



Geothermal Modeling Tools and Power Cycle Research at NREL

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Geothermal Energy Machinery and Systems Workshop

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The National Renewable Energy Laboratory

**South Table
Mountain Campus**
Golden, CO



Flatirons Campus
Arvada, CO



Alaska Campus
Fairbanks, AK



Washington, D.C.,



NREL offers distinct capabilities in foundational science, experimental facilities, component R&D, and systems integration. Capabilities for geothermal energy systems include:

- Experimental and demonstration facilities
- Datasets for electricity and heat systems
- Computational tools for techno-economic analysis



The *Energy Systems Integration Facility* (ESIF)

- Advanced research capabilities
- Experiments for 100s of devices
- Power levels up to 2 MW
- Voltage levels up to 13.2 kV



Energy Systems Integration Facility

The *Flatirons Campus*

- Extensive hardware and simulation resources
- Experiments for 1000s of devices
- Power levels up to 20 MW
- Voltage levels up to 34.5 kV



Flatirons Campus

The *Virtual Emulation Environment* (VEE)

- Sophisticated digital platform
- Emulate experiments for 1,000,000s of devices
- Any utility power
- Any voltage level
- Local to national scales

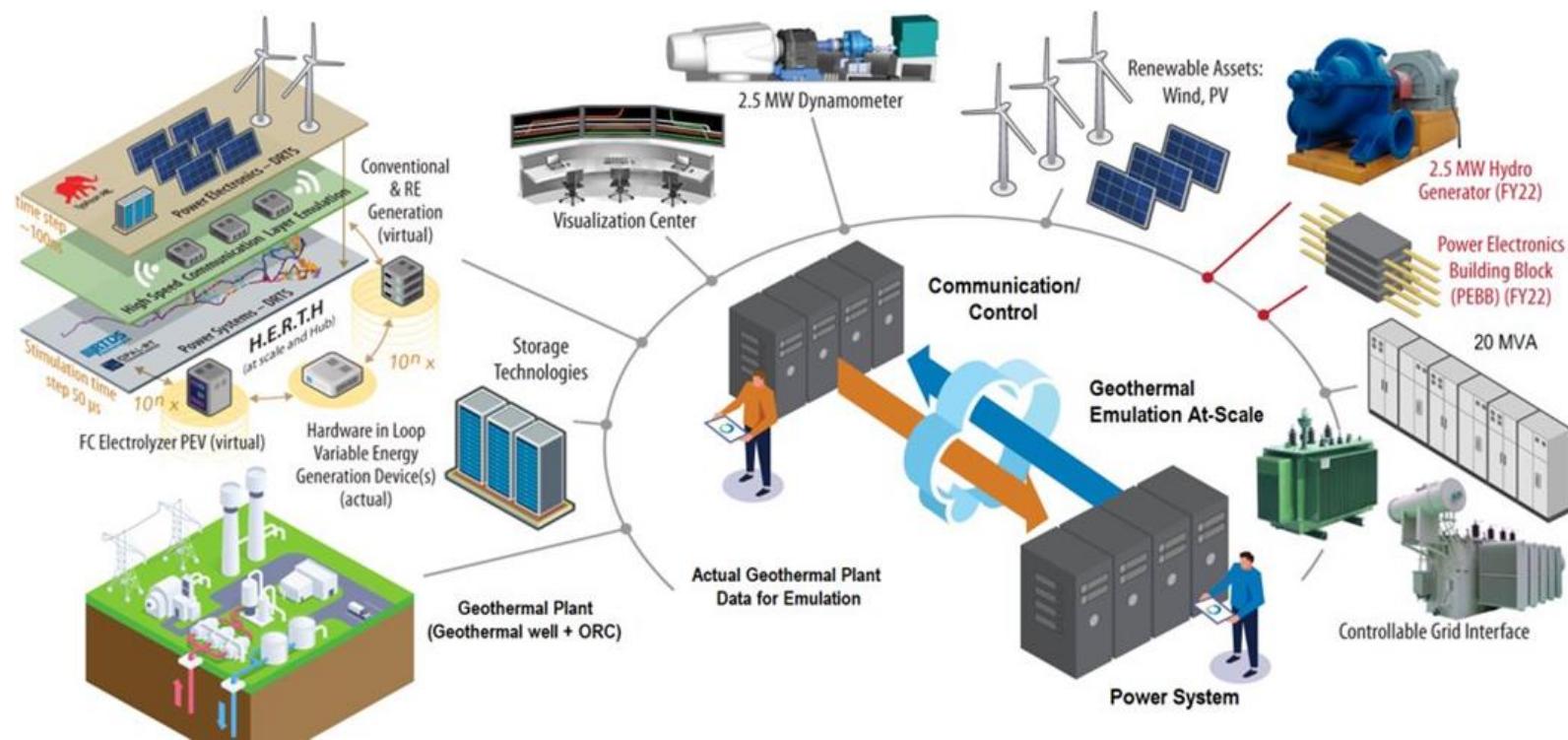
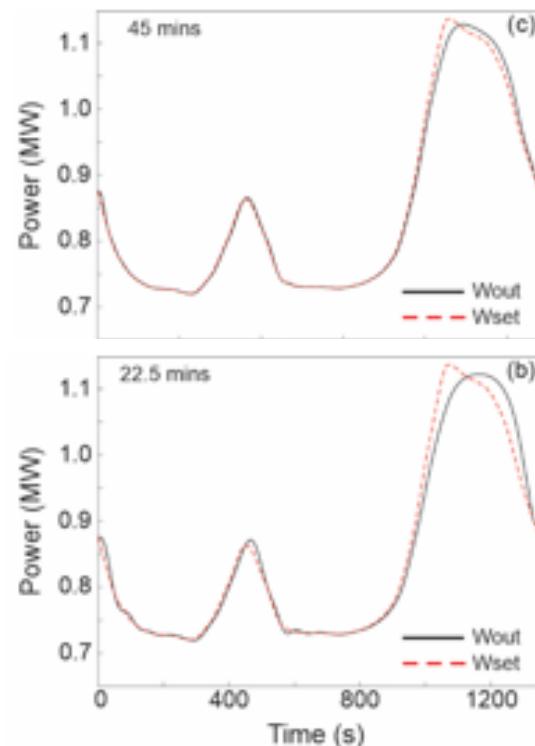


Virtual Emulation Environment

Digital Real Time Co-Emulation at ARIES

Several options to evaluate geothermal technology integrated with physical hardware in replicated grid scenarios:

