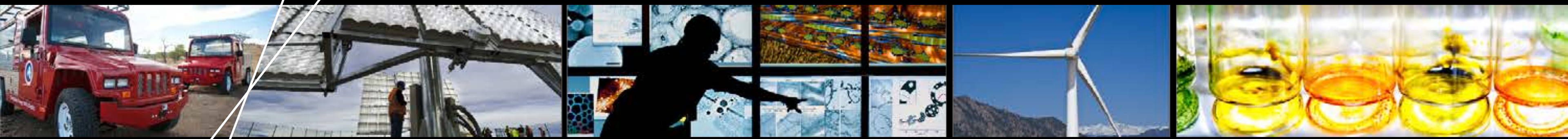
Modelling Concentrating Solar Power with Thermal Energy Storage for Integration Studies



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3rd International Solar Power Integration Workshop

October 20-22, 2013
London, UK

NREL/PR-6A20-60629

Executive Summary

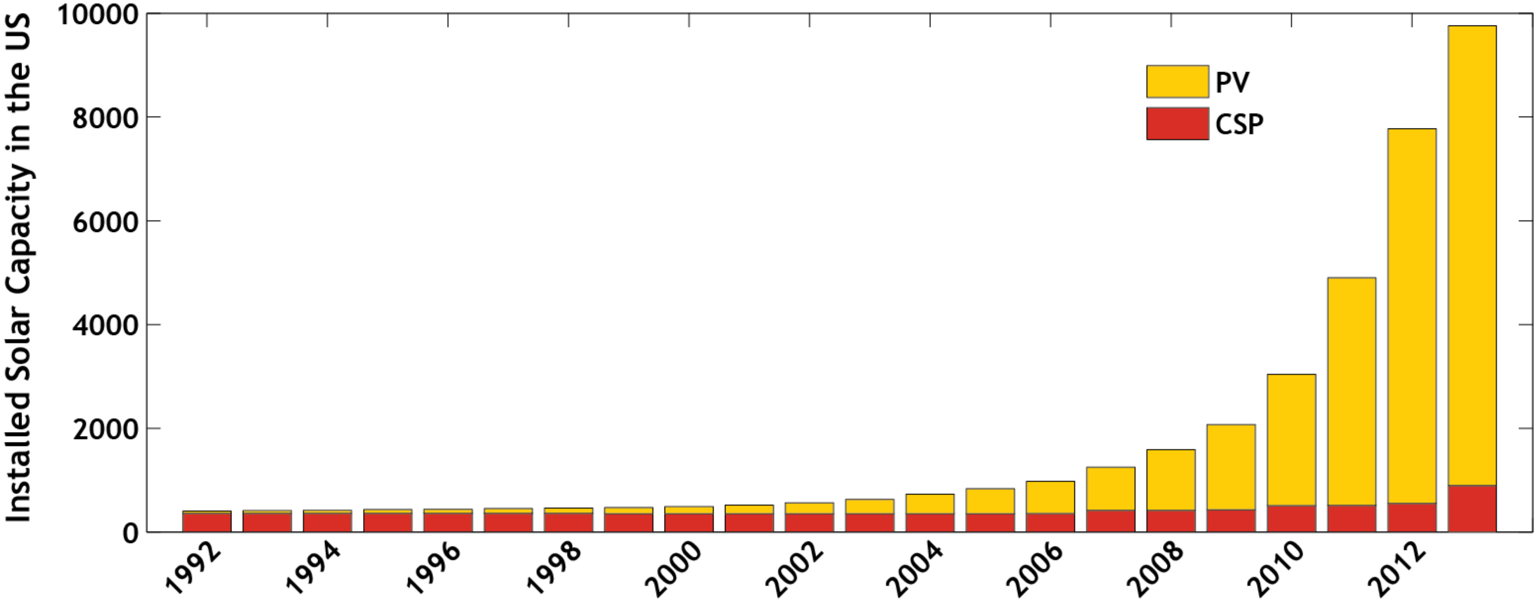
Concentrating solar power with thermal energy storage (CSP-TES) can provide multiple benefits to the grid, including low marginal cost energy and the ability to levelize load, provide operating reserves, and provide firm capacity. It is challenging to properly value the integration of CSP because of the complicated nature of this technology.

Unlike completely dispatchable fossil sources, CSP is a limited energy resource, depending on the hourly and daily supply of solar energy. To optimize the use of this limited energy, CSP-TES must be implemented in a production cost model with multiple decision variables for the operation of the CSP-TES plant.

We develop and implement a CSP-TES plant in a production cost model that accurately characterizes the three main components of the plant: solar field, storage tank, and power block. We show the effect of various modelling simplifications on the value of CSP, including: scheduled versus optimized dispatch from the storage tank and energy-only operation versus co-optimization with ancillary services.

Corresponding paper:
Hummon, M., Jorgenson, J., Denholm, P., Mehos, M., "Modelling Concentrating Solar Power with Thermal Energy Storage for Integration Studies", 3rd International Solar Power Integration Workshop, London, UK, October 20-22, 2013. (NREL CP-6A20-60365).

Motivation



EIA 2012, Energy Information Administration, Electric Power Monthly, EIA, 2012

SEGS Solar Power Plant Photo via Shutterstock

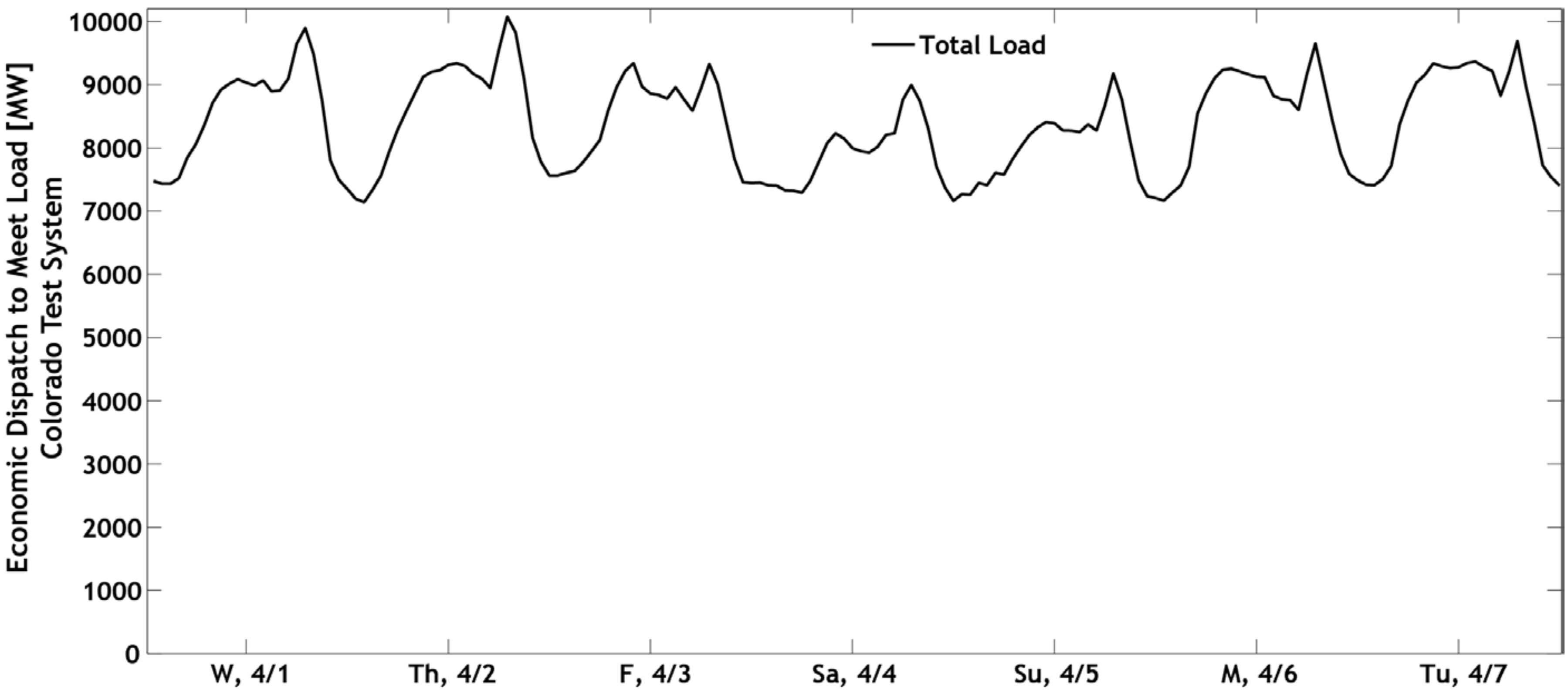
PV currently has lower installation costs.

CSP with thermal energy storage offers services to the grid that increase its value. Modeling CSP in grid operations helps us estimate the value of CSP.

Outline

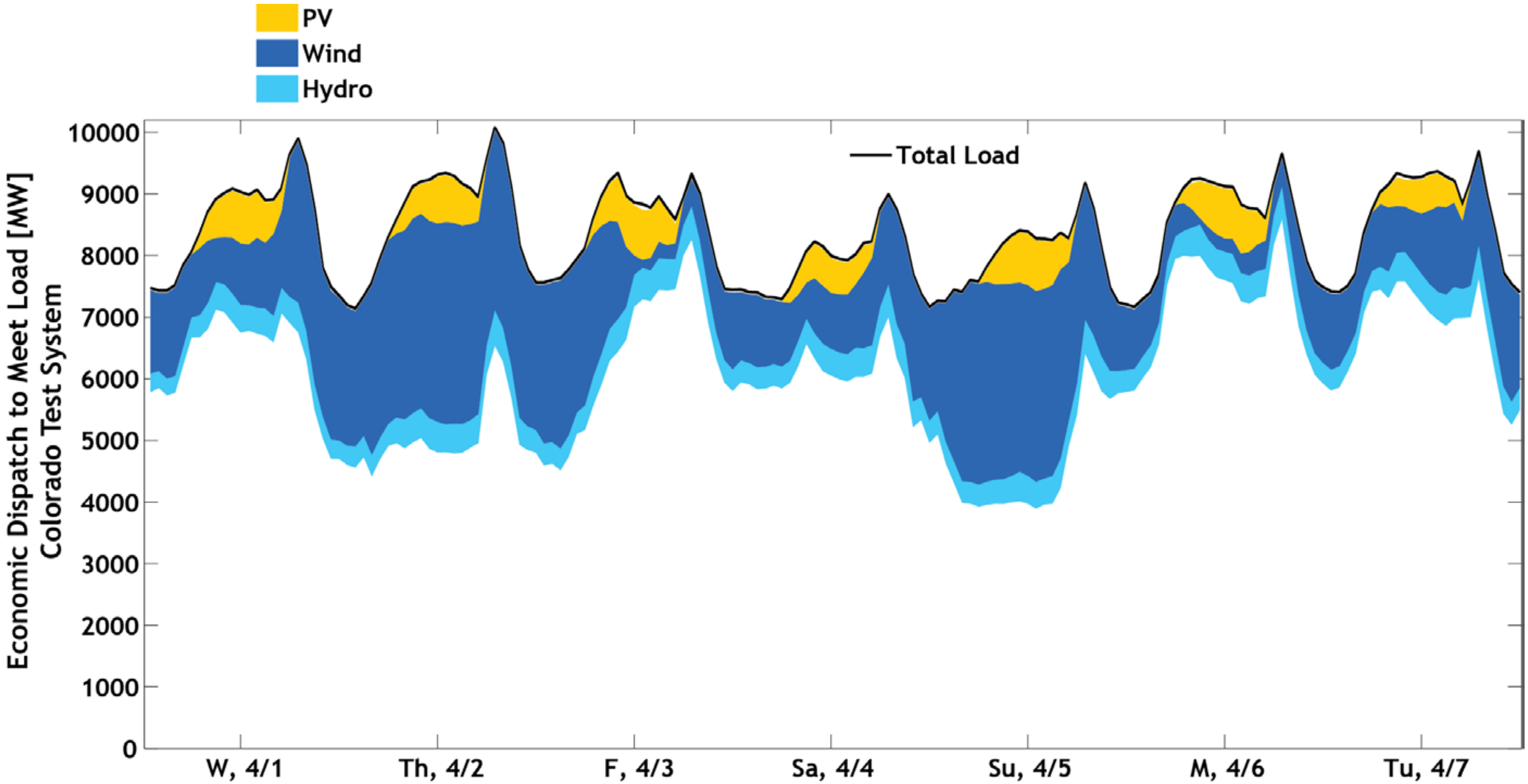
- **Production Cost Modeling – An Integration Study Tool**
- **Concentrating Solar Power (CSP)**
  - Components: solar field, thermal energy storage (TES), and power block
  - Operation of CSP-TES
- **CSP-TES modelling framework**
  - Fixed dispatch
  - Optimize storage and dispatch
  - Allow CSP-TES to provide ancillary services
- **Results**

