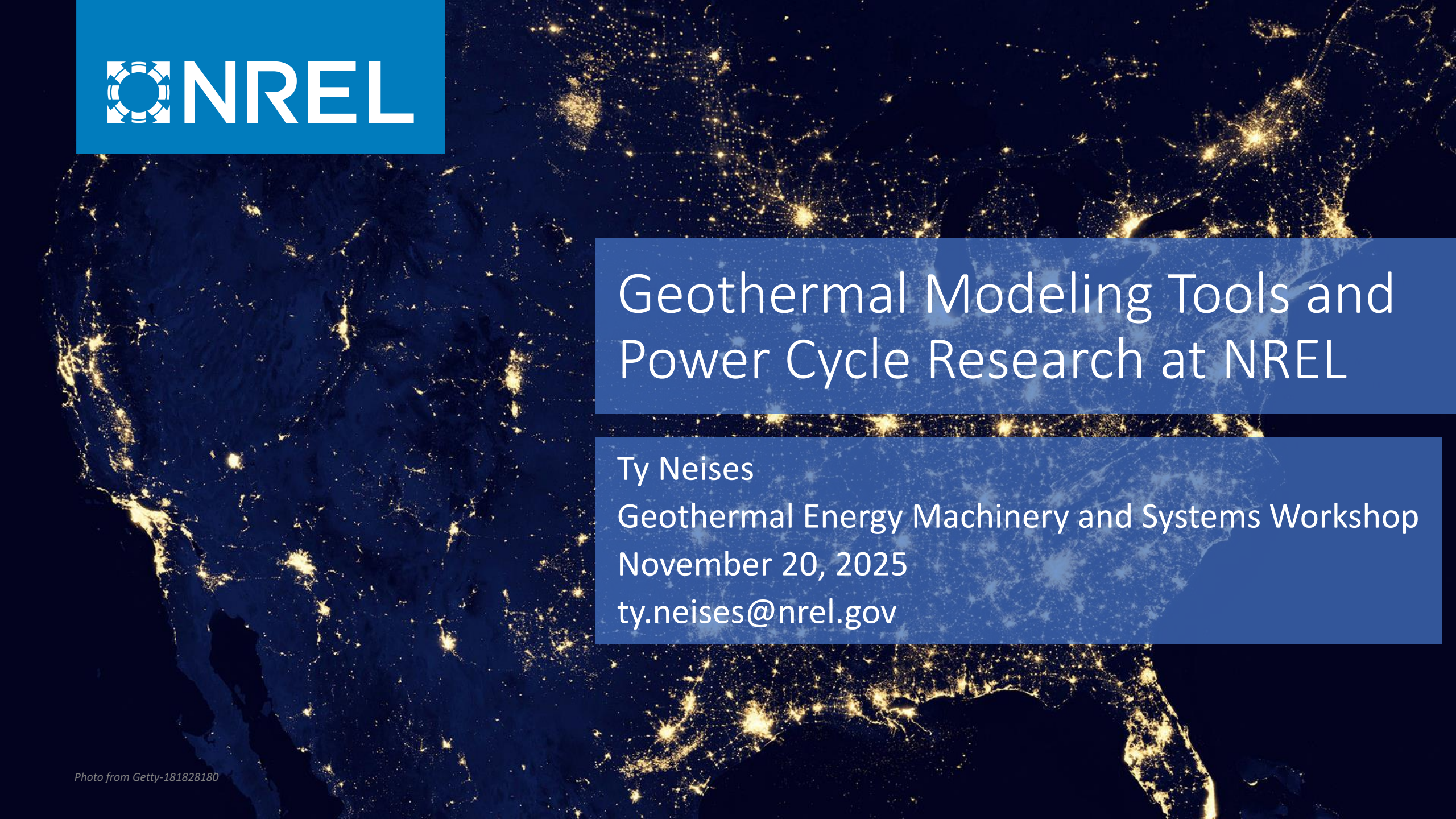


Geothermal Modeling Tools and Power Cycle Research at NREL

Ty Neises

Geothermal Energy Machinery and Systems Workshop

November 20, 2025

ty.neises@nrel.gov

Photo from Getty-181828180

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

ARIES by NREL

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)

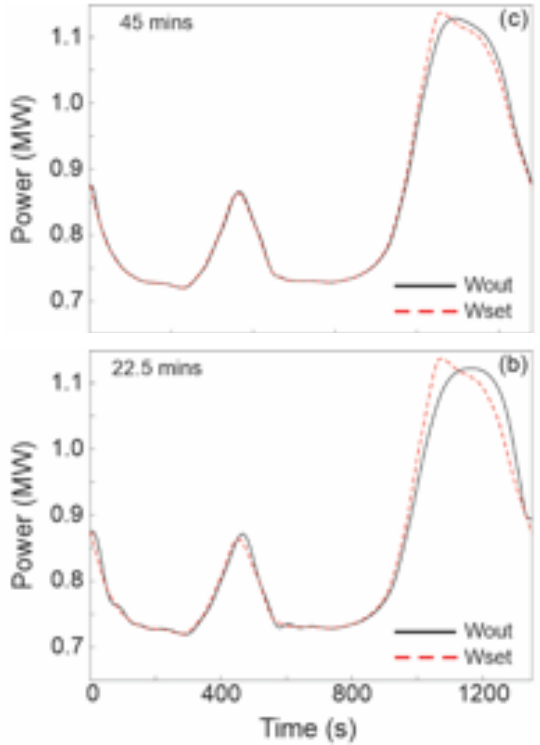
- Sophisticated digital platform
- Emulate experiments for 1,000,000s of devices
- Any utility power
- Any voltage level
- Local to national scales