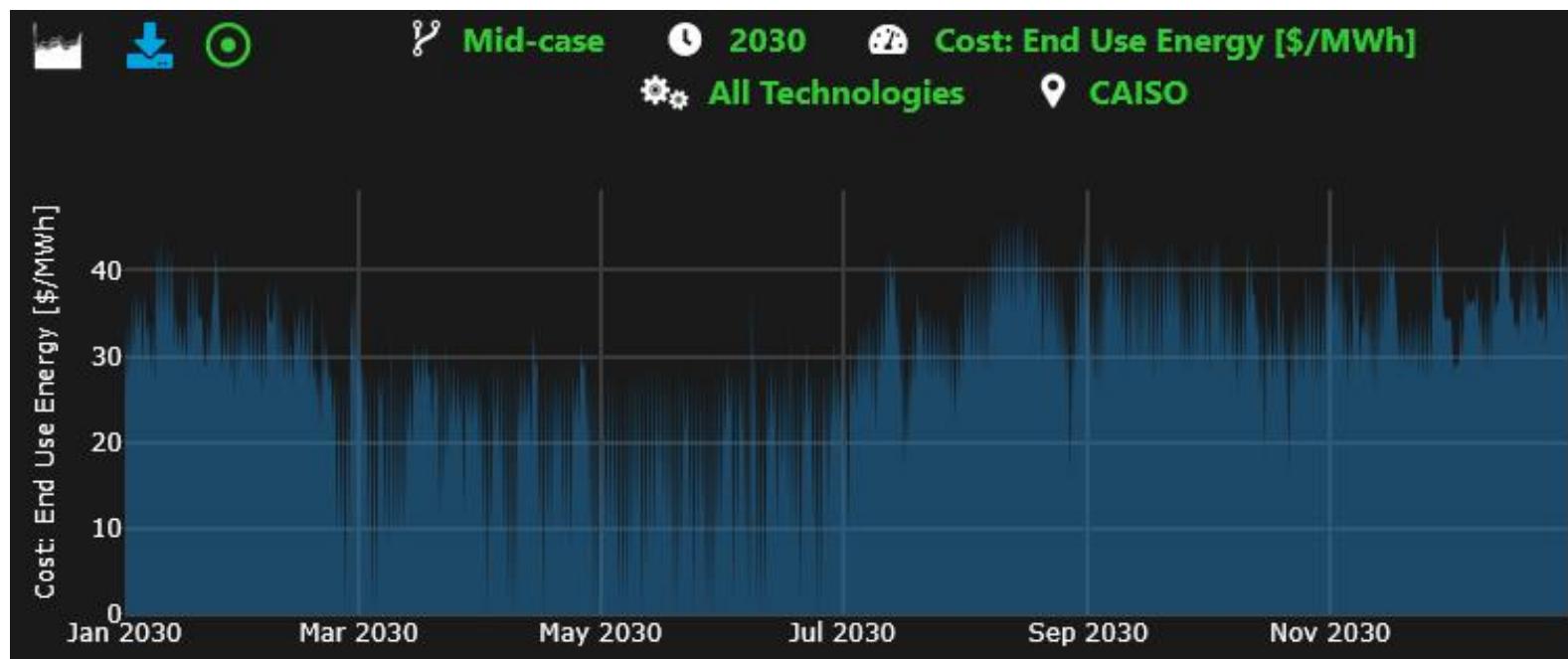
1. Model cycle and use emulator/dynamometer
2. Operate cycle off-site w/ real-time communication w/ ARIES
3. Demonstrate cycle at ARIES



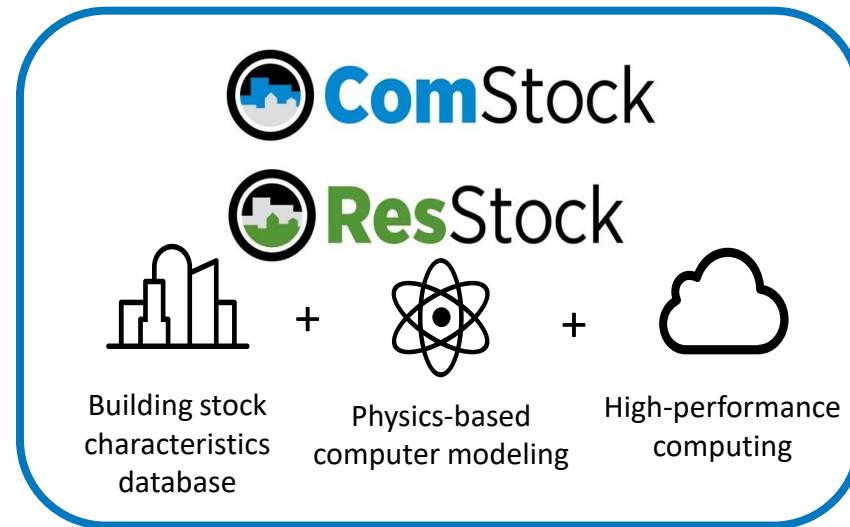
Datasets for electricity generation

Datasets provide easy access to standard inputs and scenarios to help estimate and compare techno-economic potential for electricity and heat applications

- [Cambium](#): Dataset of hourly marginal costs in future grid scenarios
- [Utility rate database \(URDB\)](#)
- [Annual technology baseline \(ATB\)](#): current and projected cost of energy technologies

