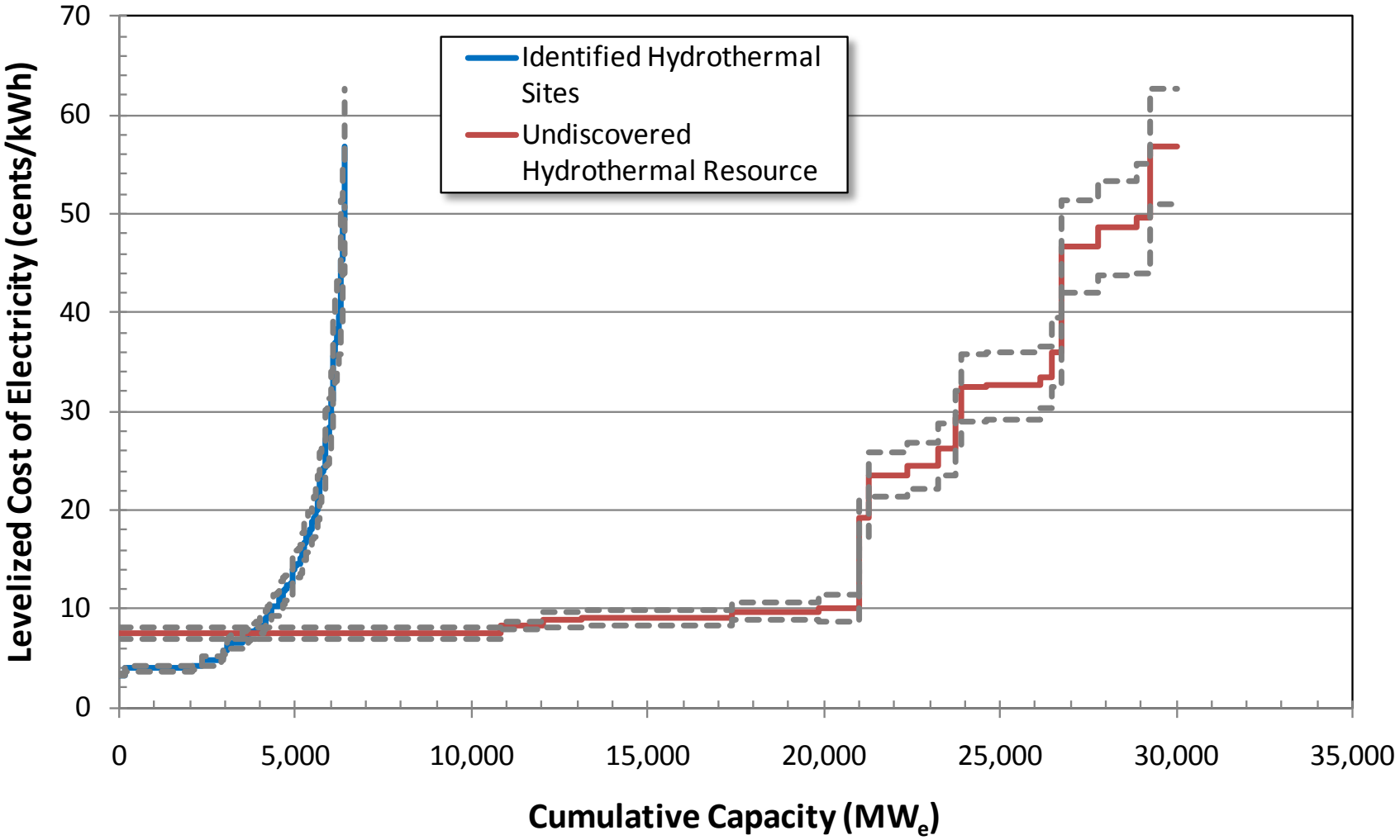
EGS

- Estimate LCOE for each temperature/depth combination using GETEM
- Two cases considered:

Enabling Technology	Base Case Value	Target Case Value
Production Well Flow Rate	30 kg/s	60 kg/s
Thermal Drawdown Rate	3.0 %/year	0.3 %/year
Production/Injection Well Ratio	2:1	2:1

