NATIONAL RENEWABLE ENERGY LABORATORY

GeoVision Analysis Supporting Task Force Report: Electric Sector Potential to Penetration

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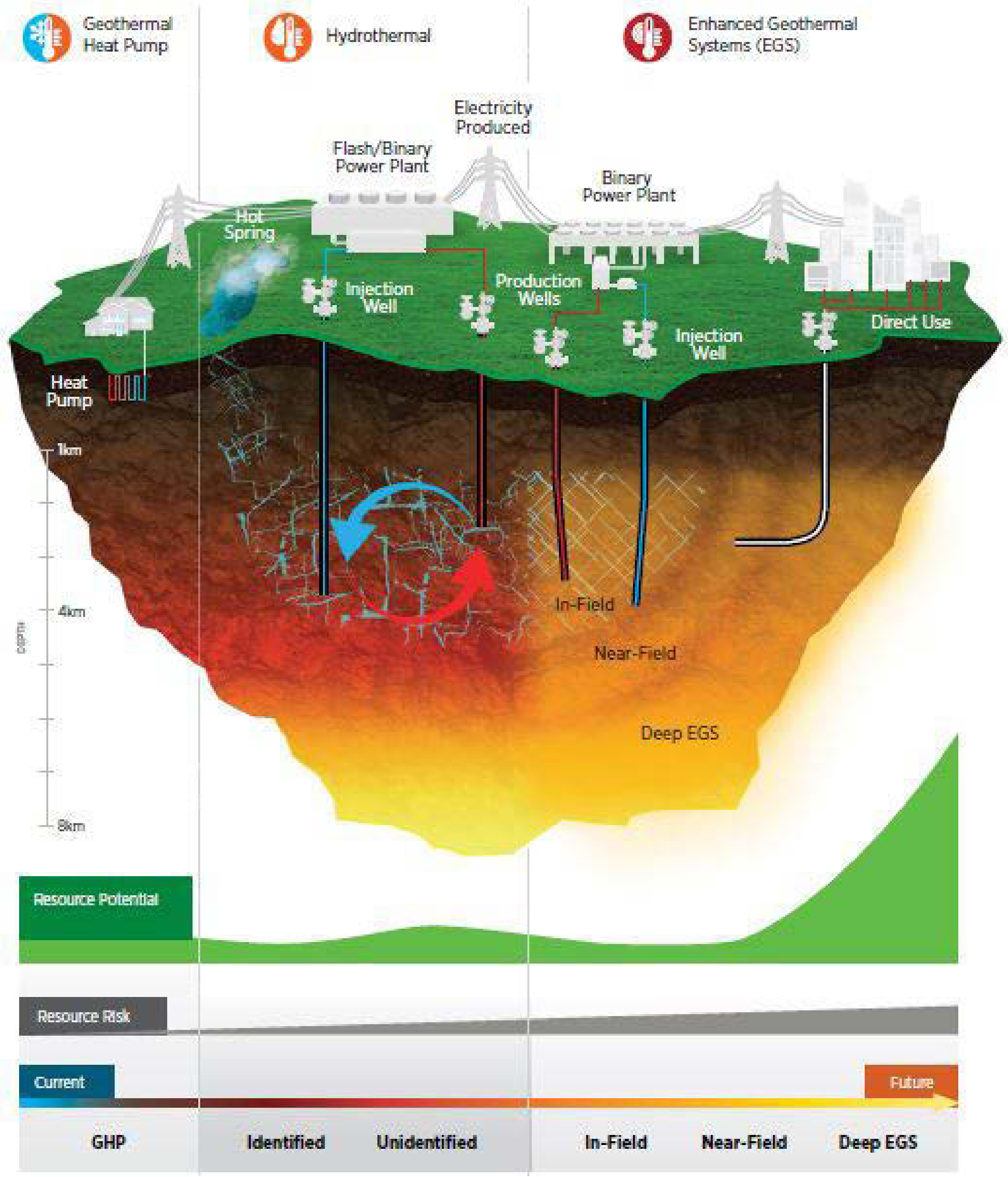
Geothermal Electric Sector

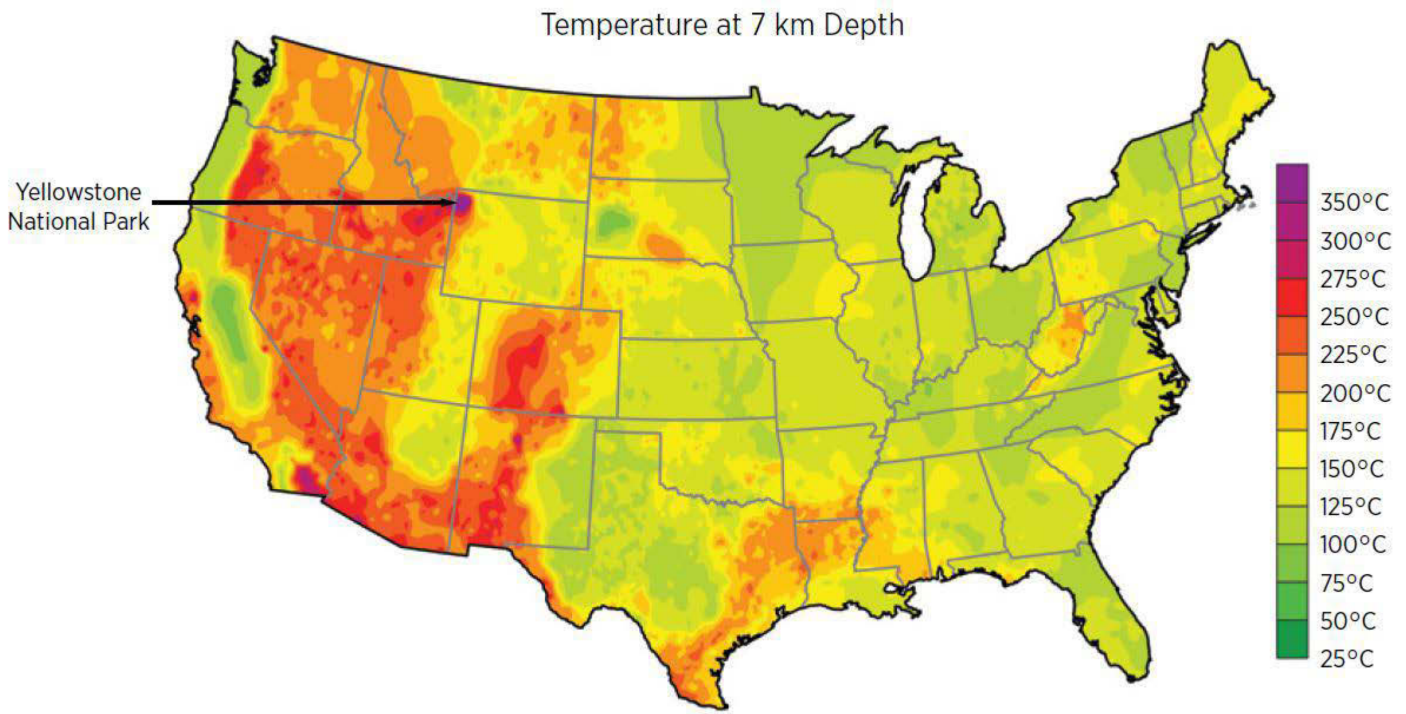
- The US has about 3.8 GWe of Geothermal installed capacity.
  - Capacity has been growing at a rate of ~2%/yr.

