NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U. S. Department of Energy
Office of Energy Efficiency and Renewable Energy
operated by the Alliance for Sustainable Energy, LLC.

Geothermal / Solar Hybrid System Modeling with Thermal Storage

Joshua McTigue,[1] Jose Castro,[2] Greg Mungas,[3] Nick Kramer,[3] John King,[3] Craig Turchi,[1] Guangdong Zhu[1]*

[1] National Renewable Energy Laboratory, Golden, Colorado [2] Coso Operating Company, California [3] Hyperlight Energy, California
* Corresponding author: Guangdong.Zhu@nrel.gov

Background

Geothermal power plants often experience declines in resource productivity over time.

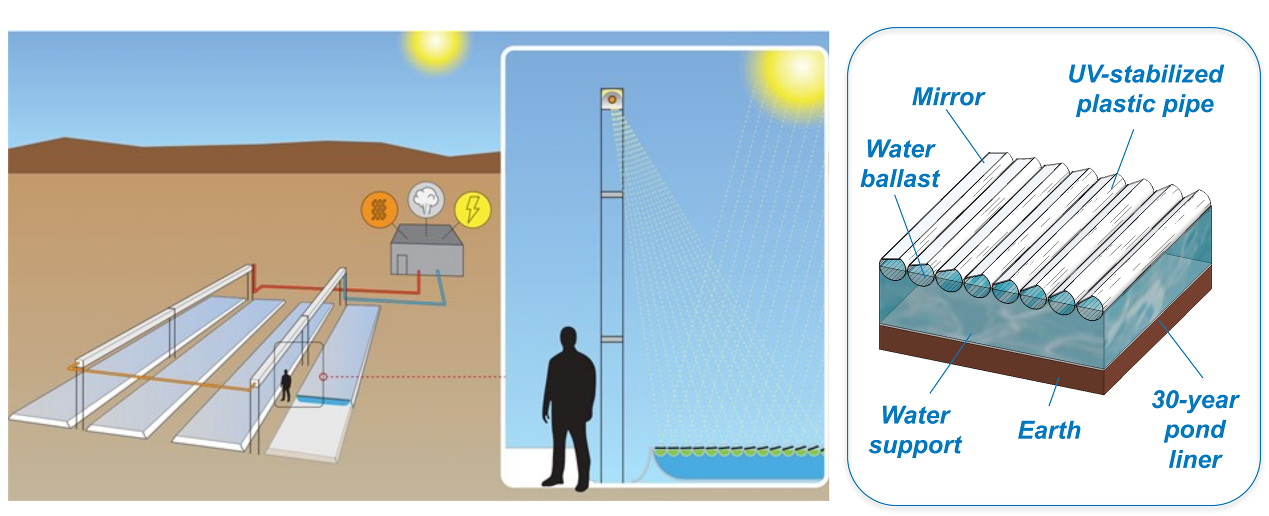
- Reasons include reservoir cooling, production fluid loss, and injection strategy (well location).
- Problem is twofold: Power plant energy drops, and as power output drops below design point, the plant's conversion efficiency decreases.

Coso Geothermal Plant

- 9 flash-steam turbines of 30 MWe, with a total capacity of 270 MWe
- Experiencing declining steam quantity from reproduction wells

Hyperlight Solar Collector

- Linear Fresnel technology developer
- Convert concentrated sunlight into thermal power



Motivation

For an underperforming geothermal plant, a solar thermal hybridization with thermal storage can add the following benefits:

- Increase power generation by adding more thermal power
- Boost geothermal power-cycle efficiency, resulting in a further power addition from underperforming geothermal resource
- Increase the dispatchability of a geothermal / solar hybrid plant and help overcome the duck curve issue
- Increase solar penetration into the market at a smaller scale
- Allow solar collector developers to further lower the collector cost through more commercial deployments