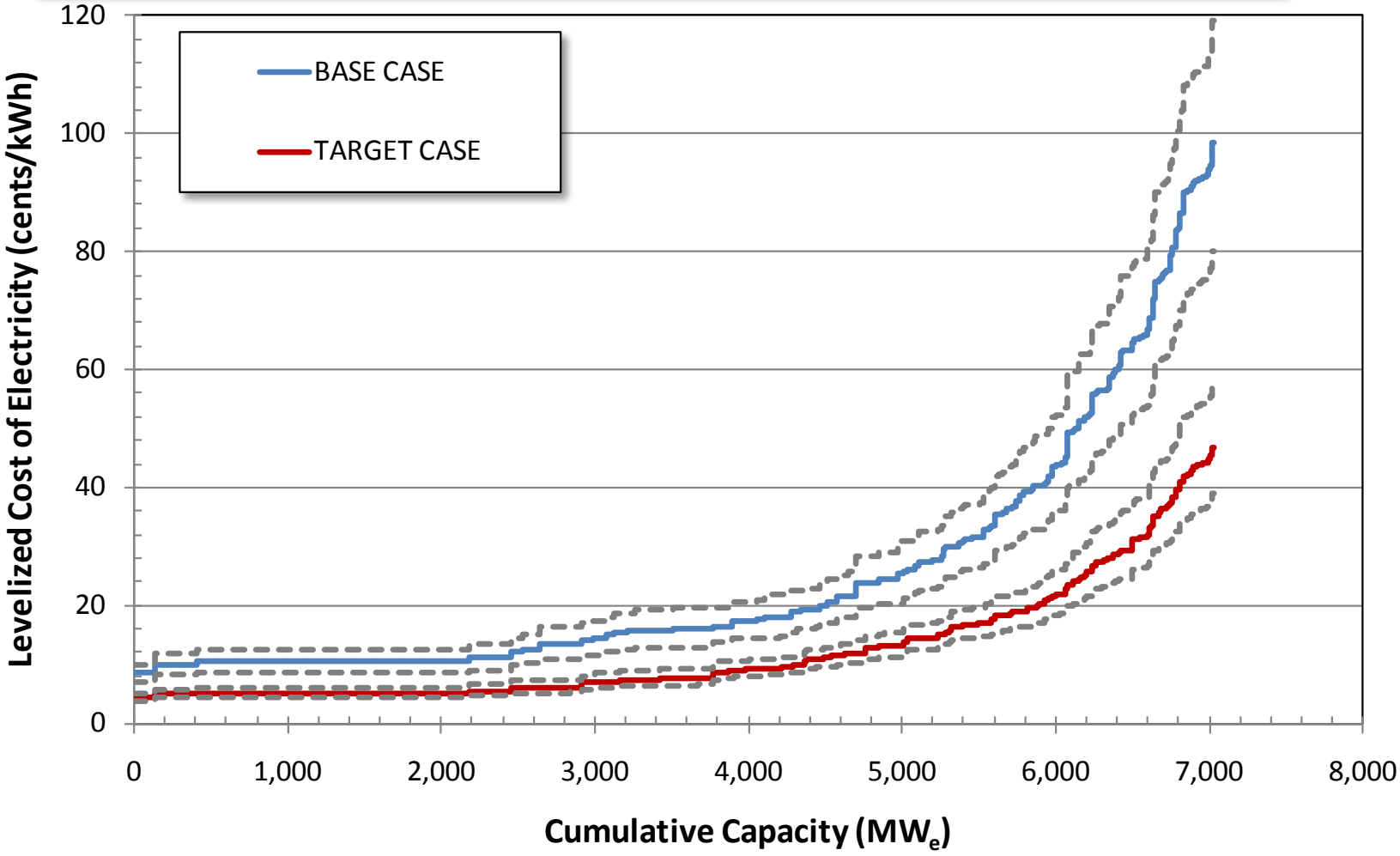
Hydrothermal Supply Curve (Identified & Undiscovered)

Grey lines show 10th%ile and 90th%ile values for supply curve.