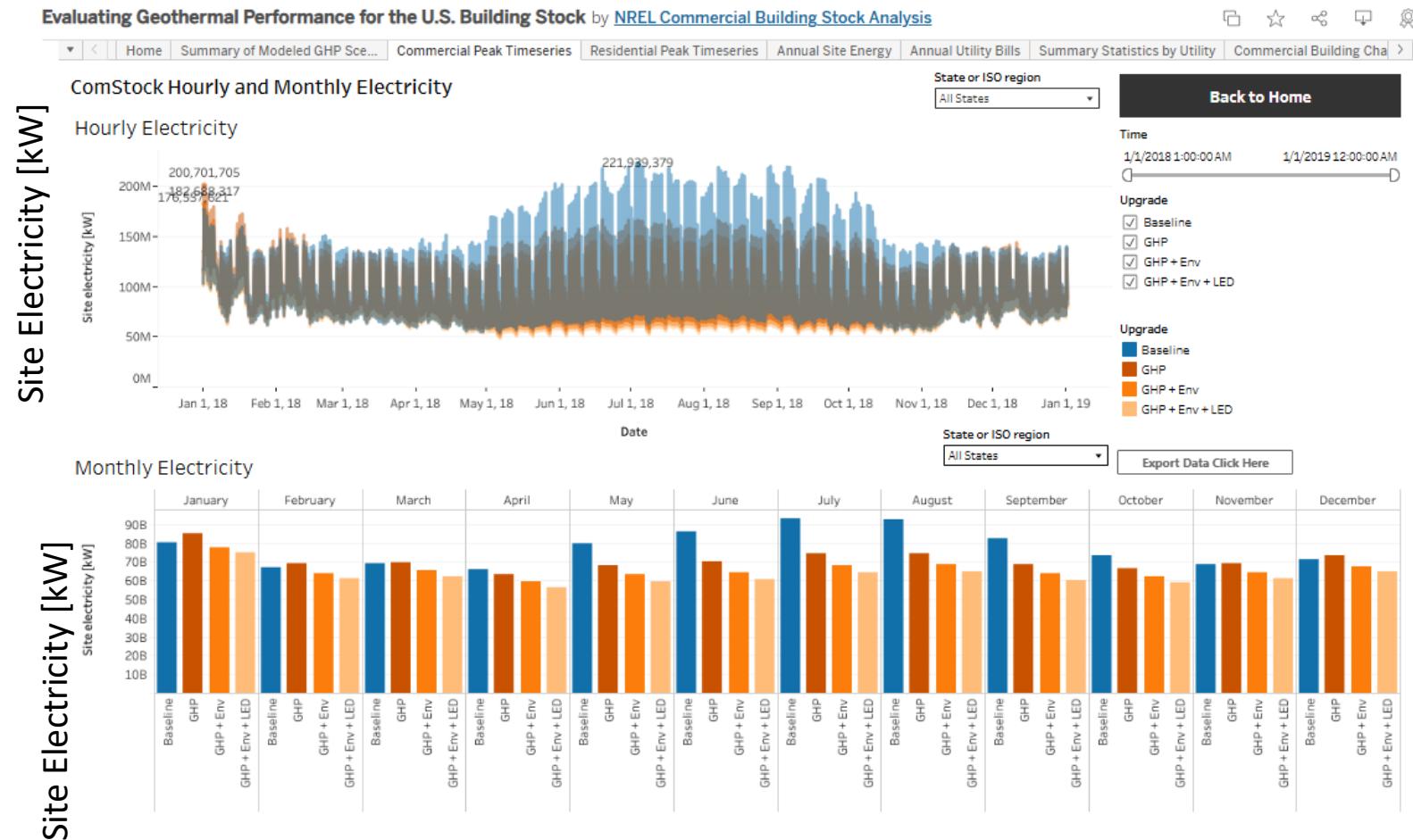


Datasets for geothermal heat pumps

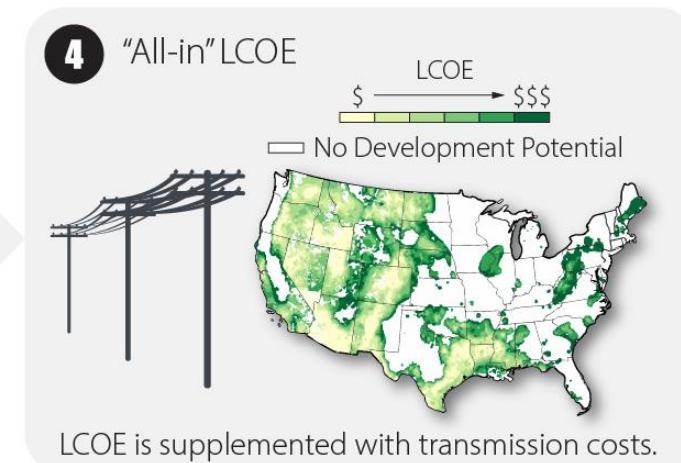
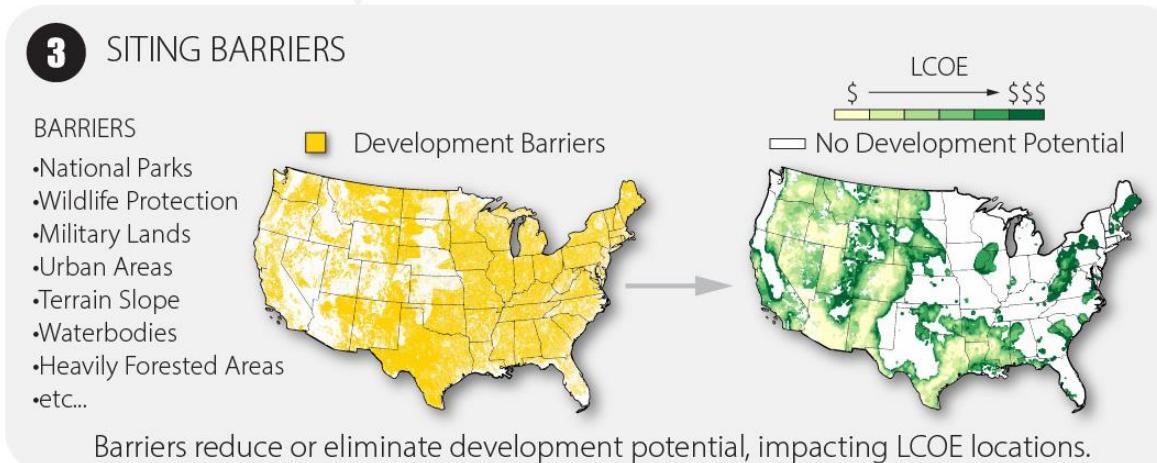
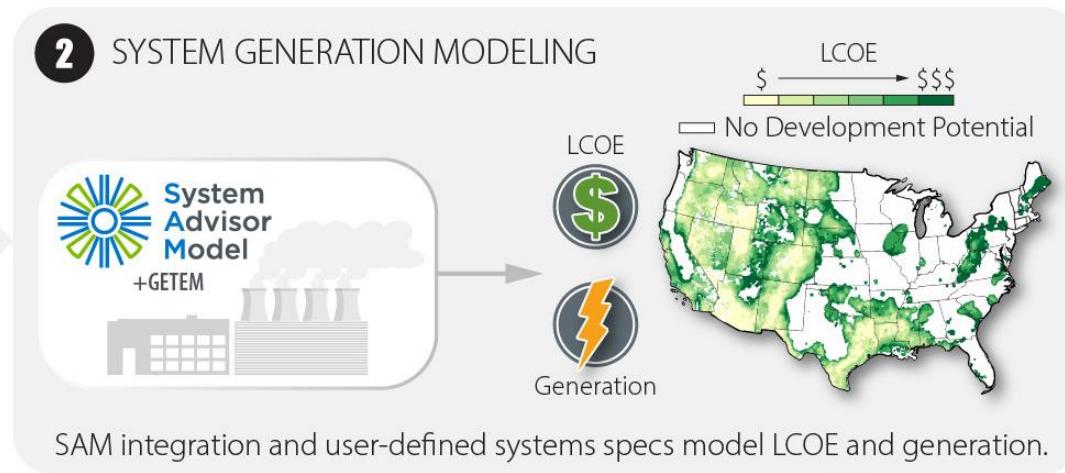
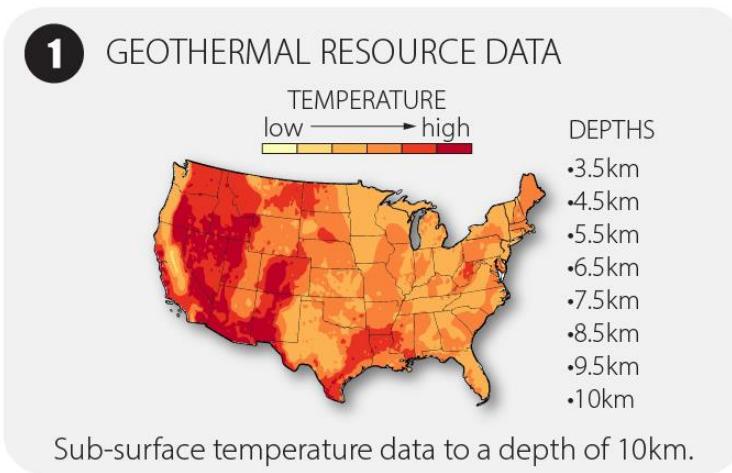