Production Cost Modeling



Objective: Balance generation and load, every hour, at least cost

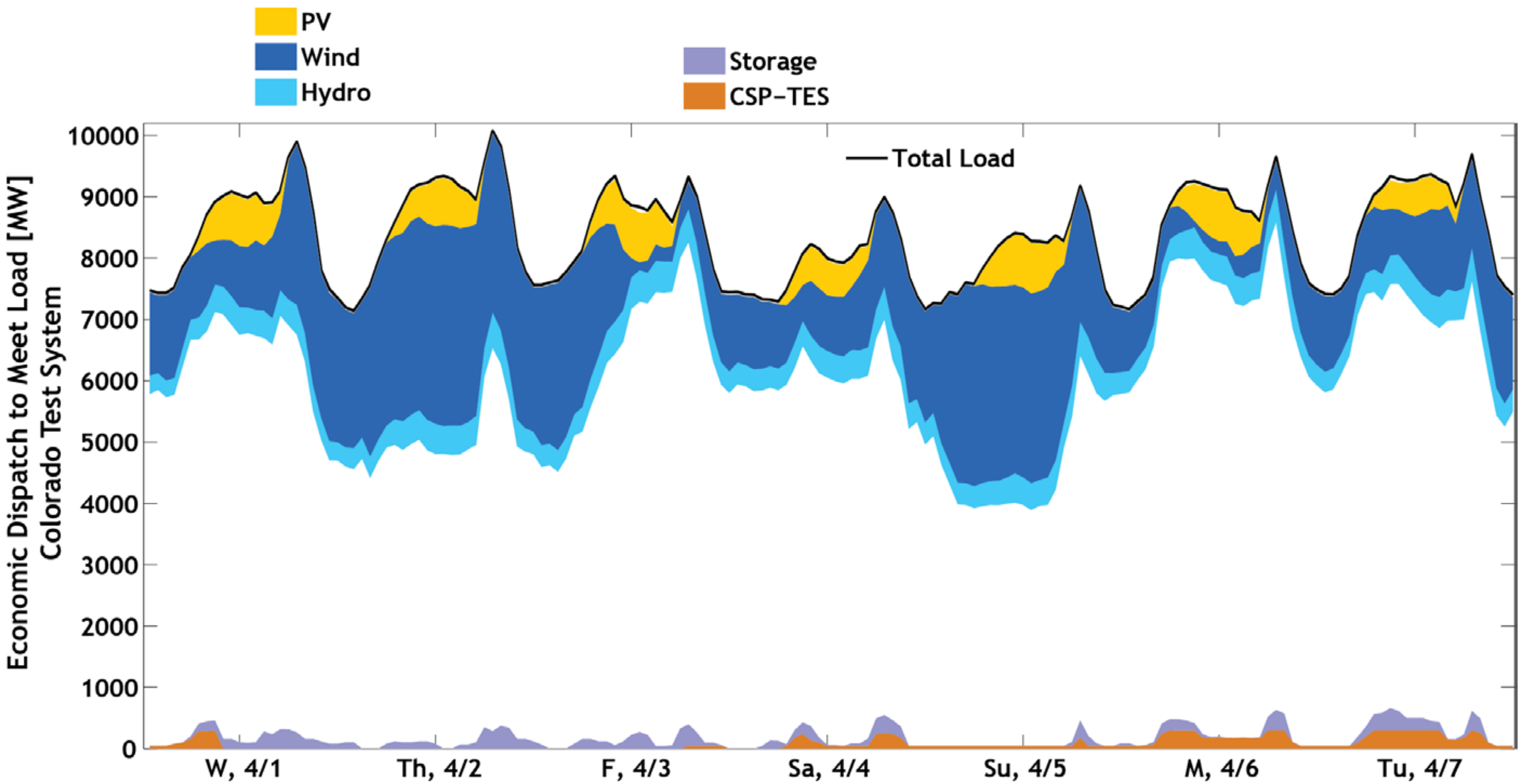
Production Cost Modeling



Objective: Balance generation and load, every hour, at least cost

- PV and Wind Generation are variable and uncertain (similar to Load)
- Generation from Hydro is often constrained by other competing uses, for example recreational use of reservoirs or fish habitat

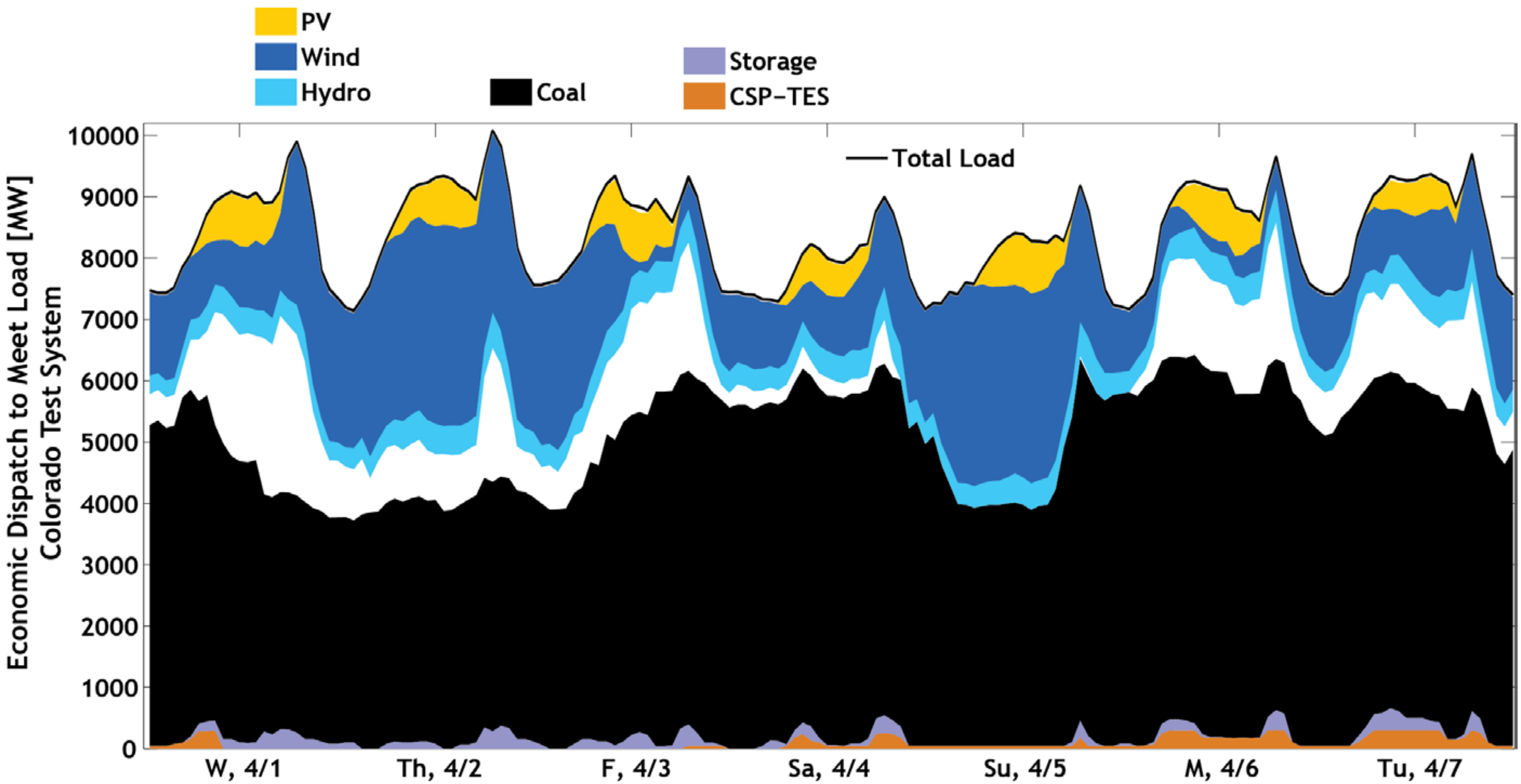
Production Cost Modeling



Objective: Balance generation and load, every hour, at least cost

- Storage and CSP-TES are low marginal cost generation and are dispatched during peak prices

