



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

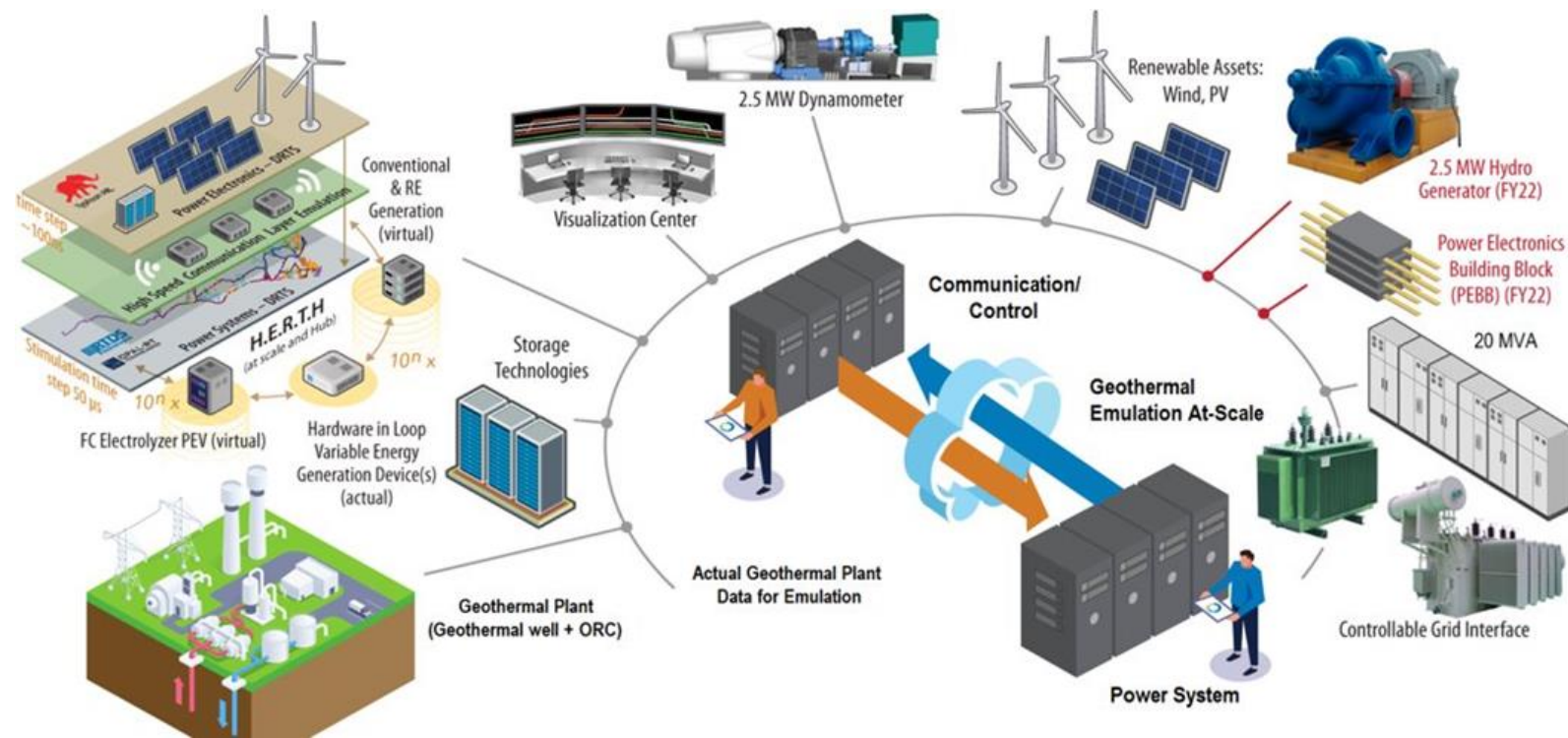
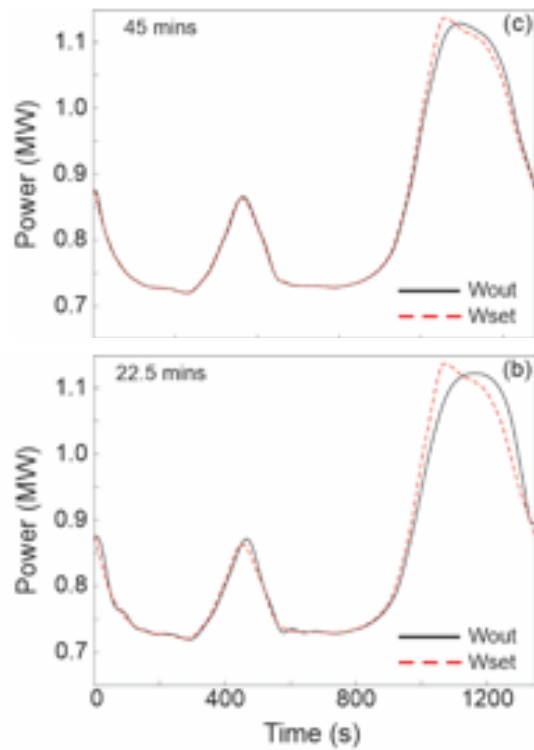