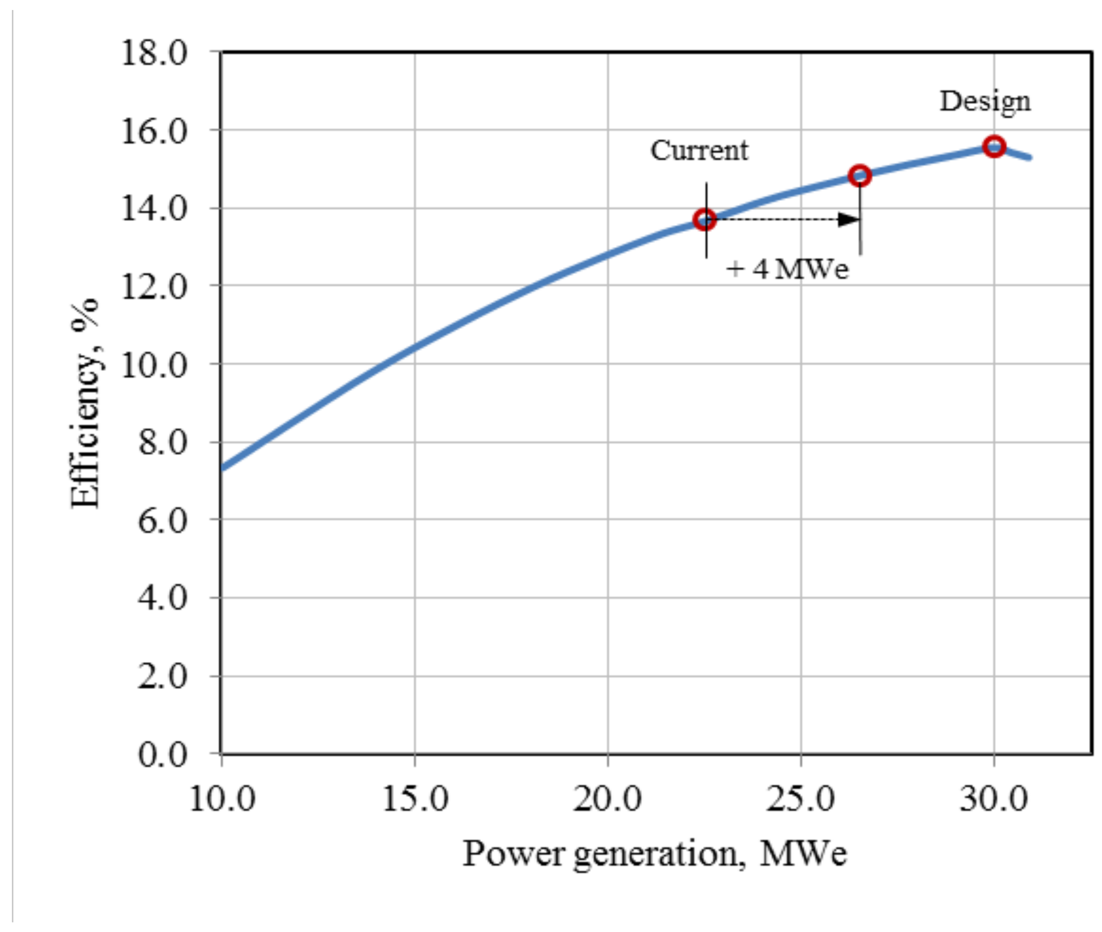
Objective

- Identify the most cost-effective thermal storage systems for geothermal / solar hybrid system to increase the plant dispatchability.
- Determine whether and/or how much thermal storage will improve the power generation, dispatchability, and economics of a geothermal / solar hybrid plant.