- Integrated GHP modeling
GHEDesigner for ground heat
exchanger sizing
- ComStock: 6 national GHP
datasets
- ResStock: 3 national GHP
datasets
- Technical Advisory Committee

ComStock Tableau Site

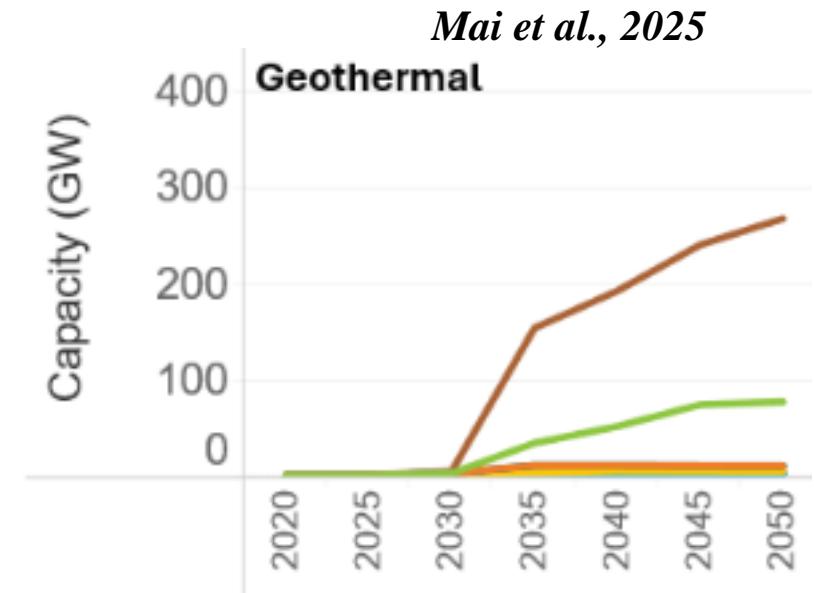
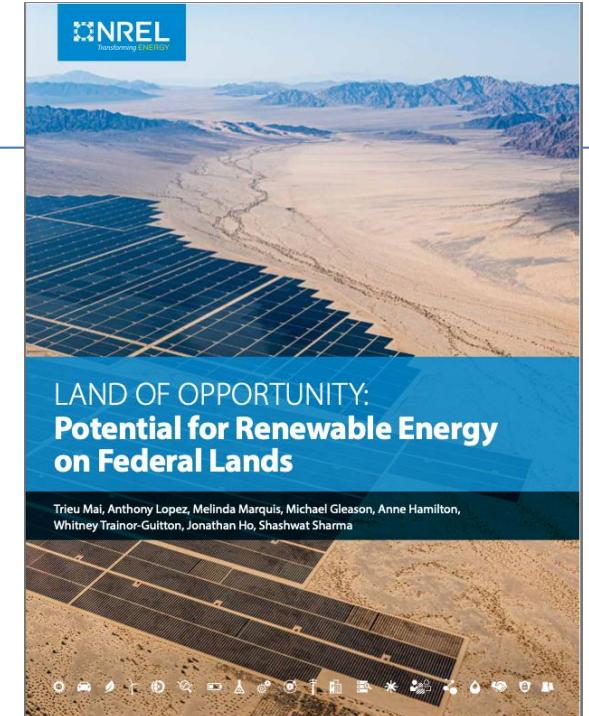
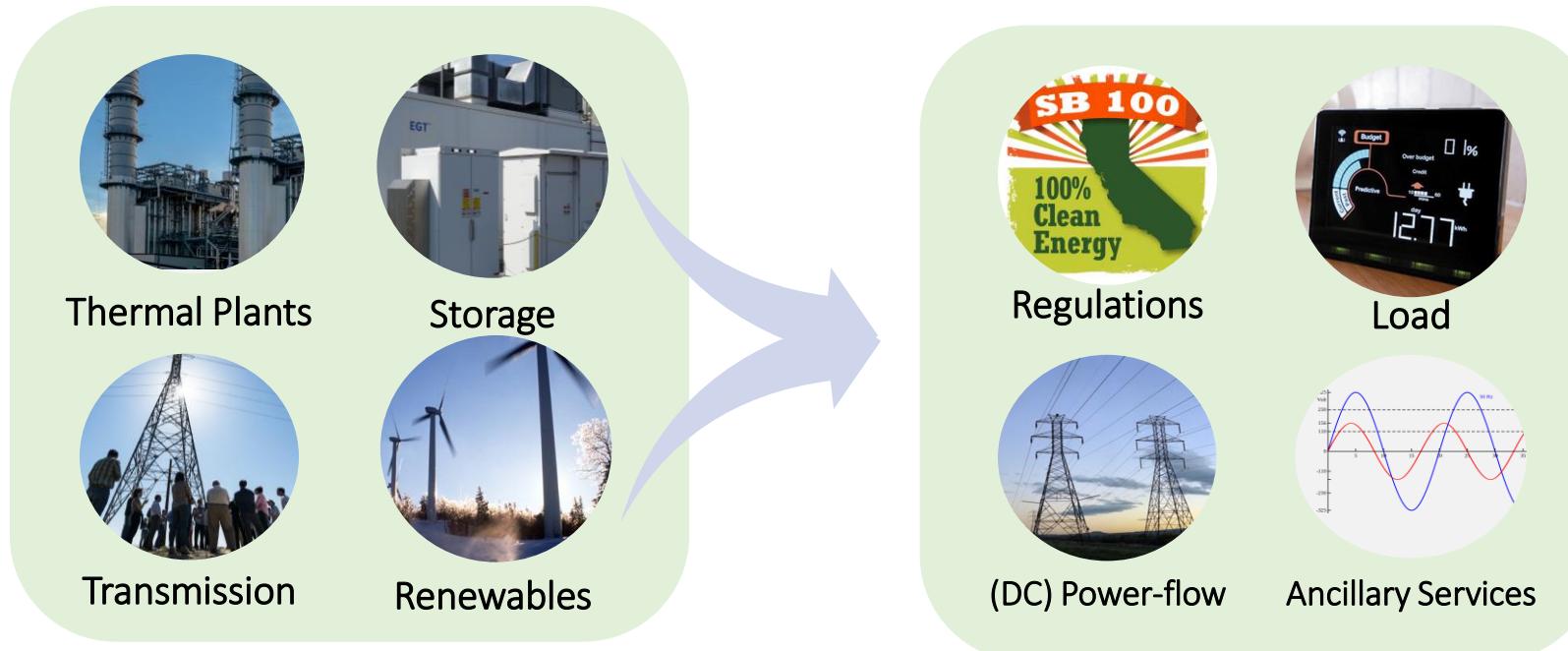