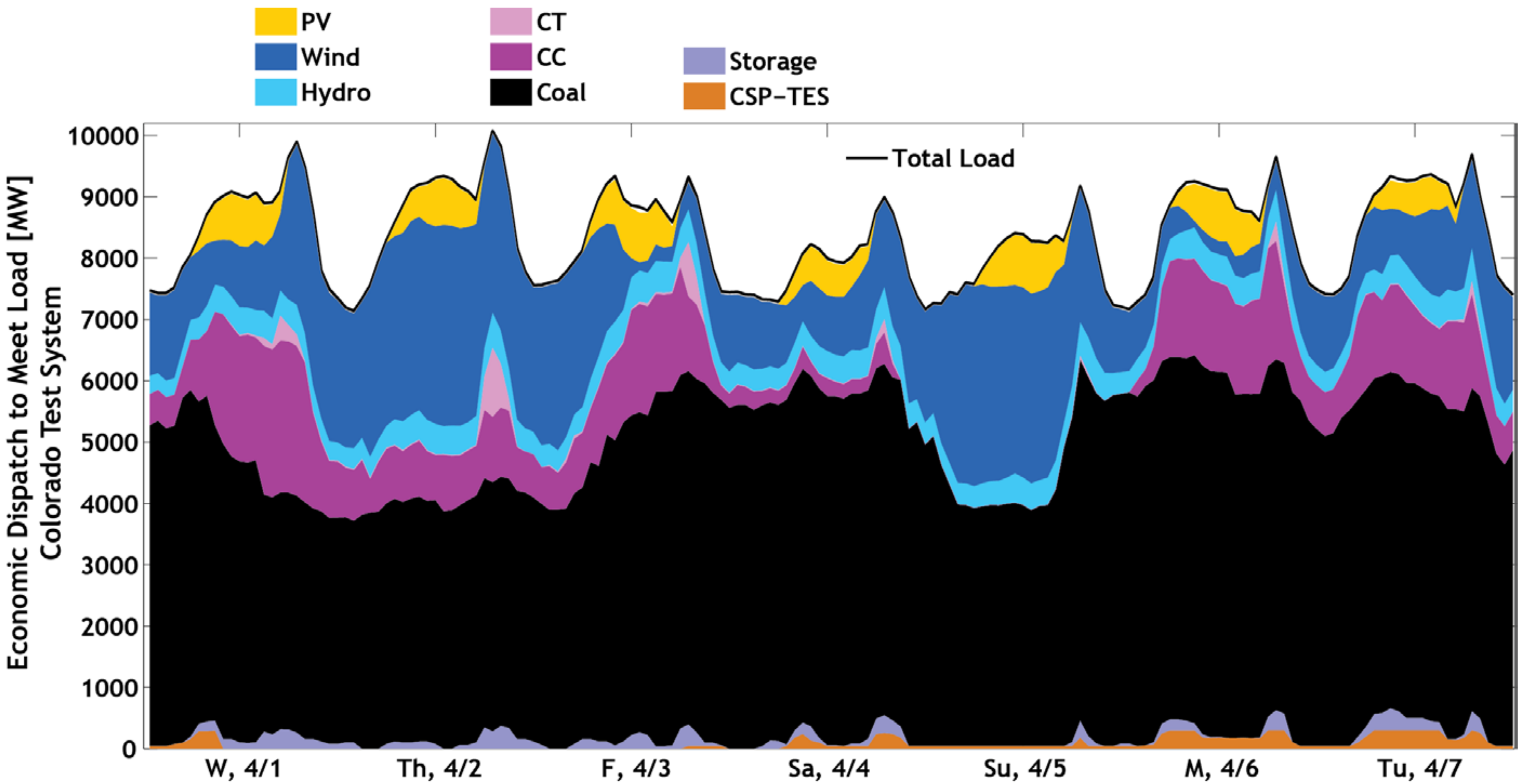
Production Cost Modeling



Objective: Balance generation and load, every hour, at least cost

- Coal generation is the next least cost source of generation. Coal generation is committed for multiple days at a time.

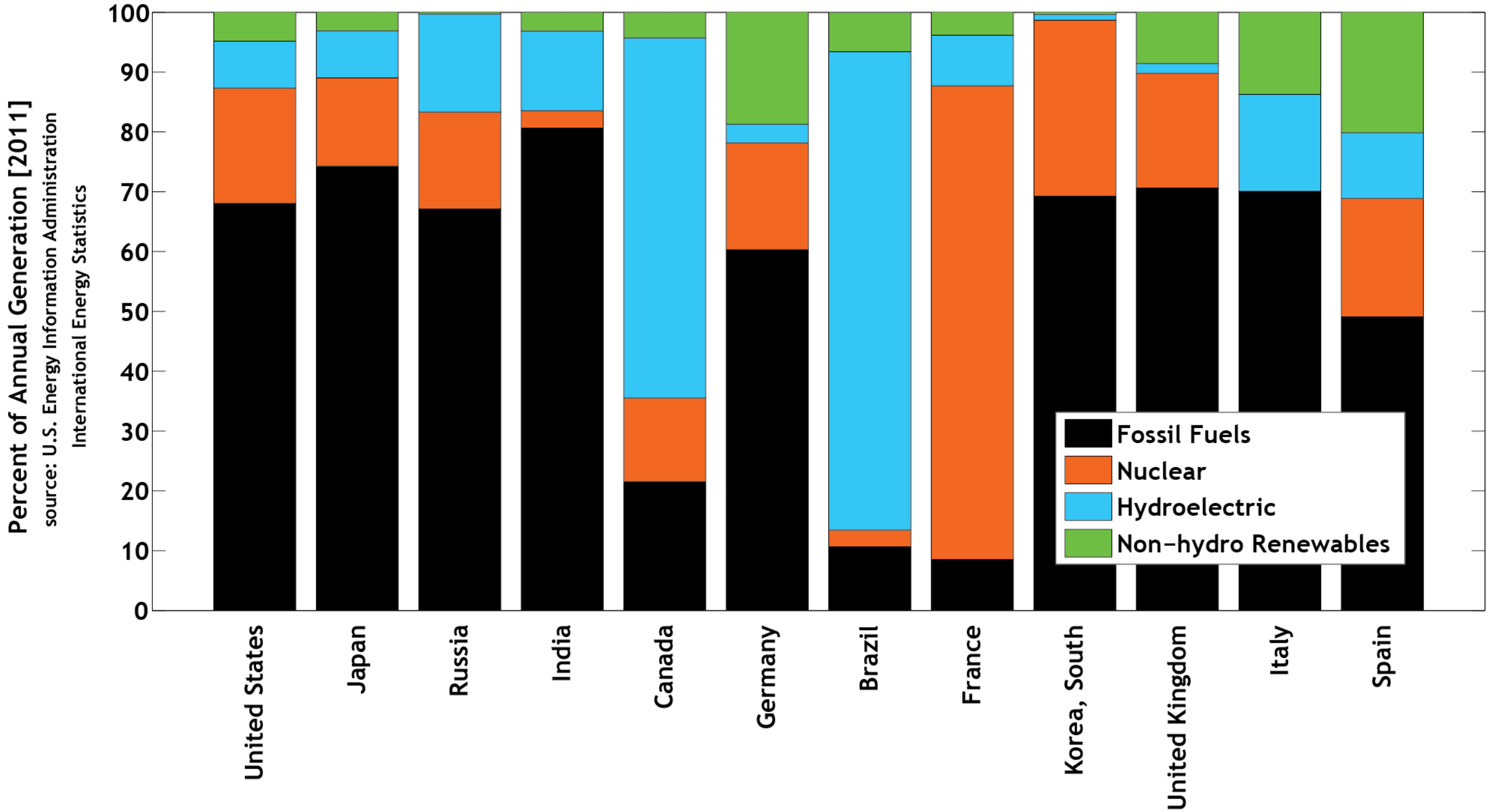
Production Cost Modeling



Objective: Balance generation and load, every hour, at least cost

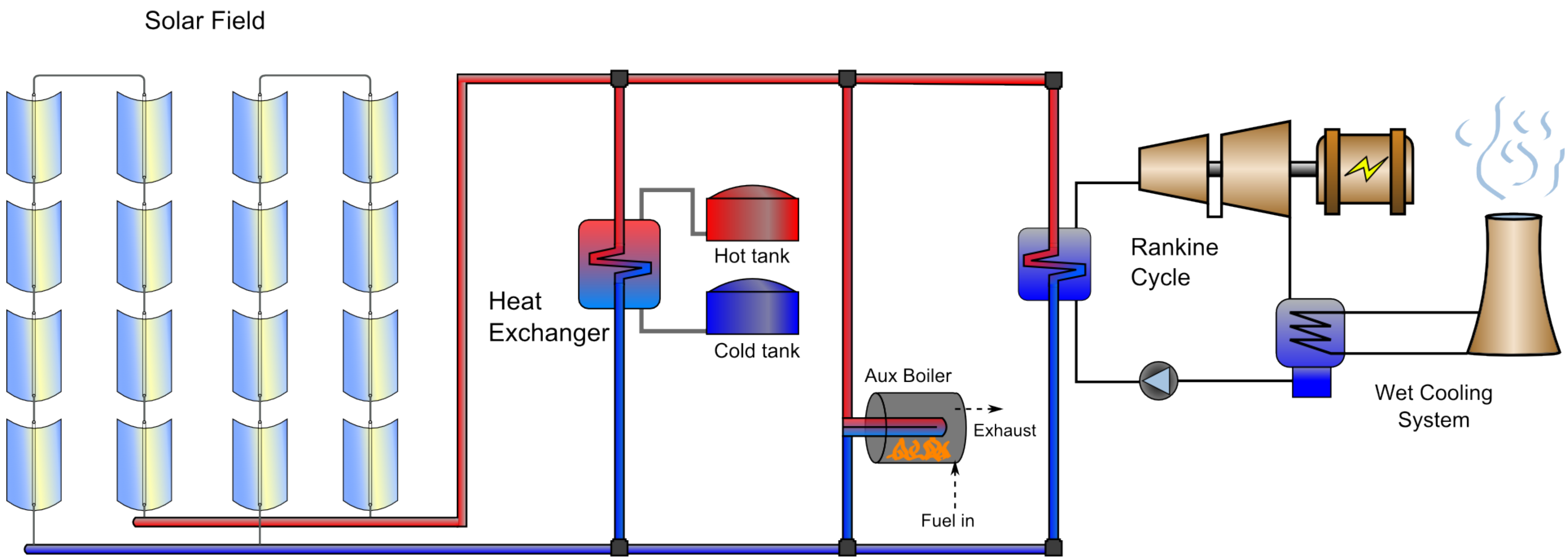
- Natural-gas fired power plants have the least constraint on on/off decisions; higher marginal operating cost that can recover startup costs within 2-8 hours