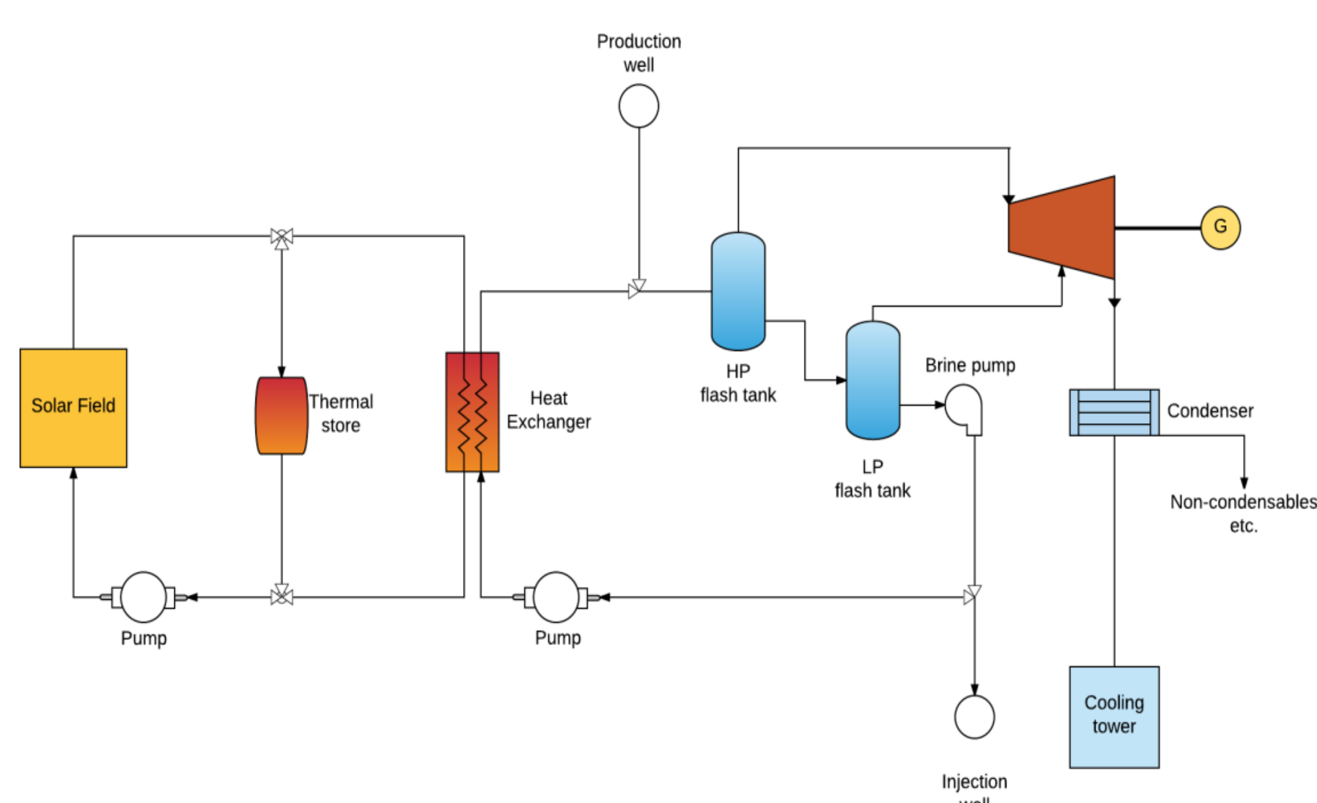
Approach

➢ Understand existing plant performance

		Design conditions		Current operating conditions	
		High pressure	*Low pressure*	*High pressure*	*Low pressure*
Mass flow	kg s^{-1}	48.0	25.0	48.0	14.3
Temperature	°C	169.2	132.5	163.4	126.1
Inlet pressure	bar	6.3	1.4	5.7	0.9
Gross power	MW_e	30.0		22.5	
Net power	MW_e	29.2		21.7	
Condenser load	MW_{th}	161.2		164.6	
Efficiency	%	15.6		13.7	