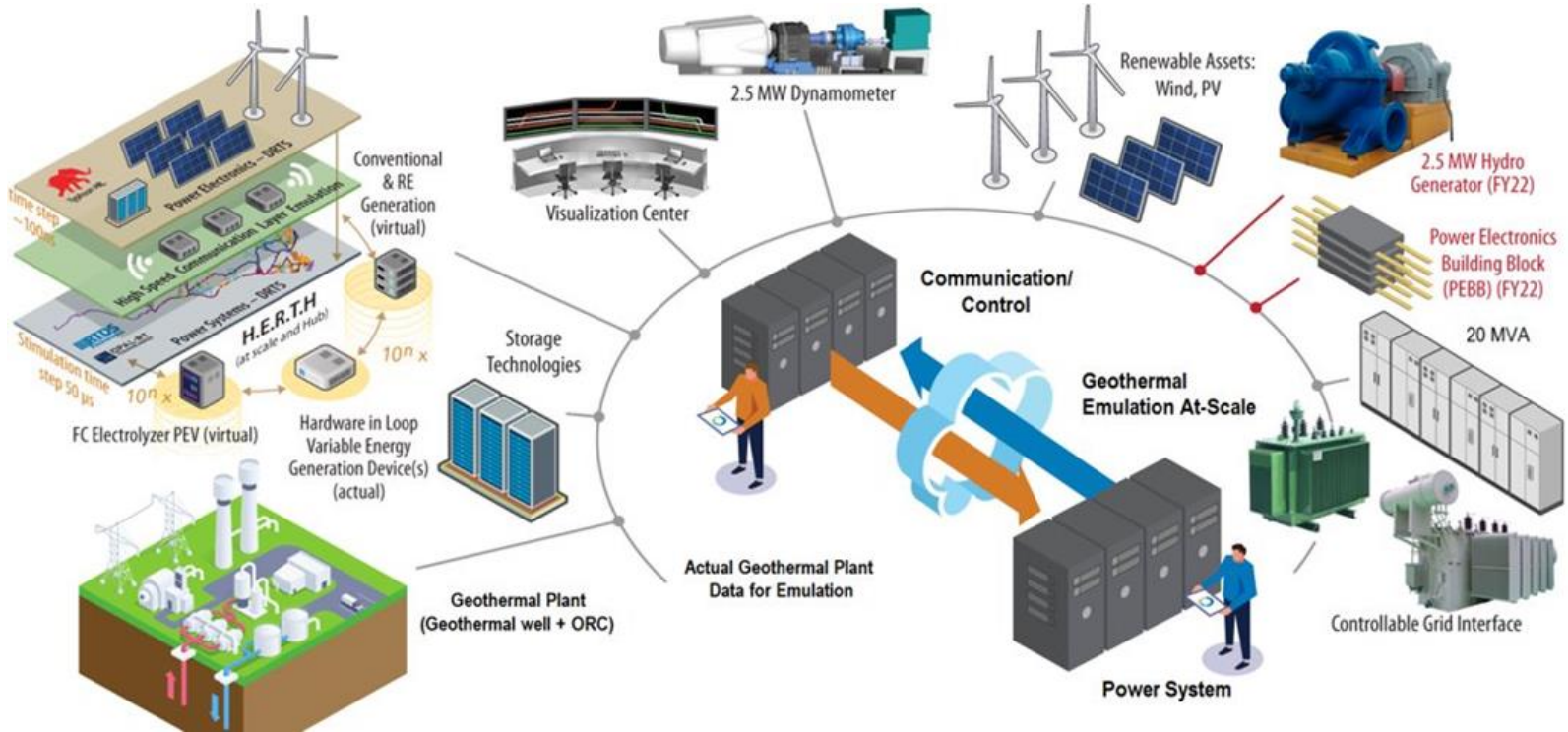
Virtual Emulation Environment

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

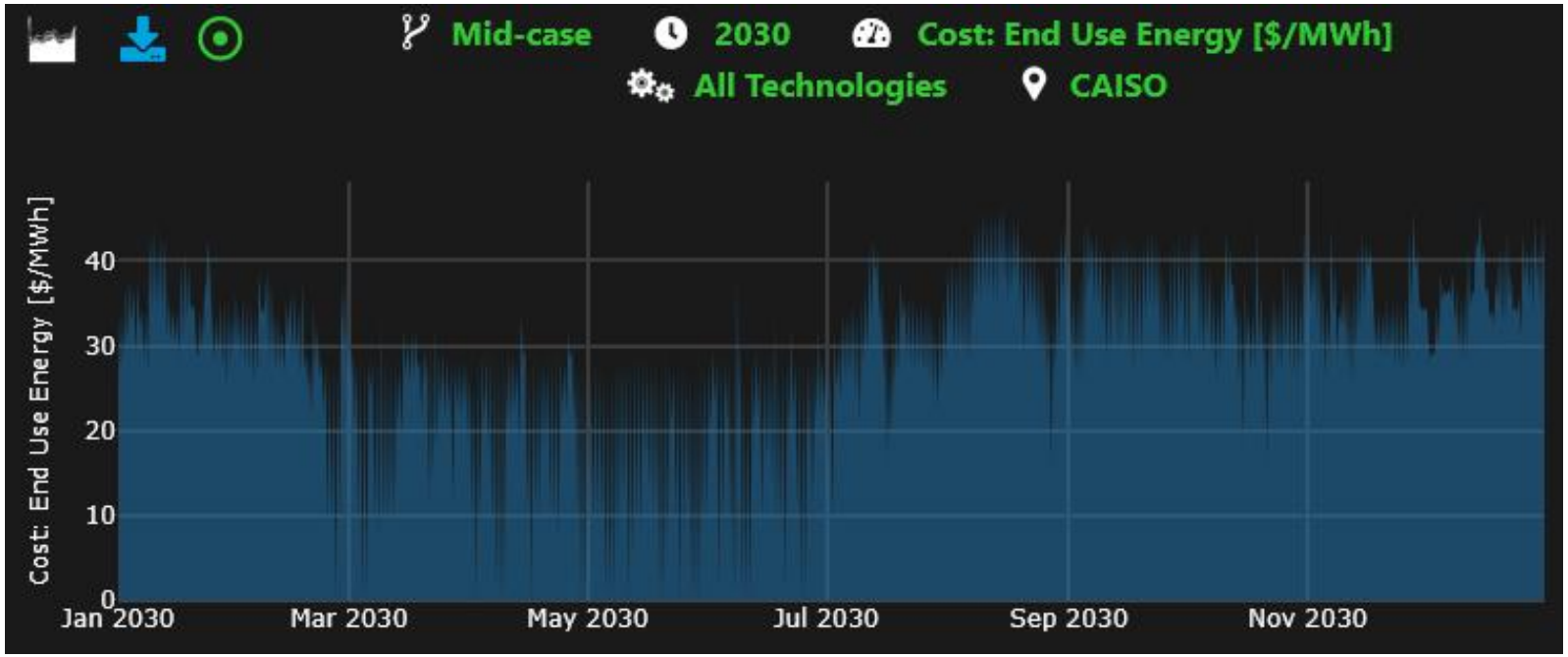




Datasets for electricity generation