- 15,920 GWh, representing about 0.4% of the nation's total electricity generation.
  - 6% of generation in CA, and 8% of generation in Nevada.
  - California has more installed geothermal capacity than any country in the world.
- Fundamental question: assuming a variety of improvements to technical and non-technical barriers, what level of geothermal deployment could be achieved through 2050?



Agenda

- Scenarios Modeled
- Methodology
  - Geothermal Resource Potential
  - Geothermal Electricity Technology Evaluation Model (GETEM)
  - Regional Energy Deployment System (ReEDS)
- Results
- Sensitivity Runs
- Conclusions



Blackwell et al. 2011

Three Electric Sector Scenarios

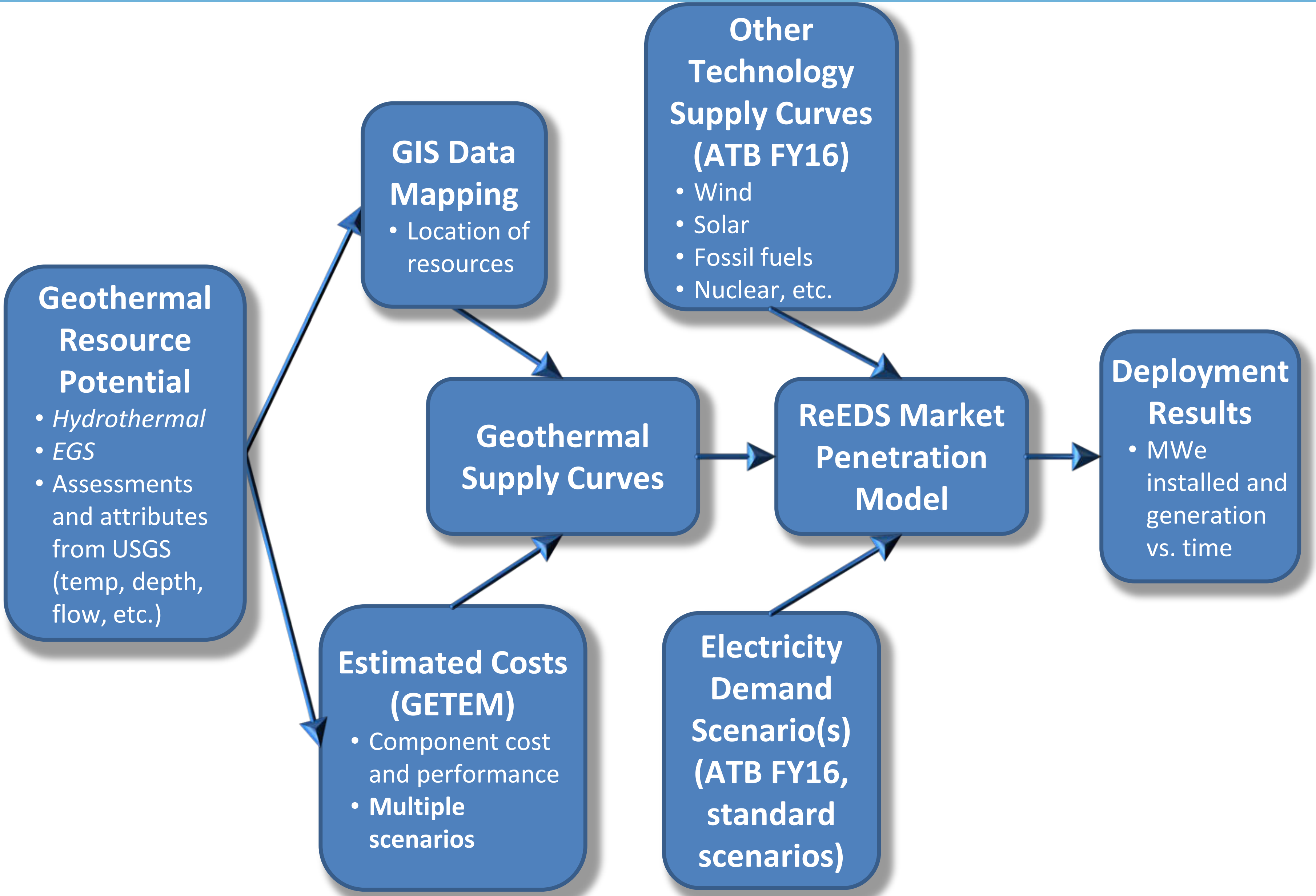
1. Business As Usual (**BAU**) – Anticipated future if industry continues on the same path as 2016 conditions. This scenario does not include any technical or non-technical improvements.

2. Improved Regulatory Timeline (**IRT**) - Considered pathways and potential combinations of approaches to streamline and reduce project development timelines. This scenario does not include any technology improvements.

3. Technology Improvement (**TI**) – Evaluated aggressive technology advances and cost reductions.

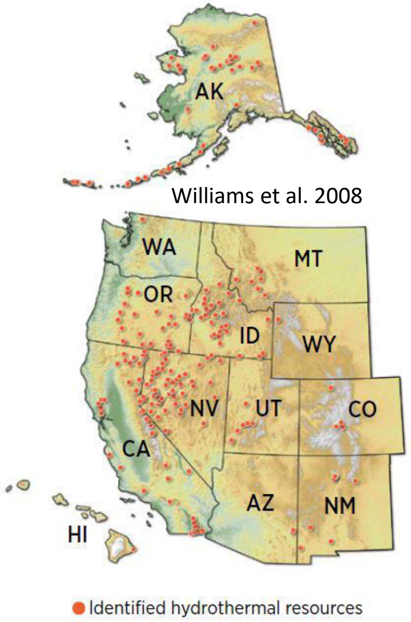
Scenario	Business-as-Usual	Improved Regulatory Timeline[72]	Technology Improvement
Description	Reflects current industry trends	Streamlined permitting increases the amount of exploration, decreases project timelines, increases resource discovery rate	IRT scenario + access and technology improvements: Advances in drilling, exploration, and EGS reservoir development reduce costs and risks
Capital + O&M Costs	BAU	BAU	Hydrothermal: some reductions EGS: large reductions
Construction Time (years)[73]	Hydrothermal: 8 EGS: 10	Hydrothermal: 4 EGS: 5	Hydrothermal: 4 EGS: 5
Financing[74]	BAU	BAU	ReEDS Standard WACC (8%)
Hydrothermal Discovery Rate[75]	1% of undiscovered resource/year	3% of undiscovered resource/year	3% of undiscovered resource/year

GeoVision Workflow for Modeling Electricity Generation



Geothermal Resource Potential

- Estimates from 2008 USGS Resource Assessment (Williams et al.) and updated Augustine 2010, 2011, & 2016.
- Four resource classes:
  - Identified hydrothermal
  - Undiscovered hydrothermal
  - Near-field EGS
  - Deep EGS (3-7km)
- Exclusions:
  - Sites <110°C
  - Existing installed capacity
  - Alaska & Hawaii



GeoVision Scenario	Identified Hydrothermal MW_e	Undiscovered Hydrothermal MW_e	Near-Field EGS MW_e	Deep EGS MW_e
BAU and IRT	5,078	18,830	1,382	3,375,275
TI	5,128	23,038	1,443	4,248,879

