The Role of Hydrogen in Future Energy Systems—Seasonal Energy Storage

Omar J. Guerra and Josh Eichman

National Renewable Energy Laboratory (NREL)

RMEL On Demand Webinar

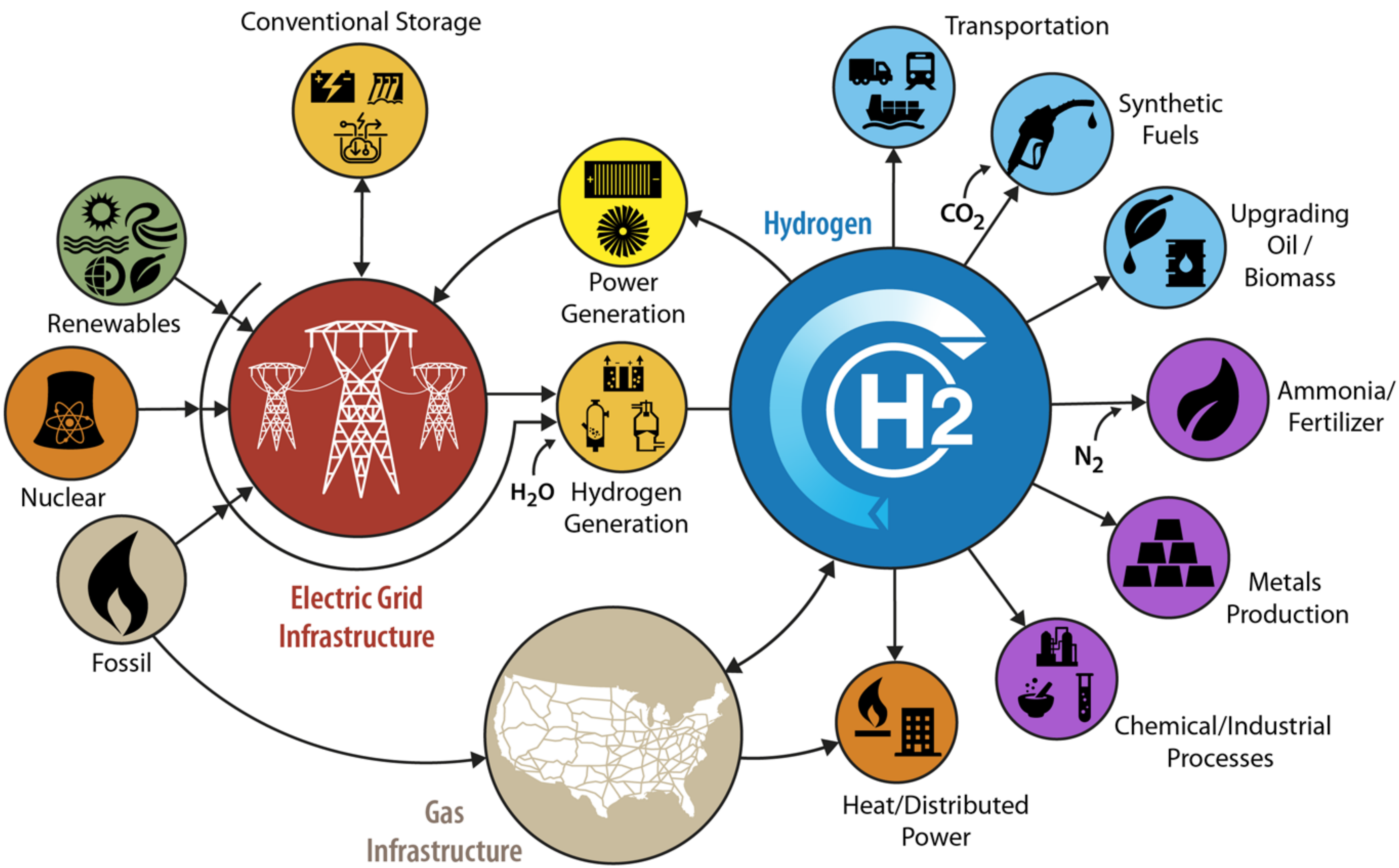
November 2, 2020

Outline

- Overview of hydrogen technologies
- The seasonal storage problem
- Case study
- Results
- Conclusions

Role of Hydrogen Technologies in Future Energy Systems

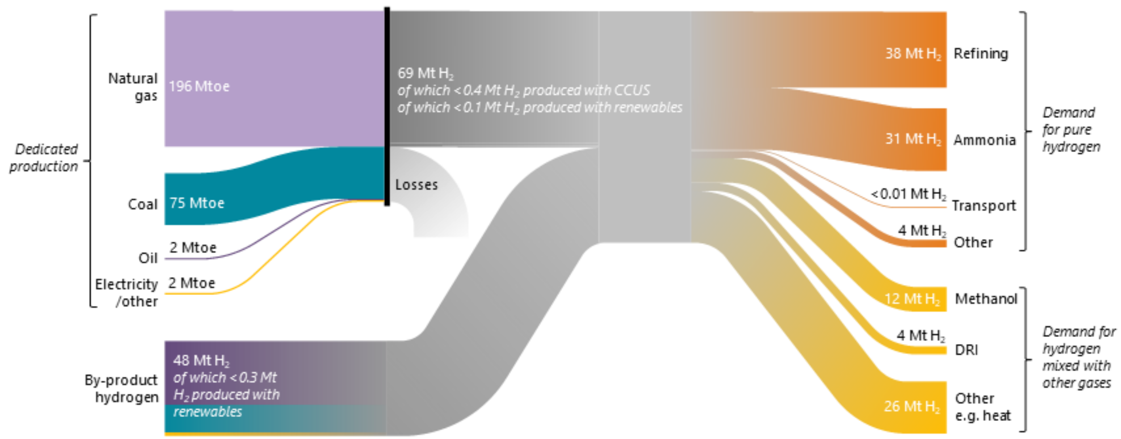
Hydrogen is a flexible and potentially a zero-carbon emission energy carrier that could enable the integration of different energy systems.