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

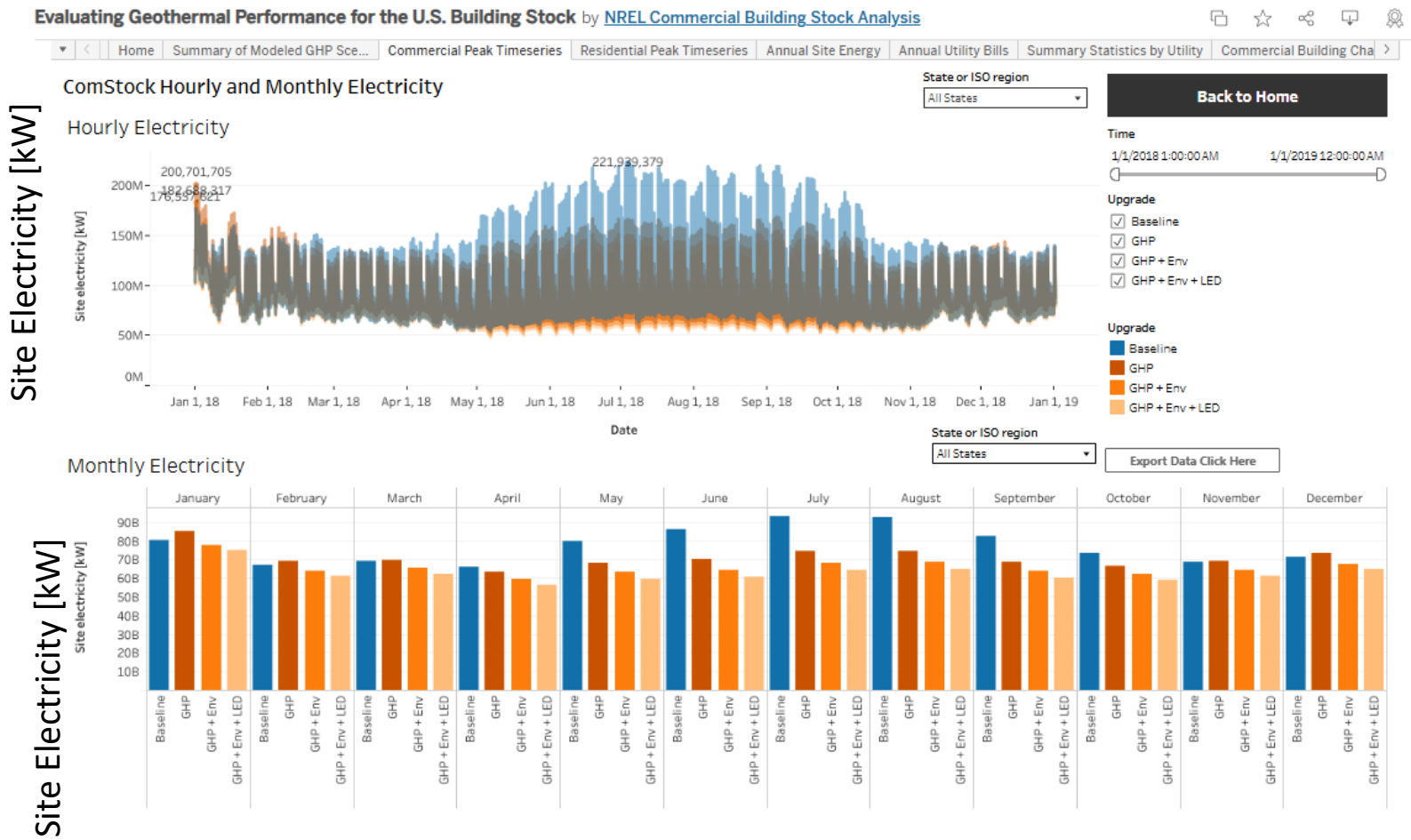
ComStock

ResStock

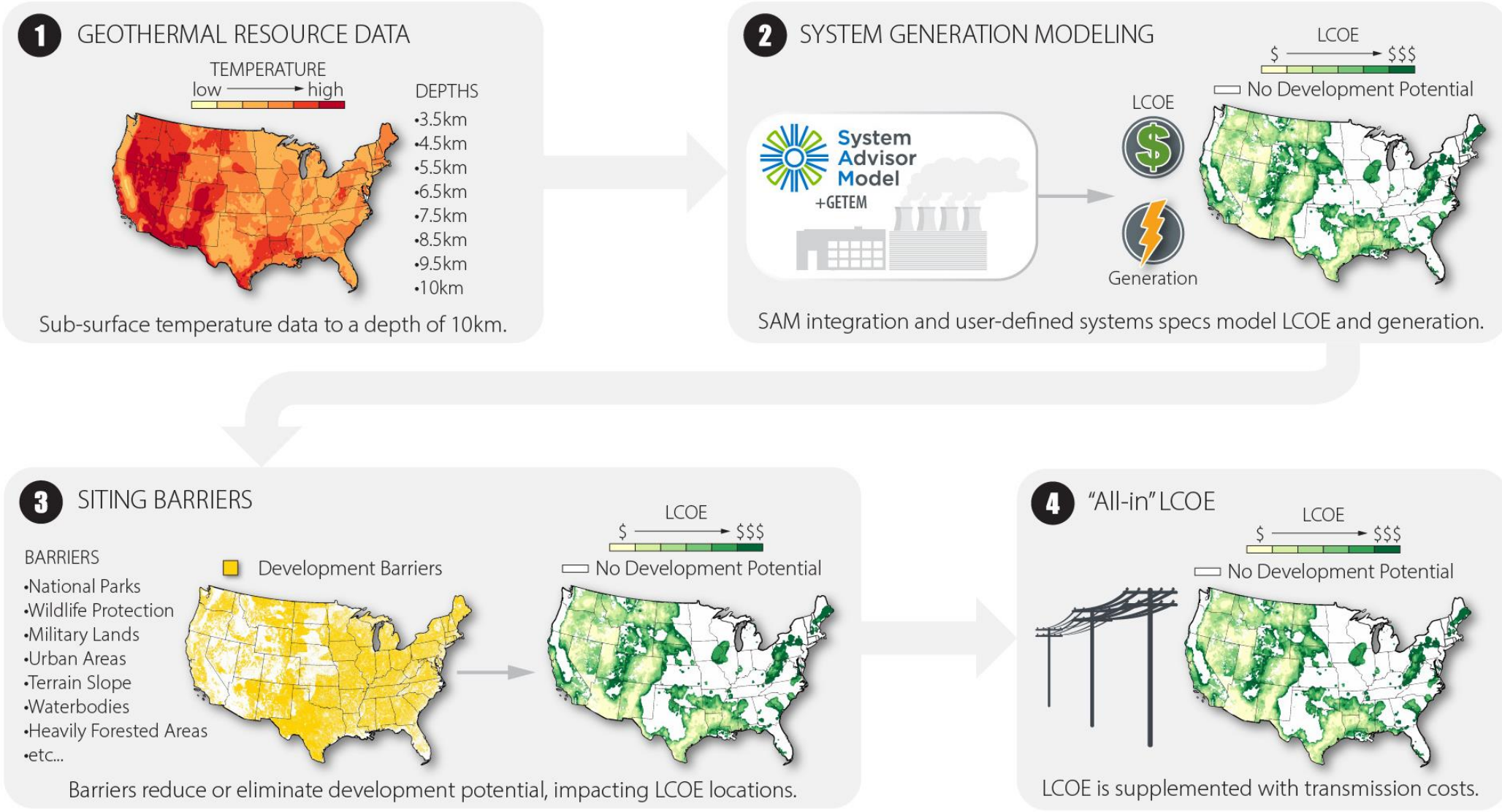
Building stock characteristics database + Physics-based computer modeling + High-performance computing