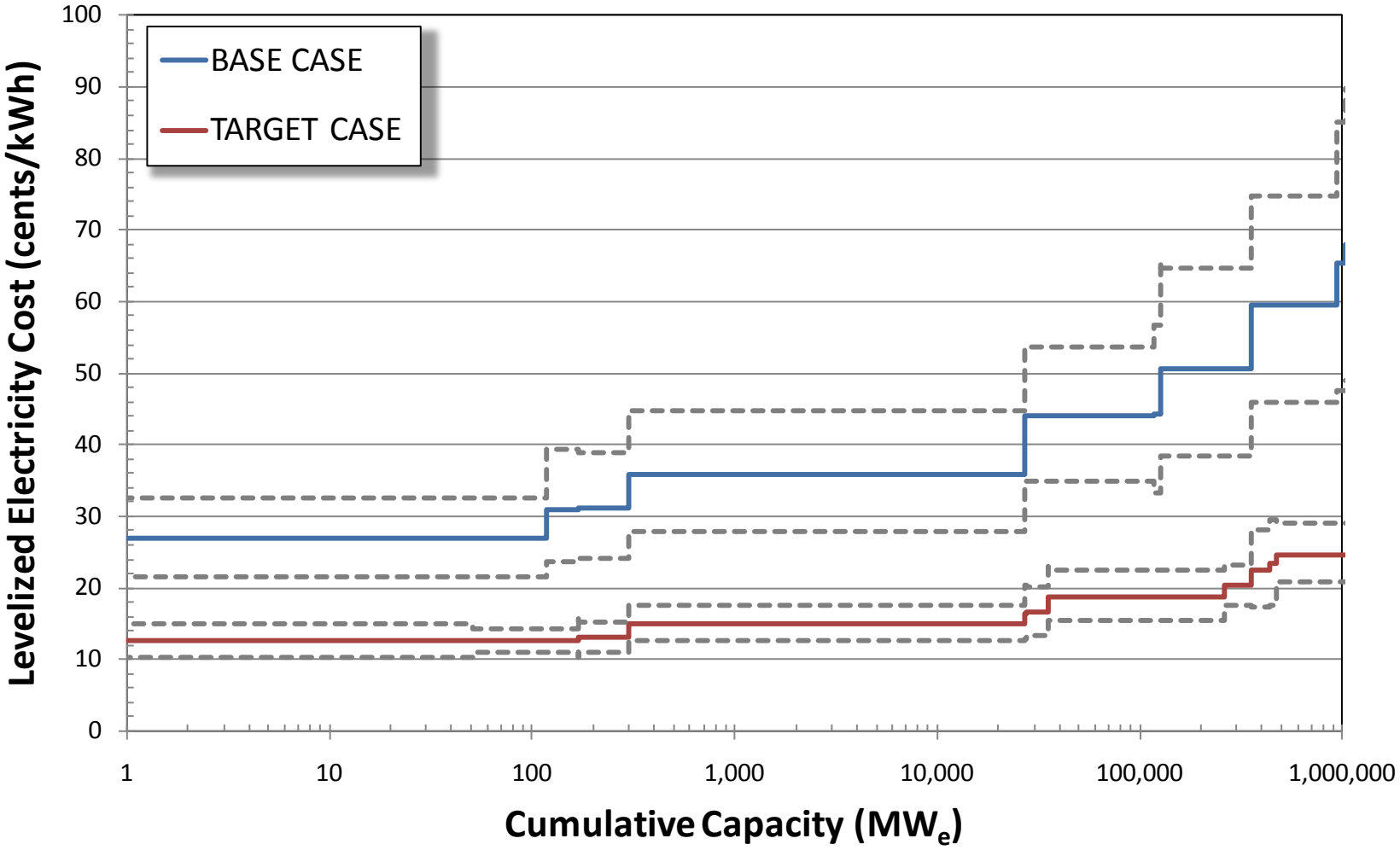
Near-Hydrothermal EGS Supply Curve

- Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
- Target Case: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate
- Grey lines show 10th%ile and 90th%ile values for supply curve.