Geospatial technical potential modeling w/ reV



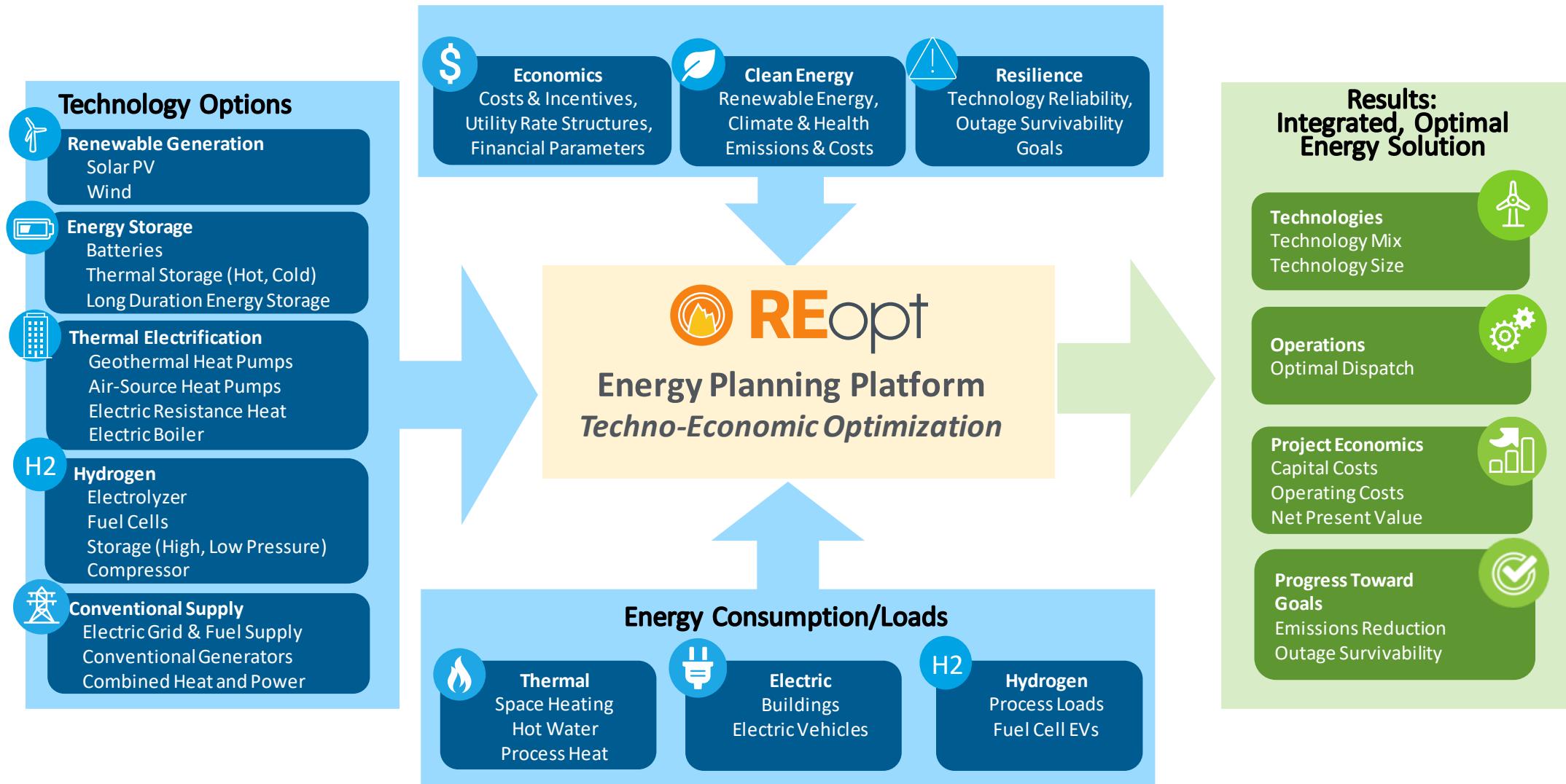
ReEDS: Regional Energy Deployment System (ReEDS) Model

The [ReEDS](#) identifies the *least cost mix and operation* of resources that simultaneously meets load, all other electricity service requirements (planning reserves, operating reserves), and physical and environmental constraints.

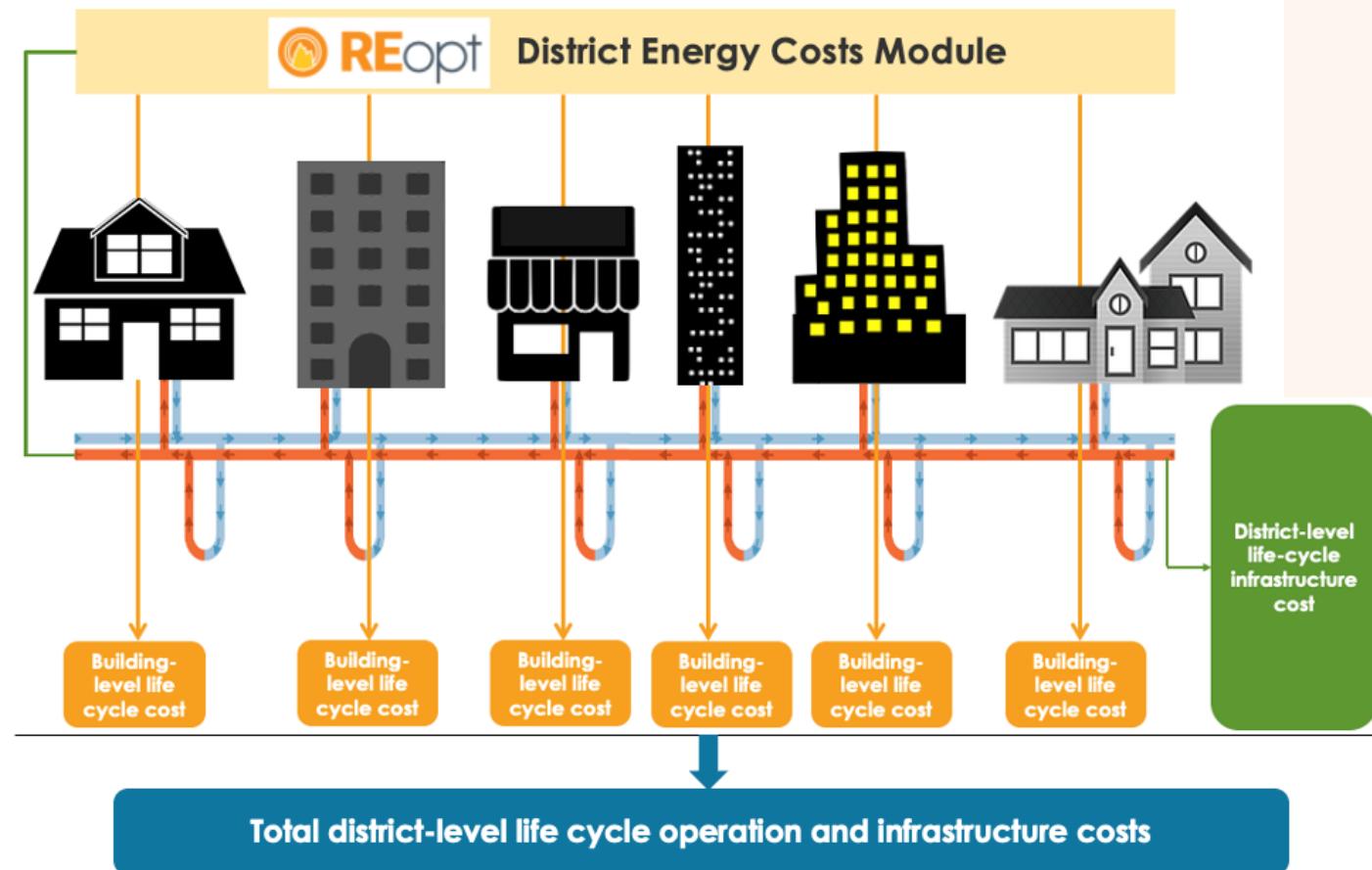


REopt Energy Planning Platform

Formulated as a mixed integer linear program (MILP), REopt provides an integrated, cost-optimal energy solution.



