Valuing concentrating solar power with thermal energy storage

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BrightSource Highlights

World – Class Leadership	▪ Deep and experienced board and senior management teams with prior successful execution in fossil power plant generation and renewable solar industries ▪ Leadership experience from top utility and IPP companies
Markets	▪ $200+ billion global solar thermal electricity generation markets ▪ $16 billion thermal enhanced oil recovery (EOR) markets ▪ Industrial process applications: use of solar steam for mining, chemicals and desalinization
Superior technology	▪ Utilize **proven technology** in power tower with conventional steam generator, converting solar energy to high-value steam using proprietary systems with **integrated storage** ▪ Strong IP portfolio (43 patents pending and approved, including 9 U.S. issued patents)
Backed by leading Investor Companies	VantagePoint Capital Partners, bp alternativenergy, Draper Fisher Jurvetson, Goldman Sachs, Riverwood, google.org, ALSTOM, Morgan Stanley, CalSTRS, Black River, DBL Investors, Chevron
Pipeline: Domestic & International	▪ Technology enables diverse applications and revenue streams from both steam & power sales ▪ One of the largest solar pipelines in the U.S. PG&E, Southern California Edison An Edison International Company
Partnerships with leading global energy & technology companies	ALSTOM, Chevron, Bechtel, nrg, Google

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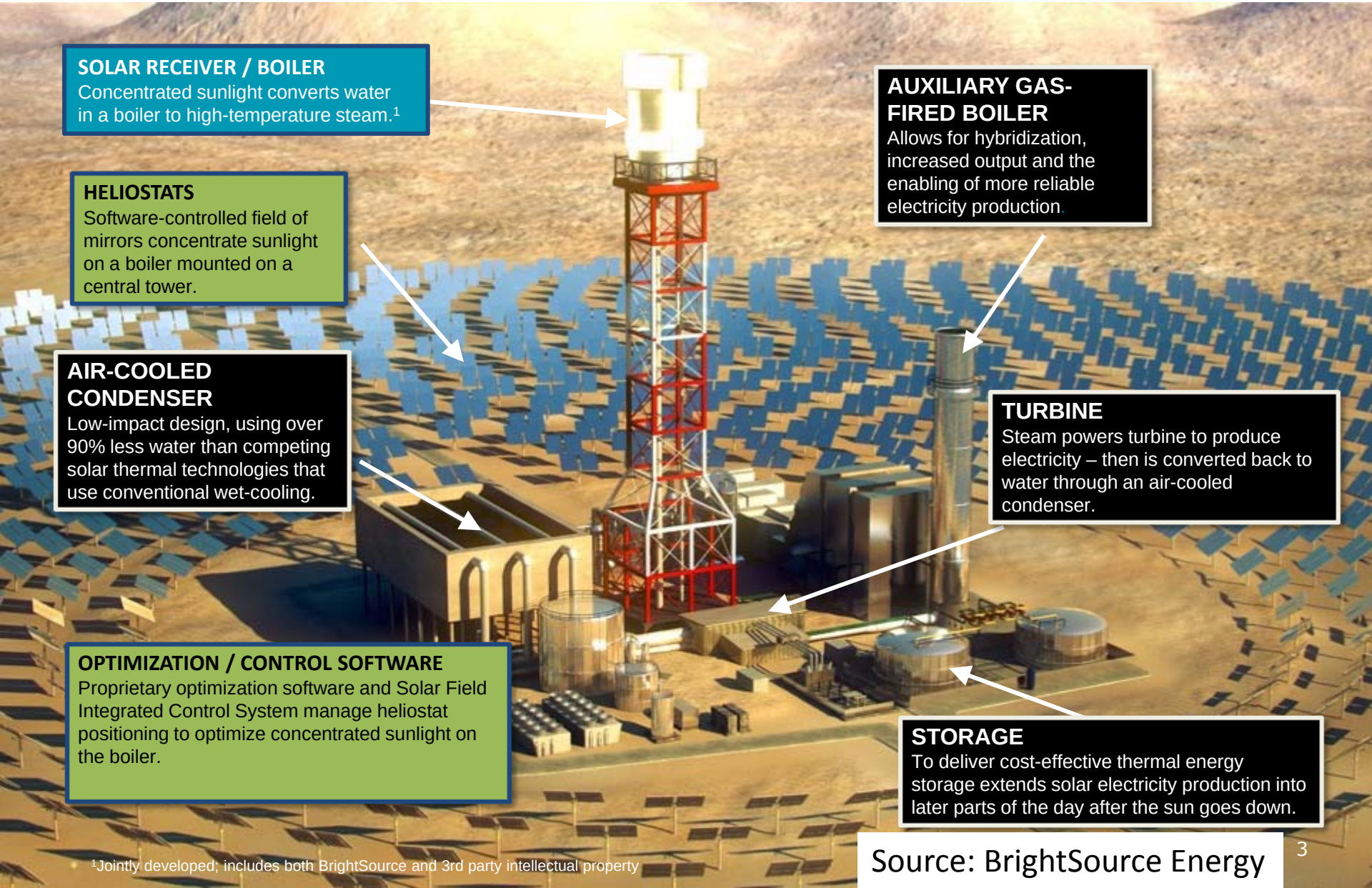
Representation of BrightSource plant design with thermal energy storage