Virtual Emulation Environment

Digital Real Time Co-Emulation at ARIES

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

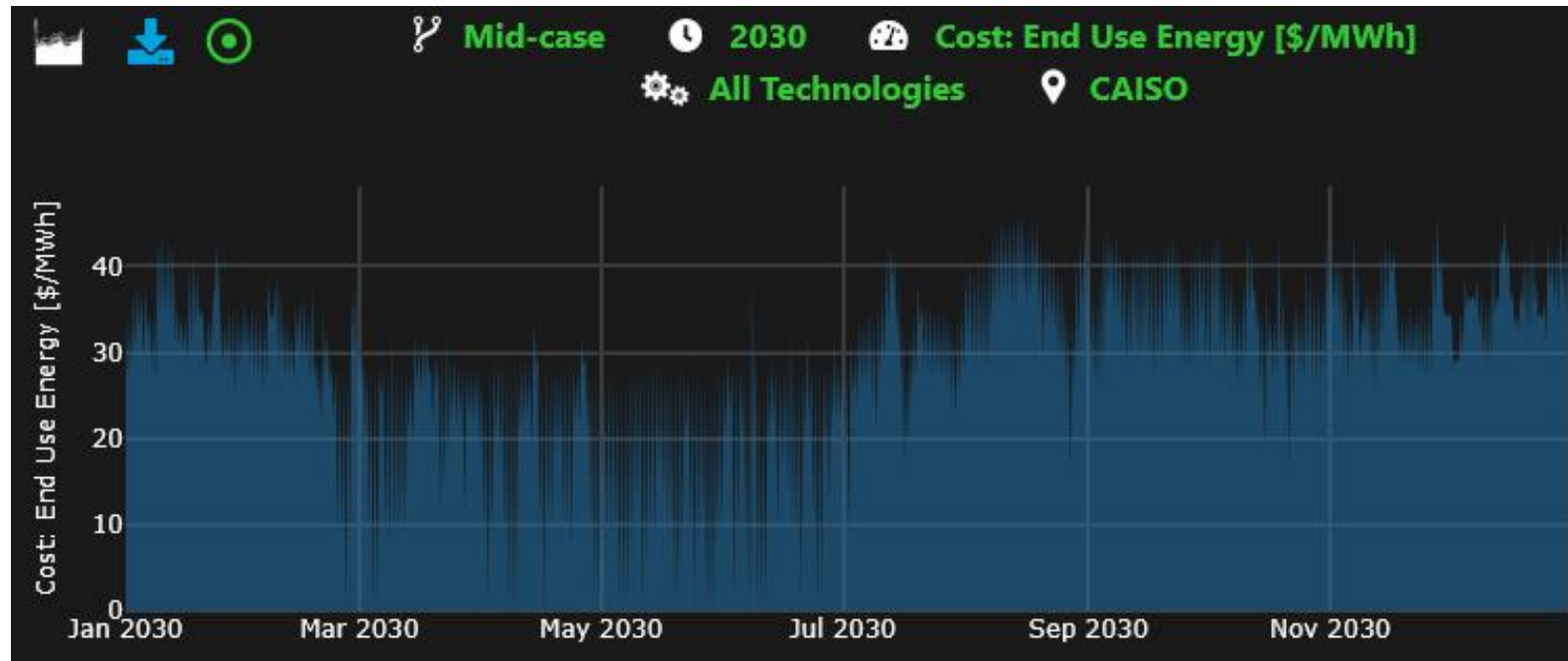
1. Model cycle and use emulator/dynamometer
2. Operate cycle off-site w/ real-time communication w/ ARIES
3. Demonstrate cycle at ARIES