Today's Hydrogen Value Chains

Existing applications of hydrogen can use hydrogen produced using alternative, cleaner production methods and from a more diverse set of energy sources.

Supply and demand of hydrogen in 2018 [REV_C]



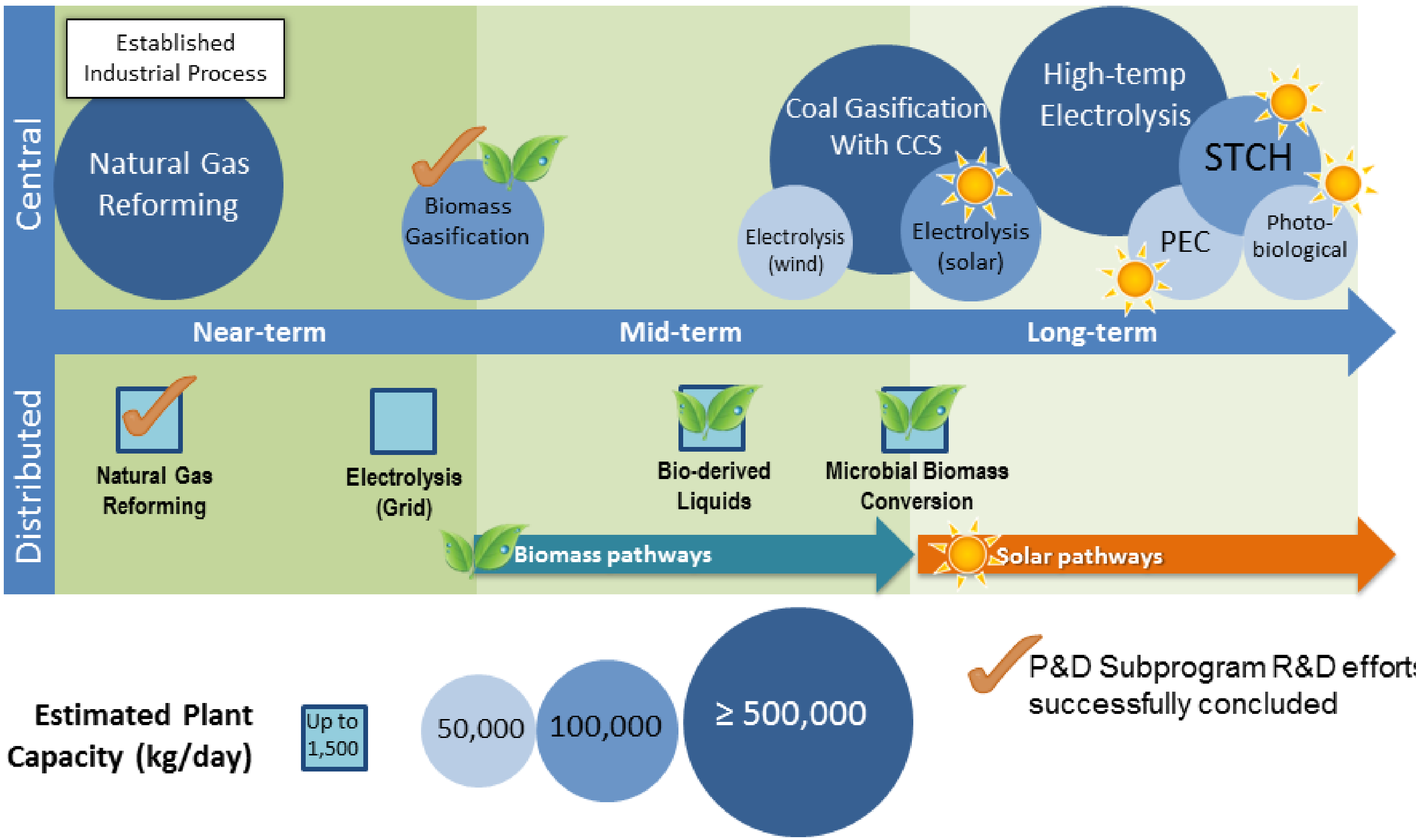
DRI: direct reduced iron steel production

Source: IEA (2019). The Future of Hydrogen: Seizing Today's Opportunities.

- Demand for hydrogen in its pure form is around 70 million tonnes per year (MtH_2/yr).
- This hydrogen is almost entirely supplied from fossil fuels, with 6% of global natural gas and 2% of global coal going to hydrogen production.

Current and Future Pathways for Hydrogen Production

There is a wide portfolio of hydrogen production processes and a wide range of production scales.