REopt for GHP



REopt: <https://reopt.nrel.gov/tool>

Geothermal Heat Pump

Require GHP purchase in the solution Yes

Heat pump configuration Distributed water-to-air heat pumps (WAH)

GHX configuration Non-hybrid

Maximum GHP size (ton) Unlimited

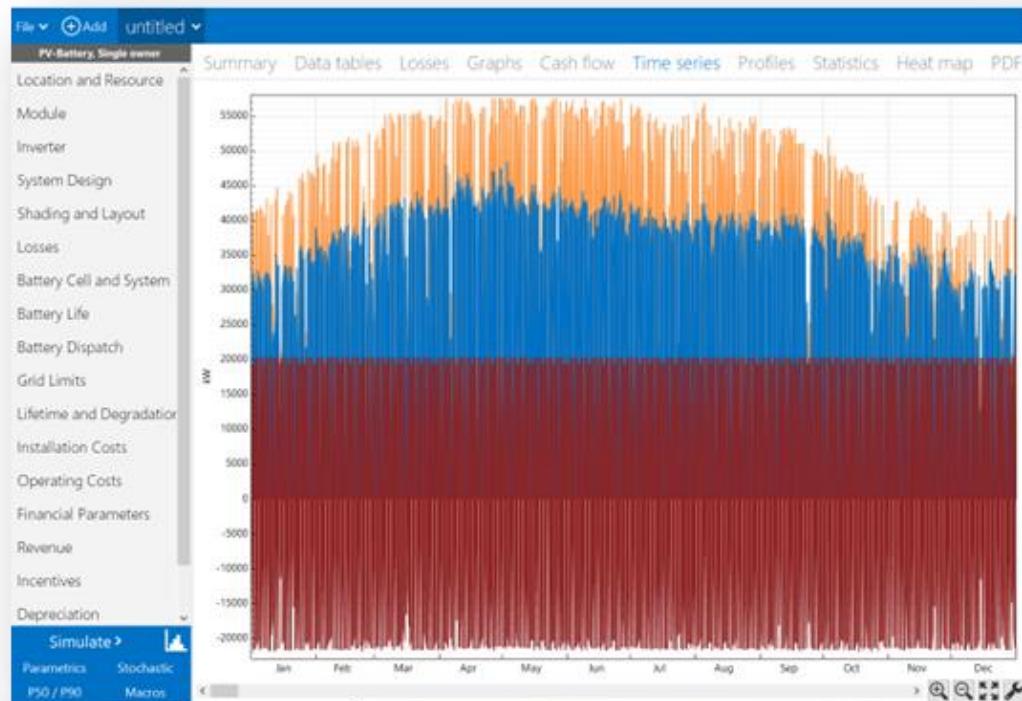
Maximum GHX size (number of boreholes) Unlimited

Total installed cost for heat pump (\$/ton) \$1,075

- Allows users to limit their GHP and GHE sizes
- Currently exploring GHP lifecycle costs for Alaska and Washington DC
- Geothermal power generation possible by importing a “fixed generator” profile. Pursuing projects to add more detailed geothermal power capabilities in 2026.

System Advisor Model (SAM)

Free open-source software that enables detailed performance and financial analysis of energy systems