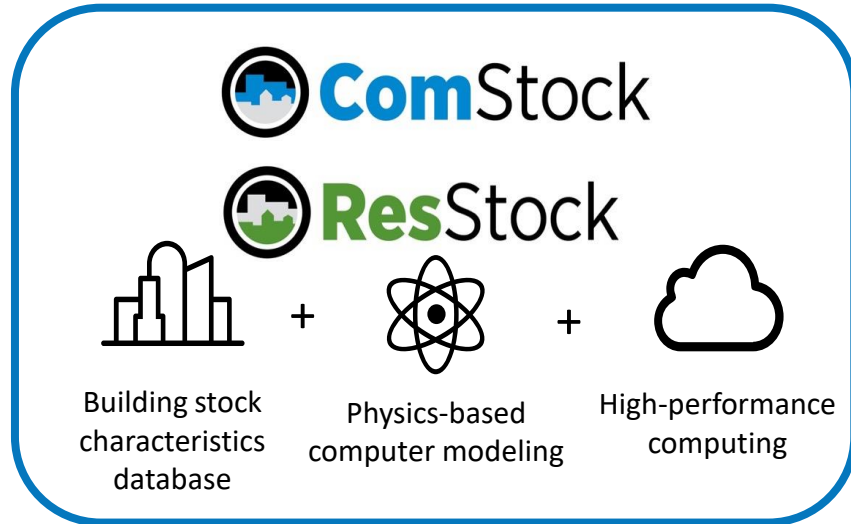
Datasets for electricity generation

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



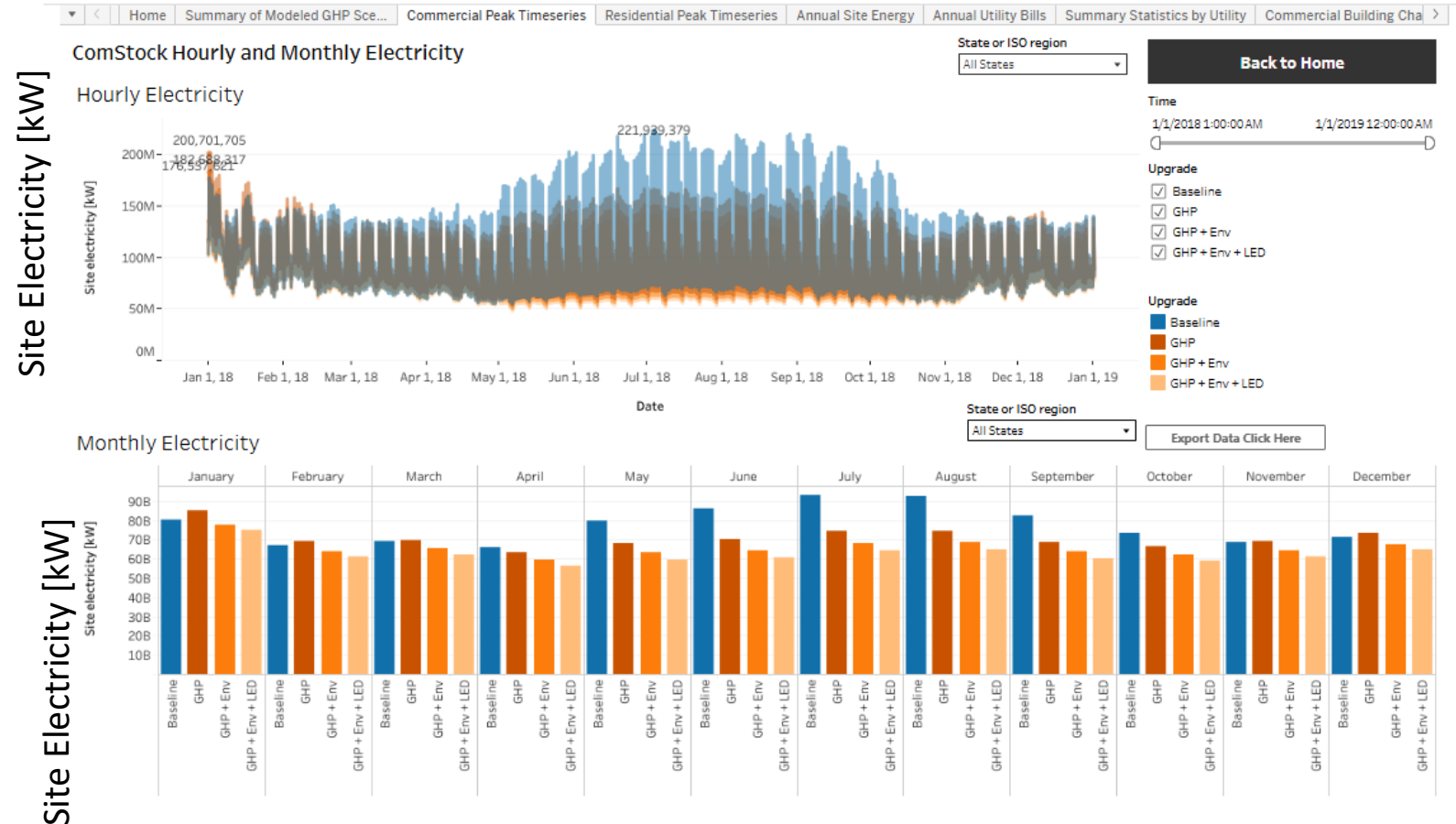
Datasets for geothermal heat pumps



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

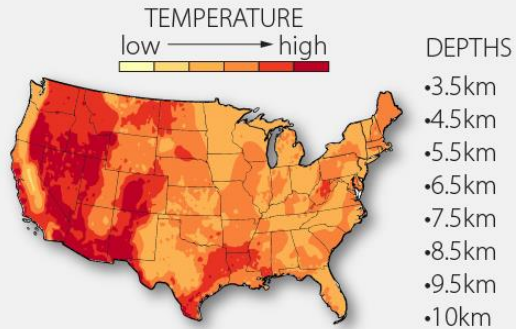
ComStock Tableau Site

Evaluating Geothermal Performance for the U.S. Building Stock by [NREL Commercial Building Stock Analysis](#)