[1]Jointly developed; includes both BrightSource and 3rd party intellectual property

Source: BrightSource Energy

KEMA and other forthcoming studies need to evaluate all the potential market and reliability benefits of CSP with thermal energy storage

- Wholesale energy market value (or avoided fuel costs for vertically integrated utilities)
- Ancillary services market revenues
- Capacity (Resource Adequacy) value
- Reduction of system integration costs associated with more intermittent energy resources
- Other operational, emissions and reliability benefits

KEMA and other forthcoming studies need to compare and contrast results using different modeling approaches

- Exogenous fixed-price models
- Endogenous price models
  - Primarily regional production simulations
- Multi-year planning/investment system models
- Probabilistic reliability models (RA capacity)
  - Loss of load probability (LOLP) models, Equivalent load carrying capability (ELCC) models
- Hourly capacity factor methods (RA capacity)
  - E.g., CPUC “net qualifying capacity (NQC)” rules

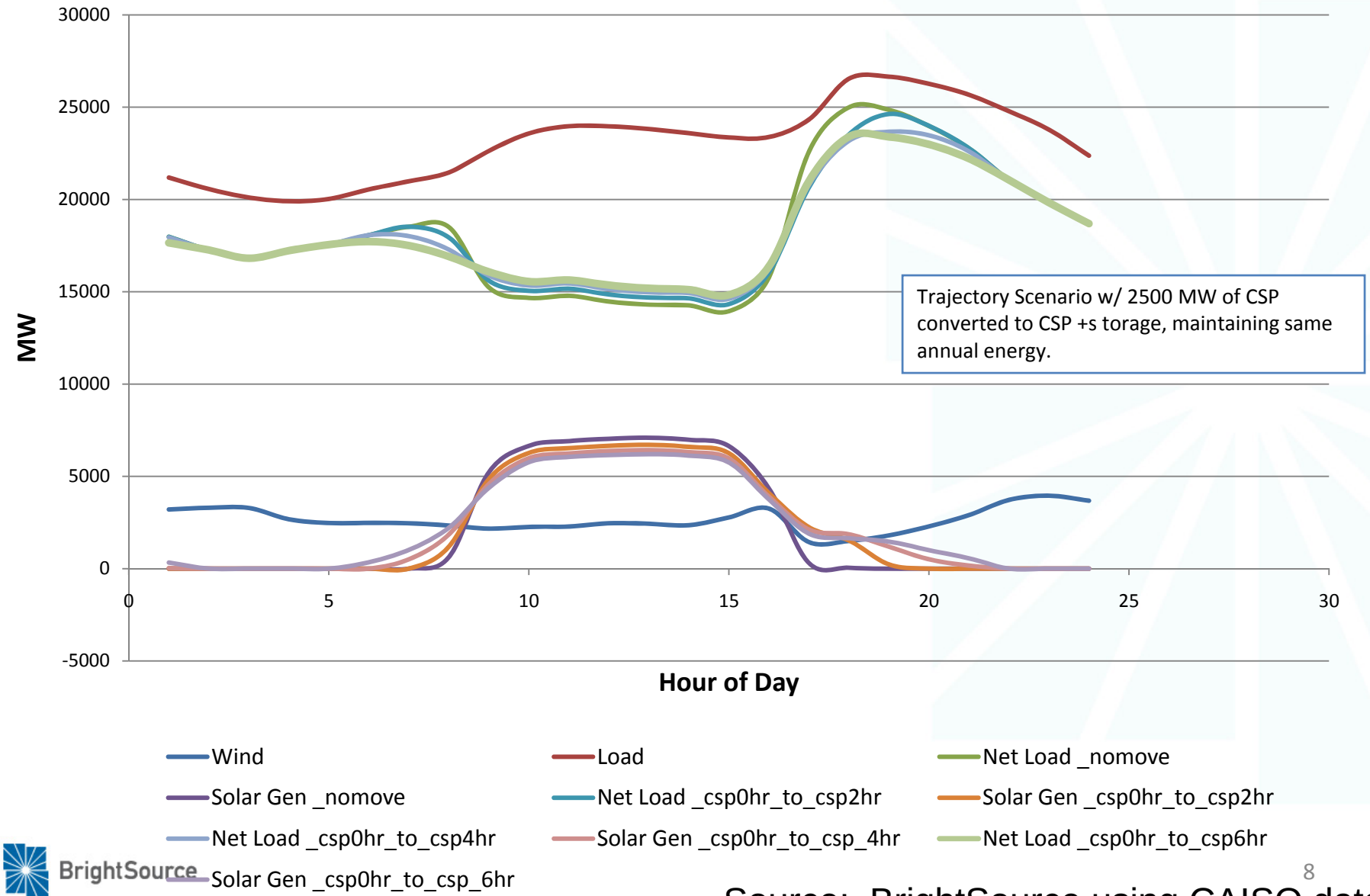
Other important criteria for policy-relevant analysis of thermal energy storage