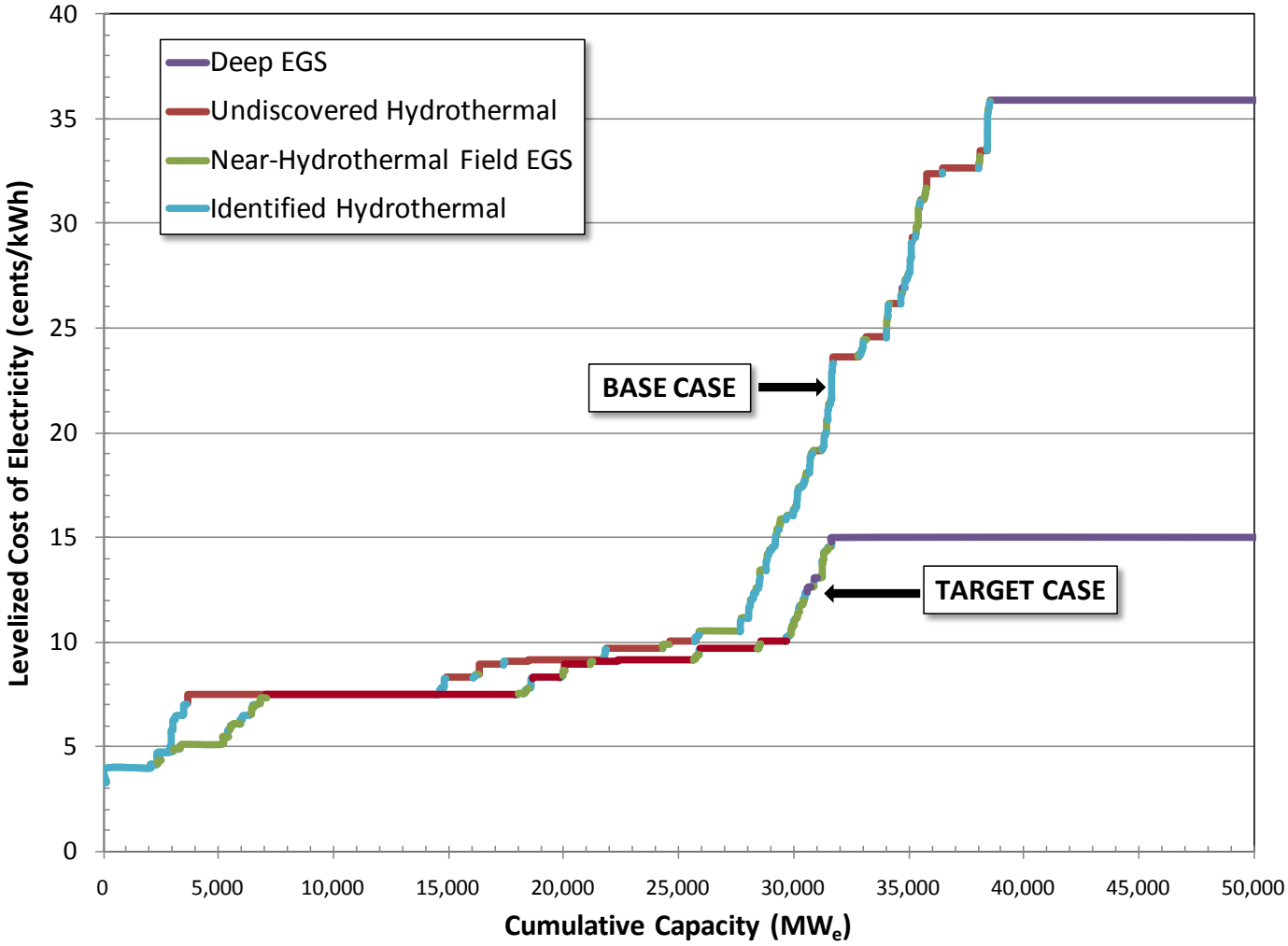
Deep EGS Supply Curve

- Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
- Target Case: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate
- Grey lines show 10th%ile and 90th%ile values for supply curve.