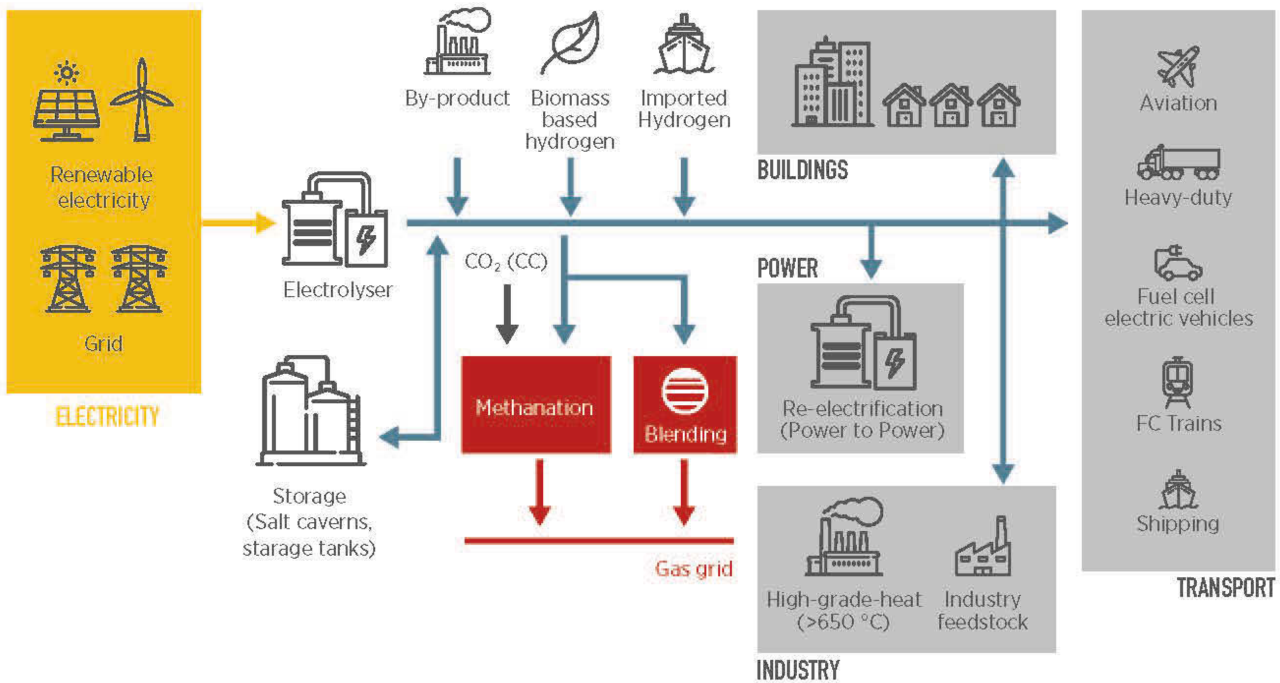


PEC: photoelectrochemical, STCH: solar thermochemical cycles for hydrogen production, CCS: carbon capture and storage

Source: DOE. (2020). "Hydrogen Production Pathways."

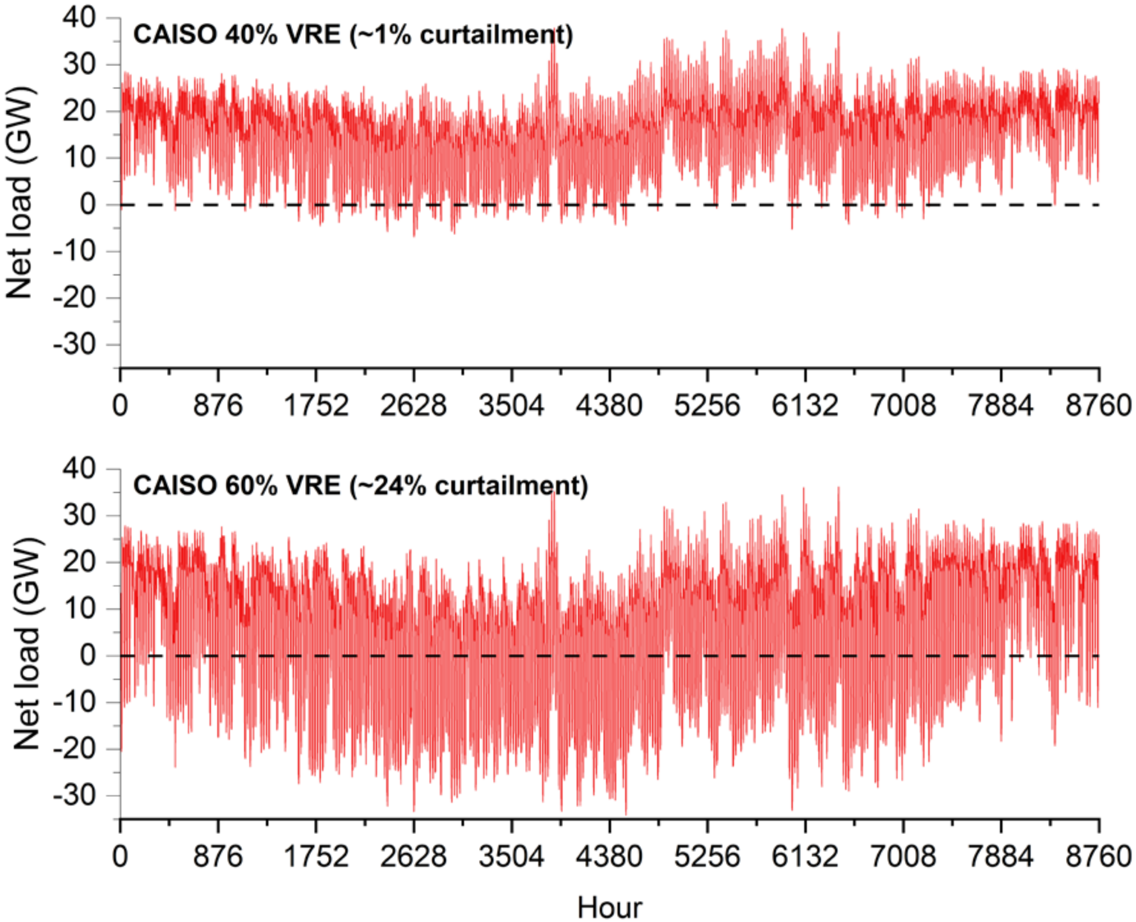
Hydrogen as an Enabling Technology for the Integration of VRE

Hydrogen can enhance the flexibility of power systems and facilitate the integration of increasing shares of variable renewable energy (VRE)* into the power system.



* Wind and solar photovoltaic (PV) power

Seasonal Energy Storage: What Is the Problem?