- Use realistic scenarios for wind and solar penetration, based on state RPS forecasts
  - E.g., modify CPUC 33% RPS scenarios
- Ideally model both historical (backcasting) and future market scenarios and examine effect of changing system conditions
- Conduct sensitivities on thermal storage parameters, particularly hours of storage, size of solar field, etc.
- Compare to other generation and storage solutions

An important missing element in current studies: Avoided integration costs due to CSP with thermal storage

- Lower production forecast error than other variable energy
- Smoothing of intra-hour production variability
- Potential to slow rate of morning net load ramp
- Potential to slow rate of late afternoon net load ramp
- Solar dispatchability could offset the need for new integration resources (beyond the capability of the planned generation fleet)

Example 1 of CSP with storage potentially smoothing ramps at 33% RPS



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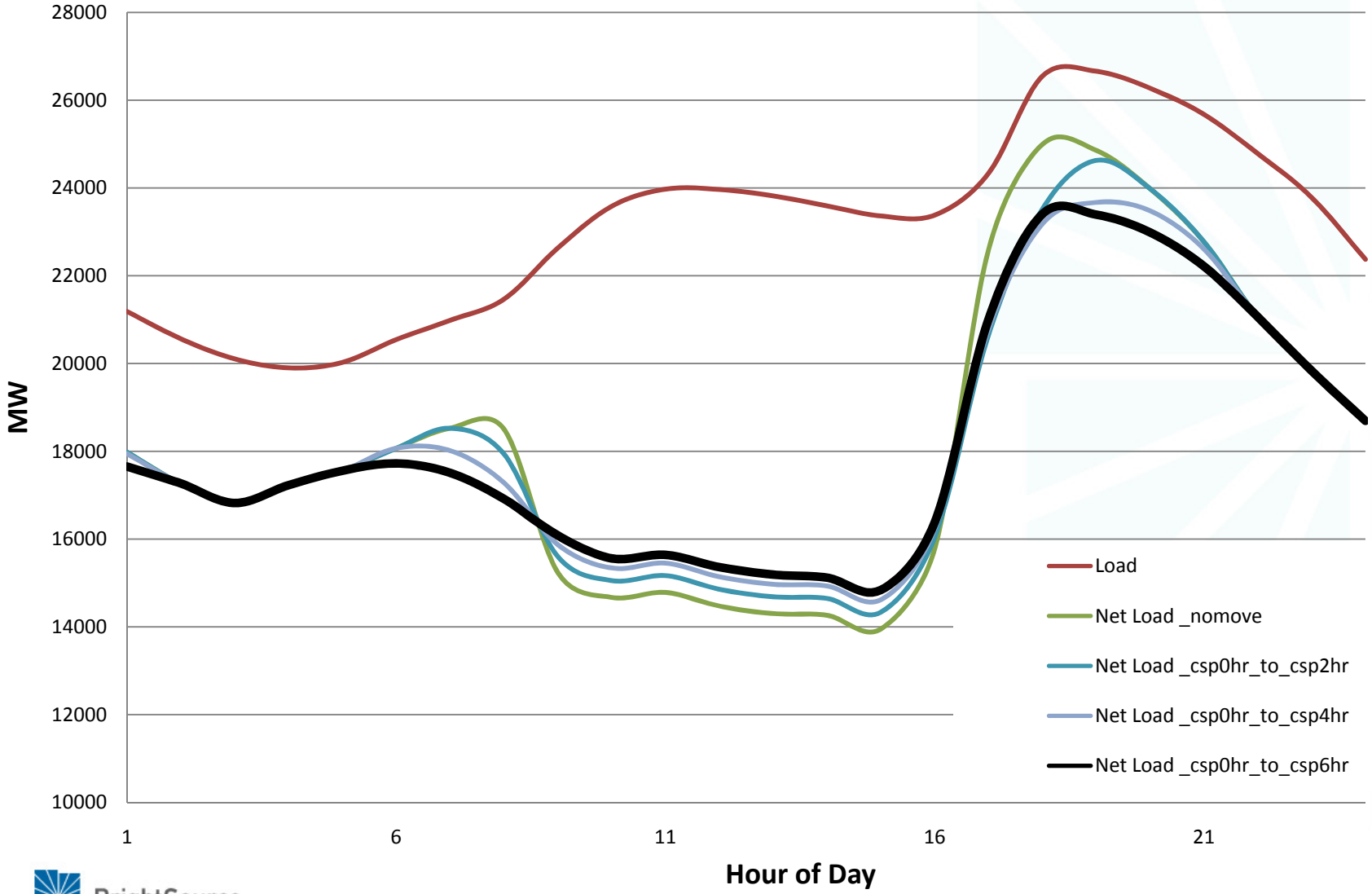
Source: BrightSource using CAISO data