- 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

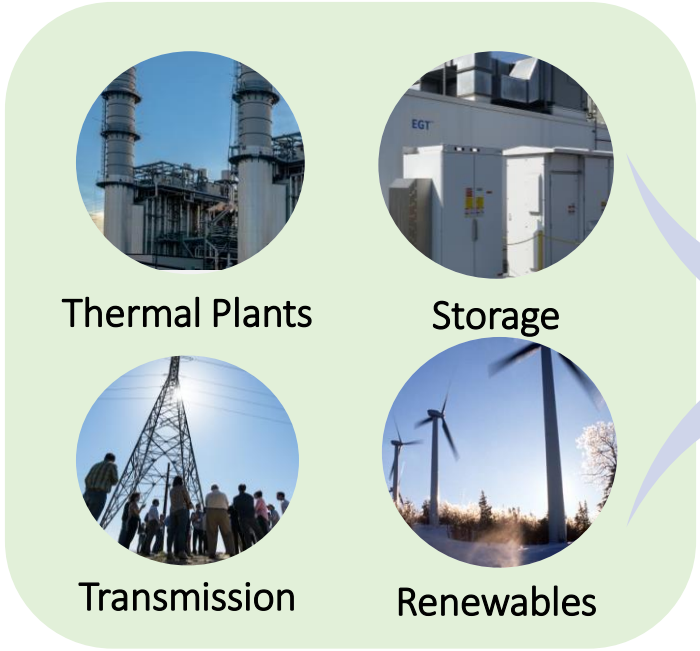


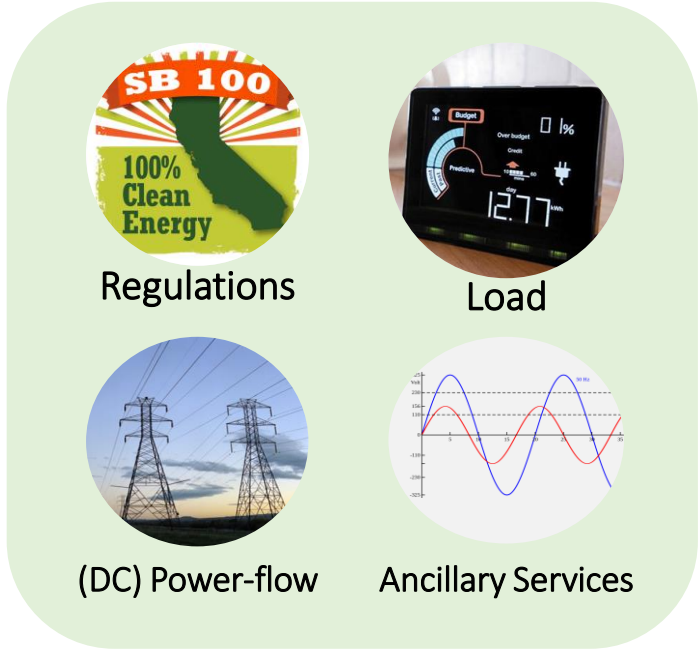
Geospatial technical potential modeling w/ reV

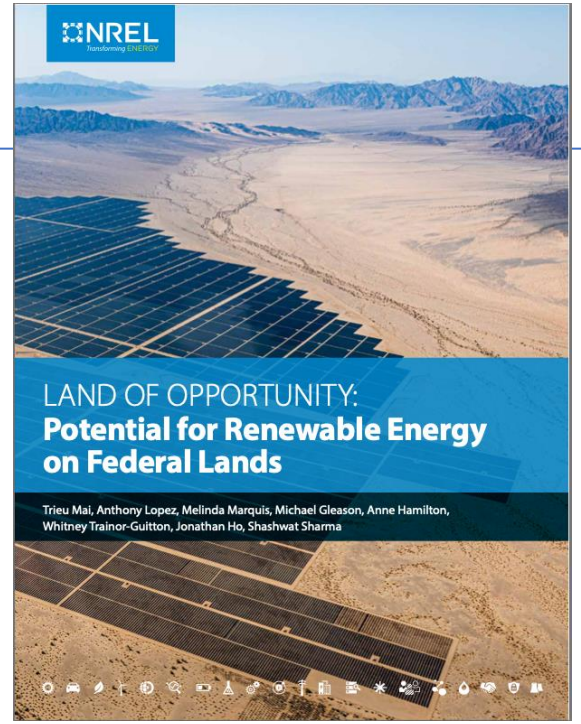


ReEDS: Regional Energy Deployment System (ReEDS) Model

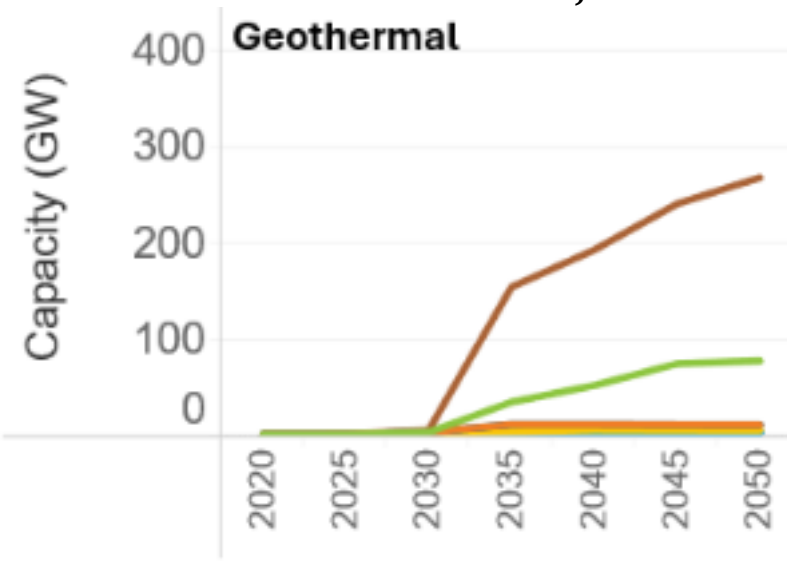
The ReEDS identifies the *least cost mix and operation* of resources that simultaneously meets load, all other electricity service requirements (planning reserves, operating reserves), and physical and environmental constraints.