Based on 2019 wind and solar PV generation

Integration of VRE versus VRE curtailment (without storage):

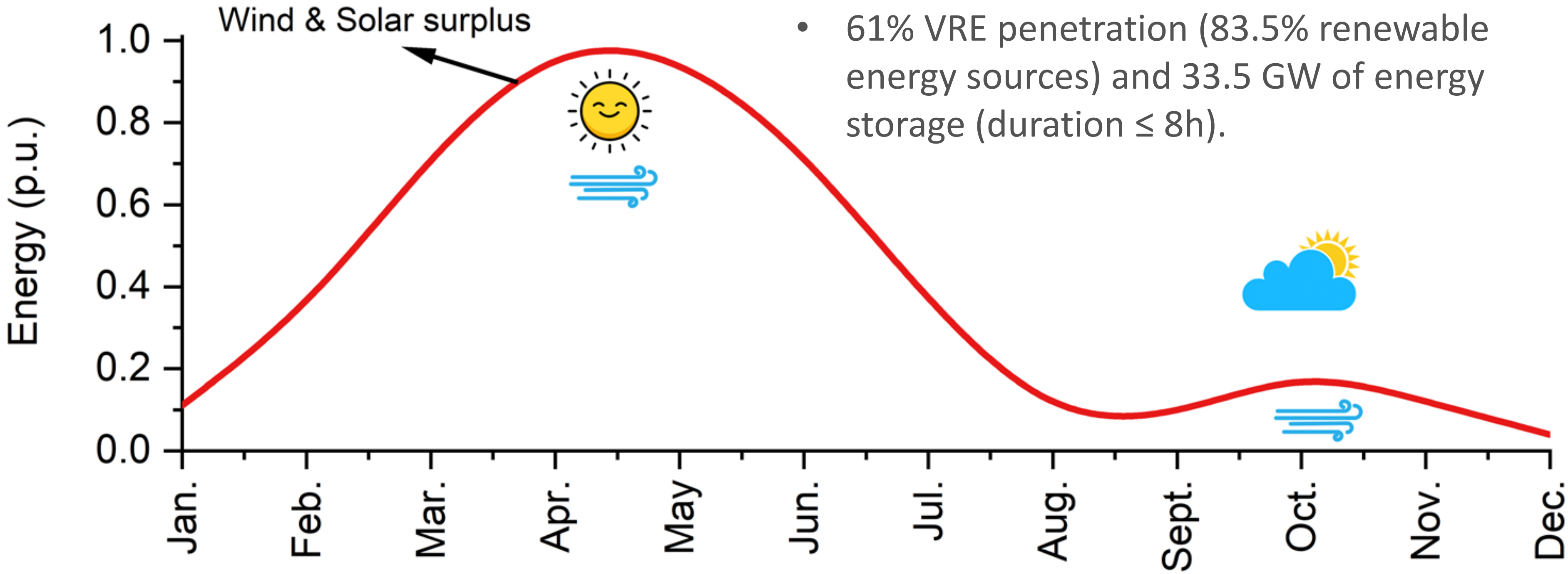
Subhourly variation: better scheduling, short-term storage devices, e.g., high-power batteries and flywheels

Diurnal shifts: devices with storage capacities from 4–8 hours, e.g., certain batteries and pumped hydro storage

Multiday periods of supply and demand imbalance: storage technologies with even longer duration (12+ hours), e.g., pumped hydro storage and compressed air storage

100% renewable power systems: require seasonal storage capacities of weeks or months, including hydrogen or other fuels.

The Need for Seasonal Storage



VRE surplus:

- 2050 VRE surplus for Southern California Edison (SCE) zone, Western Interconnection power system
- 61% VRE penetration (83.5% renewable energy sources) and 33.5 GW of energy storage (duration ≤ 8h).

Seasonal energy storage:

- Grid-integrated seasonal energy storage can reshape seasonal fluctuations of variable and uncertain power generation by reducing energy curtailment, replacing peak generation capacity, and providing transmission benefits.
- There is a lack of understanding of the value of grid-integrated seasonal energy storage technologies and their impacts on power system operations.

Short Summary of Existing Studies on Seasonal Energy Storage

Modeling seasonal energy storage is a challenging problem.

Limitations of current seasonal storage studies:

- Modeling seasonal storage has been based on the analysis of **chronological time series of VRE generation and load** without considering power system network constraints.
- The techno-economic assessment of seasonal storage has been limited to the **cost estimation of storage technologies**, i.e., without a corresponding profitability analysis.
- Including network constraints allows for **a more realistic representation of the power system and the storage device**, e.g., benefit from mitigating network congestion.

The goal:

- Including network constraints with the time-series approach above can significantly **increase computational requirements.**
- Short-duration storage→ This is mitigated by **decomposing the problem into many smaller problems and running them sequentially, e.g., PLEXOS.**
- Seasonal energy storage→ The model must consider the benefit of shifting energy across many months, thereby limiting the ability to decompose the problem temporally and again increasing computational concerns.