Geospatial technical potential modeling w/ reV

1 GEOTHERMAL RESOURCE DATA



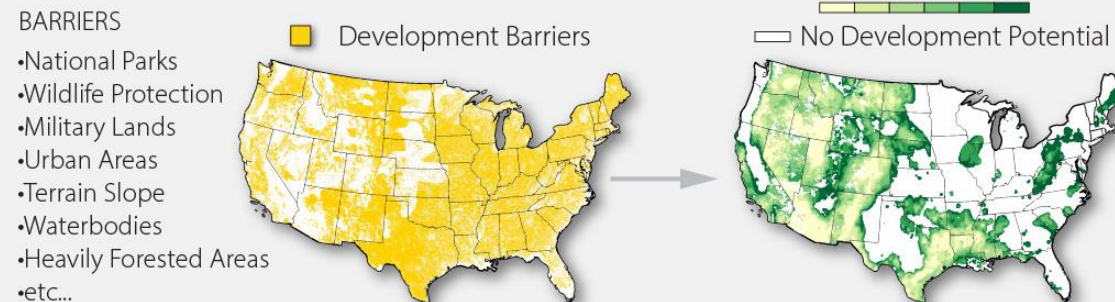
Sub-surface temperature data to a depth of 10km.

2 SYSTEM GENERATION MODELING



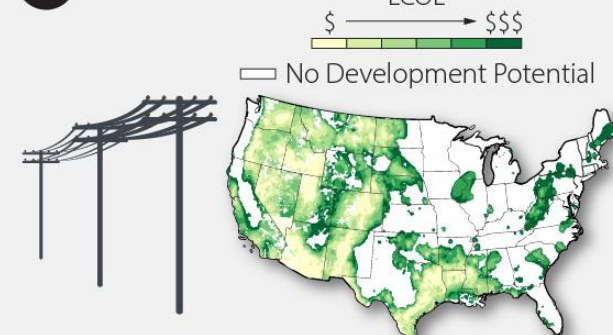
SAM integration and user-defined systems specs model LCOE and generation.

3 SITING BARRIERS



Barriers reduce or eliminate development potential, impacting LCOE locations.

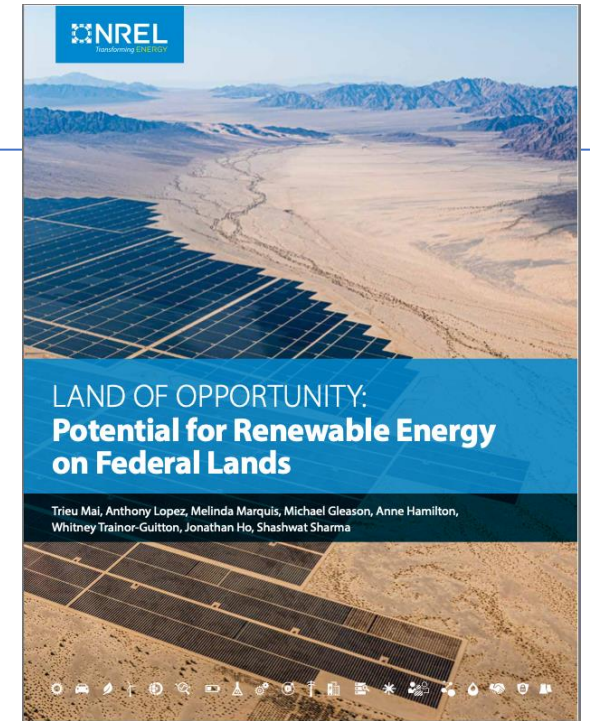
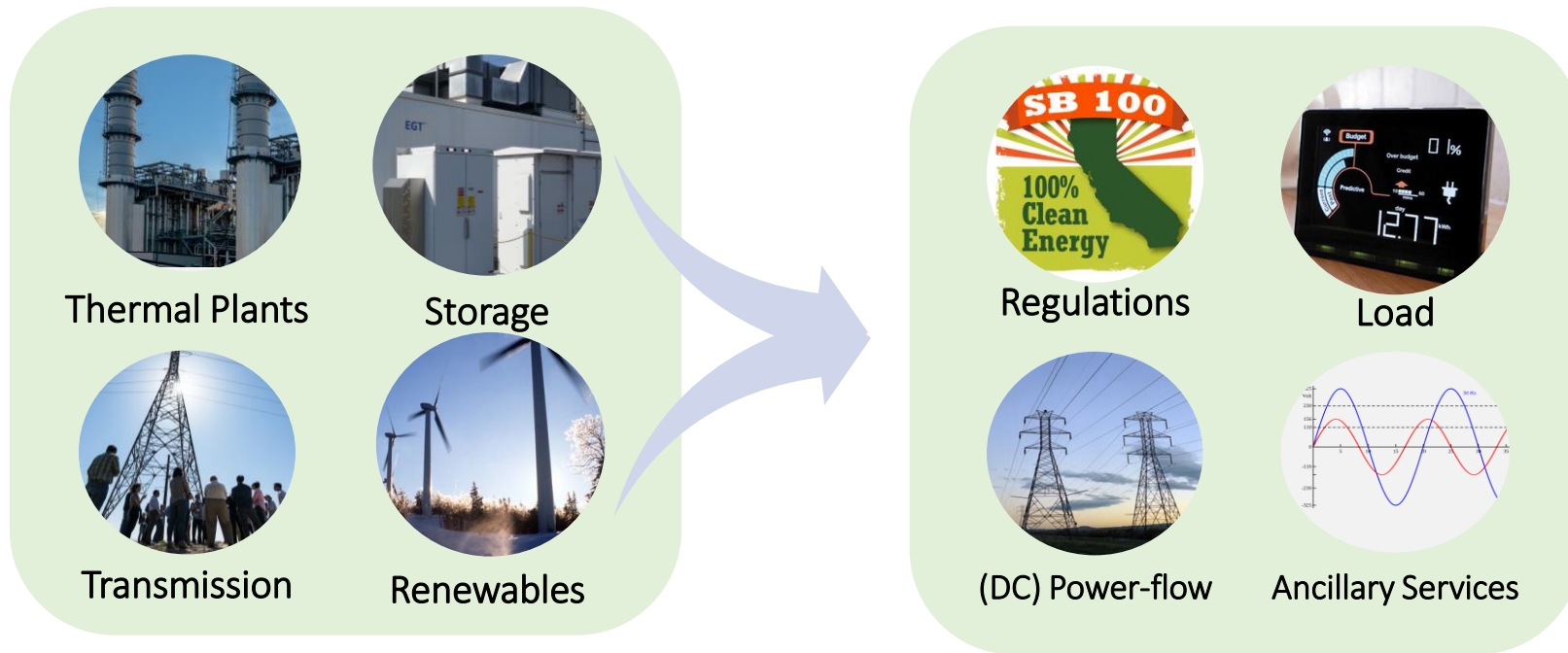
4 "All-in" LCOE