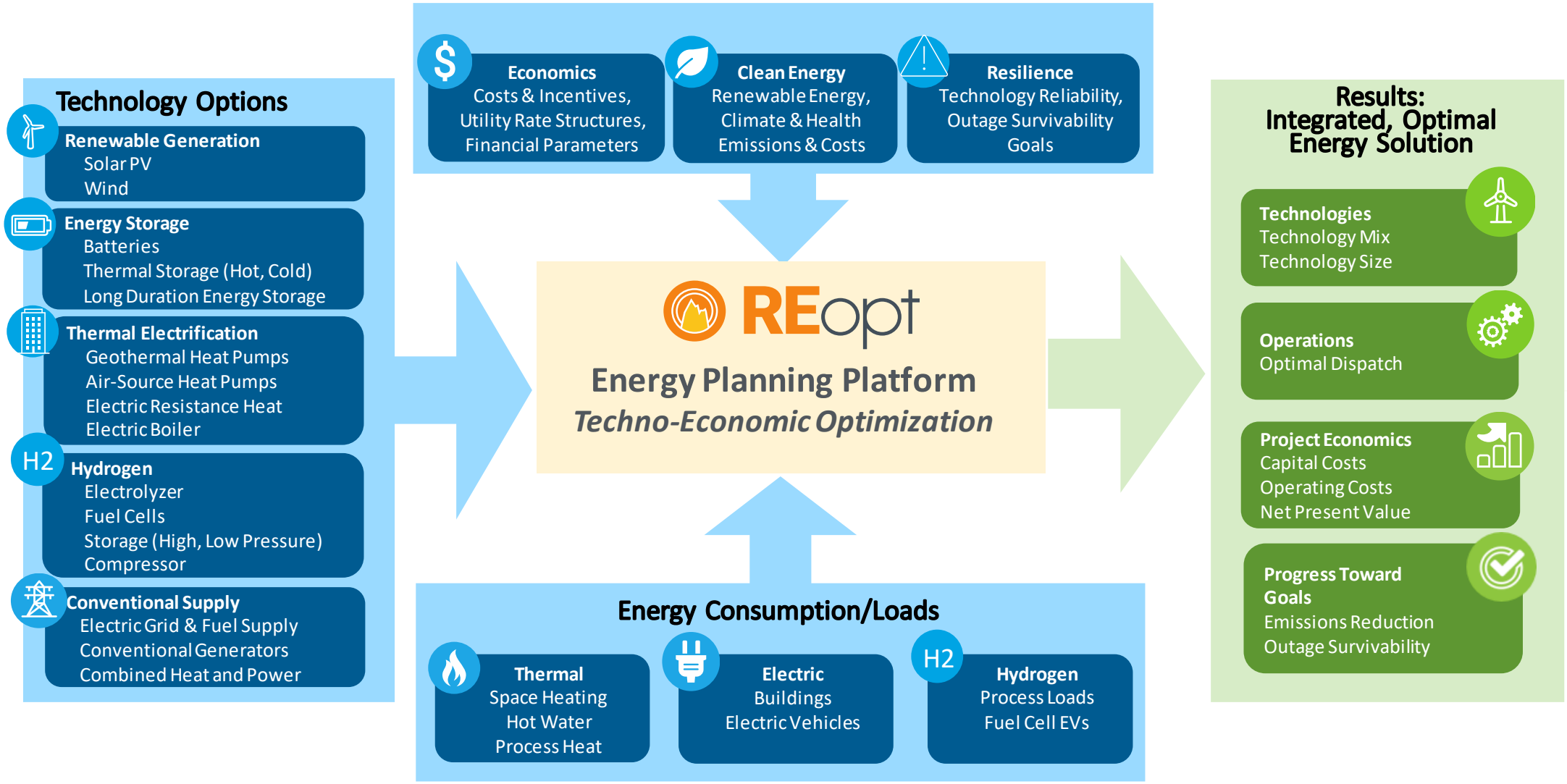


Mai et al., 2025

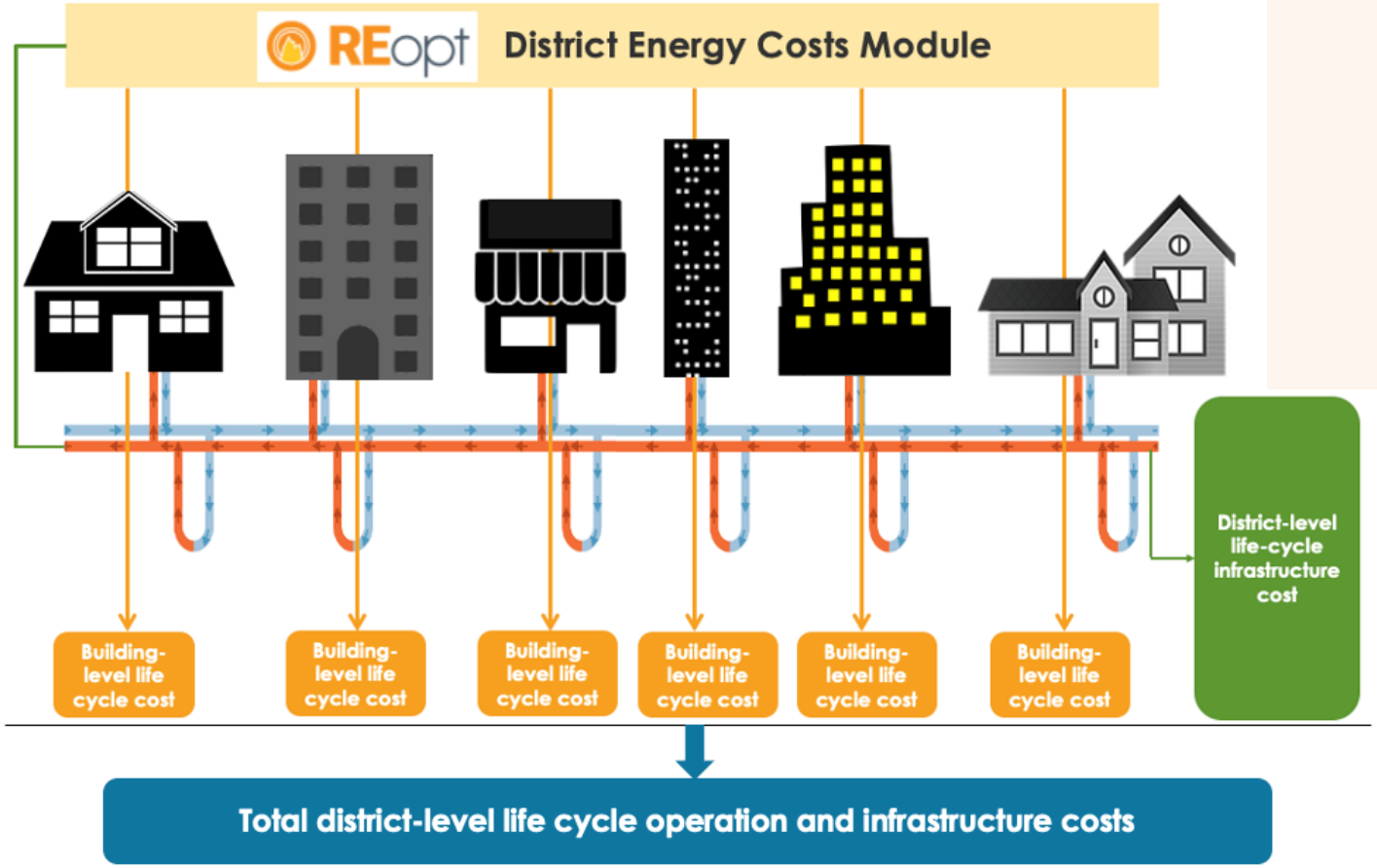


REopt Energy Planning Platform

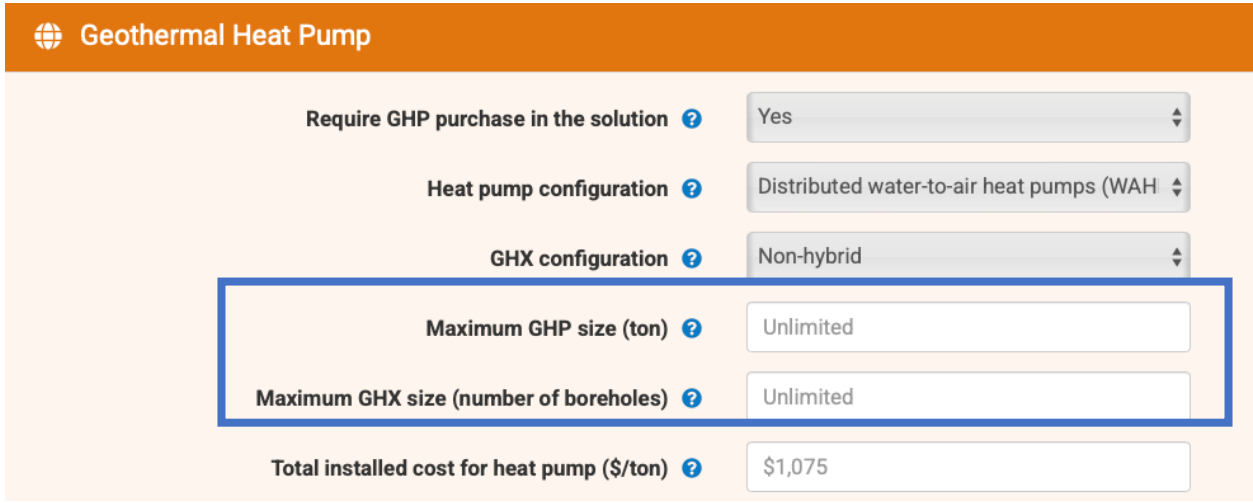
Formulated as a mixed integer linear program (MILP), REopt provides an integrated, cost-optimal energy solution.