Table 3-2. Geothermal Resources Available for Development for Electricity Generation (in megawatts-electric, MWe) in the Regional Energy Deployment System Model (ReEDS) under the *GeoVision* Analysis Scenarios

Deep-EGS Electricity-Generation Potential (MW_e)										
		Resource Temperature (°C)								
		150-175	175-200	200-225	225-250	250-275	275-300	300-325	325-350	>350
Depth (km)	3-4	74,217	2,592	100	—	—	—	—	—	—
	4-5	740,466	233,228	11,886	325	84	32	—	—	—
	5-6	517,601	724,689	373,680	57,281	4,654	195	128	—	—
	6-7	635,384	491,641	700,330	453,610	120,677	12,116	1,883	—	157

Table C-1. Updated Deep Enhanced Geothermal Systems Electricity-Generation Potential (MWe) for the Contiguous United States, Binned by Temperature and Depth Intervals (Augustine 2016)

GETEM – Geothermal Electricity Technology Evaluation Model

- GETEM estimates the Levelized Cost of Energy (LCOE) and overnight capital costs for a user defined geothermal resource type, temperature, and depth.
- Up to 109 default inputs.

		Revised Scenario	GETEM Default
Estimated LCOE	¢/kW-hr	10.01	10.01
Power Sales	kW	30,000	30,000
Power Plant Output	kW	35,088	35,088
Errors/Warnings		0	

If you wish to change any of the parameters for the evaluated scenario, enter the value in the cell with yellow background. If the default is acceptable, leave the cell blank. If not blank, GETEM will use the value in the cell, even if 0 or negative.

		Revised Value	GETEM Default	
RESERVOIR PERFORMANCE		Revised Value	GETEM Default	
Well Flow Rate				
Production Well Flow Rate	gpm		1,953.9	
Hydraulic Drawdown				
Productivity Index	lb/hr-psi		2,500.000	
Injectivity Index	lb/hr-psi		2,500.000	This value for wells drilled specifically as injection wells
Thermal Drawdown				If the temperature decline exceeds the maximum indicated, the mo
Annual Rate of Decline	%/yr		0.5%	the well field (is sufficient potential was found and does not occur
Maximum Temperature Decline Allowed	C		24.6	of project life).
Makeup Water				EGS always has makeup for subsurface and surface water losses (s those associated with cooling towers.)
Is water loss for Flash plant cooling system to be made-up?			No	Default will be no when Binary plants used. Provides option to ma with Hydrothermal Flash systems.
EGS: Subsurface Water loss as % of injected flow (≥ 0)			0.0%	Any input given for water loss or makeup cost is ignored for hydro

GETEM - Read Me | Start Here | Scenario Definition | Results | Error-Warnings | Schedule | EERE COE | DCF-COE | OUT | FC ...

Scenario Specific GETEM Revisions

GETEM Input		Business-as-Usual		Technology Improvement	
		Hydro	EGS	Hydro	EGS
RESOURCE EXPLORATION	*Exploration — Pre-Drilling Costs ($/project)*	$600K–$1.2M	$250K	Same as BAU	
	Exploration — Drilling Costs ($/project)	$3.3M–$5.4M	$1.5M–$5M	2/3 of BAU	
	Full-Sized Confirmation Well Costs[107]	Base + 20%	Base + 50%	Ideal + 0% (no premium)	
	Full-Sized Confirmation Well Success Rate	50%	50%	75% (with stimulation)	
	Number of Full-Sized Confirmation Wells Required	3	9	3	
DRILLING	Drilling success rate	75%		90%	
	Drilling costs	Base		Ideal	
GEOFLUID GATHERING SYSTEM AND PUMPING		*No changes*			
RESERVOIR CREATION	Wells stimulated?	No	Yes	Yes	
	Well flow rate (flow rate per production well)	Binary: 110 kg/s Flash: 80 kg/s	40 kg/s	Binary: 110 kg/s Flash: 80 kg/s	
	Well productivity	4.6 kg/s/bar 5.8 gpm/psi	0.46 kg/s/bar 0.58 gpm/psi	4.6 kg/s/bar 5.8 gpm/psi	
O&M		*No changes*			
POWER PLANT		*No changes*			

Geothermal Resource Supply Curves from GETEM

- Costs increase quickly as resource temp drops
- Both NF-EGS & deep EGS resources are likely too expensive to deploy in the BAU scenario
- Undiscovered resource potential > identified
- Deep EGS capital costs are reduced significantly in the TI scenario
- Deep EGS makes up majority of additional available capacity in the TI scenario

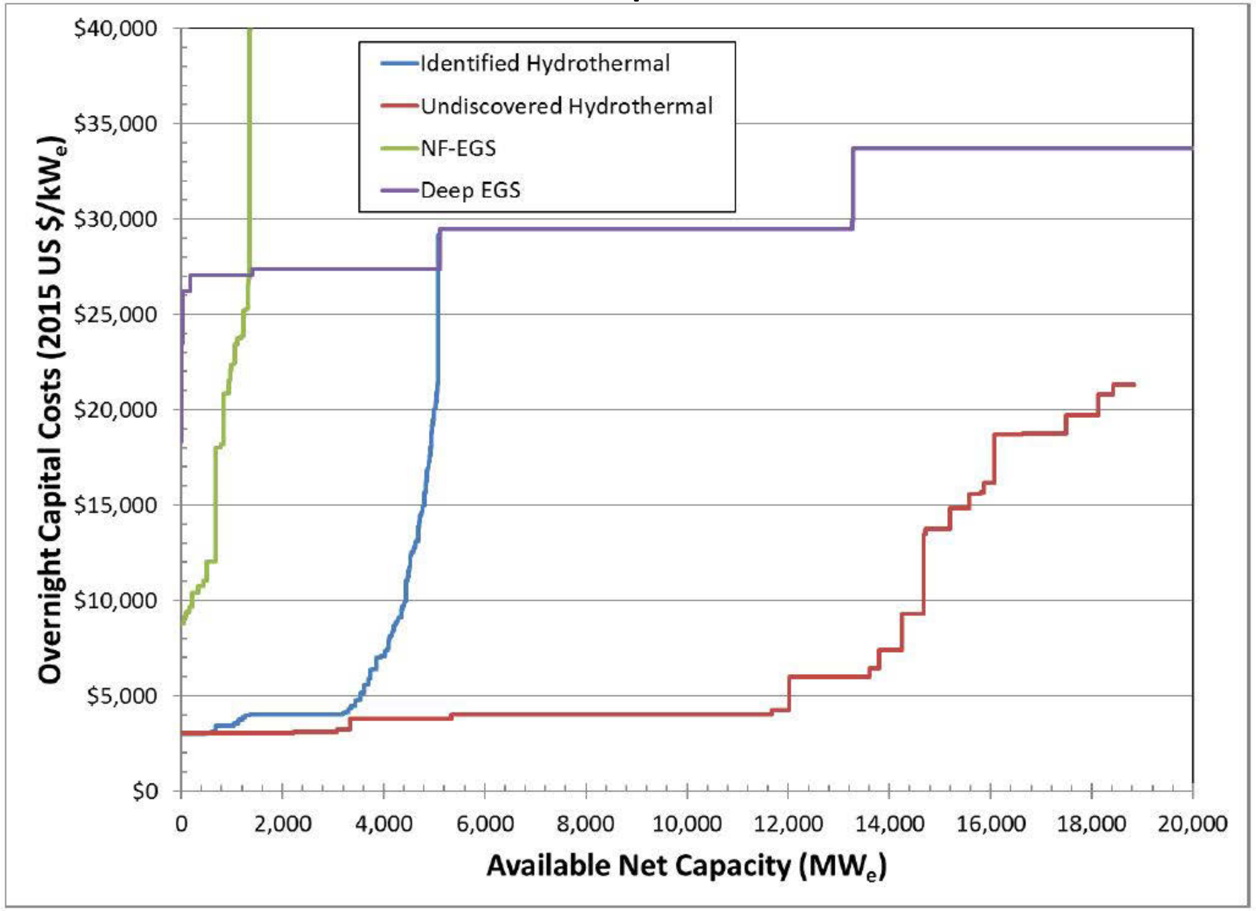


Figure 6. Geothermal supply curve for the *GeoVision* BAU scenario. The net capacity and capital cost axes are truncated for readability.