Wide variety of electricity generation systems

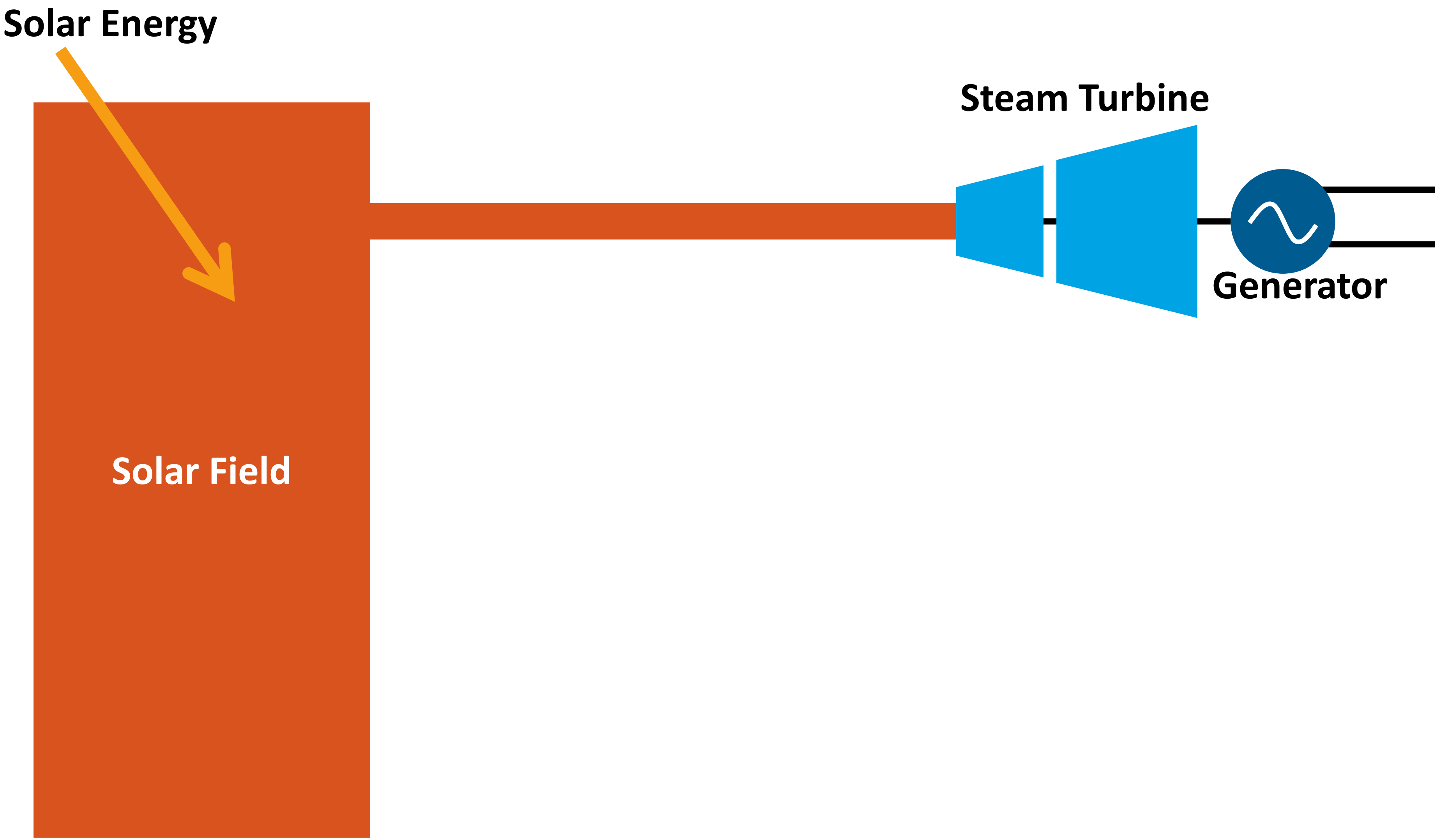


The costs and benefits of integrating a new technology will change between systems; being able to model new technologies reduces the barriers to integration.

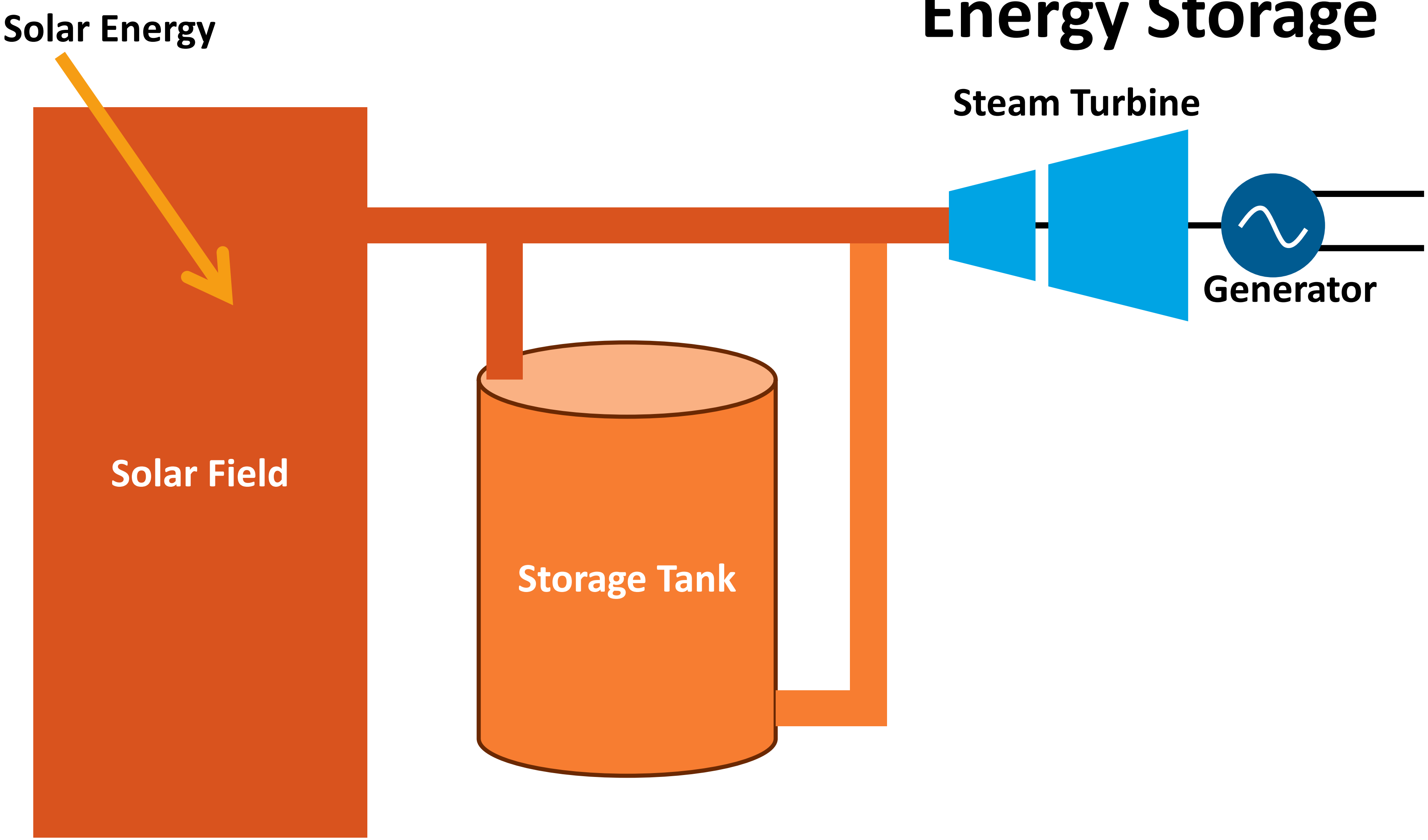
Concentrating Solar Power Plant



Concentrating Solar Power

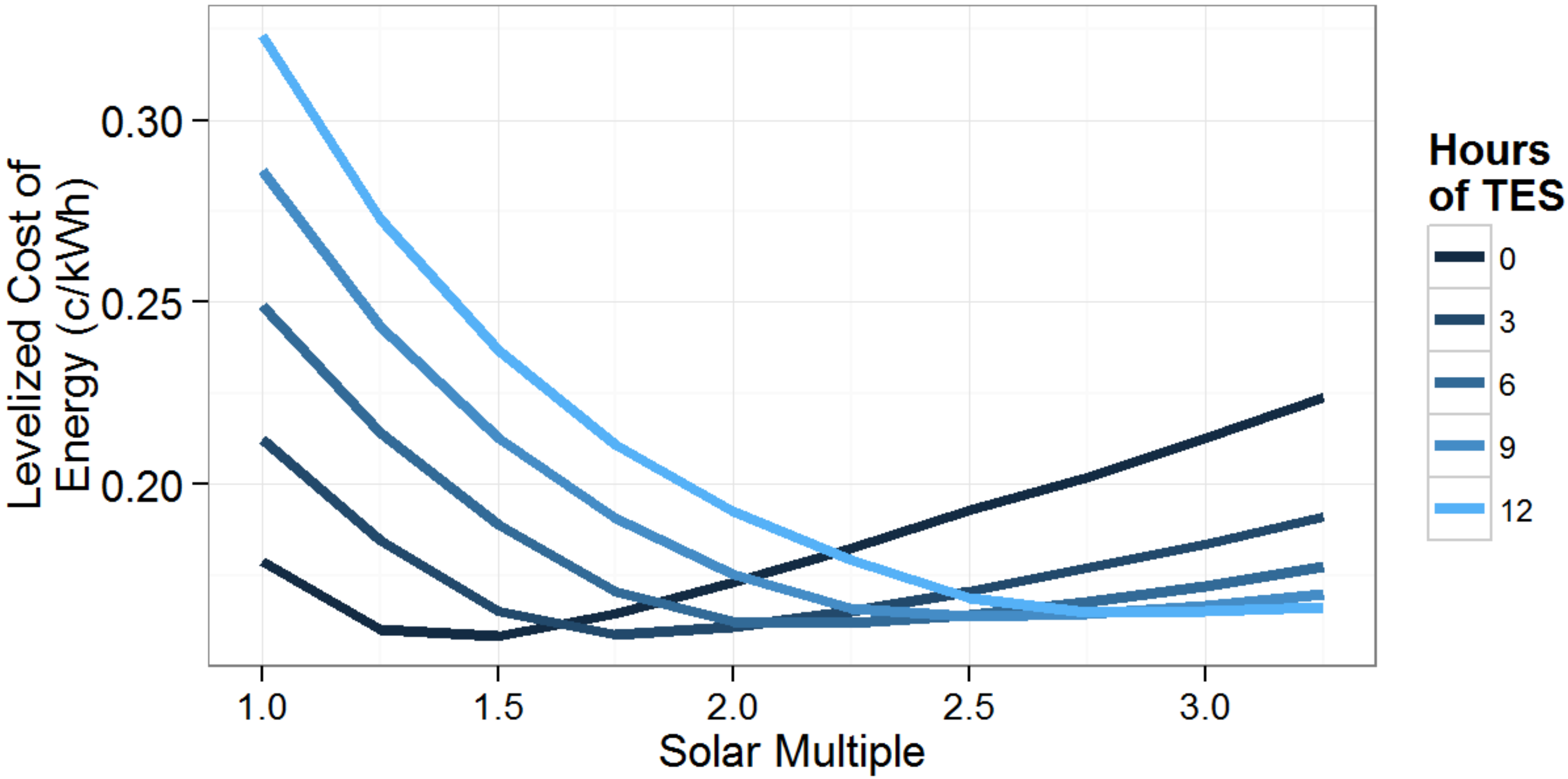


Concentrating Solar Power with Thermal Energy Storage

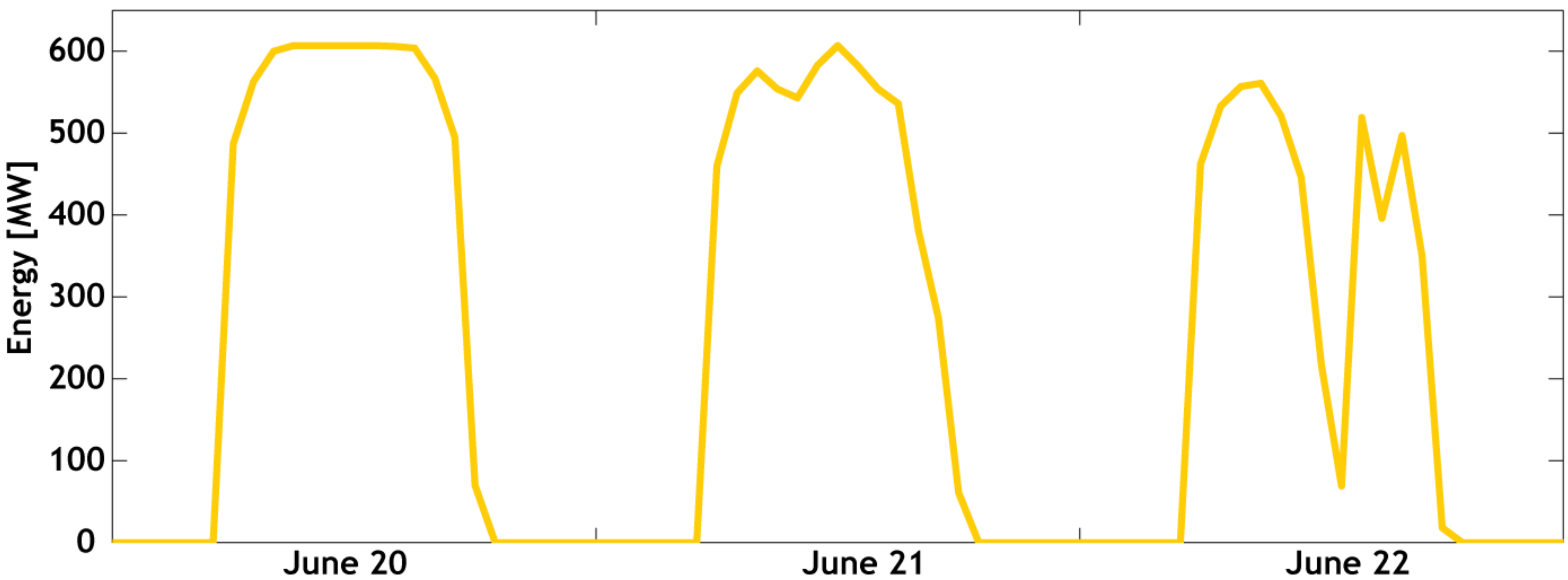


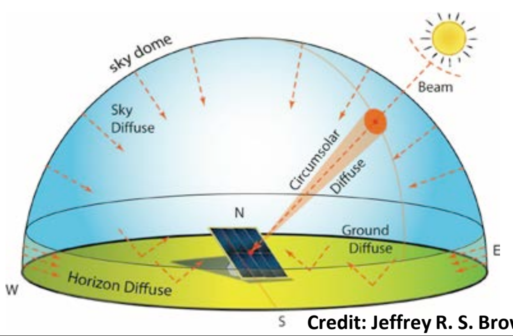
Another Optimization Problem:

Relative sizes of the CSP-TES components.



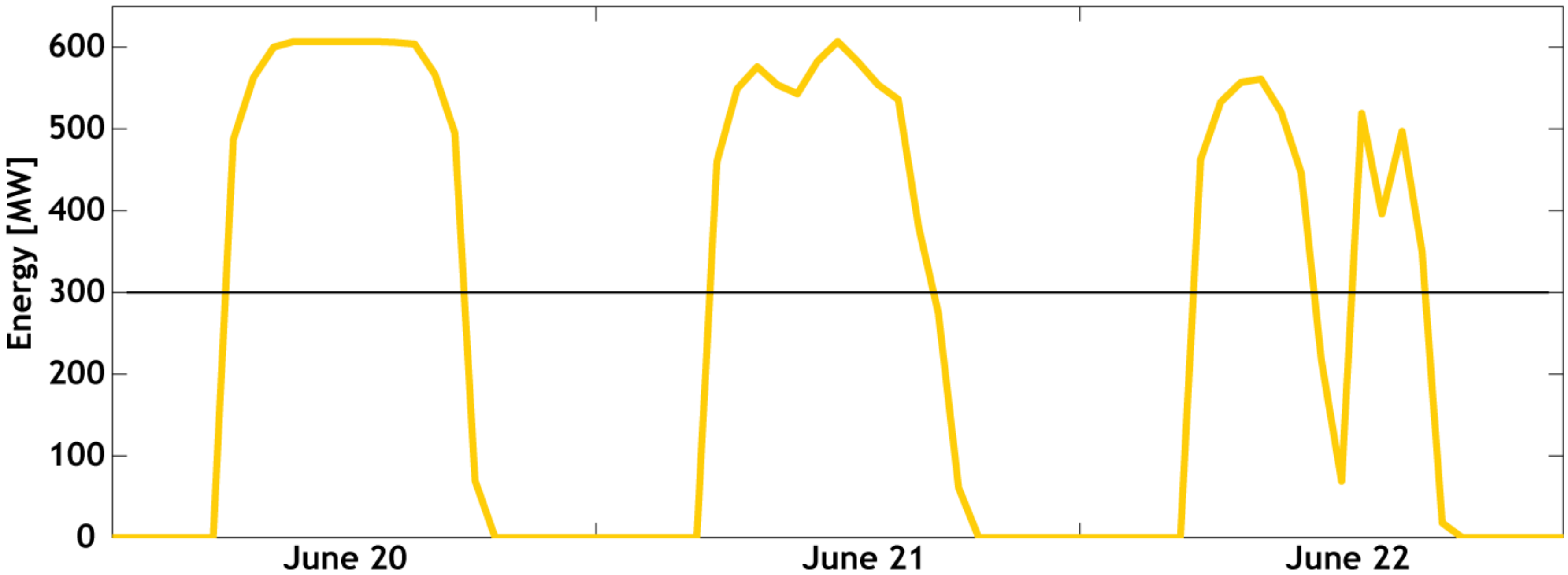
Solar Energy (Electrical Equivalent)