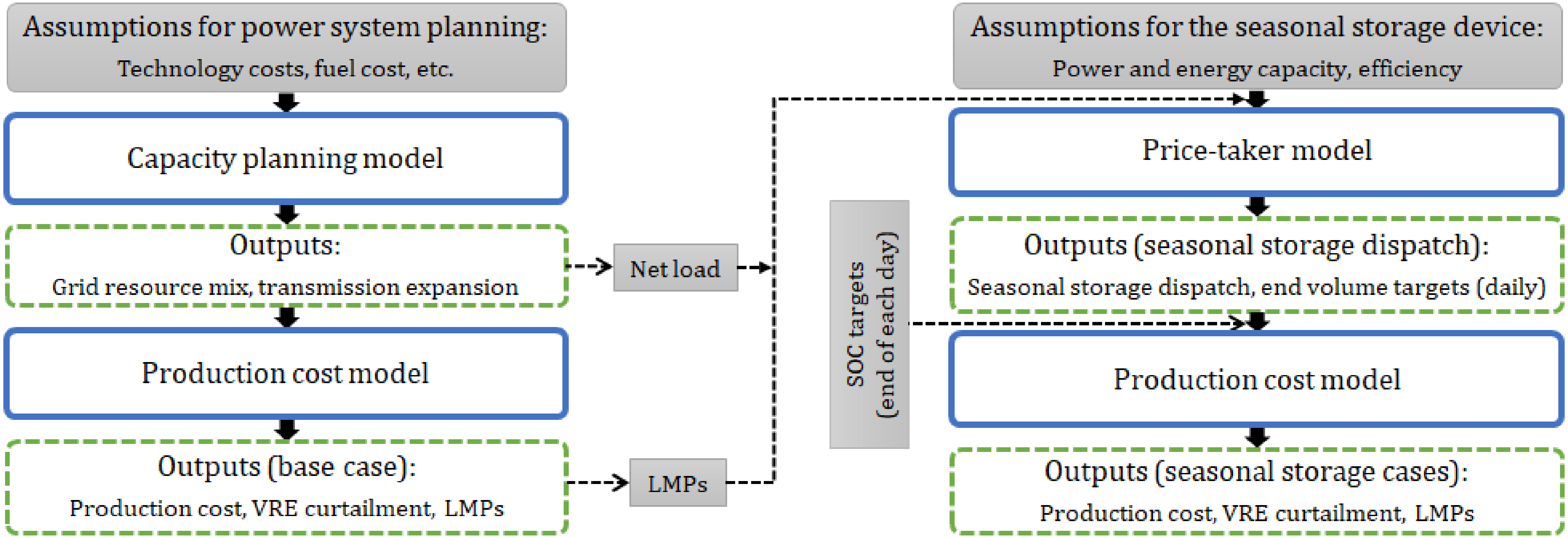
Approach: Multi-Model Strategy

The approach is based on existing power system modeling and simulation tools.

LMP: Locational marginal price

SOC: state of charge

Multi-model approach for the assessment of seasonal storage:

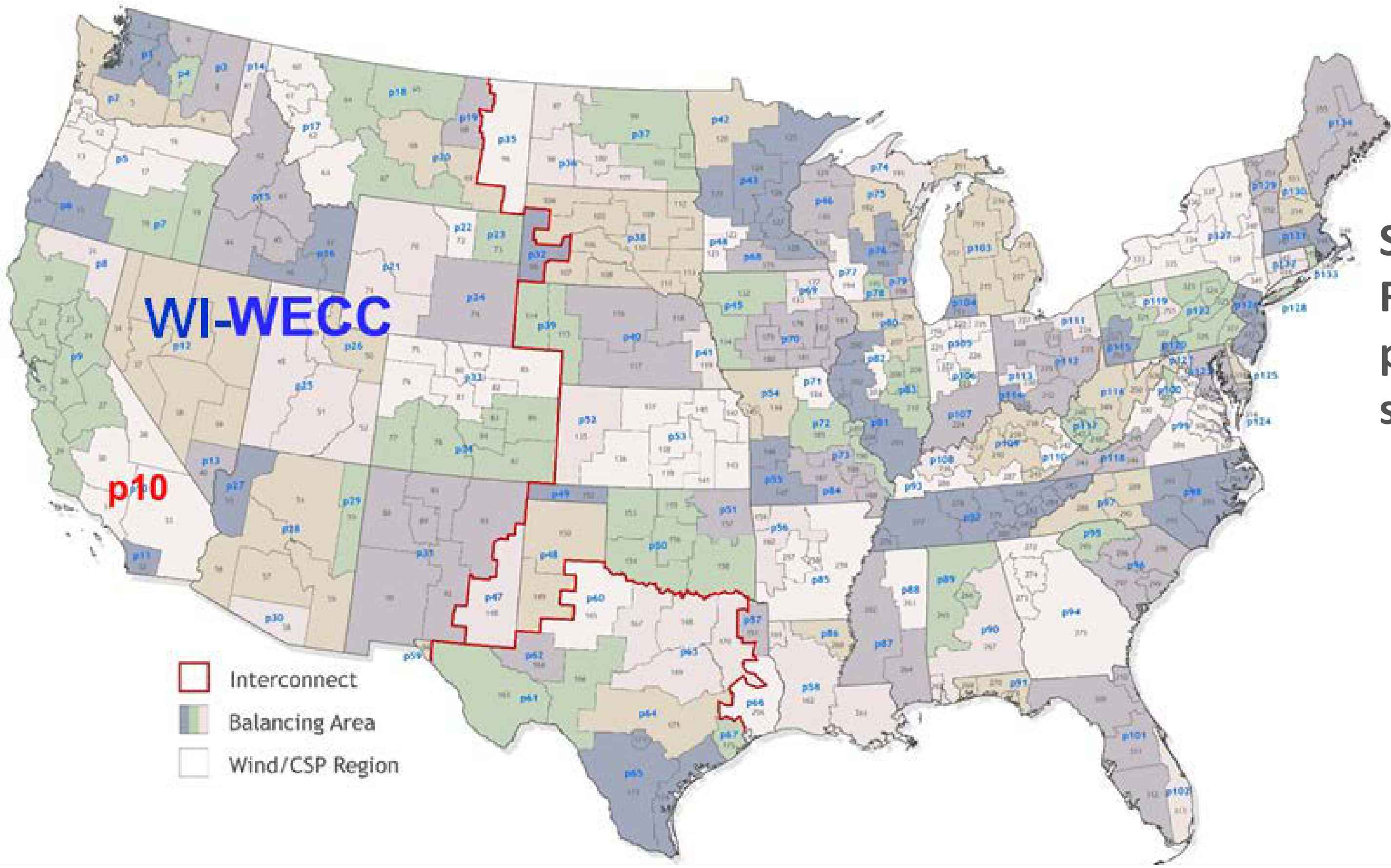


Novelty of our approach:

- Our approach allows the problem to be discretized into days and run sequentially based on daily end-volume targets from a price-taker model.
- Our approach uses the benefit-to-cost (BCR) metric for the economic assessment of seasonal storage technologies based on the total system value—avoided production costs (operational value) and avoided capacity costs (capacity value).