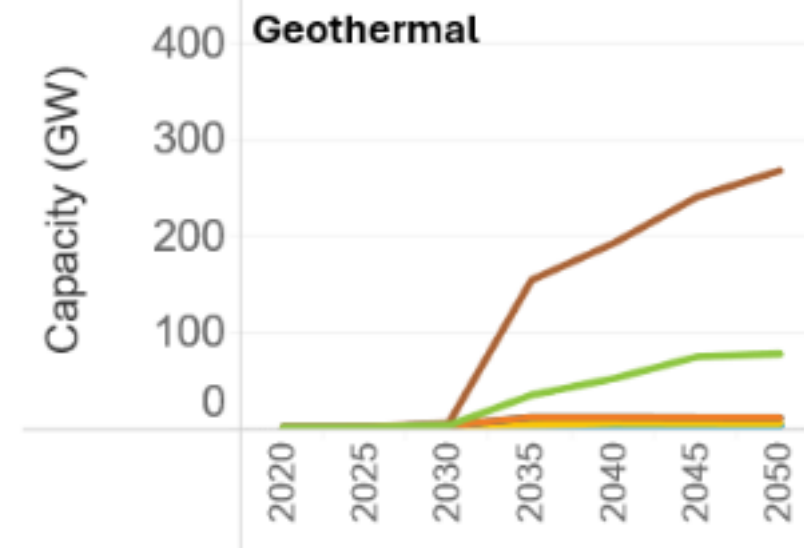
LCOE is supplemented with transmission costs.

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.