Closer look at prior example



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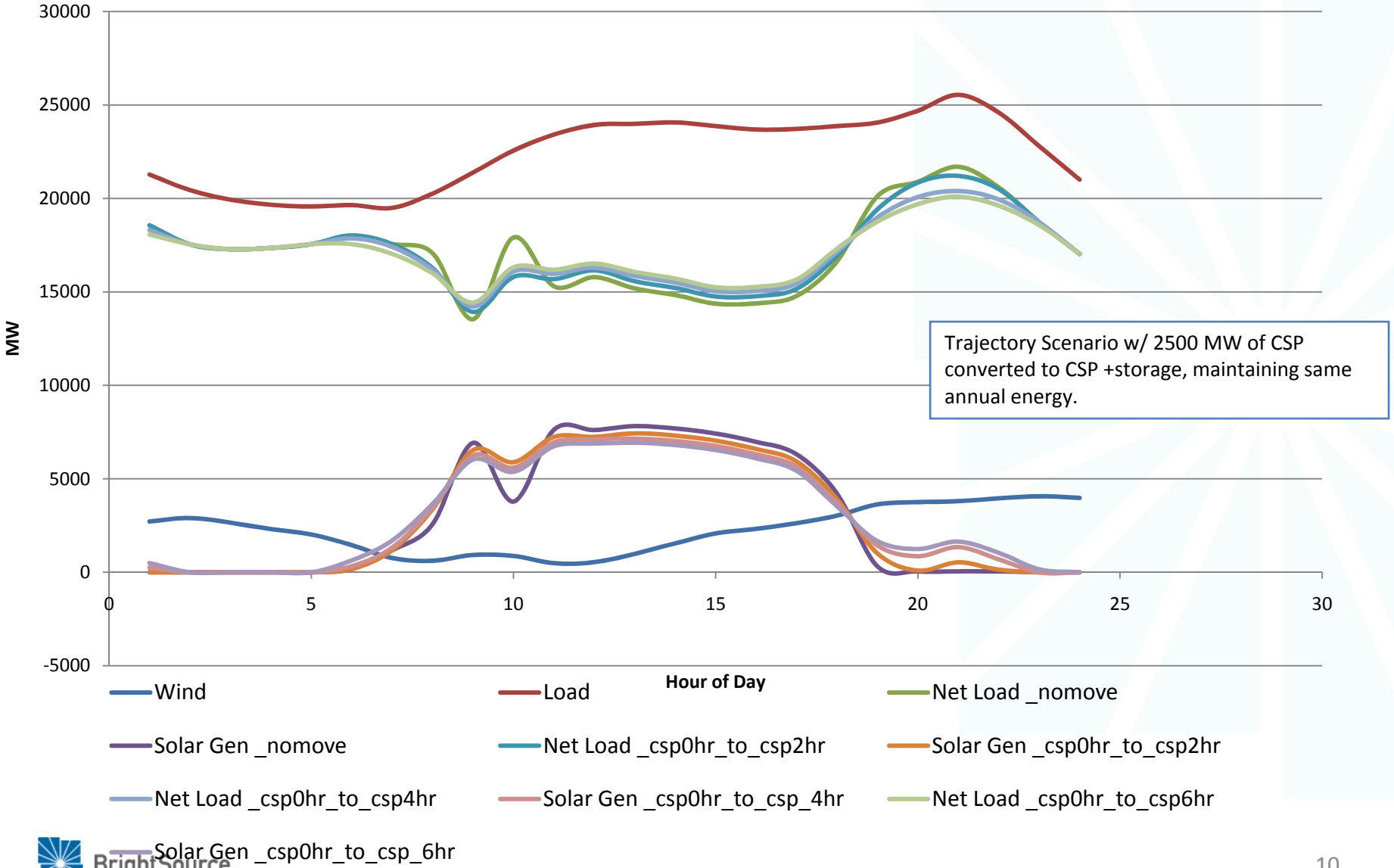
Example 2 of CSP with storage potentially smoothing ramps at 33% RPS