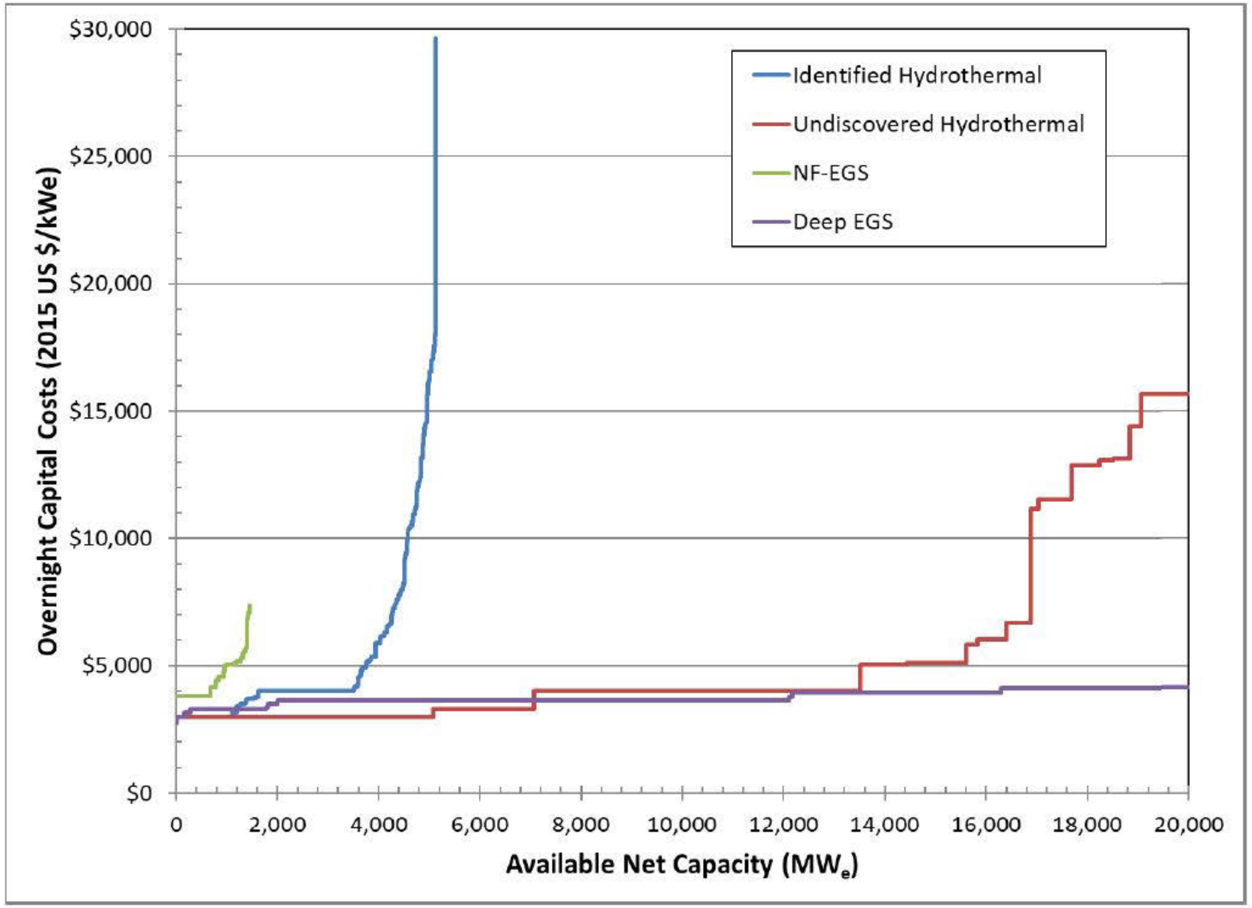


Figure 9. Geothermal supply curve for the *GeoVision* TI scenario. The capacity and capital cost axes are truncated for readability.

ReEDS – Regional Energy Deployment System

- A spatially and temporally resolved model of capacity expansion in the U.S. electric sector.
- Designed to explore potential electric-sector growth scenarios in the U.S. out to 2050 under different economic, technology, and policy assumptions.
- For every 2 years, ReEDS finds the regional mix of technologies that meet requirements of the electric sector *at least cost*. Primary requirements include:
  - Regional demands for electricity in each *time-slice*
  - Regional *planning reserve* requirements in each time-slice
  - Regional *operating reserve* requirements In each time-slice
  - Any policy requirements (e.g. RPS)
- In addition to these *constraints*, ReEDS includes:
  - Technology-specific regional resource constraints
  - Transmission constraints
  - Other physical constraints, etc.
- Technologies include conventionals (coal, oil, gas, nuclear), renewables, storage, demand-side tech.