Case Study

Western Interconnection power system:



Scenarios: Renewable portfolio standards

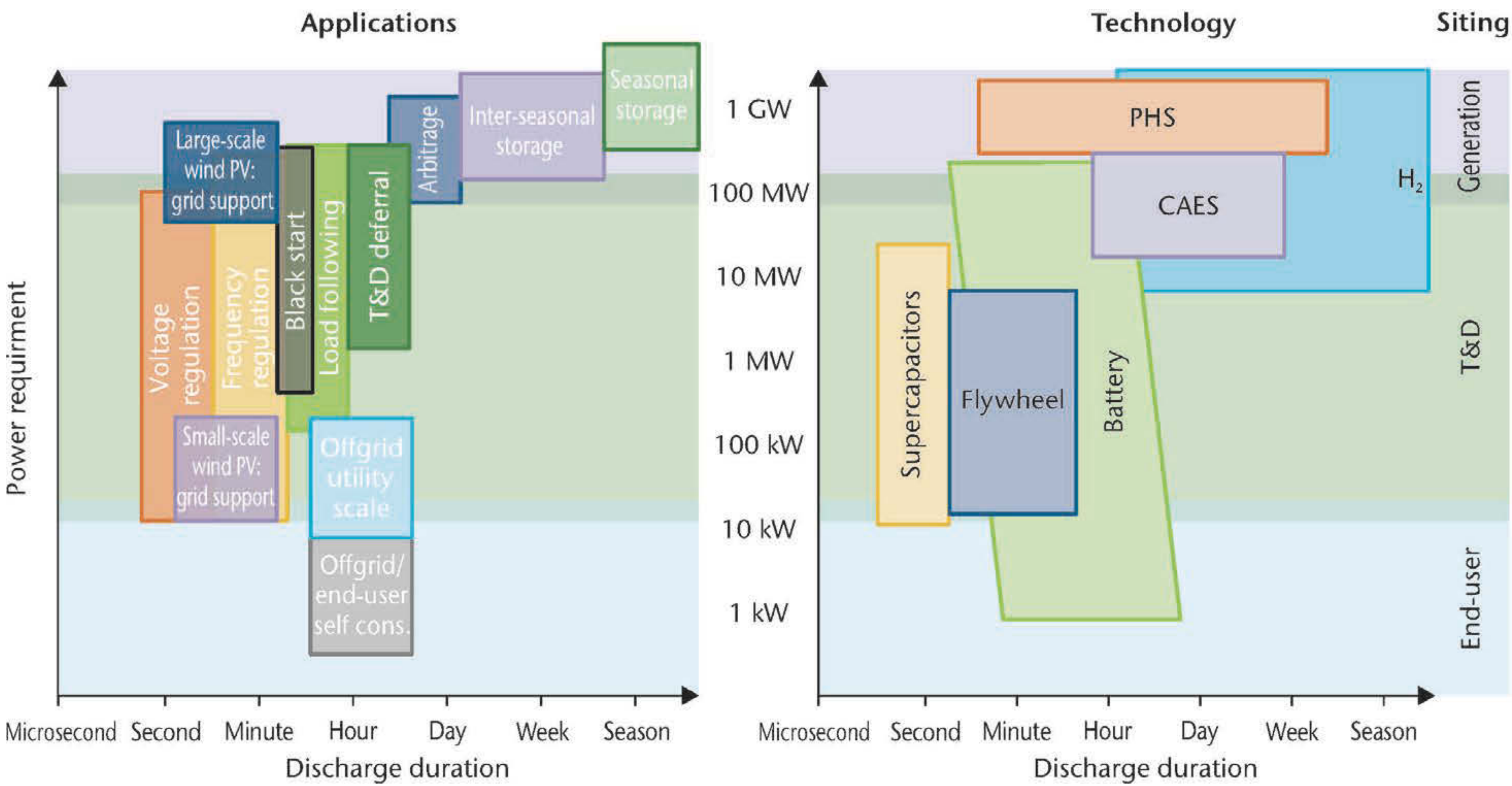
- Geographic location of the Western Interconnection (WI) power system, based on the capacity planning model Regional Energy Deployment System (ReEDS)
- Region p10 corresponds to SCE territory.

Case Study

Seasonal energy storage: Technologies

Electricity storage applications and technologies:

Source: IEA (2014). Technology Roadmap: Hydrogen and Fuel Cells.



Case Study

Techno-economic assumptions:
Storage power capacity: 2 GW (SCE zone)
Discharge duration: 1 day (1d), 2 days (2d), 1 week (1w), 2 weeks (2w), and 1 month (1m)