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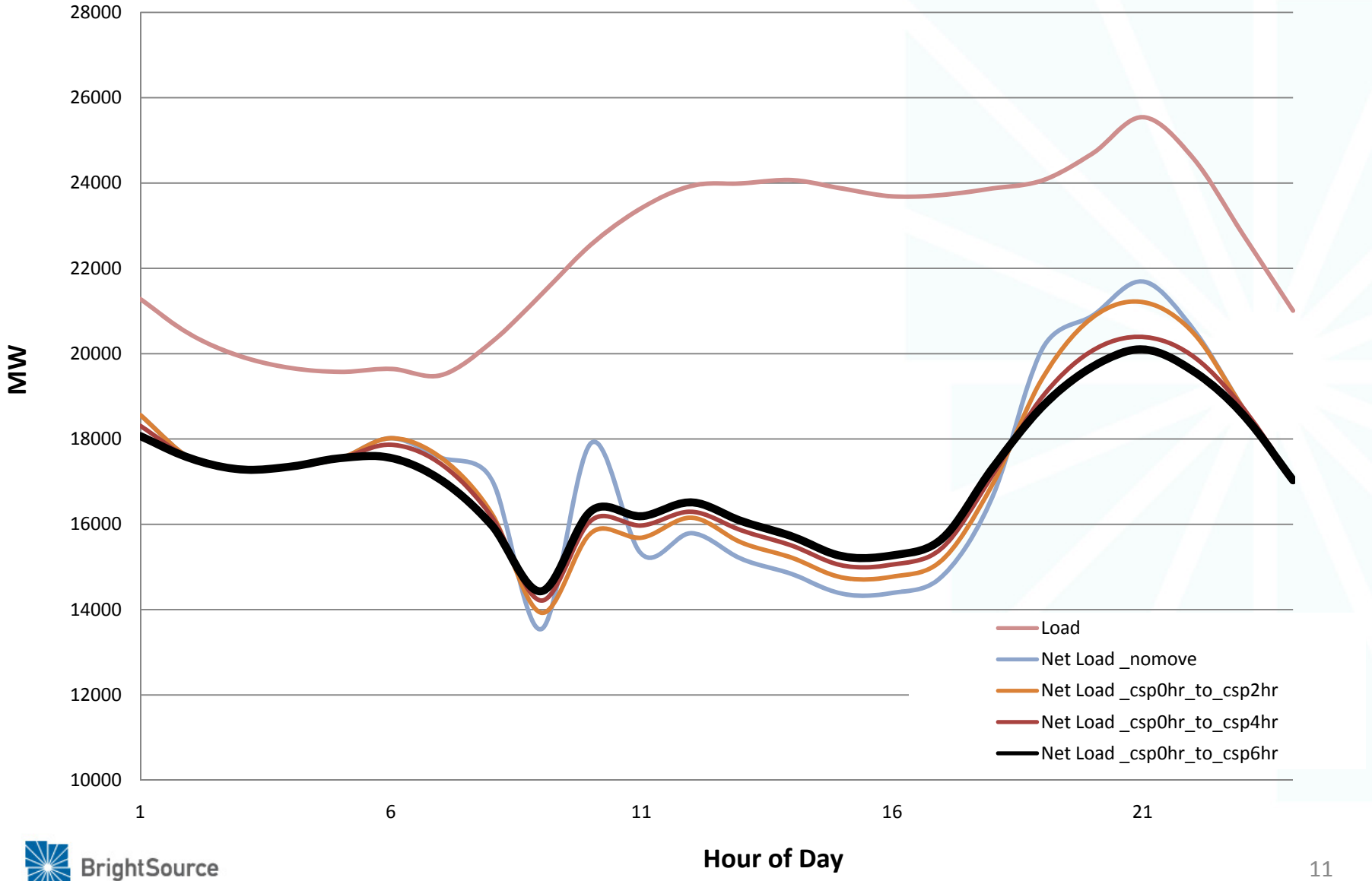
Source: BrightSource using CAISO data