➢ Thermodynamic analysis of hybrid system using IPSEpro

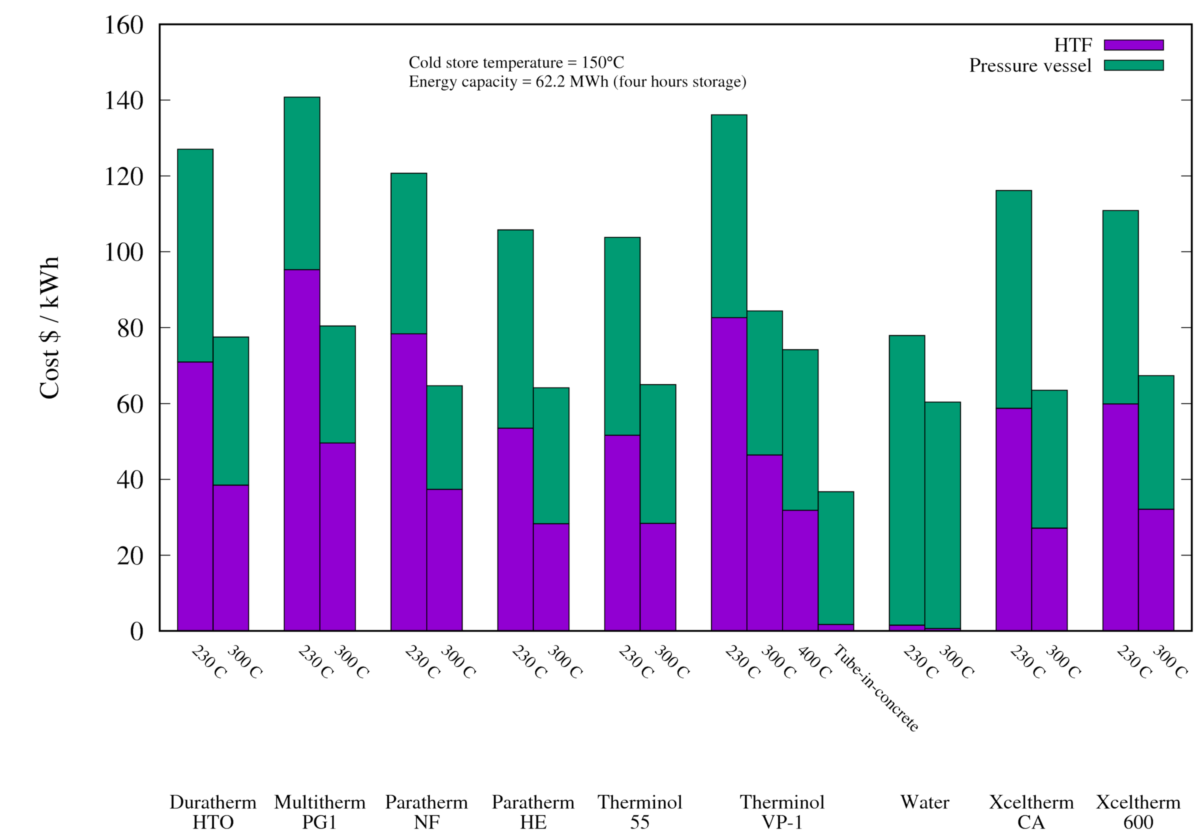


➢ Annual energy modeling

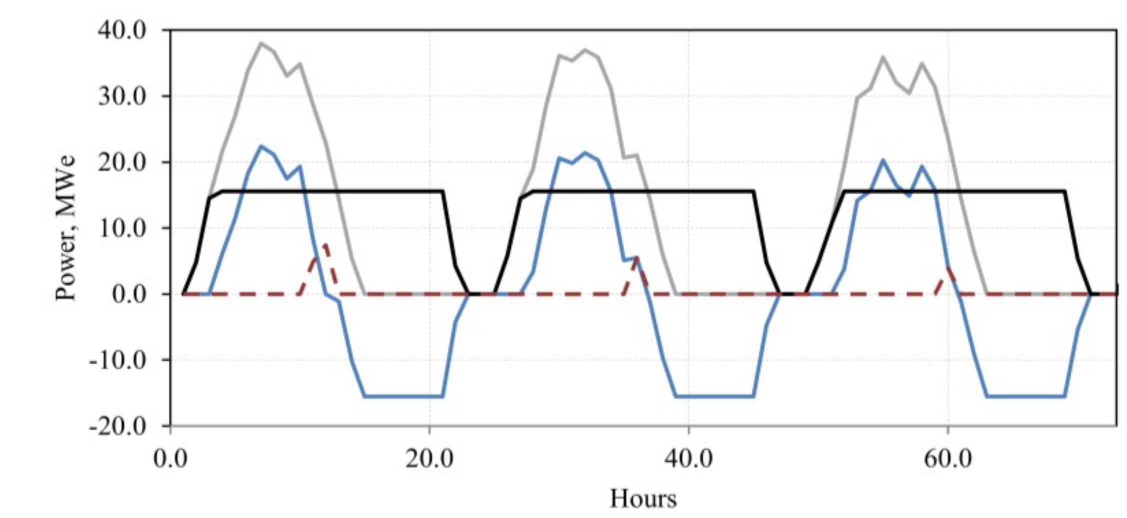
		4 hours of storage		8 hours of storage		8 hours of storage	
Solar-field sizing							
Required power	MW_{th}	15.6		15.6		15.6	
Solar multiple	-	2.4		2.4		3.9	
Design solar power	MW_{th}	39.6		36.9		60.8	
Solar field area	m^2	67 170.0		67 170.0		110583.1	
Solar field area	acres	16.6		16.6		27.3	
Peak HTF mass flow	kg s^{-1}	233.8		233.8		384.9	
Thermal storage sizing		TT	PB	TT	PB	TT	PB
Hot-storage volume	m^3	1912.4	625.6	3827.9	1251.2	3824.9	1250.2
Cold-storage volume	m^3	1830.0		3663.1		3660.2	
Energy storage	MWh	62.2		124.4		124.4	
Hours of storage	h	4.0		8.0		8.0	
Performance							
Total solar input	GWh	331.8		331.8		546.3	
Total thermal energy	GWh	68.4		68.4		112.6	
Energy produced	GWh	59.7		67.8		84.5	
Excess energy	GWh	8.7 (12.7%)		0.6 (0.82%)		28.1 (24.9%)	
Efficiency *	%	18.0		20.4		15.5	
Average power	MW_{th}	6.8		7.7		9.6	
Capacity factor	%	43.8		49.8		62.0	
Average storage discharge	MW_{th}	10.3		11.8		13.4	
Average discharge duration	h	4.0		5.6		6.3	
Utilization of storage	%	63.1		49.5		74.5	