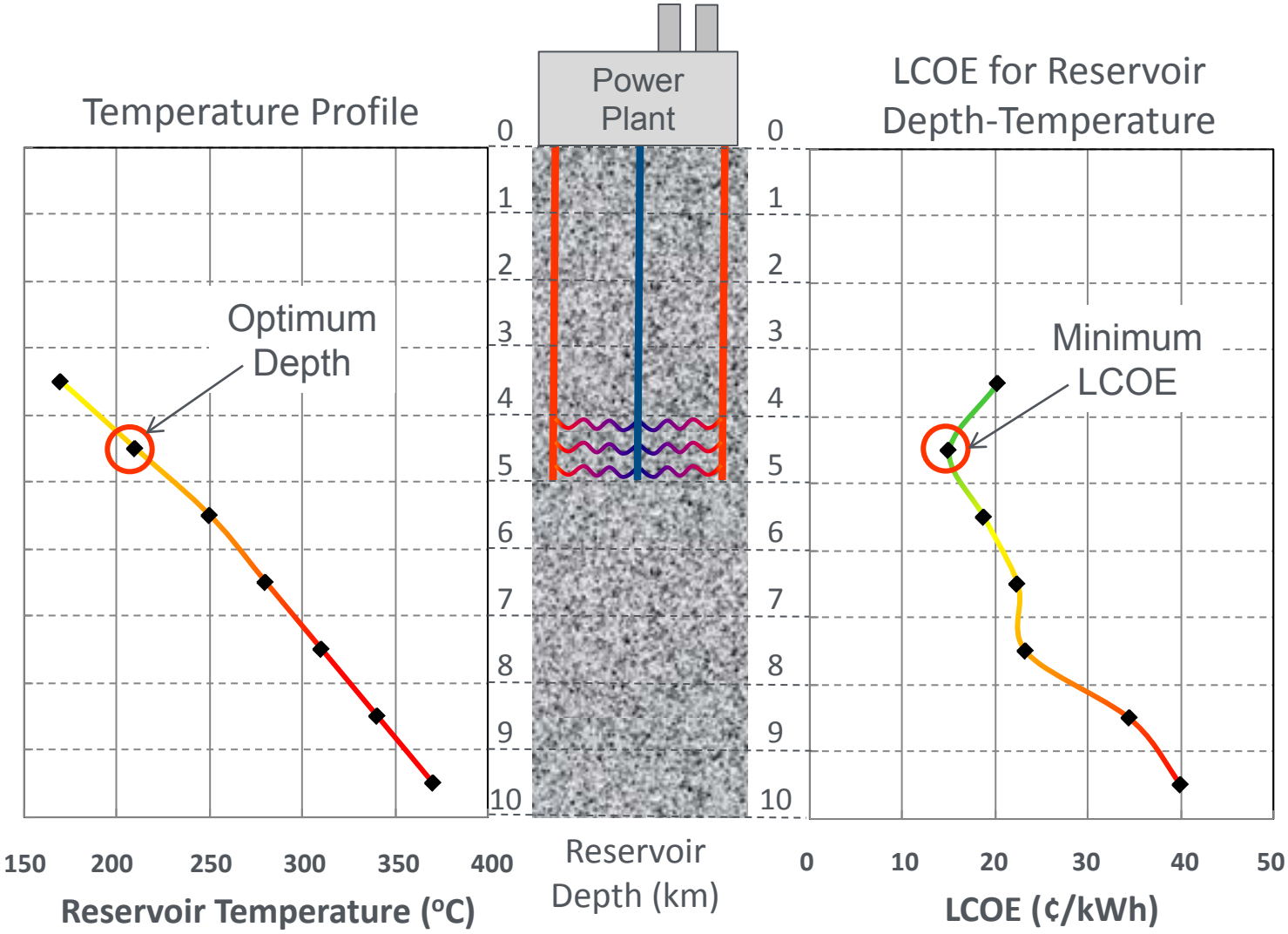


Aggregated Supply Curve

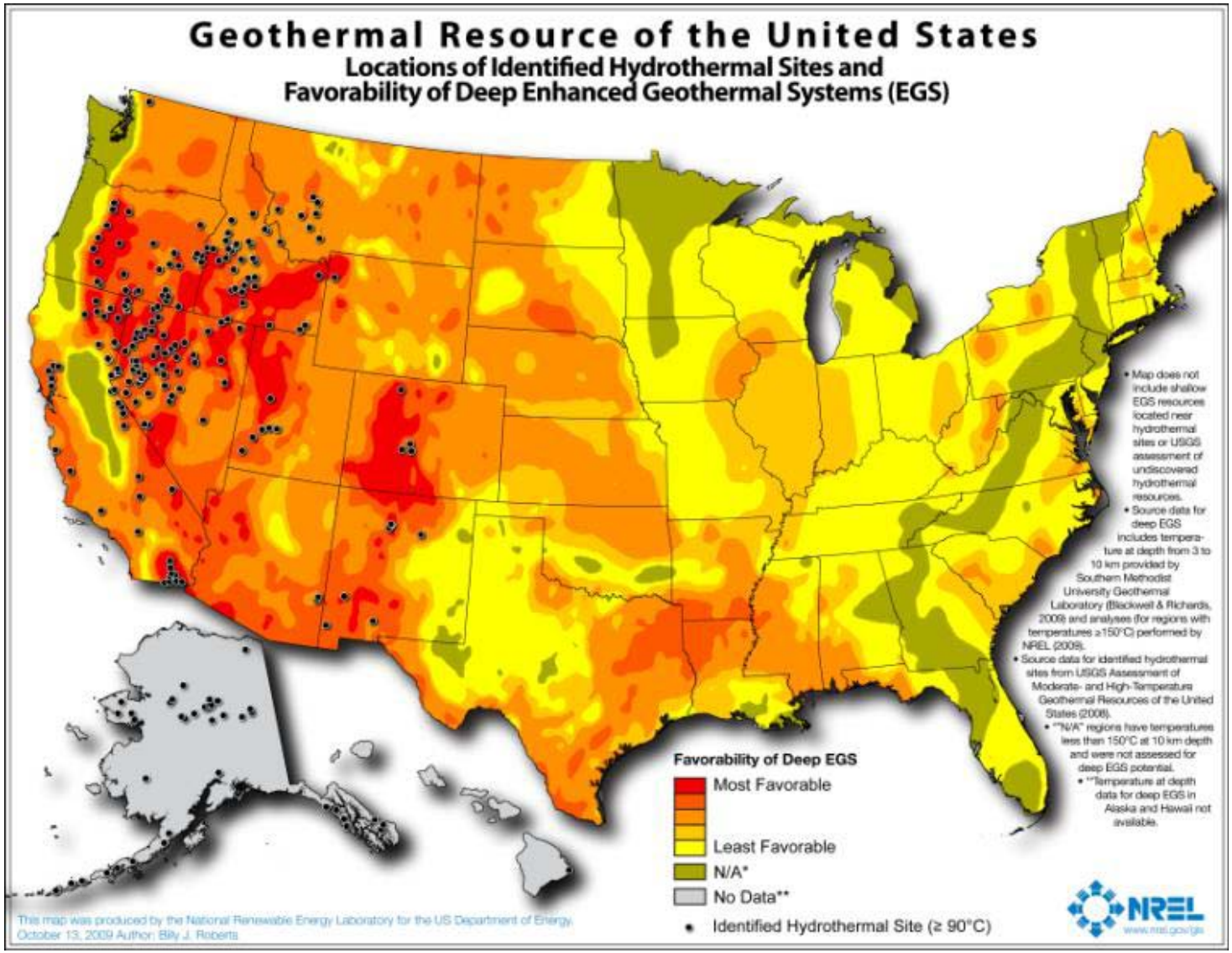
- Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
- Target Case: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate



Deep EGS: Optimum Reservoir Temperature-Depth



Updated U.S. Geothermal Supply Curve



Conclusions/Recommendations

Geothermal Resource and Supply Curve

1. 36.4 GW undeveloped hydrothermal available (majority undiscovered)
2. Near-hydrothermal field EGS resource has potential to be low-cost method of expanding capacity around existing fields
3. Deep EGS is huge resource, but deployment controlled by economics
4. Meeting GTP reservoir engineering goals (target case) could significantly lower EGS costs and deployment levels

Caveats and Limitations

1. Results dependent on assumptions in base/target cases
2. Supply curve results assumed relatively high drilling costs compared to current drilling cost trends
3. Geothermal similar to oil & gas – as exploration and recovery techniques improve, amount of recoverable reserves should increase

More Resource Assessment Needed

1. Undiscovered hydrothermal and near-hydrothermal field EGS need more thorough assessment
2. Deep EGS – better resolution data need for temperature vs. depth maps
3. Co-produced fluids assessment needed

Thank You

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