REopt for GHP



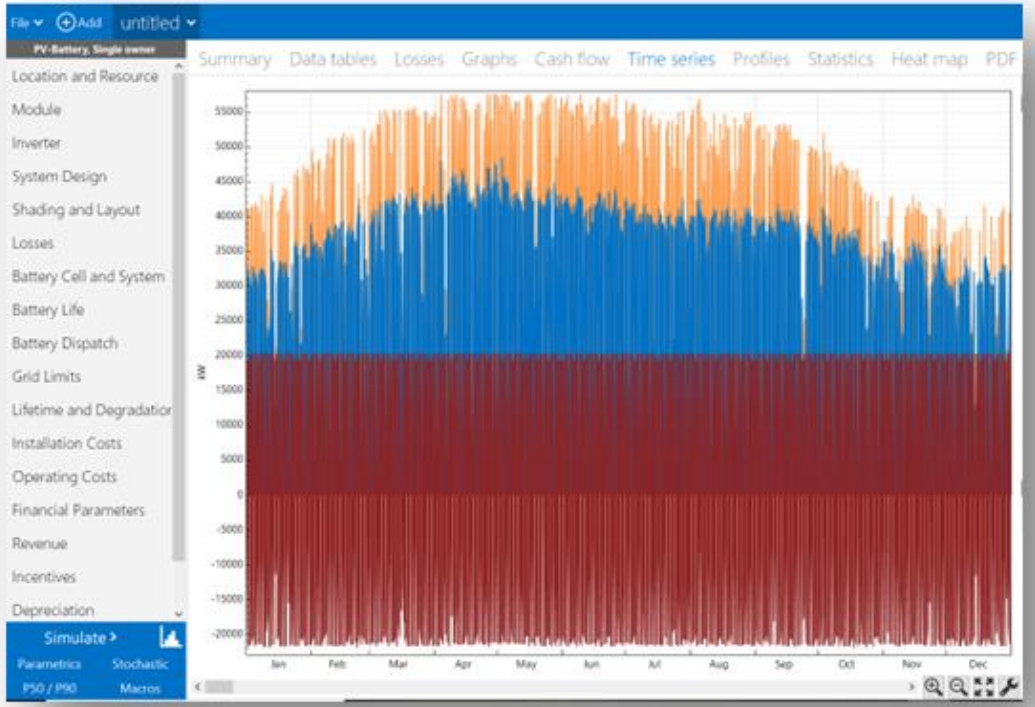
REopt: https://reopt.nrel.gov/tool

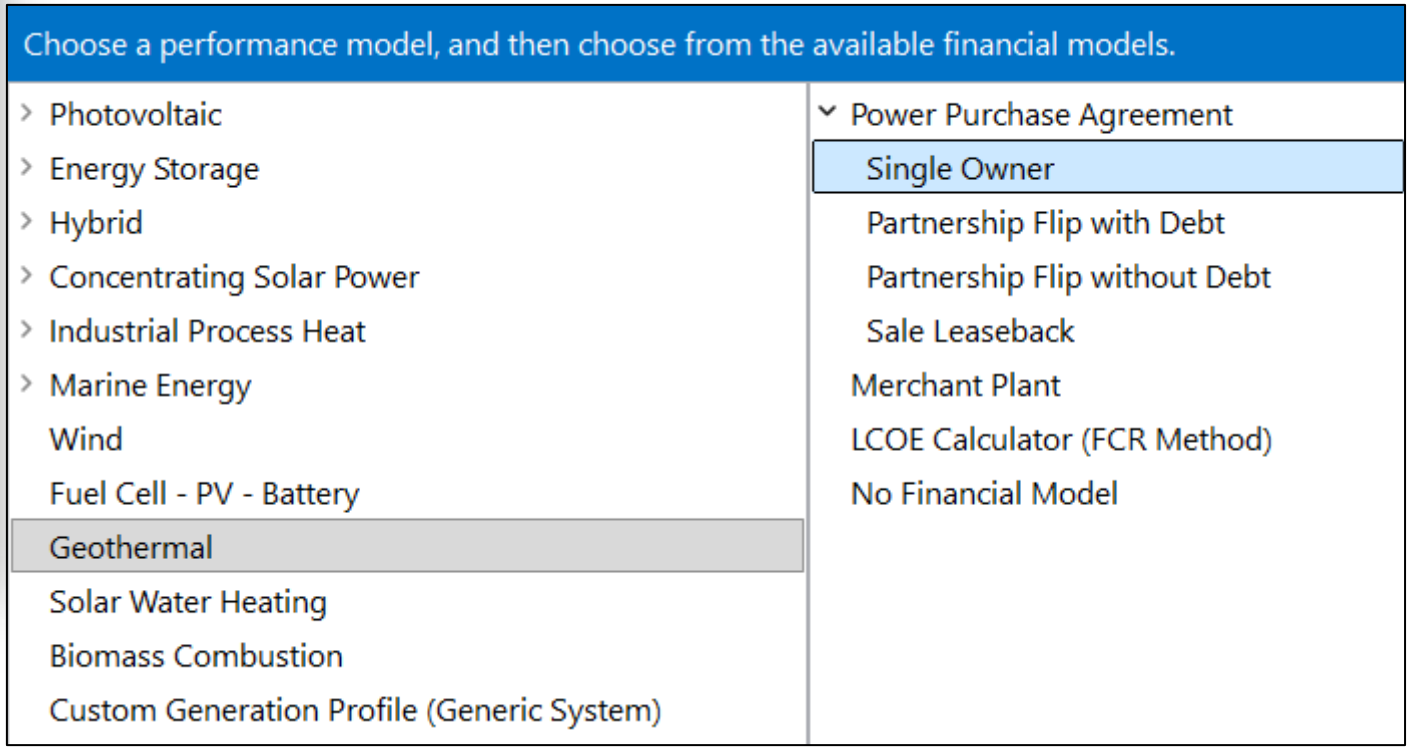


- Allows users to limit their GHP and GHE sizes
- Currently exploring GHP lifecycle costs for Alaska and Washington DC
- Geothermal power generation possible by importing a “fixed generator” profile. Pursuing projects to add more detailed geothermal power capabilities in 2026.

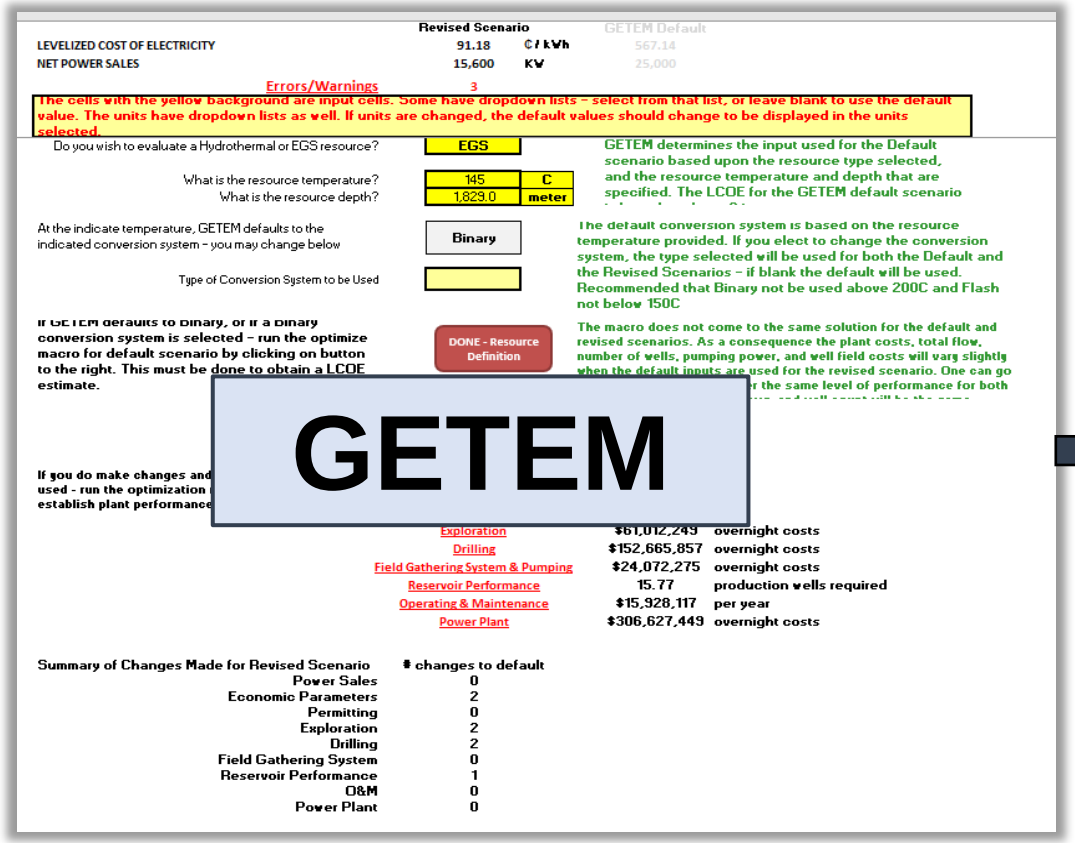
System Advisor Model (SAM)