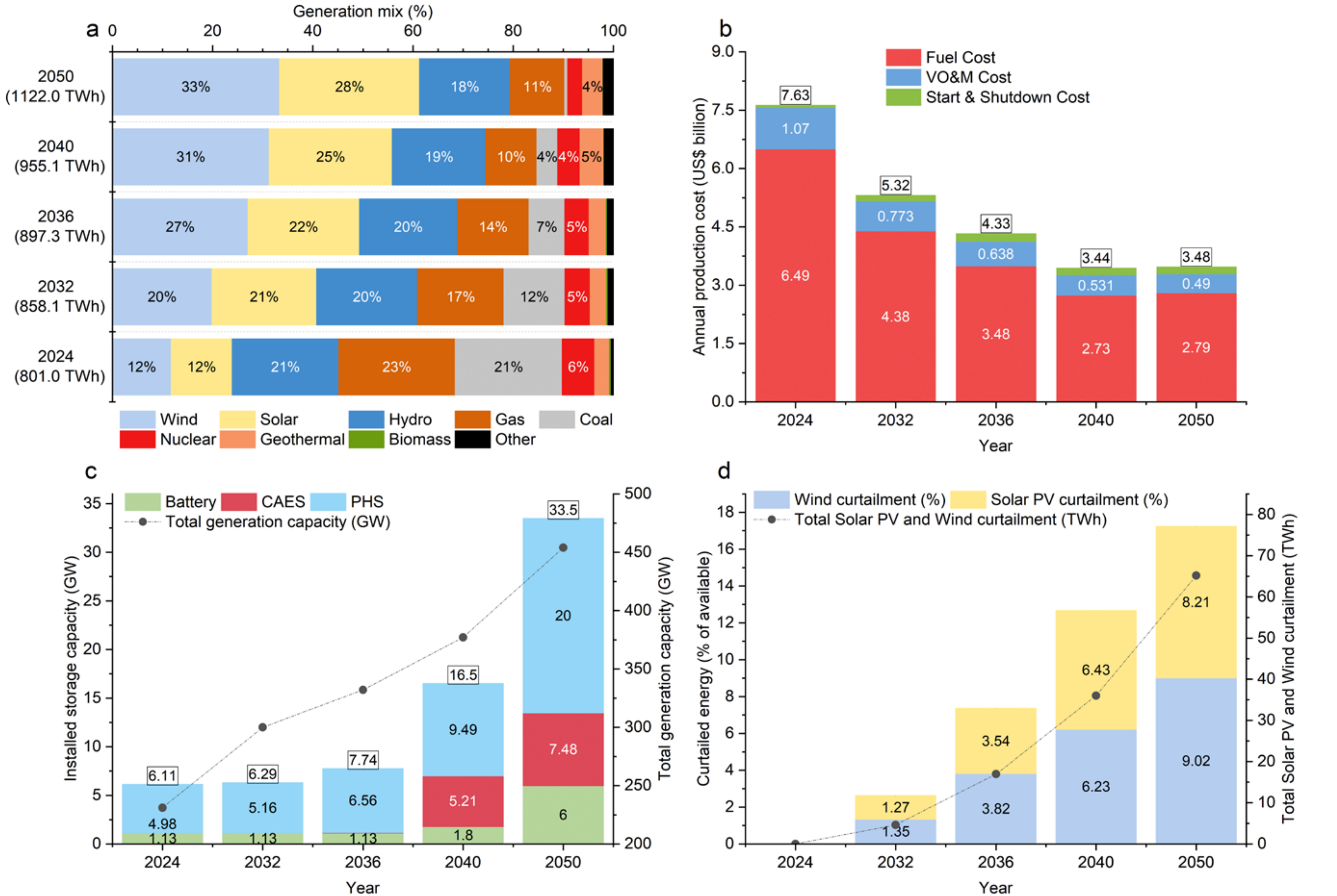
Technology (Round-Trip Efficiency, Lifetime)	Year	Power capacity cost ($ kW^{-1})			Energy capacity cost ($ kWh^{-1})		
		Min	Ref.	Max	Min	Ref.	Max
Hydrogen (40%, 18 years)	2025	1,507	3,013	4,520	1.8	3.7	5.5
	2050	650	1,300	1,950	0.5	1.0	1.5
CAES (60%, 30 years)	2025	434	817	984	9.1	34.9	80.8
	2050	415	755	947	8.9	31.0	81.6
PHS (80%, 55 years)	2025	573	1,156	1,819	17.4	50.3	101.8
	2050	573	1,164	2,807	17.3	50.9	97.4

Sources: Schmidt et al. (2019); IRENA. (2017). IEA (2015).

- The analysis also includes generic storage technologies with 40%, 60%, and 80% round-trip efficiency and three possible lifetimes—18 years, 30 years, and 50 years—for a total set of 9 generic storage technologies (combinations of 3 efficiencies and 3 lifetimes).
- Operational value → Based on the reduction of production cost; Capacity value → Based on the capacity credit approach (the ability of the seasonal storage device to supply energy during periods of peak net load (top 10 peak net load hours).