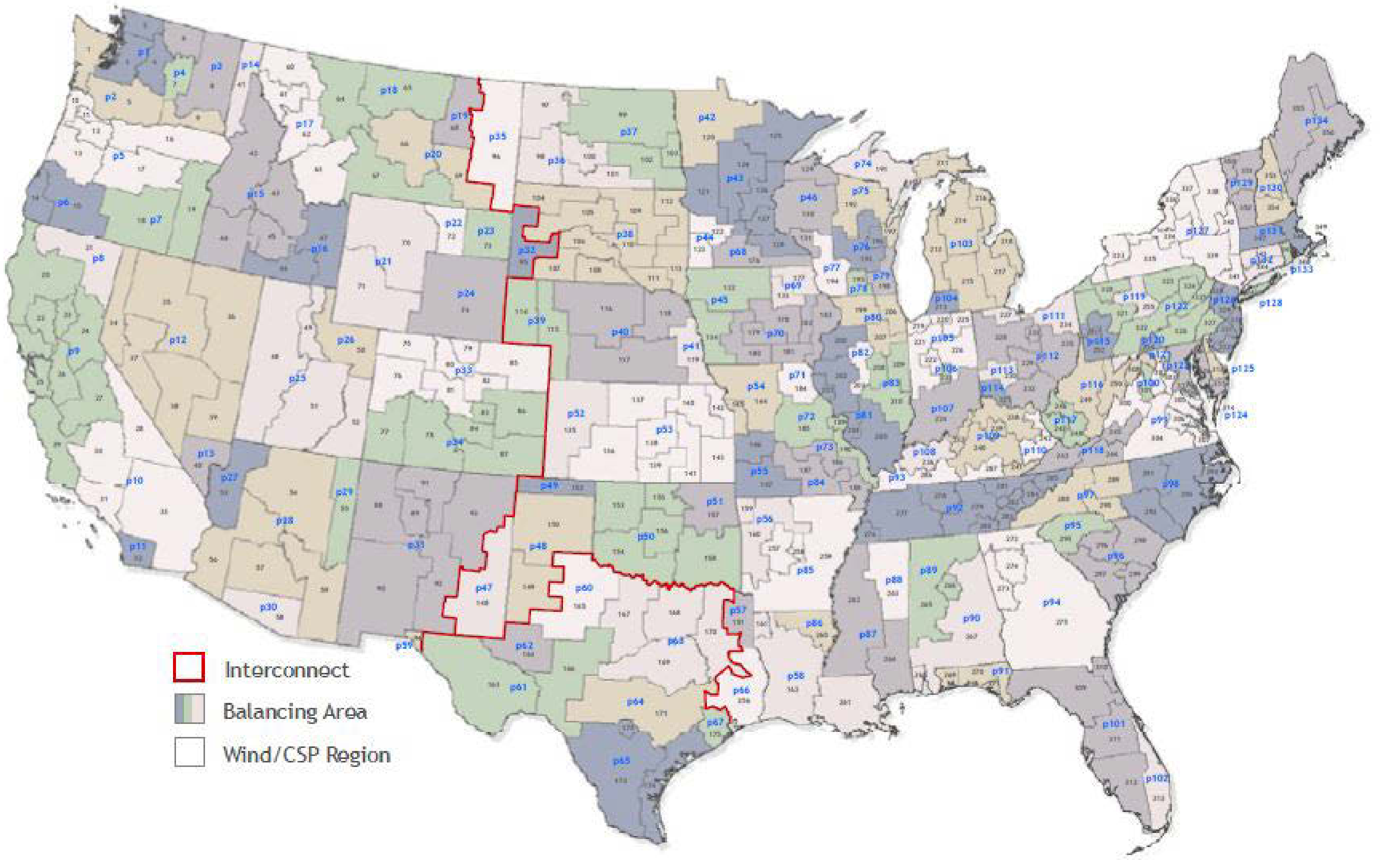


Figure C-5. Map showing the Regional Energy Deployment System regional structure

Figure Note: ReEDS includes three interconnections, 134 model BAAs, and 356 wind and concentrating solar power resource regions.

Results – BAU and IRT Scenarios

- IRT assumes
  - Geothermal categorical exclusions (CX) for resource confirmation activities
  - Centralized coordinated permitting offices
  - NEPA streamlining (expanded use of pre-leasing EAs and Programmatic EIS)
  - Reduced construction timeline
  - Increased resource exploration and rate of discovery

- Scenarios do not include improved technologies (EGS)

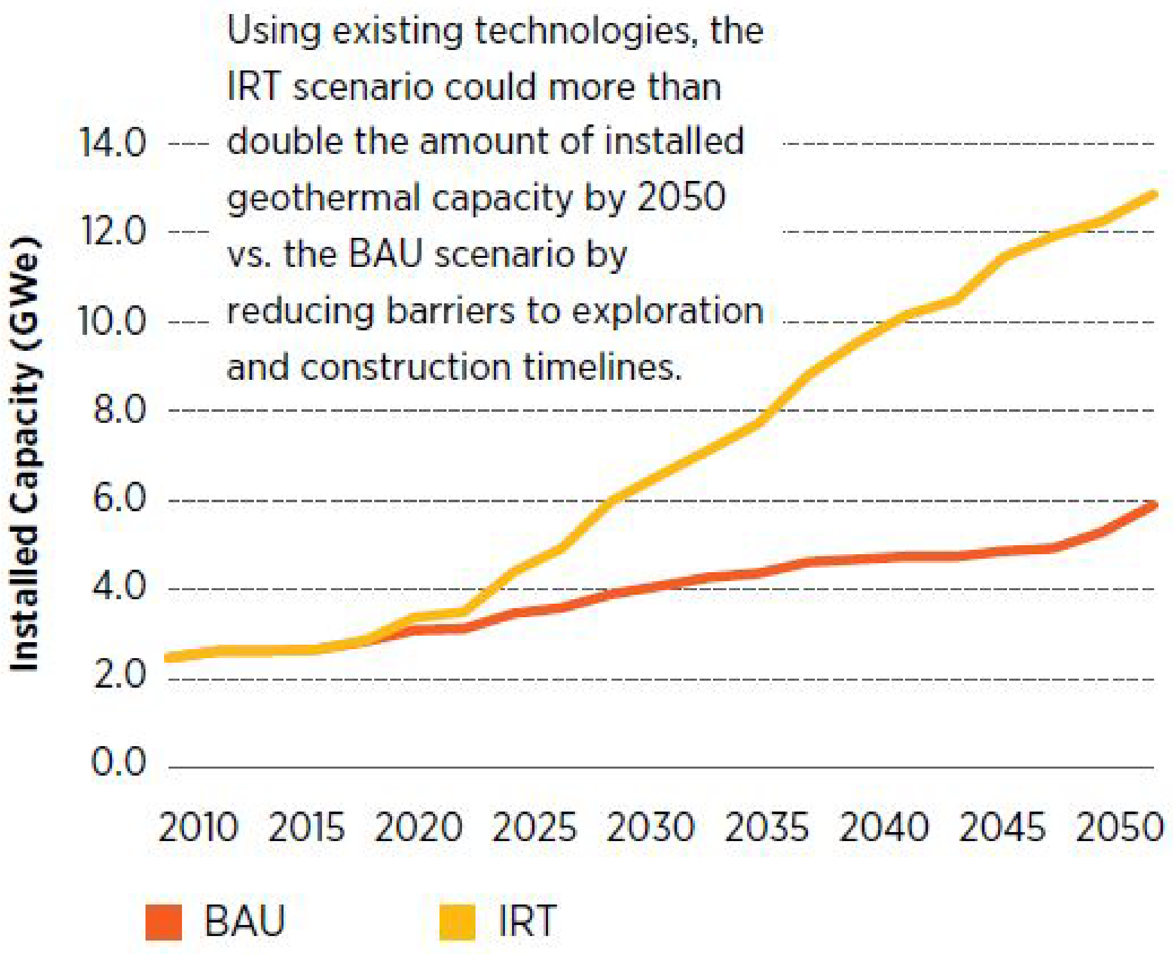


Figure 4-1. Improved Regulatory Timeline scenario results and comparison to the Business-as-Usual scenario for conventional hydrothermal resources

Results – TI Scenario

- Deployment could reach 60 GWe with aggressive technology improvements

- Improvements include better exploration, drilling, and well stimulation.
  - Find resources faster and target wells with improved precision and success.
  - Drill faster and more cost-effectively.
  - Stimulate wells more effectively and at lower cost.