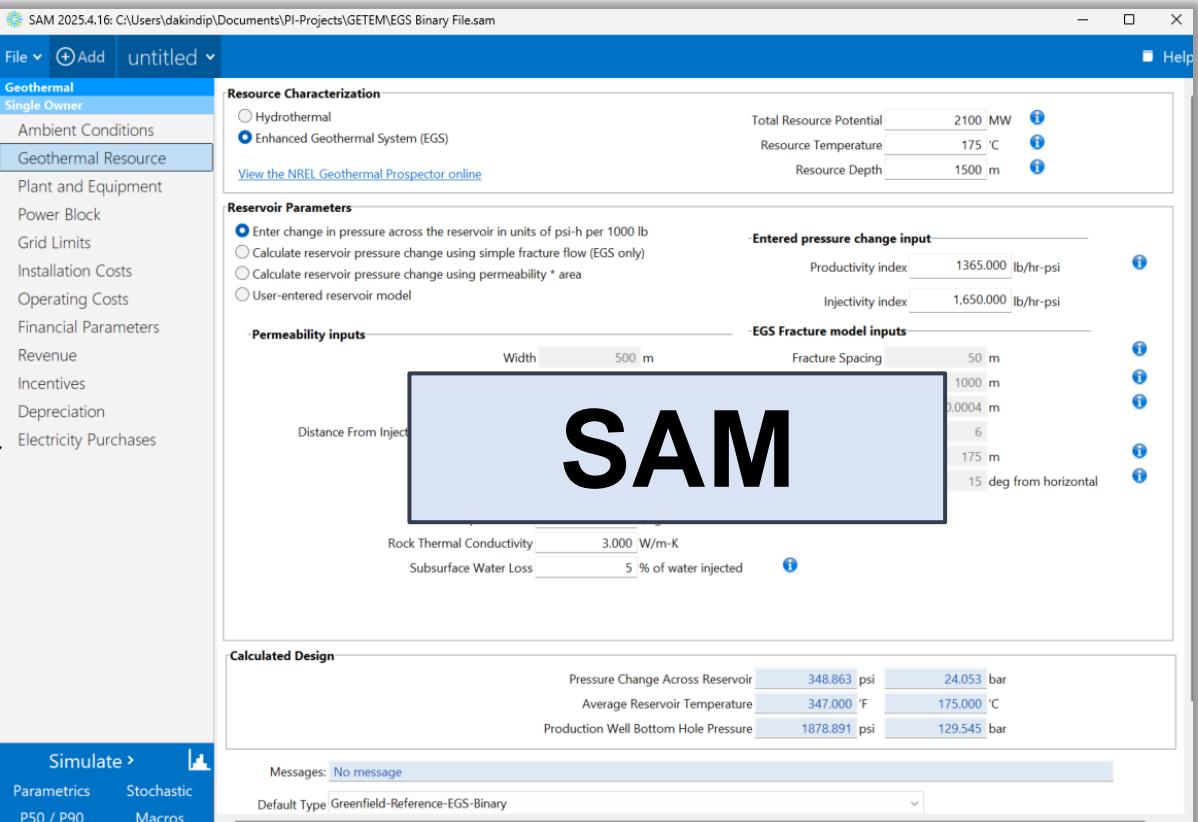
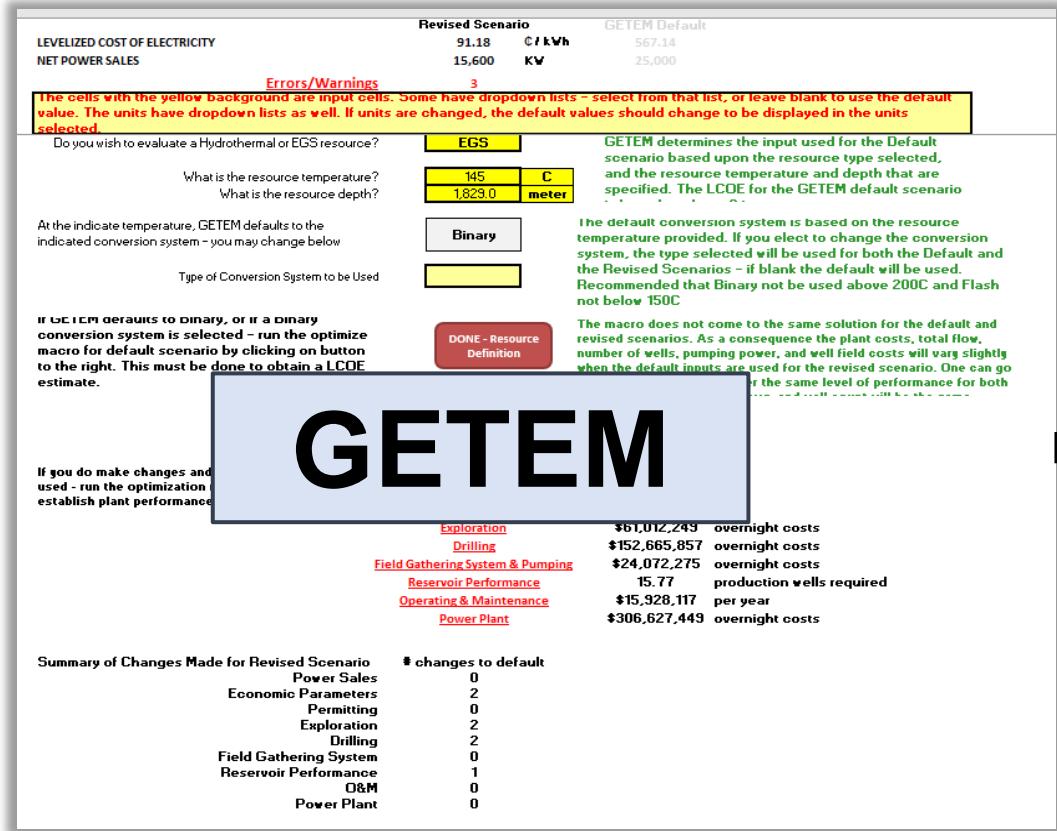
Choose a performance model, and then choose from the available financial models.

- › Photovoltaic
- › Energy Storage
- › Hybrid
- › Concentrating Solar Power
- › Industrial Process Heat
- › Marine Energy
- Wind
- Fuel Cell - PV - Battery
- Geothermal**
- Solar Water Heating
- Biomass Combustion
- Custom Generation Profile (Generic System)

▼ Power Purchase Agreement

- Single Owner**
- Partnership Flip with Debt
- Partnership Flip without Debt
- Sale Leaseback
- Merchant Plant
- LCOE Calculator (FCR Method)
- No Financial Model

Geothermal in SAM



- GETEM developed by Greg Mines (INL) as an Excel model
- Conversion to SAM enables a graphical user interface, detailed financial models, comparison to other generation technologies, updates tracking (GitHub), and user inputs/feedback.

SAM User Inputs

- Simple representation of power cycle design-point
- Default model assumes design performance for blocks of time and derates for temperature decline

Geothermal
Single Owner

Ambient Conditions
Geothermal Resource
Plant and Equipment
Power Block
Grid Limits
Installation Costs
Operating Costs
Financial Parameters
Revenue
Incentives
Depreciation
Electricity Purchases

Plant Configuration

Specify plant output: 40000 kW
 Use exact number of wells: 3 wells
Conversion Plant Type: Binary (Plant efficiency set as percentage of max plant efficiency) Flash
Plant Efficiency: 80.6 %
Subtype: Unconstrained Single Flash

Number of Wells in Analysis: 5.559 wells
Actual Plant Efficiency: 9.294 w-hr/lb
Gross Plant Output: 45.106 MW
Net Plant Output: 40.000 MW

Plant Design Temperature: 200 °C
Temperature Loss in Prod. Well: 0.000 °C
 Calculate temperature loss in production well

Plant Utilization Factor

The System Availability Losses are generation outages and losses that decrease the utilization factor of a plant. This utilization factor is also termed the net capacity factor in GETEM. It accounts for plant availability and ambient temperature variability but does not include the effect of declining resource productivity/degradation. Resource productivity decline is included separately in the LCOE calculation.

Edit losses... Constant loss: 5.0 %
Time series losses not enabled
Custom periods not enabled

Temperature Decline

Specify temp decline rate: 0.5 %/yr
 Calculate temp decline rate (EGS only)

Allow reservoir replacements
Max. temp decline before reservoir replacement: 30 °C

Flash Technology

Use wet bulb temperature from weather file
Wet Bulb Temperature: 10 °C
Wet-bulb Temp from Weather File: 2.880 °C
Ambient Pressure: 14.7 psi

GETEM assumption: 15°C for Flash and 10°C for Binary plants. Please change when switching between plants.

Pumping Parameters

Production Well Flow Rate: 110 kg/s per well
Pump Efficiency: 67.5 %
Pressure Difference Across Surface Equipment: 40 psi
Excess Pressure at Pump Suction: 50 psi

Pump Depth: 1123.120 ft
Pump Work: 5.106 MW
Production Pump Size: 733.646 hp
Injection Pump Size: 2769.030 hp

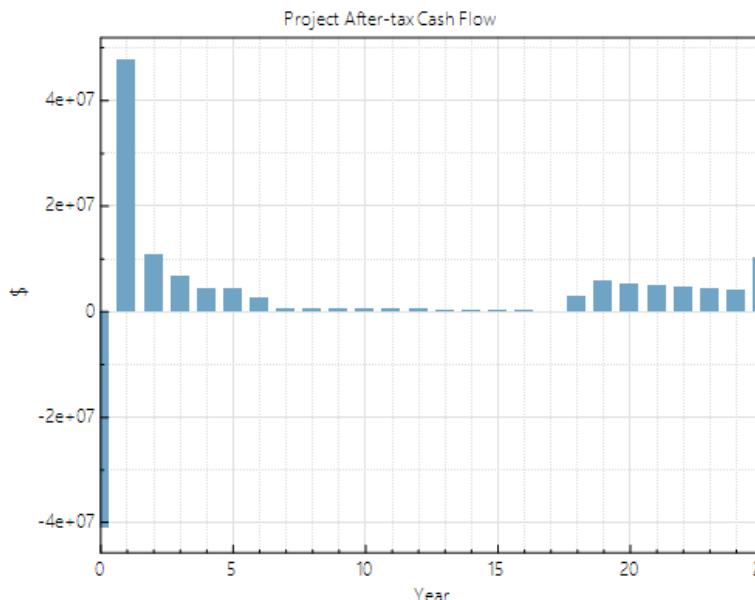
Specify Pump Work
Specified Pump Work: 0 MW