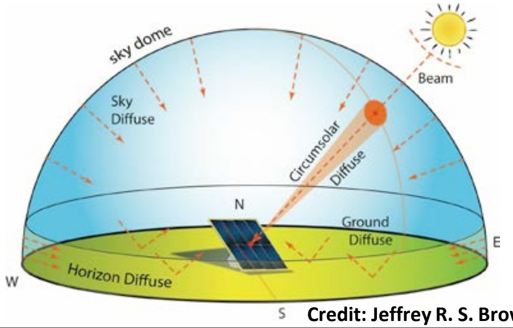




Credit: Jeffrey R. S. Brownson

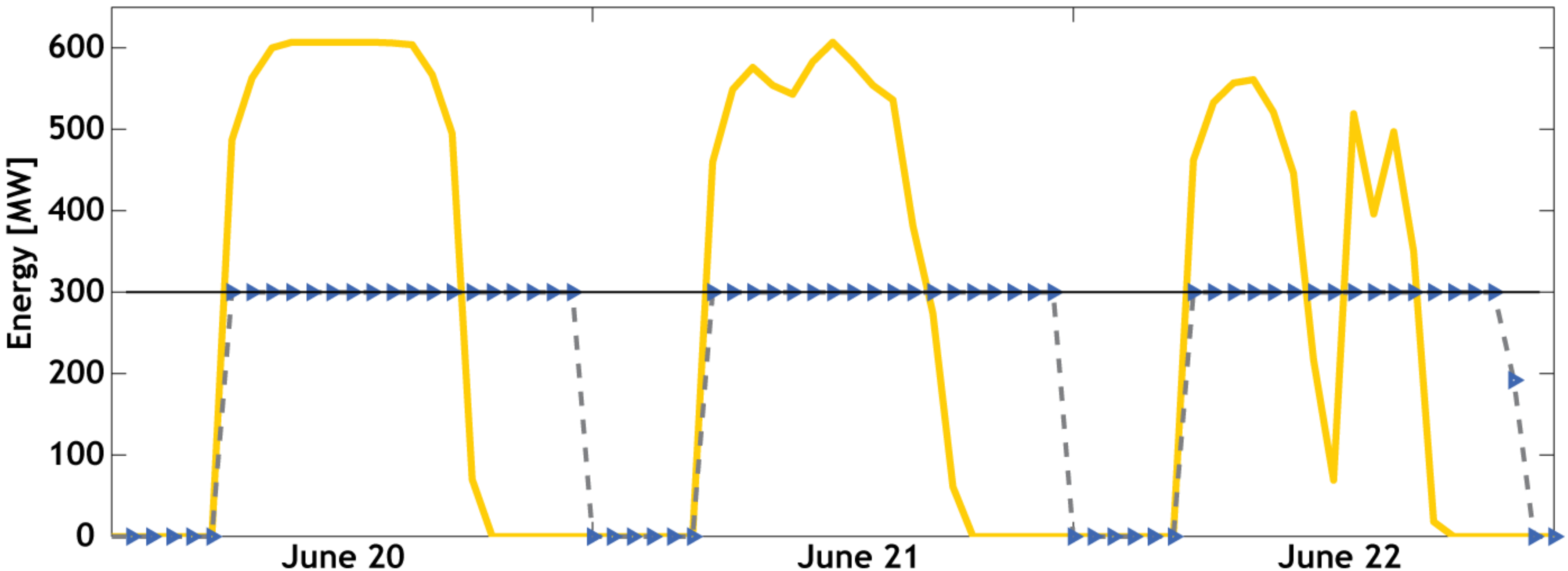
Dispatch of CSP-TES

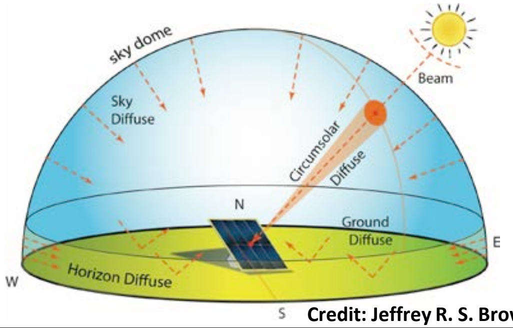




Credit: Jeffrey R. S. Brownson

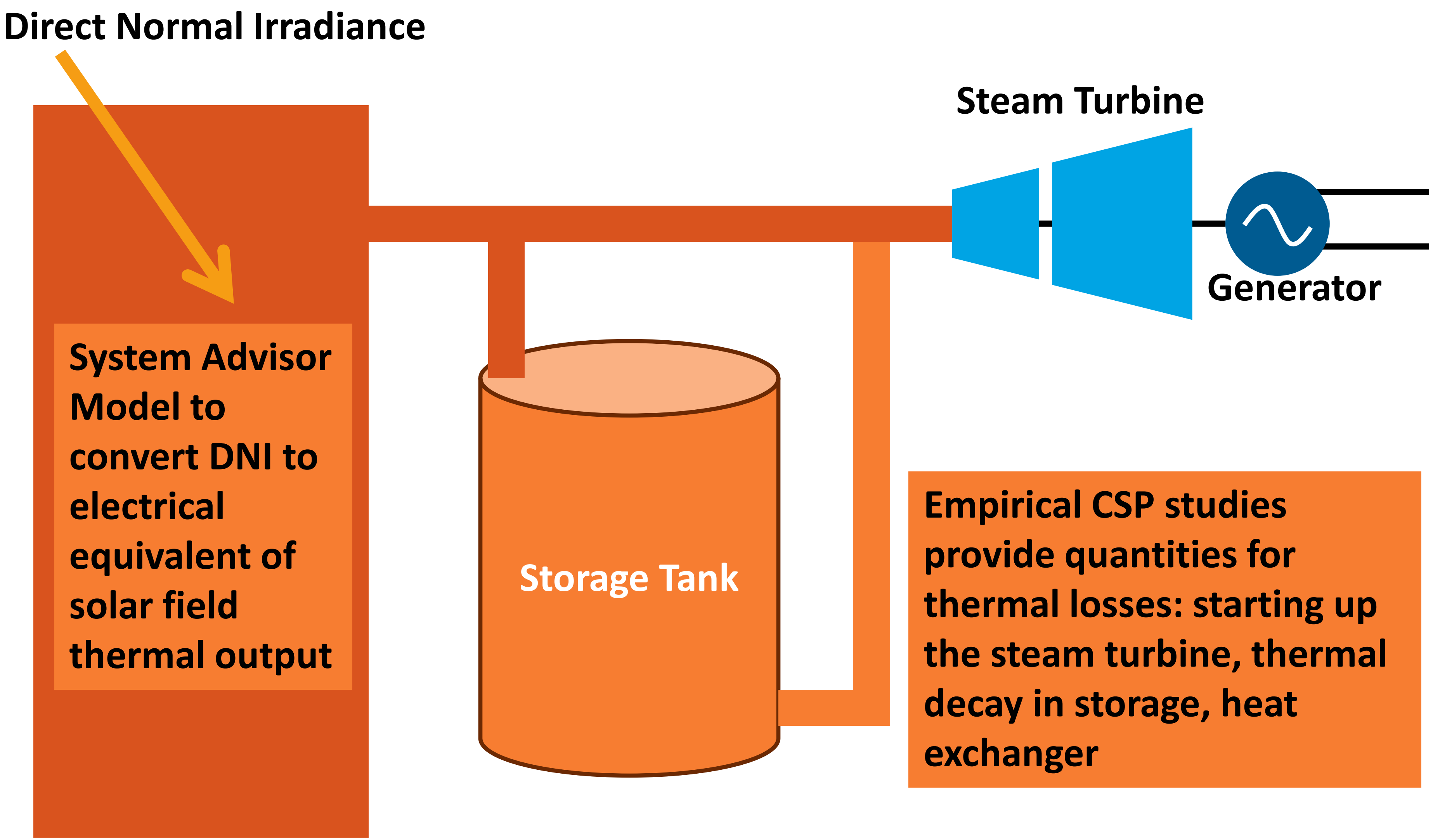
Dispatch of CSP-TES



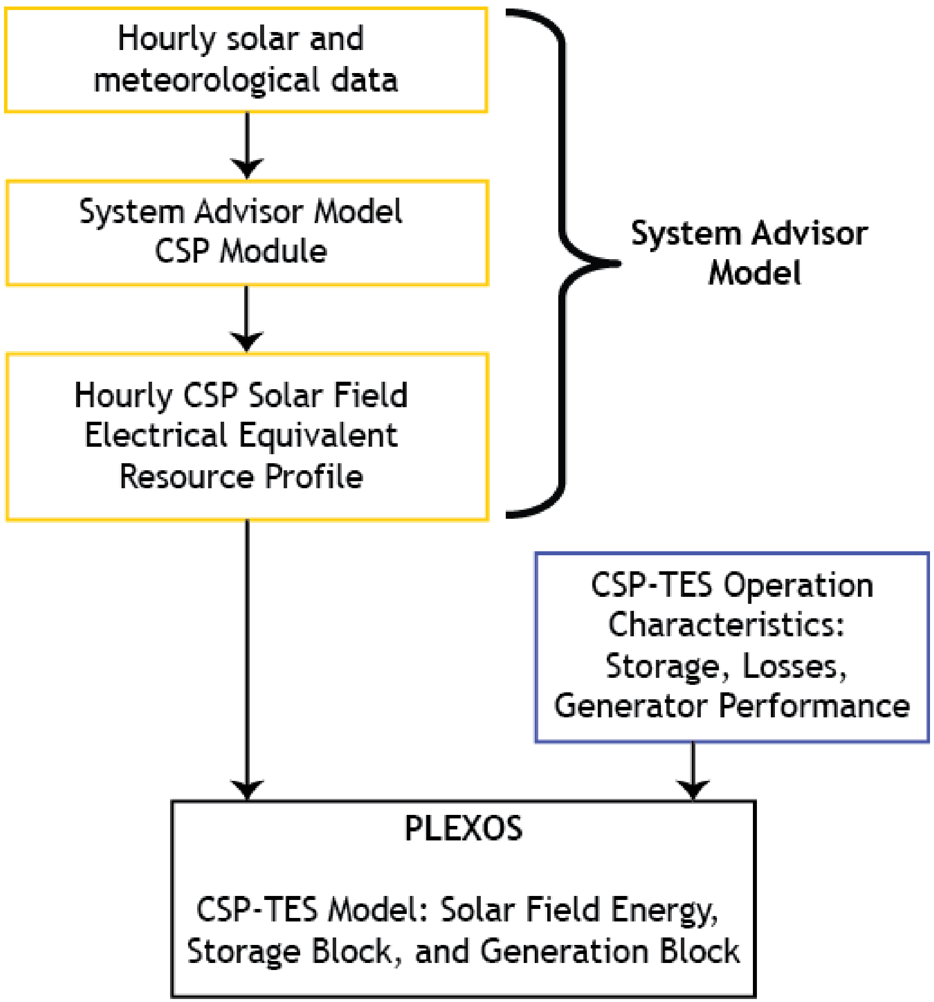


Credit: Jeffrey R. S. Brownson

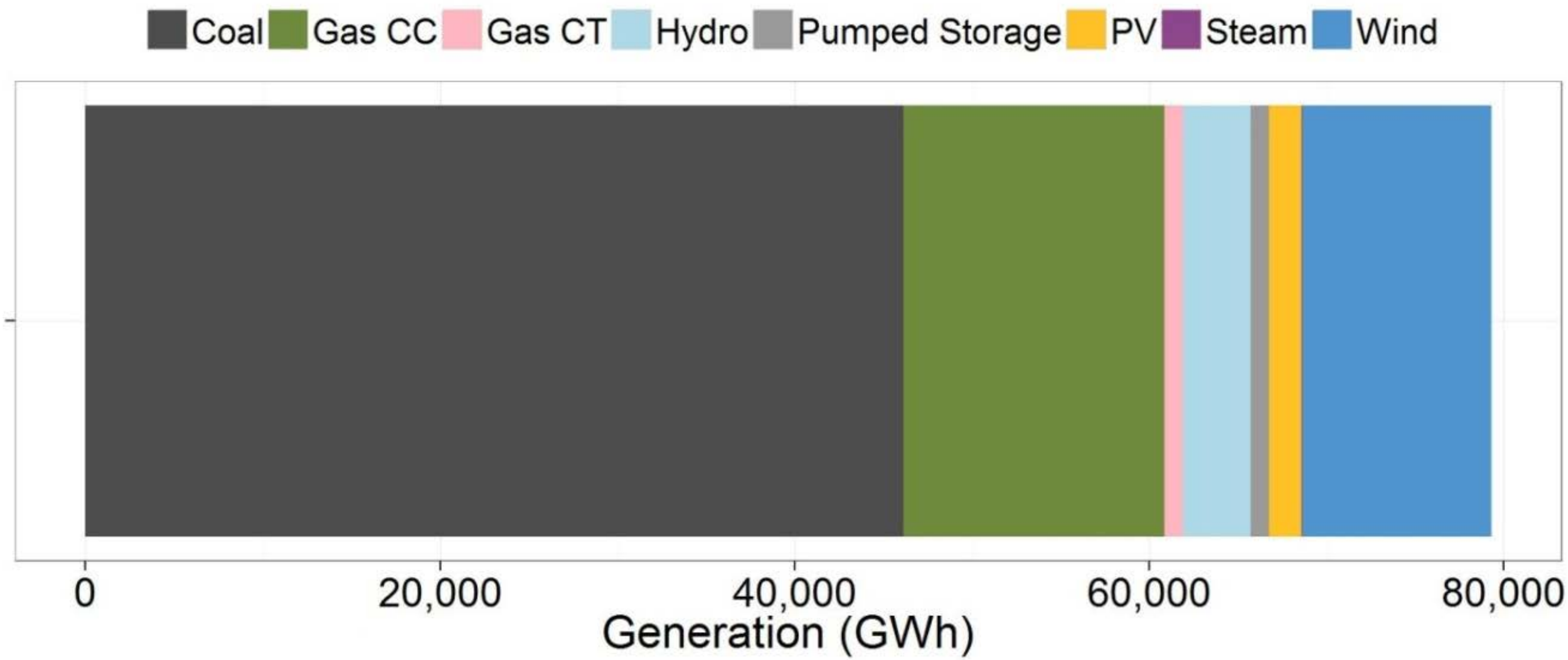
Concentrating Solar Power



SAM: Electrical equivalent for solar field



Colorado Test System



System peak: 14 GW

Installed Capacity: ~ 18 GW

Annual simulation, hourly resolution, 48-hour optimization horizon, 24-hour rolling optimization

Scenarios

CSP-TES
Max Cap: 300 MW
Solar multiple (SM) = 2.2
Storage = 6 hours

High Flex

Operation Property	High Flex
Minimum Generation Point	45 MW
Ramp Rate	30 MW/min
Minimum up/down time	1 hour
Number of starts per day	Unconstrained
Start-up energy	60 MWh
Start-up cost	$3,000
Variable O&M	$1.1/MWh

Low Flex

Operation Property	Low Flex
Minimum Generation Point	75 MW
Ramp Rate	12 MW/min
Minimum up/down time	6 hours
Number of starts per day	1
Start-up energy	180 MWh
Start-up cost	$30,000
Variable O&M	$3/MWh

Pre-scheduled

Solar Field energy is scheduled for storage/dispatch (outside of PLEXOS)

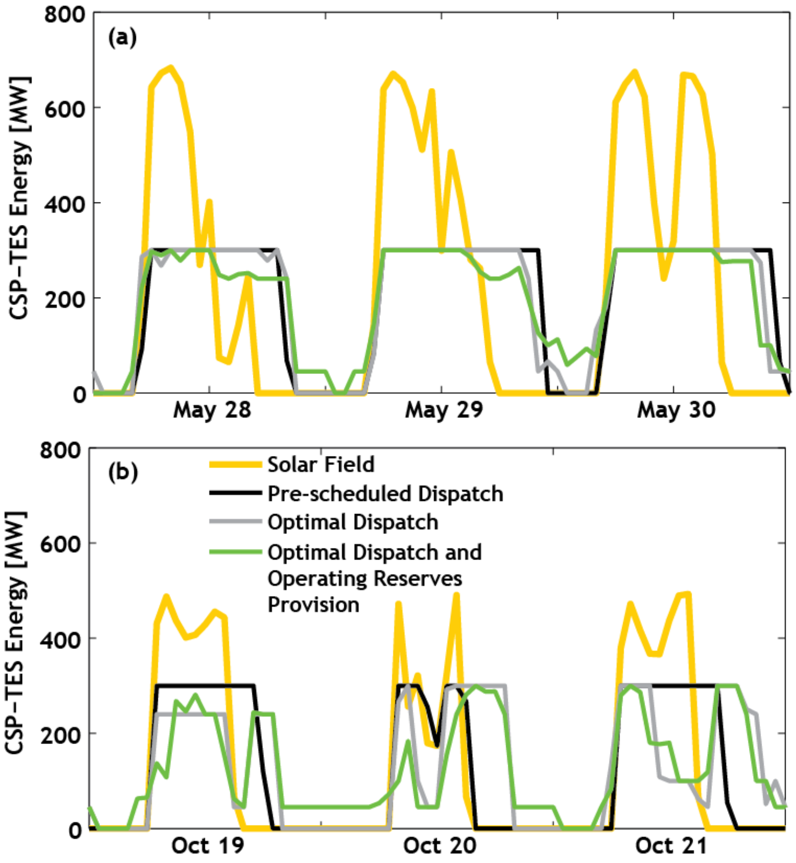
Optimal

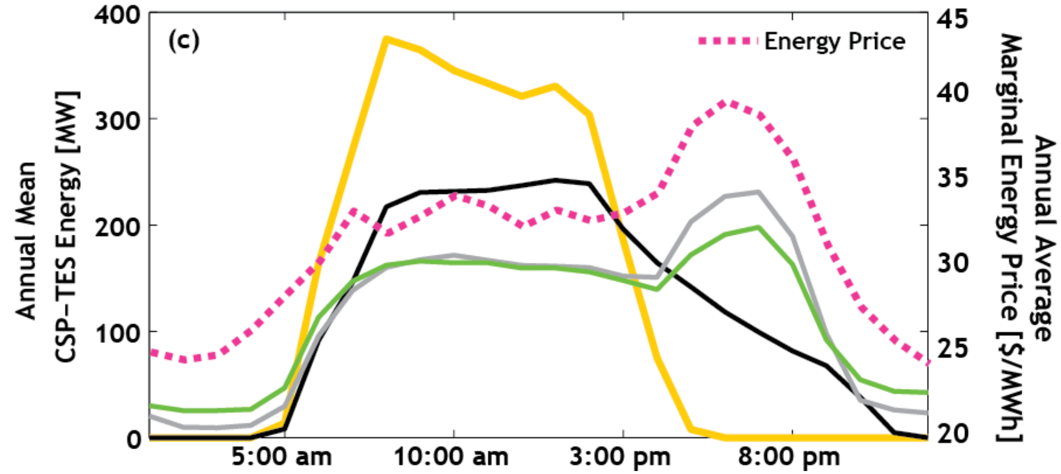
Solar Field energy is optimally scheduled by PLEXOS