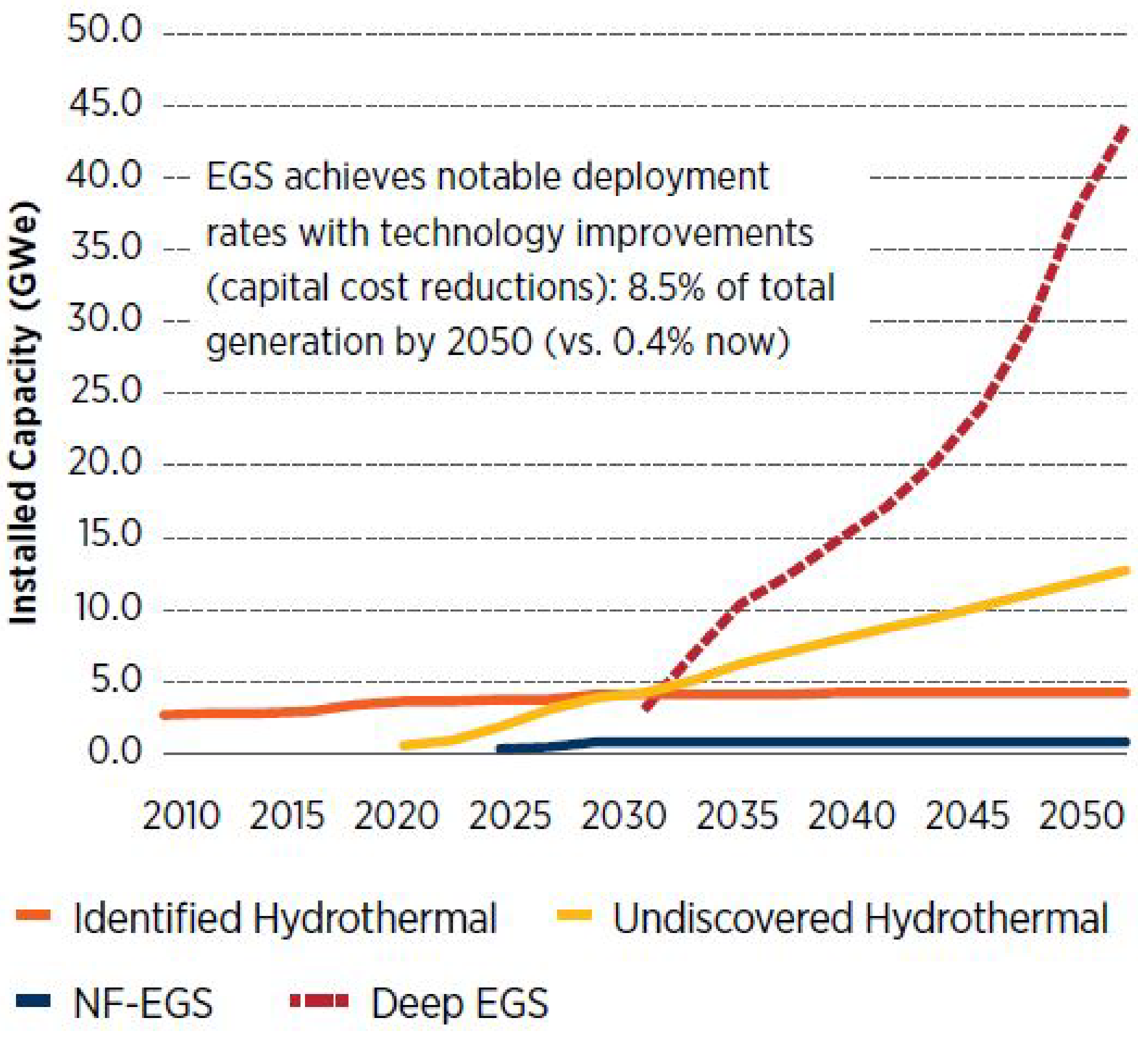


Figure 4-3. Technology Improvement scenario results by resource type

Results – Modeled Generation by Year

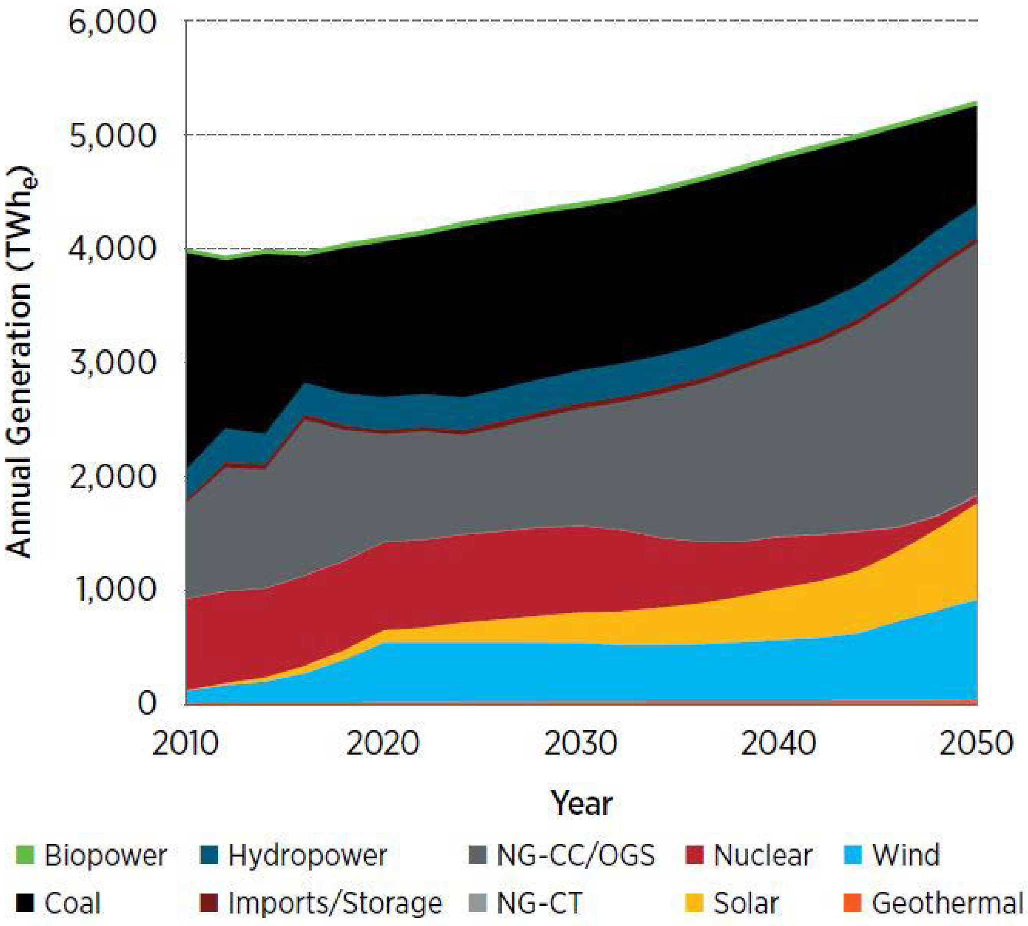


Figure C-10. Annual electricity generation by year for all technologies in the Regional Energy Deployment System for the Business-as-Usual scenario