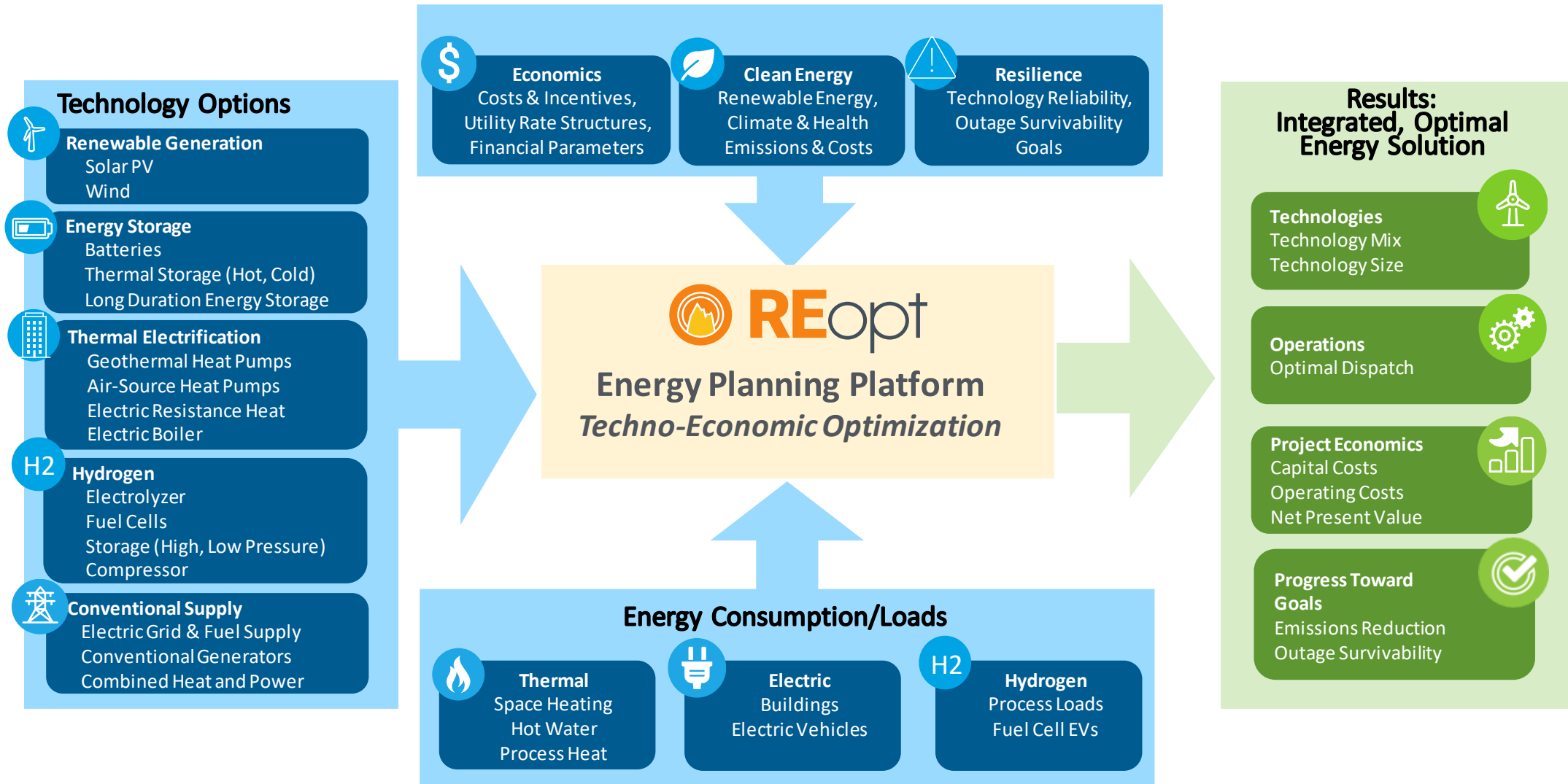


Mai et al., 2025

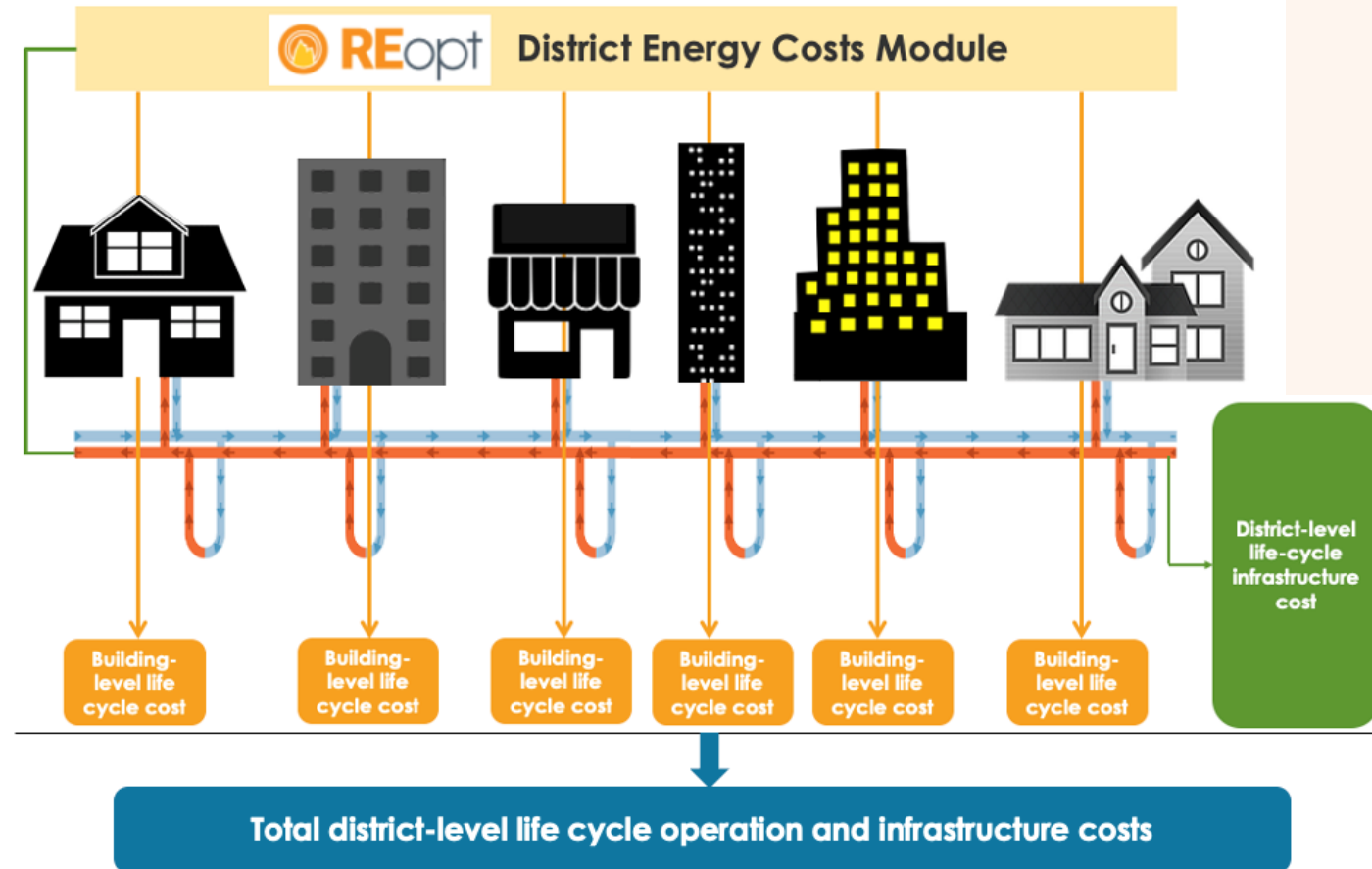


REopt Energy Planning Platform

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

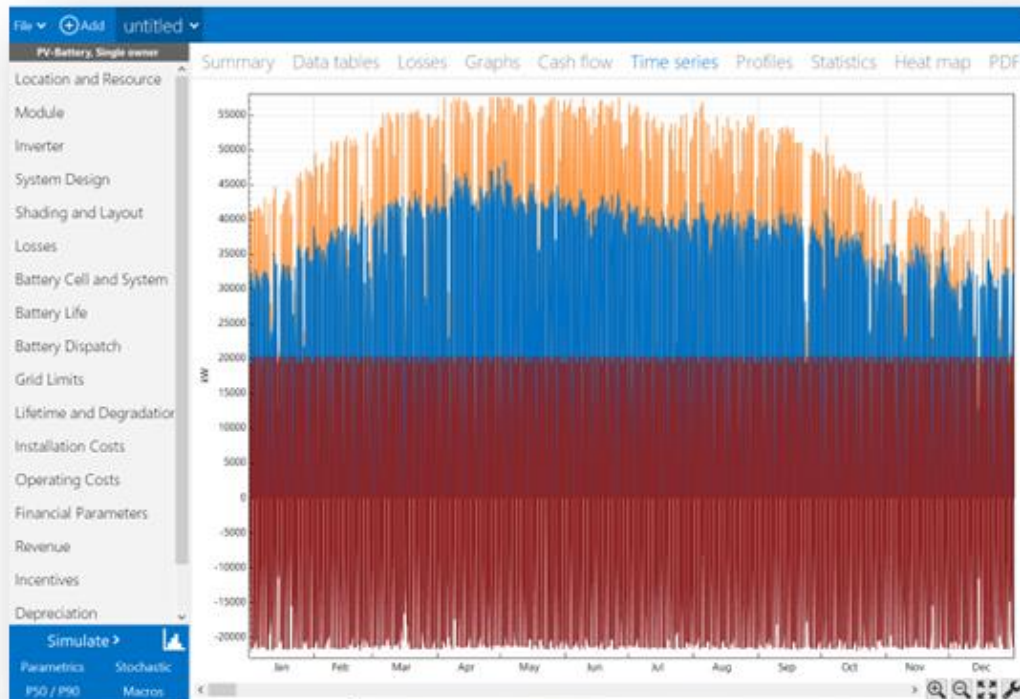
Maximum GHX size (number of boreholes) ? Unlimited

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

LEVELIZED COST OF ELECTRICITY
NET POWER SALES

Revised Scenario
91.18
15,600

GETEM Default
567.14
25,000

Errors/Warnings
3

The cells with the yellow background are input cells. Some have dropdown lists – select from that list, or leave blank to use the default value. The units have dropdown lists as well. If units are changed, the default values should change to be displayed in the units selected.

Do you wish to evaluate a Hydrothermal or EGS resource? **EGS**

What is the resource temperature? **145 C**

What is the resource depth? **1823.0 meter**

At the indicate temperature, GETEM defaults to the indicated conversion system – you may change below

Type of Conversion System to be Used **Binary**

if GETEM defaults to Binary, or if a Binary conversion system is selected – run the optimize macro for default scenario by clicking on button to the right. This must be done to obtain a LCDE estimate.