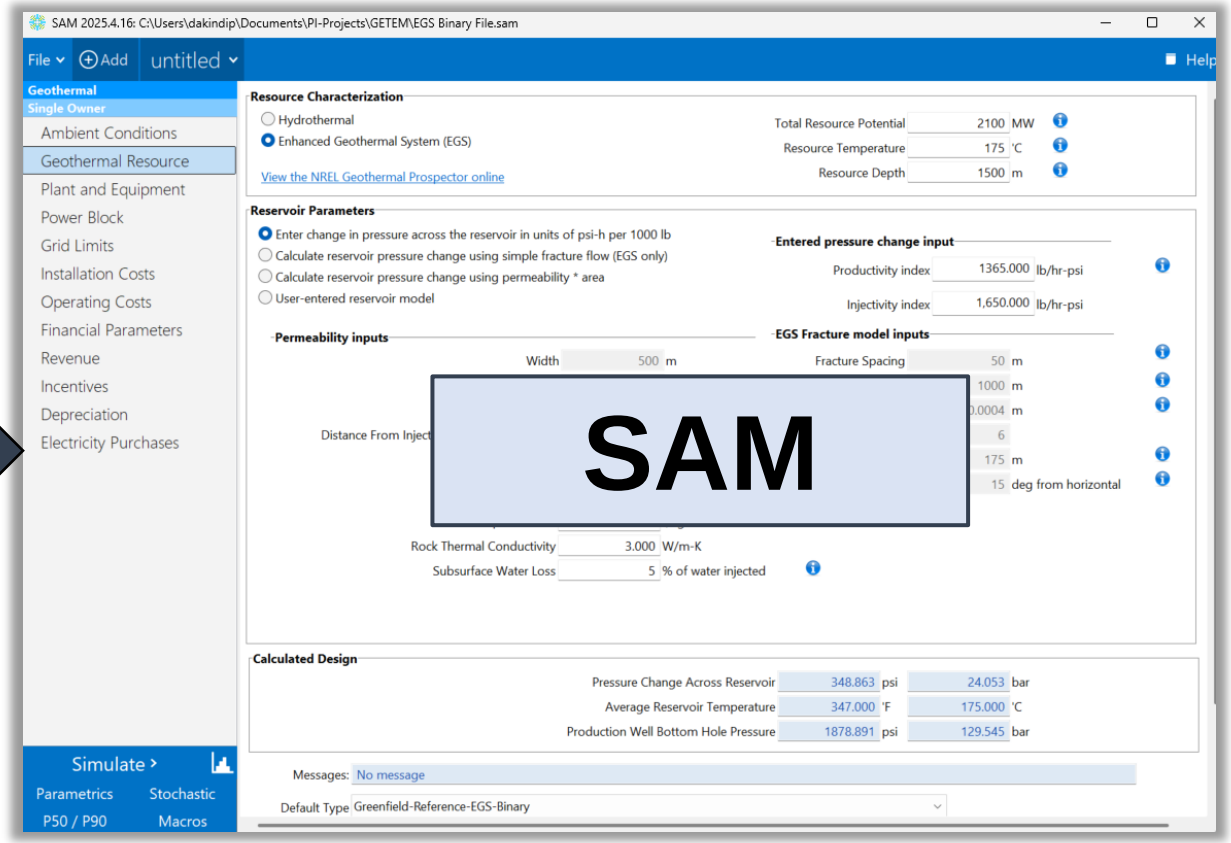
Free open-source software that enables detailed performance and financial analysis of energy systems