Closer look at prior example



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Summary of study findings* to date

- Concentrating solar power with thermal storage has significant additional market value compared to non-dispatchable solar (CSP or PV), including:
  - Total incremental value estimates for energy and ancillary services in the $5-10/MWh range for *current* market conditions (e.g., CAISO 2005, 2010-11 market prices) [Madaeni et al, 2010-11; BrightSource internal estimates, unpublished 2011-12]
  - Capacity value of CSP with thermal storage approaches full rating on turbine as a function of hours of storage, size of solar field, regulatory or market incentives [Madaeni et al, 2011]
  - Marginal capacity value of CSP with thermal storage is retained at high solar penetration, while value of non-dispatchable solar declines; the value gap could be $15-20/MWh, depending on the level of solar penetration, CSP plant configuration and assumed cost of new generation capacity [Mills and Wiser, 2012]
  - Significantly lower integration costs, leading to avoided integration costs higher than $5/MWh, depending on the power system and other factors, such as number of hours of storage [Mills and Wiser, 2012; infer from CAISO 33% RPS data; Navigant, et al., 2011; other studies]

* *See next slide*

Selected literature survey

- Borenstein, S., "The Market Value and Cost of Solar Photovoltaic Electricity Production," Center for the Study of Energy Markets Working Paper 176, January 2008
- California ISO (CAISO), 33% RPS simulations [2011-present]
  - "Track I Direct Testimony of Mark Rothleder on Behalf of the California Independent System Operator Corporation," Before the Public Utilities Commission of the State of California, Order Instituting Rulemaking to Integrate and Refine Procurement Policies and Consider Long-Term Procurement Plans, Rulemaking 10-05-006, Submitted July 11, 2011.
- Denholm, P. and M. Mehos, Enabling Greater Penetration of Solar Power via the Use of CSP with Thermal Energy Storage, National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20-52978, November 2011, available at http://www.nrel.gov/csp/pdfs/52978.pdf.
- Denholm, P., S.H. Madaeni and R. Sioshansi, Capacity Value of Concentrating Solar Power Plants, National Renewable Energy Laboratory, Technical Report, NREL/TP-6A20-51253, June 2011, available at http://www.nrel.gov/docs/fy11osti/51253.pdf
- Madaeni, S.H.,, R. Sioshansi, and P. Denholm, "Estimating the Capacity Value of Concentrating Solar Power Plants with Thermal Energy Storage: A Case Study of the Southwestern United States," *IEEE Transactions on Power Systems,* 2011.
- Madaeni, S.H., R. Sioshansi, and P. Denholm, "How Thermal Energy Storage Enhances the Economic Viability of Concentrating Solar Power," *Proceedings of the IEEE*, 2011.
- Mills, A., and R. Wiser, "Changes in the Economic Value of Variable Generation at High Penetration Levels," LBNL-5445E, June 2012
- Mills, A., A. Phadke, and R. Wiser, Exploration of Resource and Transmission Expansion Decisions in the Western Renewable Energy Zone Initiative, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, LBNL-3077E, February 2010, available at http://eetd.lbl.gov/ea/emp/reports/lbnl-3077e.pdf.
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- Sioshansi, R., and P. Denholm, "The value of concentrating solar power and thermal energy storage," National Renewable Energy Laboratory, NREL/TP-6A2-45833, Feb. 2010.