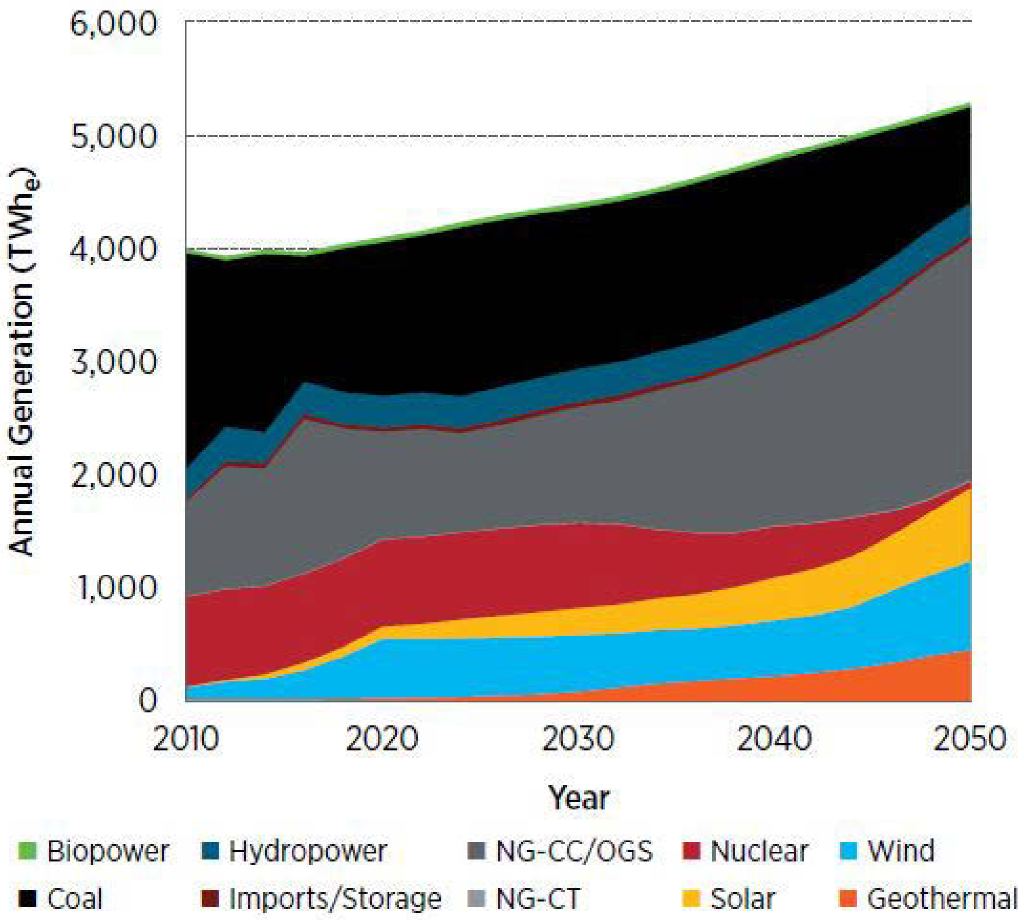
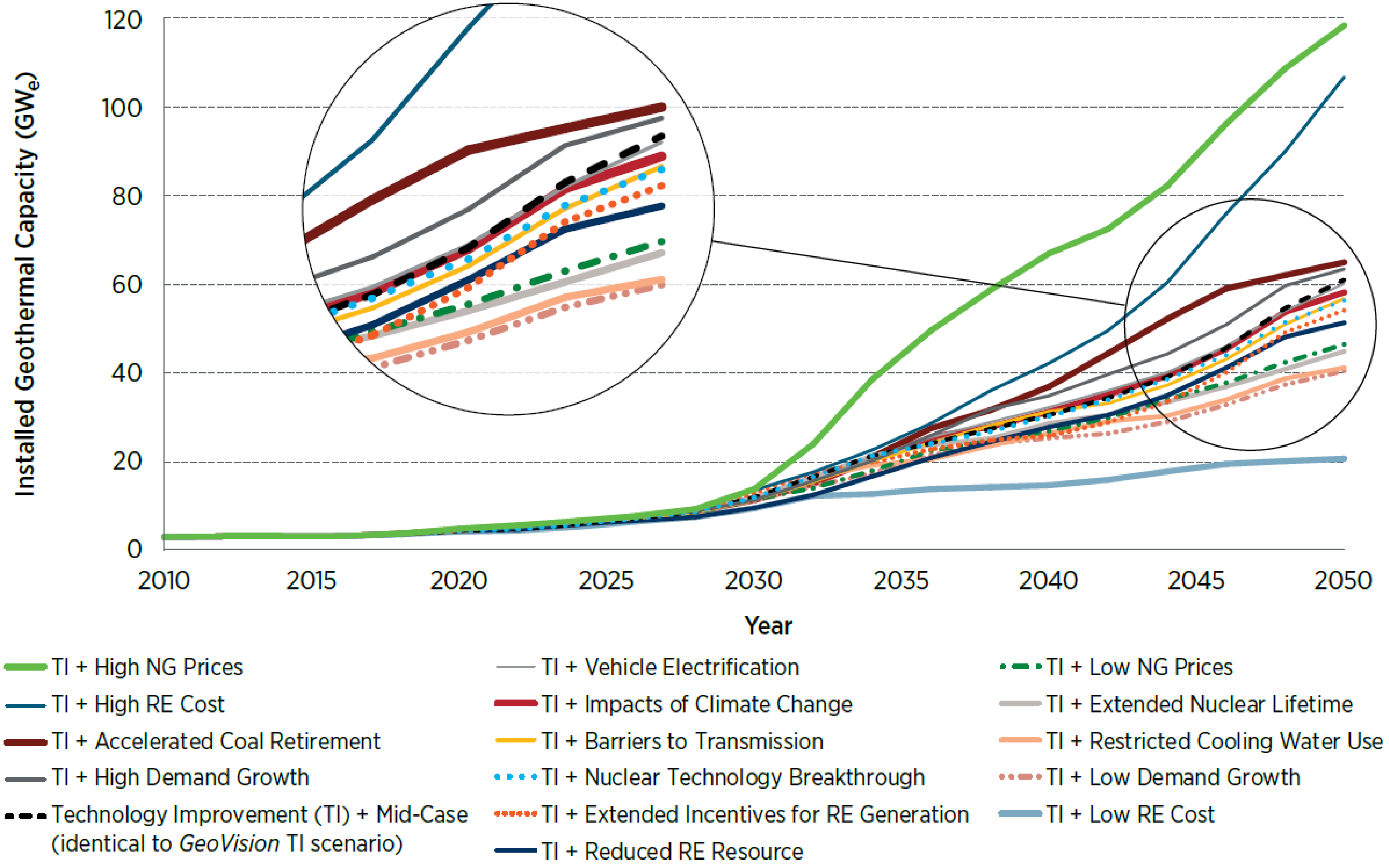


Figure C-16. Annual electricity generation by year for all technologies in the Regional Energy Deployment System for the Technology Improvement scenario