SAM Financial Outputs

- Key metrics such as LCOE, NPV, IRR, etc...
- Detailed annual cash flows

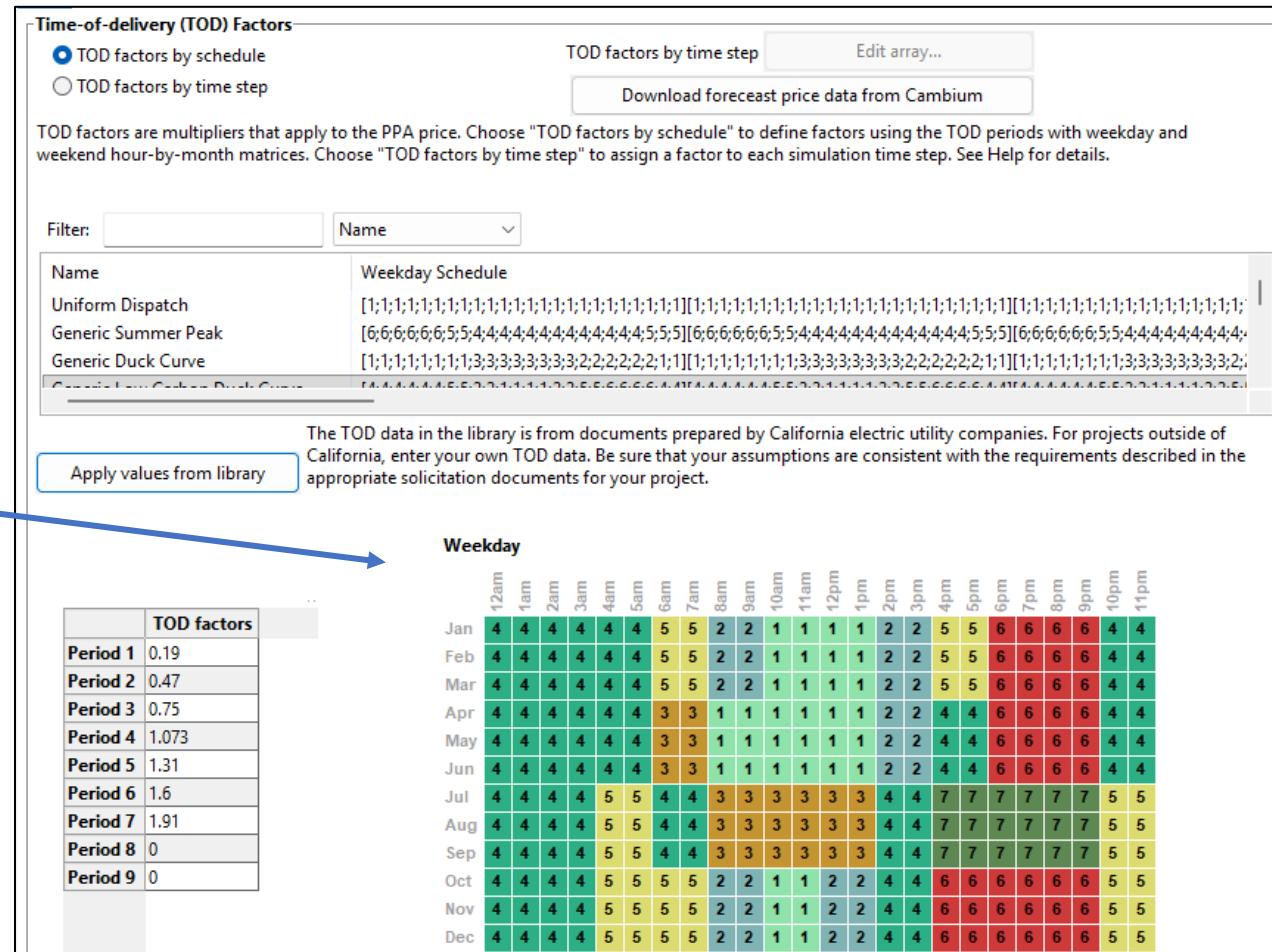
	0	1	2	3	4	5	6	7
Property tax net assessed value (\$)	0	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312
OPERATING EXPENSES								
O&M fixed expense (\$)								
O&M fixed expense (\$)	0	0	0	0	0	0	0	0
O&M production-based expense (\$)	0	0	0	0	0	0	0	0
O&M capacity-based expense (\$)	0	5,823,764	5,969,358	6,118,592	6,271,556	6,428,346	6,589,054	6,753,780
Electricity purchase (\$)	0	0	0	0	0	0	0	0
Property tax expense (\$)	0	1,260,313	1,260,313	1,260,313	1,260,313	1,260,313	1,260,313	1,260,313
Insurance expense (\$)	0	630,157	645,910	662,058	678,610	695,575	712,964	730,788
Total operating expenses (\$)	0	7,714,234	7,875,582	8,040,963	8,210,479	8,384,234	8,562,331	8,744,882
EBITDA (\$)								
EBITDA (\$)	0	13,189,235	12,970,898	12,742,768	12,504,747	12,256,733	11,998,622	11,730,310
OPERATING ACTIVITIES								
EBITDA (\$)								
EBITDA (\$)	0	13,189,235	12,970,898	12,742,768	12,504,747	12,256,733	11,998,622	11,730,310
Interest earned on reserves (\$)	0	111,624	111,582	111,519	111,434	111,328	111,200	111,051
plus PBI if not available for debt service:								
Federal PBI income (\$)	0	0	0	0	0	0	0	0

Metric	Value
Annual AC energy (year 1)	261,293,360 kWh
Capacity factor (year 1)	99.4%
PPA price in Year 1	8.00 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	8.61 ¢/kWh
LPPA Levelized PPA price real	6.95 ¢/kWh
LCOE Levelized cost of energy nominal	7.23 ¢/kWh
LCOE Levelized cost of energy real	5.83 ¢/kWh
NPV Net present value	\$31,716,692
IRR Internal rate of return	47.12 %
Year IRR is achieved	20
IRR at end of project	47.13 %
Net capital cost	\$150,127,072
Equity	\$41,219,976
Size of debt	\$108,907,088
Debt percent	72.54%



2026 Planned Improvements to SAM

- Improve off-design modeling capability to capture influence of ambient temperature, brine temperature, brine mass flow rate
 - Want to quantify value of time-of-use generation
 - Initial focus on ORCs for EGS
- Update cost correlations
- Improve design-point feedback in user interface
- Improve documentation





Thank you!

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