Co-optimized

Solar Field energy and power block capacity is co-optimized for energy and reserves

Performance of CSP-TES

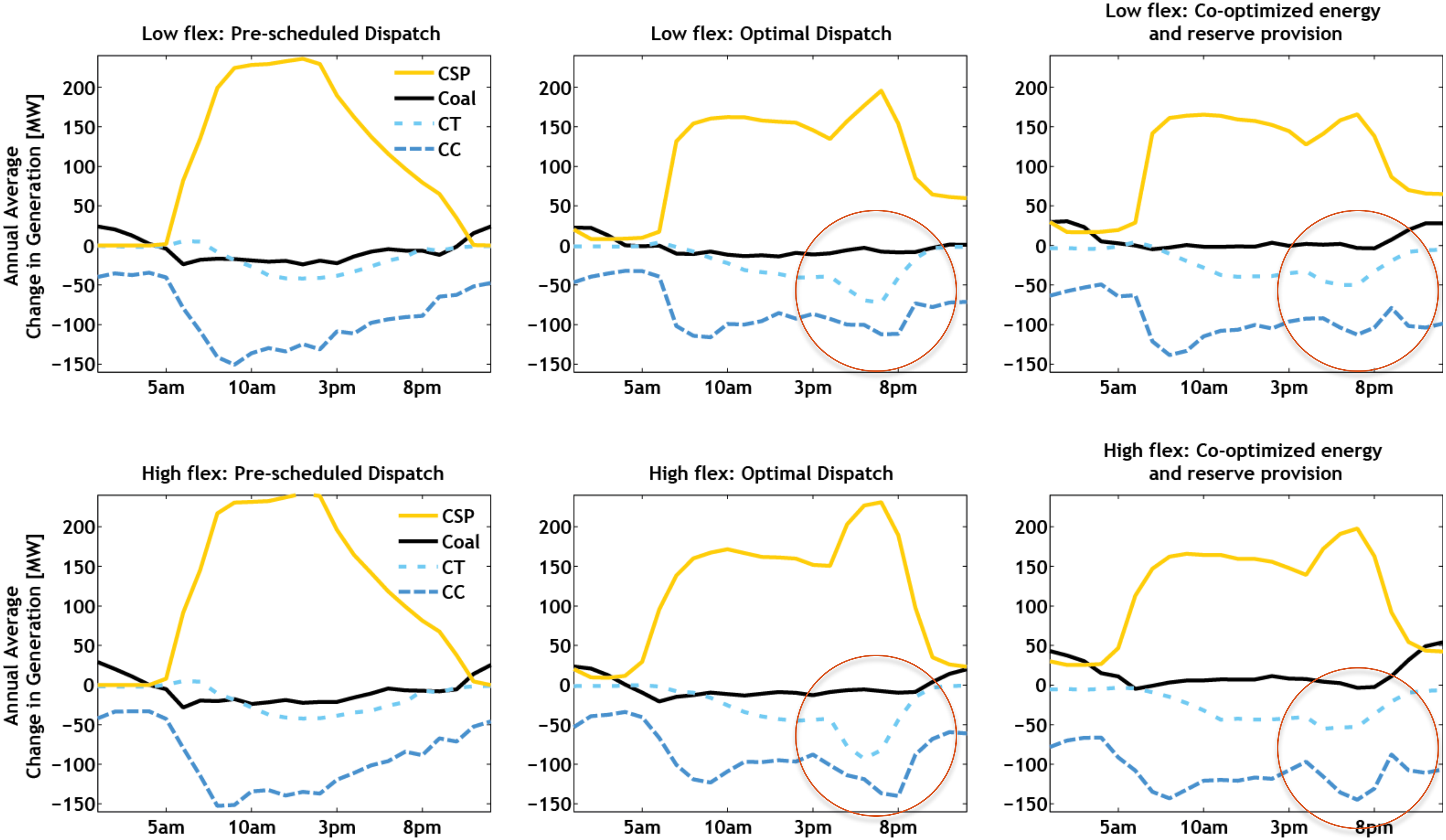




Pre-scheduled dispatch is not a terrible estimate

Optimal dispatch and co-optimized dispatch improve the use of CSP-TES from the system perspective: overnight operation and evening peak.

CSP-TES Schedule Effects Displaced Generation



Displaced Generation and Fuel

	Base Case	CSP-TES with High Flexibility Operation		
		Pre-scheduled Dispatch	Optimal Dispatch	Co-optimized Dispatch and Reserve Provision
Generator Class	[GWh]	Increase from Base Case [GWh / %]		
Coal	46089	-65 / -0.1	-31 / -0.1	125 / 0.3
Combined Cycle (CC)	14791	-802 / -5.4	-760 / -5.1	-960 / -6.5
Gas Turbine/Gas Steam	1035	-146 / -14	-232 / -22.2	-225 / -21.6
Other	95	-1 / -0.9	-1 / -0.9	-6 / -6.2
Hydro	3792	0 / 0	0 / 0	0 / 0
Pumped Hydro Storage	1040	11 / 1.1	-2 / -0.2	-103 / -9.9
Wind	10705	0 / 0	0 / 0	0 / 0
PV	1834	0 / 0	0 / 0	0 / 0
CSP	*0*	*1017 / -*	*1021 / -*	*1018 / -*

Fuel Class	[MMBTU]	Increase from Base Case [MMBTU/ %]		
Coal Offtake	487589	-772 / -0.2	-390 / -0.1	1310 / 0.3
Gas Offtake	126771	-7871 / -6.2	-8749 / -6.9	-10659 / -8.4

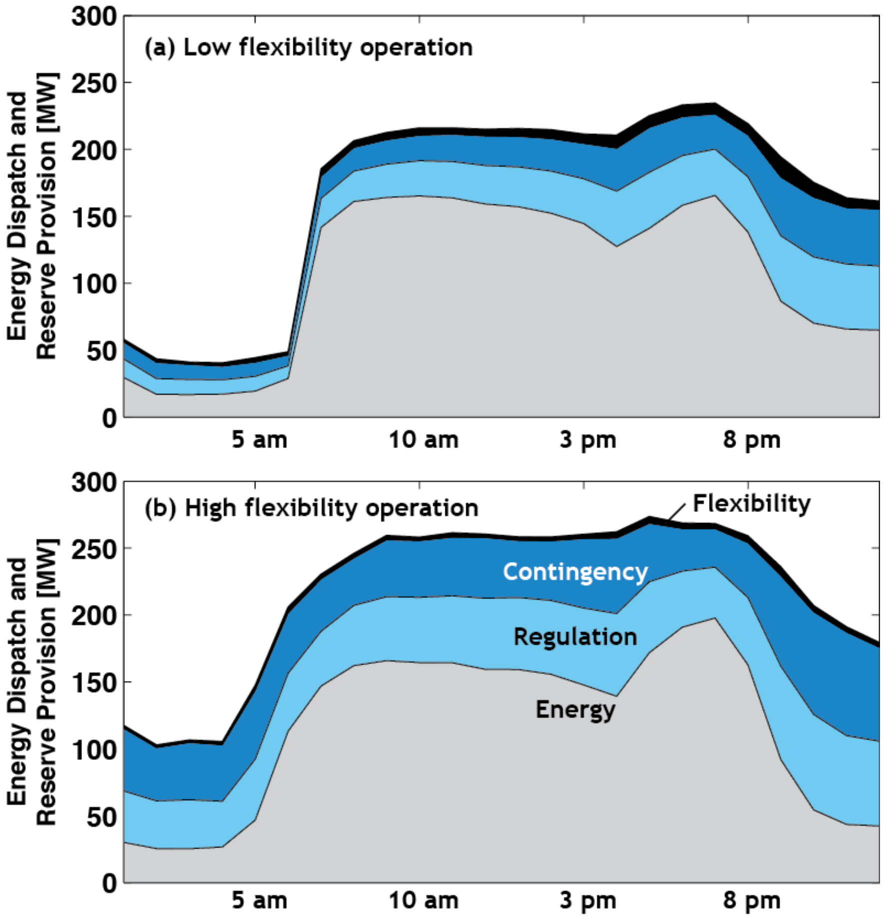
- CSP-TES displaces gas-fired generation (higher marginal cost than coal without emission penalties)
- Optimal CSP dispatch increases displacement of gas-fired CTs
- Co-optimized CSP-TES has a complex affect on system operation

Change in Production Costs

	Base Case	CSP-TES with High Flexibility Operation		
		Pre-scheduled Dispatch	Optimal Dispatch	Co-optimized Dispatch and Reserve Provision
	[M$]	change from base case [M$ / %]		
Fuel Cost	1210	-34 / -2.8	-37 / -3.1	-43 / -3.5
VO&M Cost	152	0 / 0	-1 / -0.7	-1 / -0.6
Start & Shutdown Cost	59	0 / 0.3	-2 / -4.2	-1 / -1.3
Regulation Bid Cost	5	0 / -0.1	0 / 1.2	-1 / -15.4
Total Generation Cost	**1426**	**-34 / -2.4**	**-41 / -2.9**	**-45 / -3.2**

- Most of the production cost savings is displaced fuel.
- Optimal dispatch of CSP-TES results in fewer starts.
- Co-optimized CSP-TES avoids regulation bid costs by displacing slightly higher bid cost of combined cycle units, $6/MWh, with the CSP-TES bid cost of $4/MWh.