Geothermal in SAM

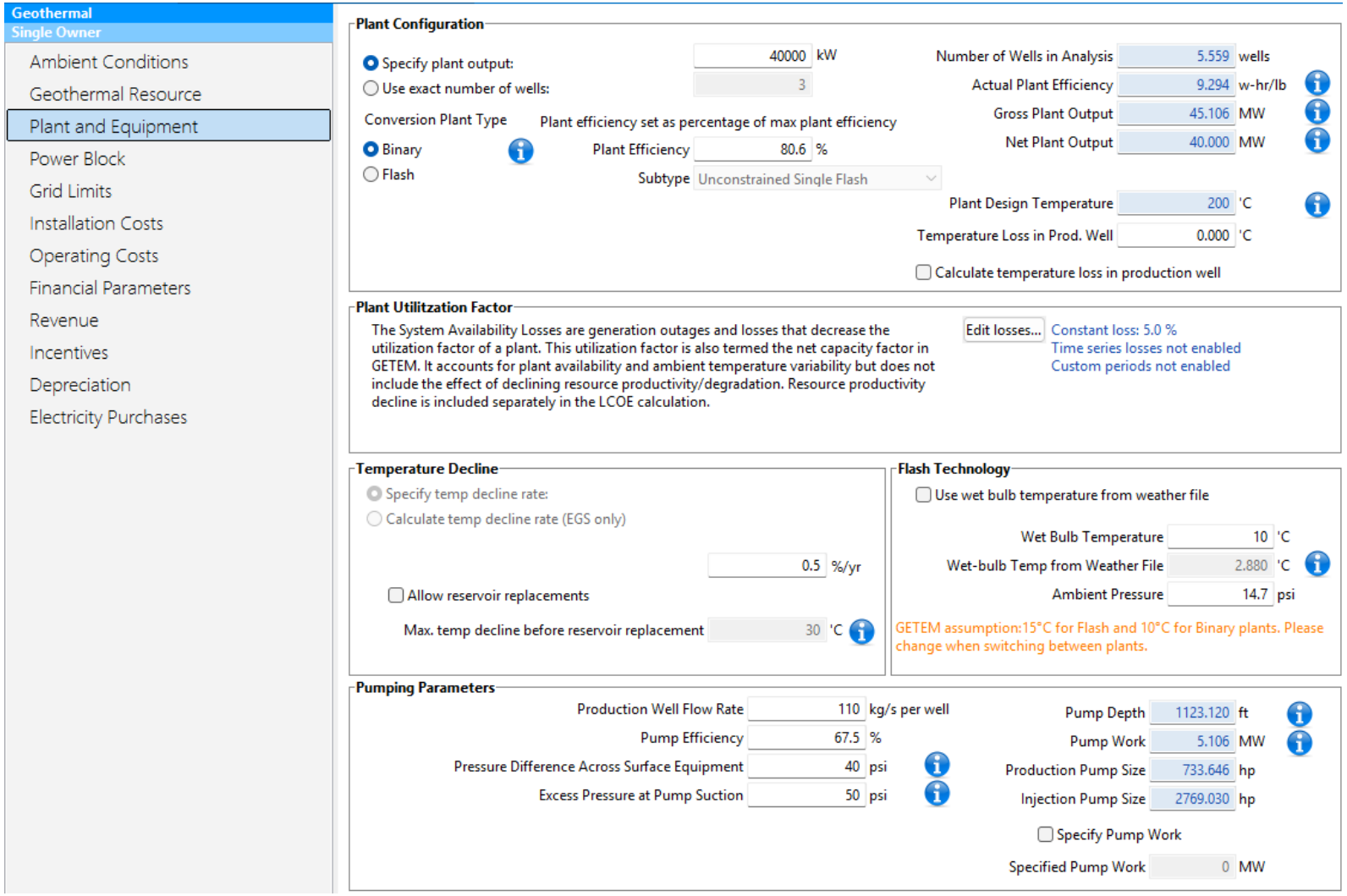




- GETEM developed by Greg Mines (INL) as an Excel model
- Conversion to SAM enables a graphical user interface, detailed financial models, comparison to other generation technologies, updates tracking (GitHub), and user inputs/feedback.

SAM User Inputs

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



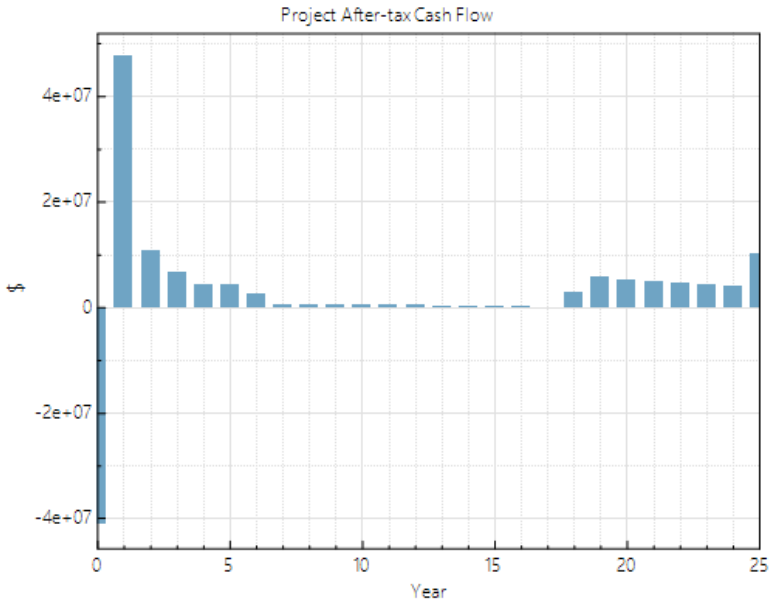
SAM Financial Outputs

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

Copy to clipboard | Save as CSV | Send to Excel | Send to Excel with Equations

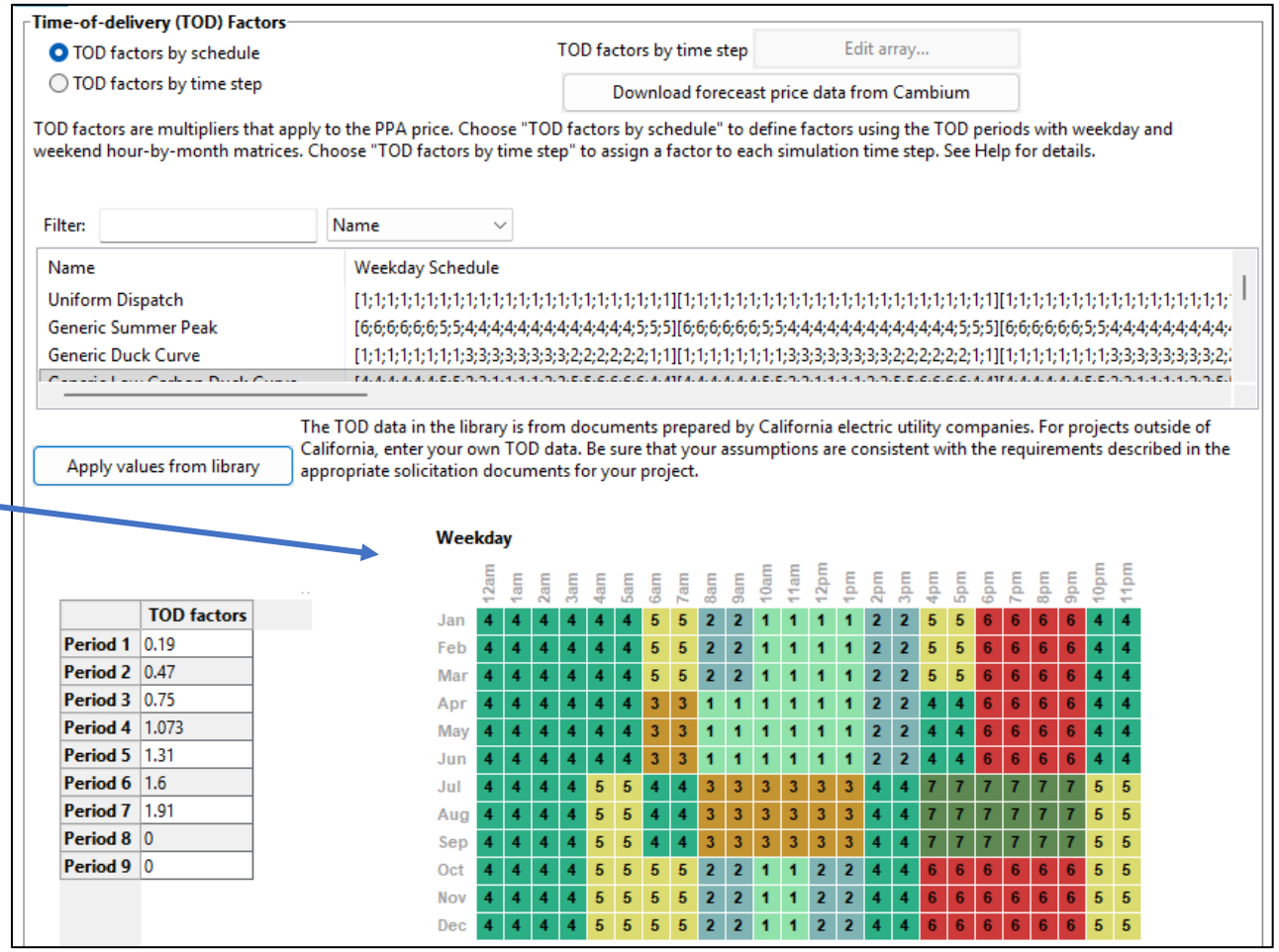
	0	1	2	3	4	5	6	7
Property tax net assessed value ($)	0	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312
OPERATING EXPENSES								
O&M fixed expense ($)	0	0	0	0	0	0	0	0
O&M production-based expense ($)	0	0	0	0	0	0	0	0
O&M capacity-based expense ($)	0	5,823,764	5,969,358	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

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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