DONE - Resource Definition

GETEM

Exploration \$61,012,249 overnight costs

Drilling \$152,665,857 overnight costs

Field Gathering System & Pumping \$24,072,275 overnight costs

Reservoir Performance 15.77 production wells required

Operating & Maintenance \$15,328,117 per year

Power Plant \$306,627,449 overnight costs

Summary of Changes Made for Revised Scenario

	# changes to default
Power Sales	0
Economic Parameters	2
Permitting	0
Exploration	2
Drilling	2
Field Gathering System	0
Reservoir Performance	1
O&M	0
Power Plant	0



SAM 2025.4.16: C:\Users\dakindip\Documents\PI-Projects\GETEM\EGS Binary File.sam

File Add untitled Help

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

Resource Characterization

Hydrothermal

Enhanced Geothermal System (EGS)

Total Resource Potential 2100 MW

Resource Temperature 175 °C

Resource Depth 1500 m

View the NREL Geothermal Prospector online

Reservoir Parameters

Enter change in pressure across the reservoir in units of psi-h per 1000 lb

Calculate reservoir pressure change using simple fracture flow (EGS only)

Calculate reservoir pressure change using permeability * area

User-entered reservoir model

Entered pressure change input

Productivity index 1365.000 lb/hr-psi

Injectivity index 1,650.000 lb/hr-psi

Permeability inputs

Width 500 m

Fracture Spacing 50 m

Distance From Inject 1000 m

0.0004 m

6

175 m

15 deg from horizontal

Rock Thermal Conductivity 3.000 W/m-K

Subsurface Water Loss 5 % of water injected

EGS Fracture model inputs

Calculated Design

Pressure Change Across Reservoir 348.863 psi 24.053 bar

Average Reservoir Temperature 347.000 °F 175.000 °C

Production Well Bottom Hole Pressure 1878.891 psi 129.545 bar

Messages: No message

Default Type Greenfield-Reference-EGS-Binary

Simulate >

Parameters Stochastic

P50 / P90 Macros

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

Conversion Plant Type

Plant efficiency set as percentage of max plant efficiency

☒ Binary

Plant Efficiency 80.6 %

☐ Flash

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:

☐ Calculate temp decline rate (EGS only)

0.5 %/yr

☐ 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

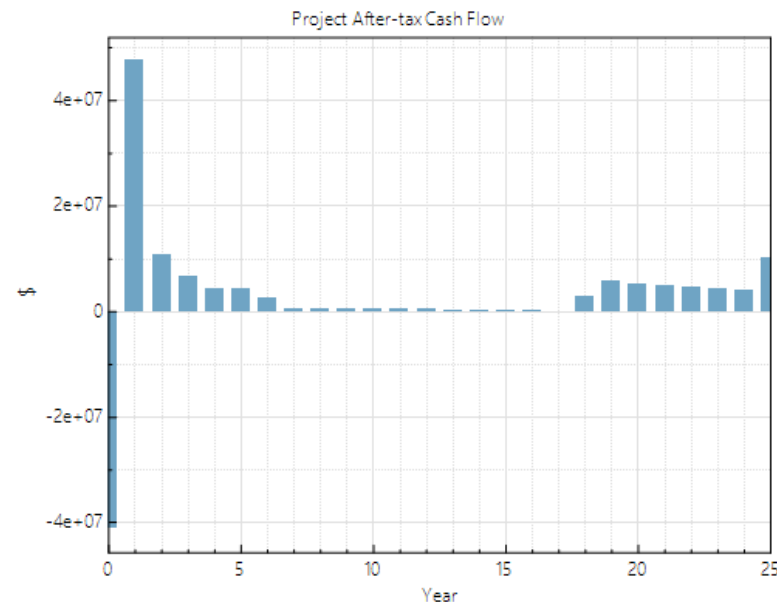
☐ Specify Pump Work

Specified Pump Work 0 MW

SAM Financial Outputs

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

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%



Copy to clipboard	Save as CSV	Send to Excel	Send to Excel with Equations						
	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 (\$)	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 (\$)	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 (\$)	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	

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

Time-of-delivery (TOD) Factors

☒ TOD factors by schedule
☐ TOD factors by time step

TOD factors are multipliers that apply to the PPA price. Choose "TOD factors by schedule" to define factors using the TOD periods with weekday and weekend hour-by-month matrices. Choose "TOD factors by time step" to assign a factor to each simulation time step. See Help for details.

Filter:

Name	Weekday Schedule
Uniform Dispatch	[1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1][1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1][1;1;1;1;1;1;1;1;1;1;1;1;1;1;1;1]
Generic Summer Peak	[6;6;6;6;6;6;5;5;4;4;4;4;4;4;4;4;5;5][6;6;6;6;6;6;5;5;4;4;4;4;4;4;4;4;5;5][6;6;6;6;6;6;5;5;4;4;4;4;4;4;4;4;5;5]
Generic Duck Curve	[1;1;1;1;1;1;1;1;3;3;3;3;3;3;2;2;2;2;1;1][1;1;1;1;1;1;1;1;3;3;3;3;3;3;2;2;2;2;1;1][1;1;1;1;1;1;1;1;3;3;3;3;3;3;2;2;2;2;1;1]

The TOD data in the library is from documents prepared by California electric utility companies. For projects outside of California, enter your own TOD data. Be sure that your assumptions are consistent with the requirements described in the appropriate solicitation documents for your project.

Apply values from library



Thank you!

www.nrel.gov

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