Sensitivity Runs

- ReEDS standard scenarios
- Drilling cost curves
- Regional EGS maps



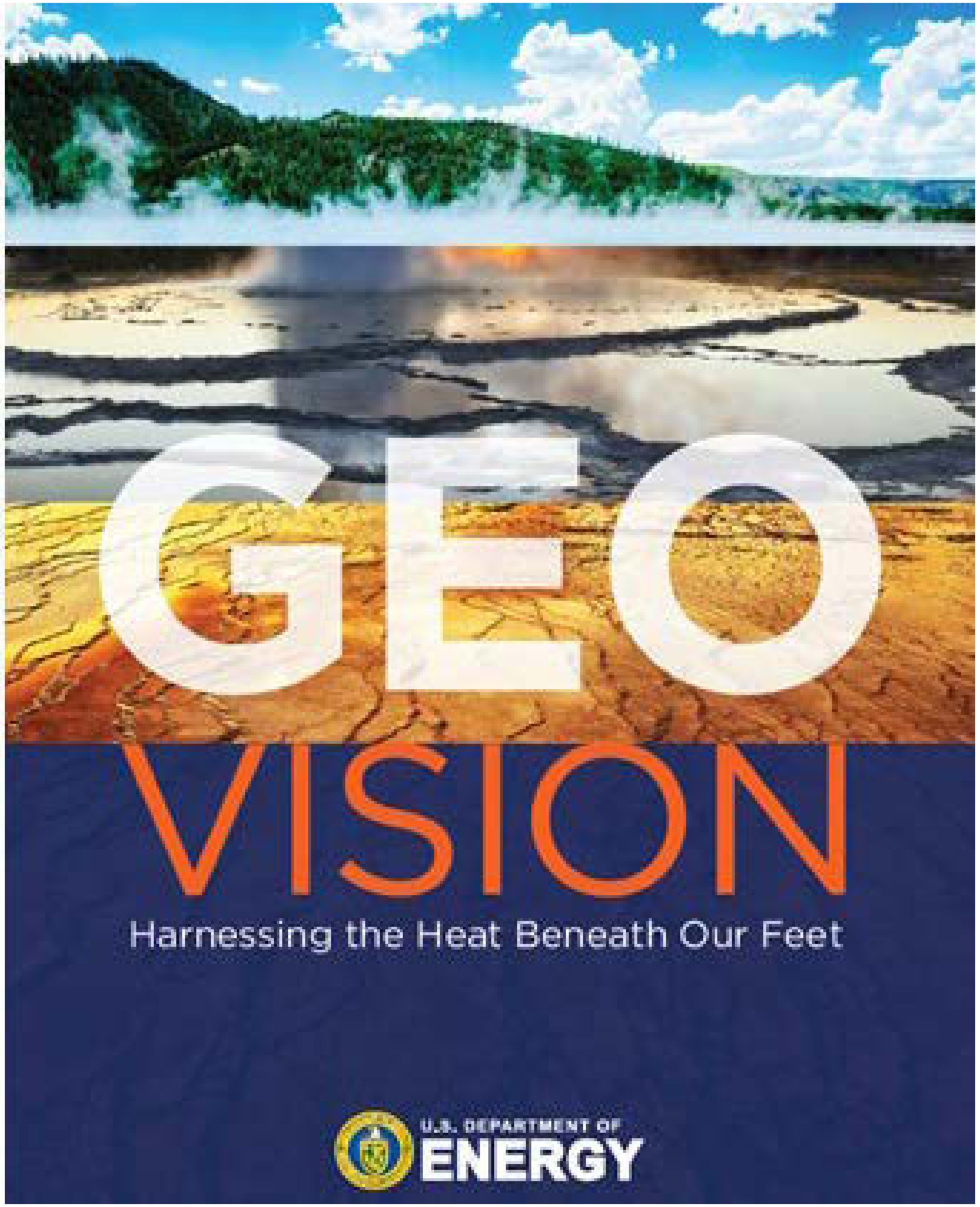
Conclusions

- The BAU scenario in ReEDS projects 5,924 MWe of total installed geothermal capacity by 2050.
- The IRT scenario in ReEDS estimates 12,891 MWe of total installed geothermal capacity by 2050; more than double the installed capacity in the BAU scenario.
- EGS technologies do not deploy in either the BAU or IRT scenario because the technology is not yet advanced enough to be commercially feasible.
- Regulatory reforms alone could greatly increase geothermal deployment.
- Expanded and improved exploration is essential to discovery and deployment of undiscovered hydrothermal resources.

Conclusions

- The TI scenario in ReEDS estimates 60,701 MWe by 2050, mostly from the rapid deployment of EGS resources starting in 2030.
- ReEDS standard scenarios show that geothermal deployment can be robust under numerous future scenarios.
- Detailed regional maps of EGS resources are needed to identify the most favorable EGS sites.
- In order to achieve accelerated geothermal deployment EGS technologies must be advanced through research and development.

Questions?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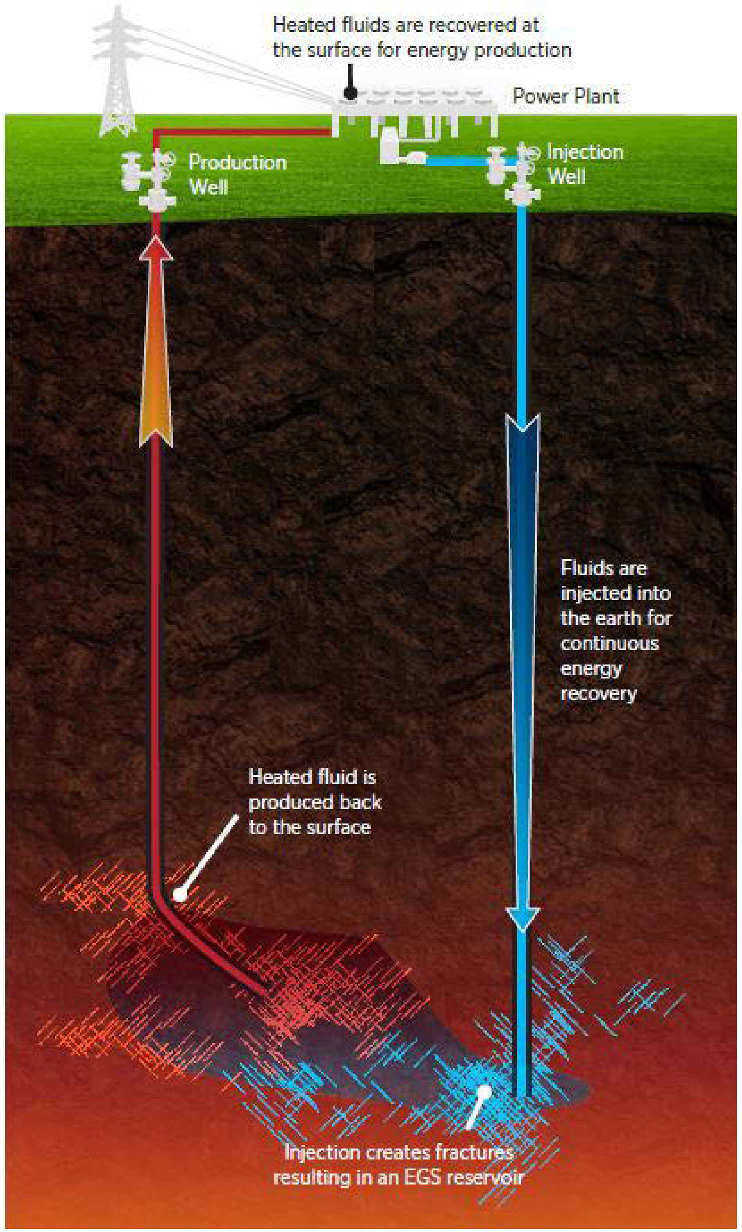
Heated fluids are recovered at the surface for energy production
Power Plant
Production Well
Injection Well
Fluids are injected into the earth for continuous energy recovery
Heated fluid is produced back to the surface
Injection creates fractures resulting in an EGS reservoir

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