Co-optimized CSP-TES provides Reserves



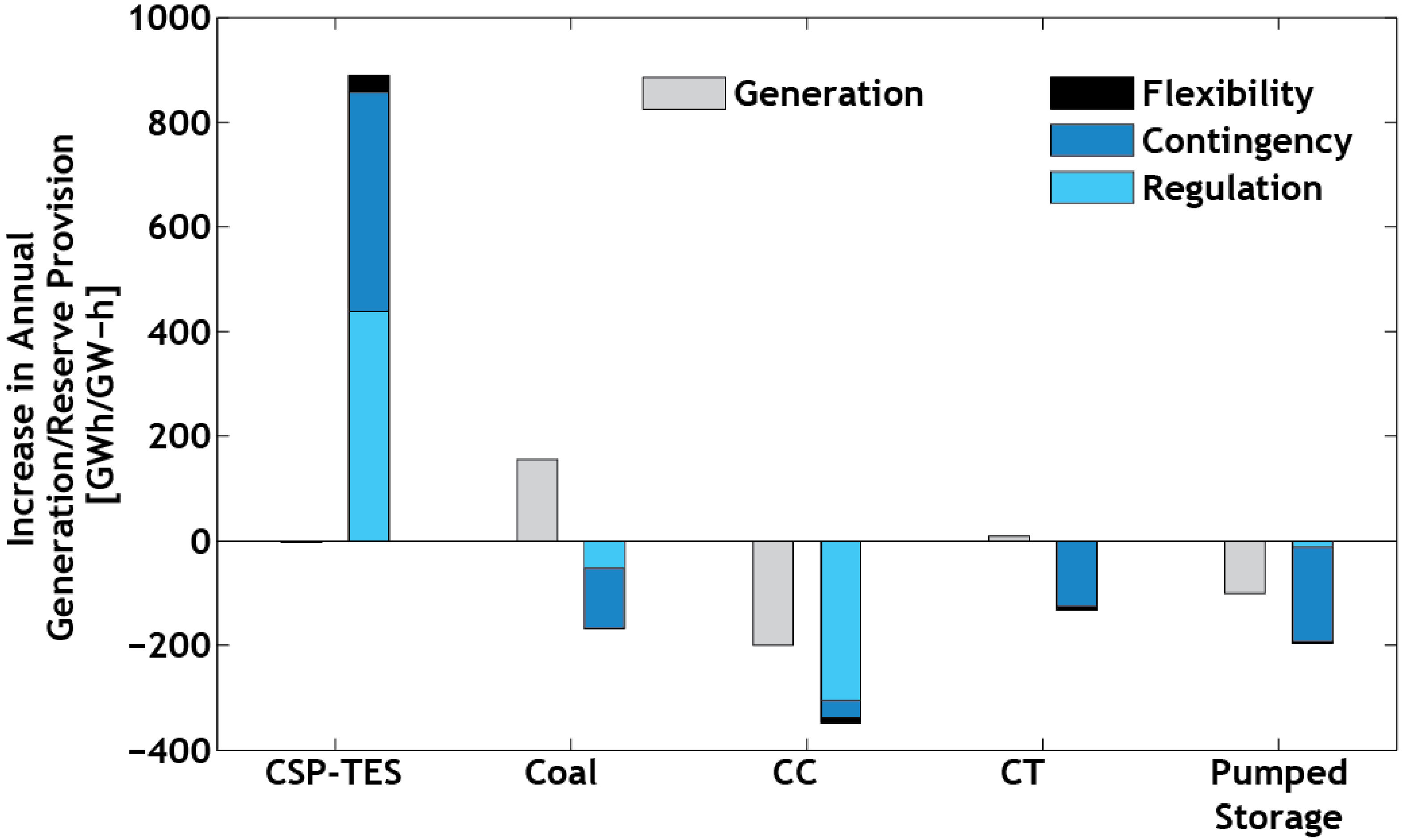
CSP-TES provides 17% (10%) of the annual reserve requirement in the high (low) flexibility scenario, split equally between regulation and contingency reserves.

Regulation is energy neutral over 25 minutes; Contingencies are estimated to be drawn once every 2-3 days for 10-20 minutes.

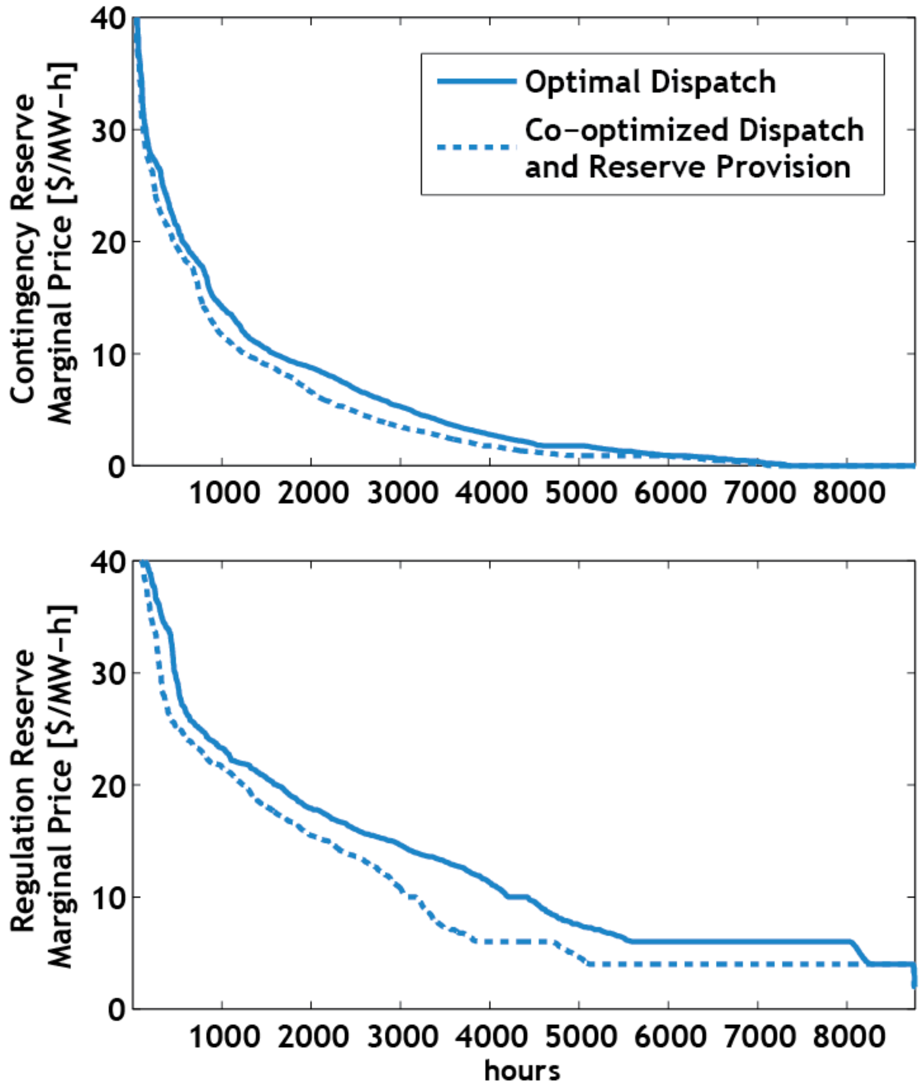
CSP-TES is ramp rate constrained is responding to ancillary service requests.

Co-optimized CSP-TES

Optimal CSP-TES Dispatch → Co-optimized CSP-TES Dispatch And Reserve Provision

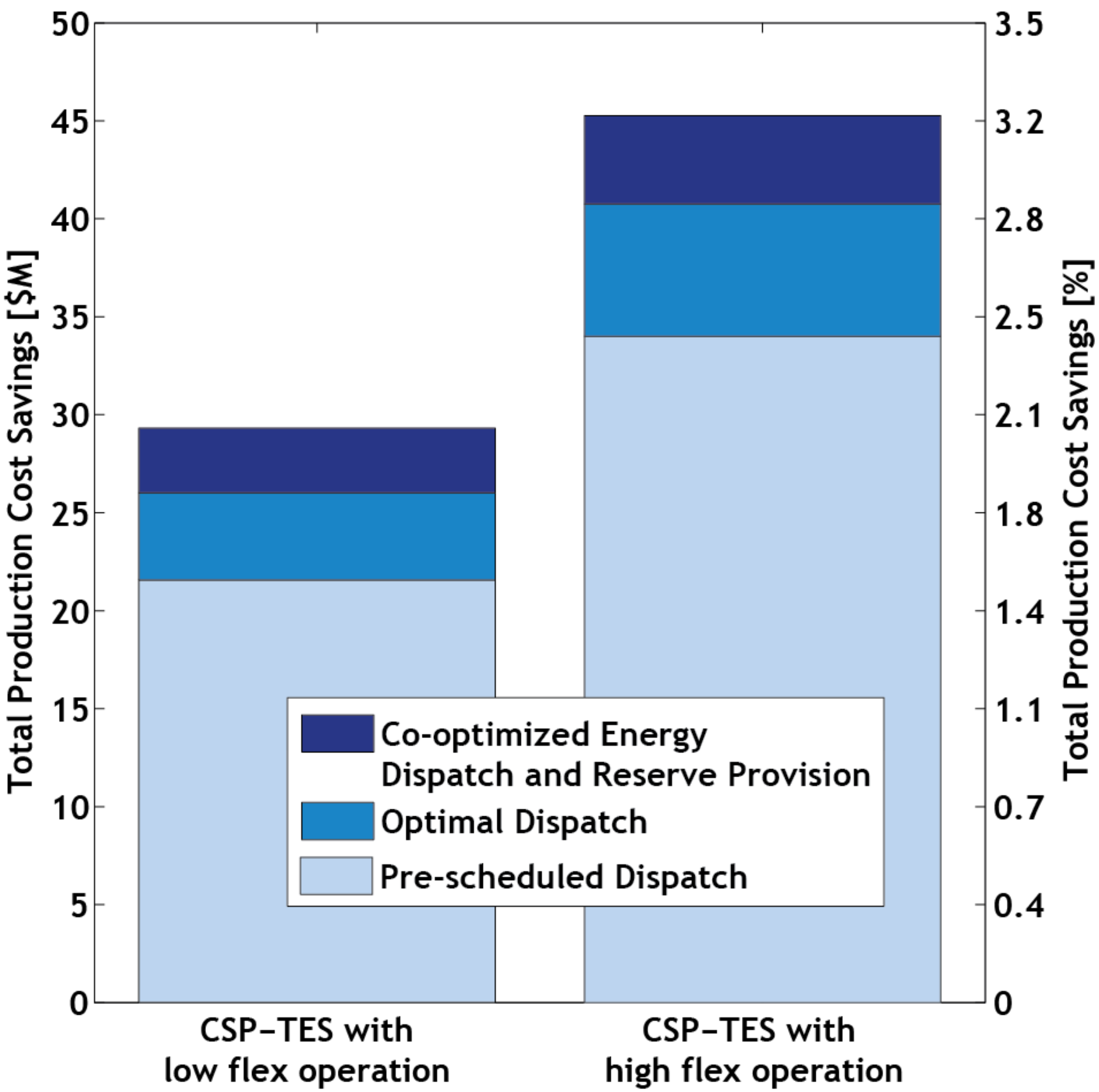


Reserve Prices



CSP-TES reduces the marginal price of regulation and contingency reserves.

Production Cost Savings



Production cost savings ranges from 2-3% of the total production cost. It is attributed to:

~75% due to energy from CSP-TES

~15% due to optimally dispatching the CSP-TES energy

~10% due to provisioning reserves from CSP-TES spinning capacity

Conclusions

- **Most of the value of CSP is in displacing high-cost fuels; which is captured in fixed-dispatch modeling.**
- **Further 25% increase in system value when CSP is modeled with separate storage & generation components and co-optimized for energy and operating reserves.**
- **Co-optimization yields complicated results; the effect and value of CSP-TES on new systems can be be captured more accurately with more detailed modeling.**

Thank You

Questions?

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