Thermal Storage Evaluation

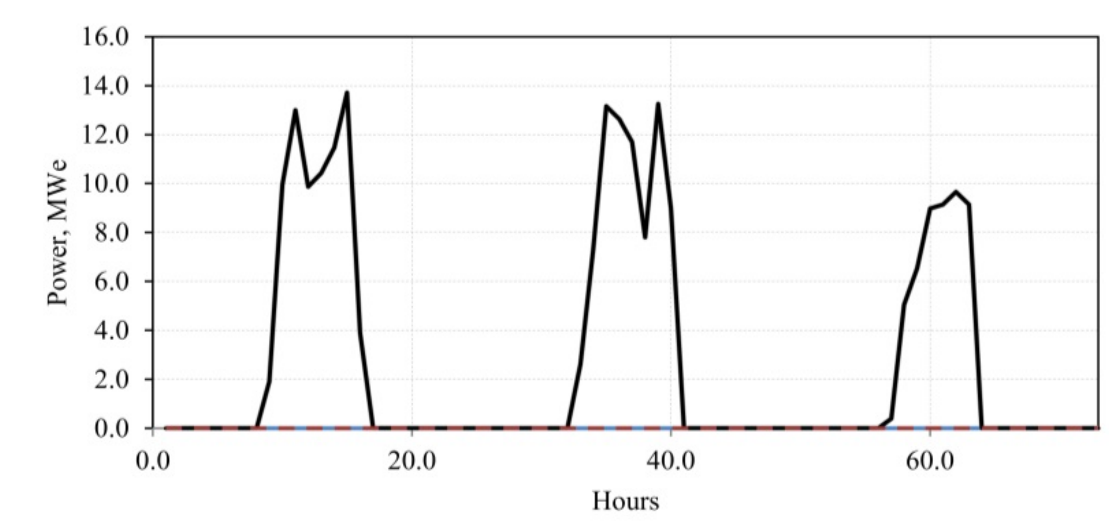
➢ Population of thermal storage fluids



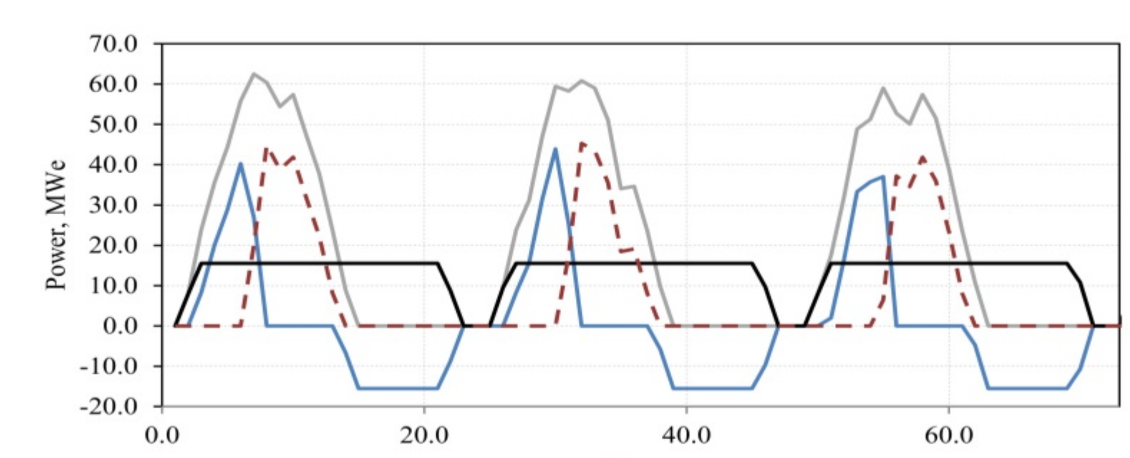
➢ Thermal storage optimization



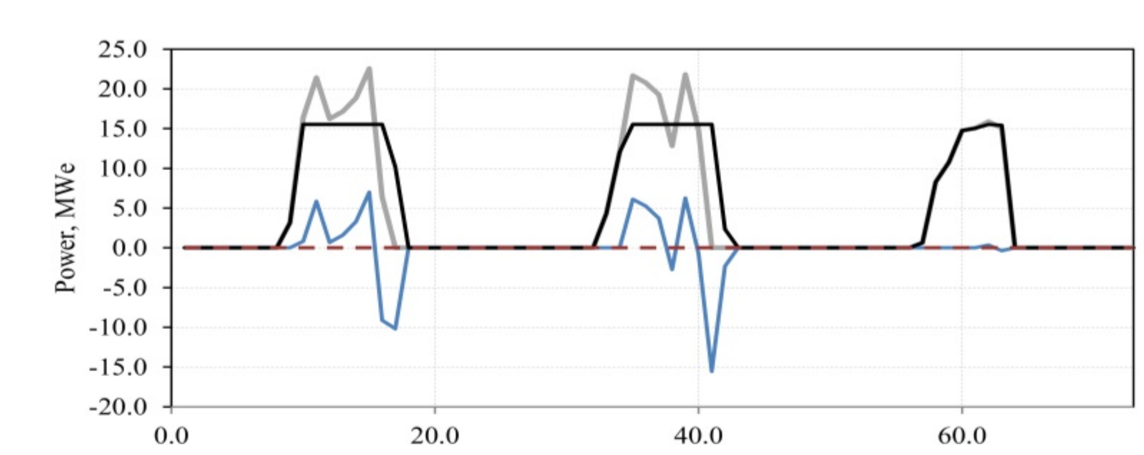
(a) Summer solstice. Solar multiple = 2.4



(b) Winter solstice. Solar multiple = 2.4



(c) Summer solstice. Solar multiple = 3.9



(d) Winter solstice. Solar multiple = 3.9

Available thermal power — Storage — Dispatched power — Excess pow

Future Work

- Refine thermodynamic models in IPSEpro.
- Complete annual energy model for hybrid systems.
- Perform techno-economic optimization on thermal storage size, solar field size, and selection of thermal storage fluids.

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 to the National Renewable Energy Laboratory.