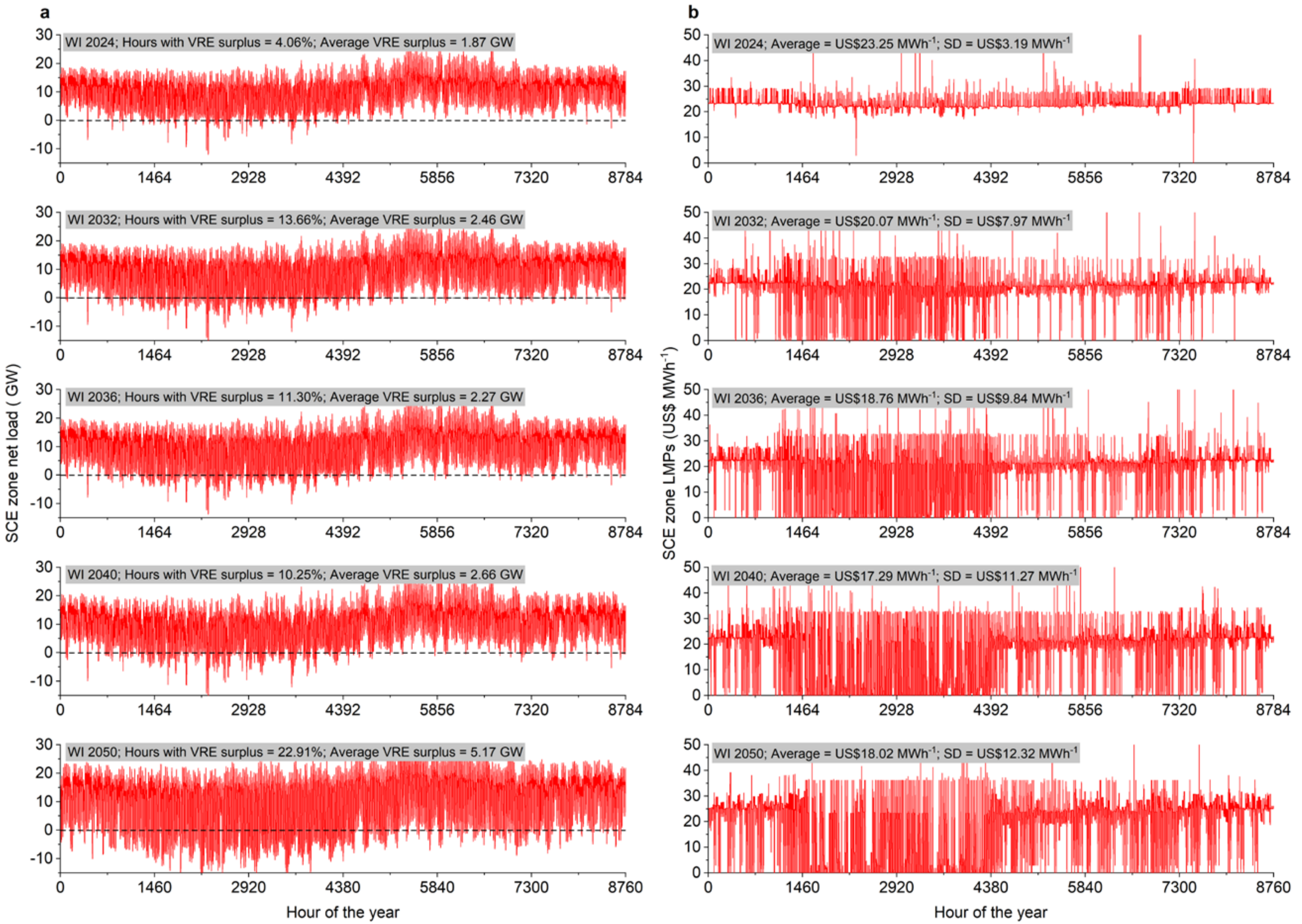
Results: Without Seasonal Storage

Evolution of the Western Interconnection power system from 2024–2050 in the base cases (PLEXOS):



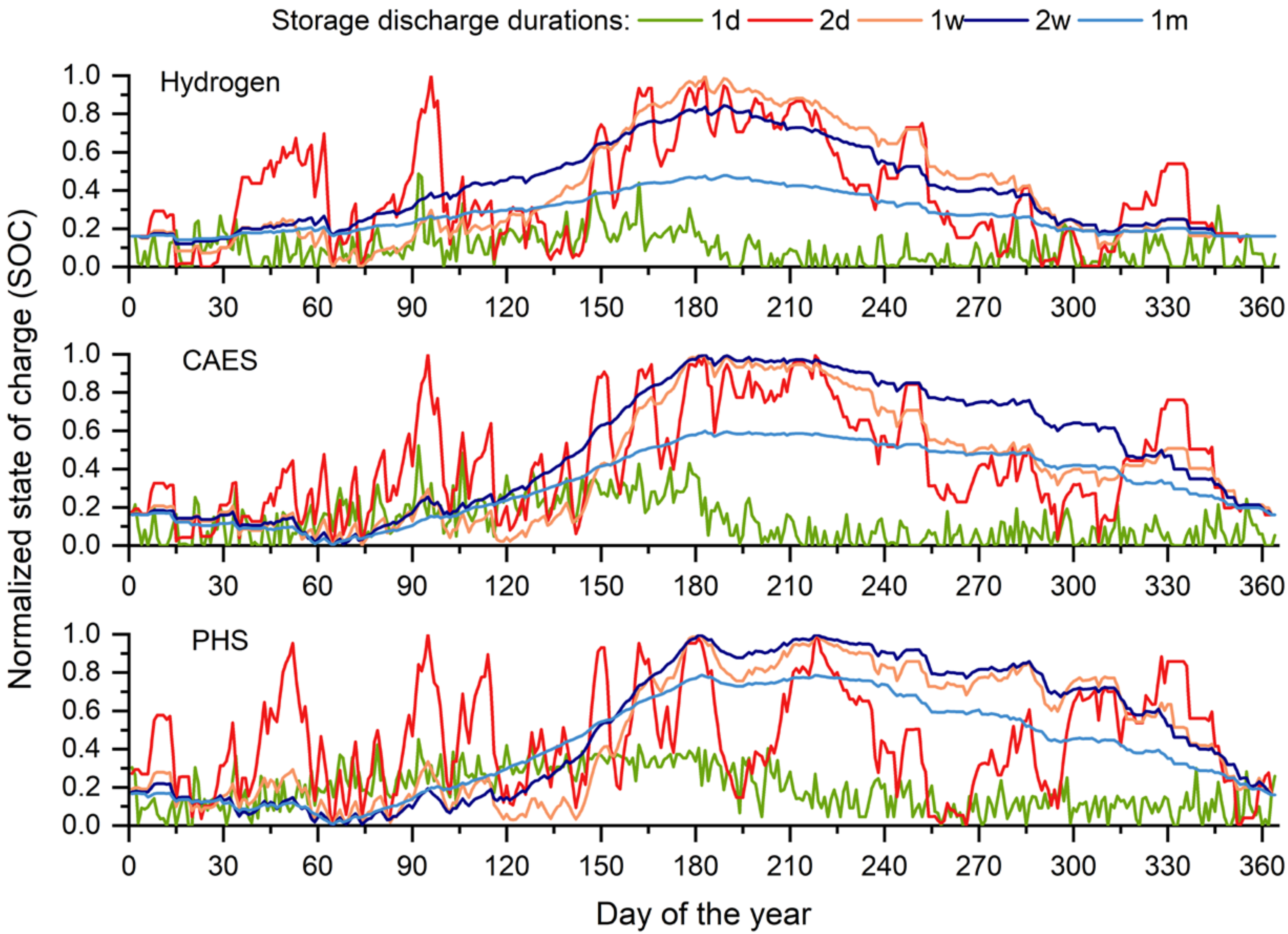
Results: Without Seasonal Storage

Hourly net load and LMPs in the SCE zone from 2024–2050 (opportunities for seasonal storage):



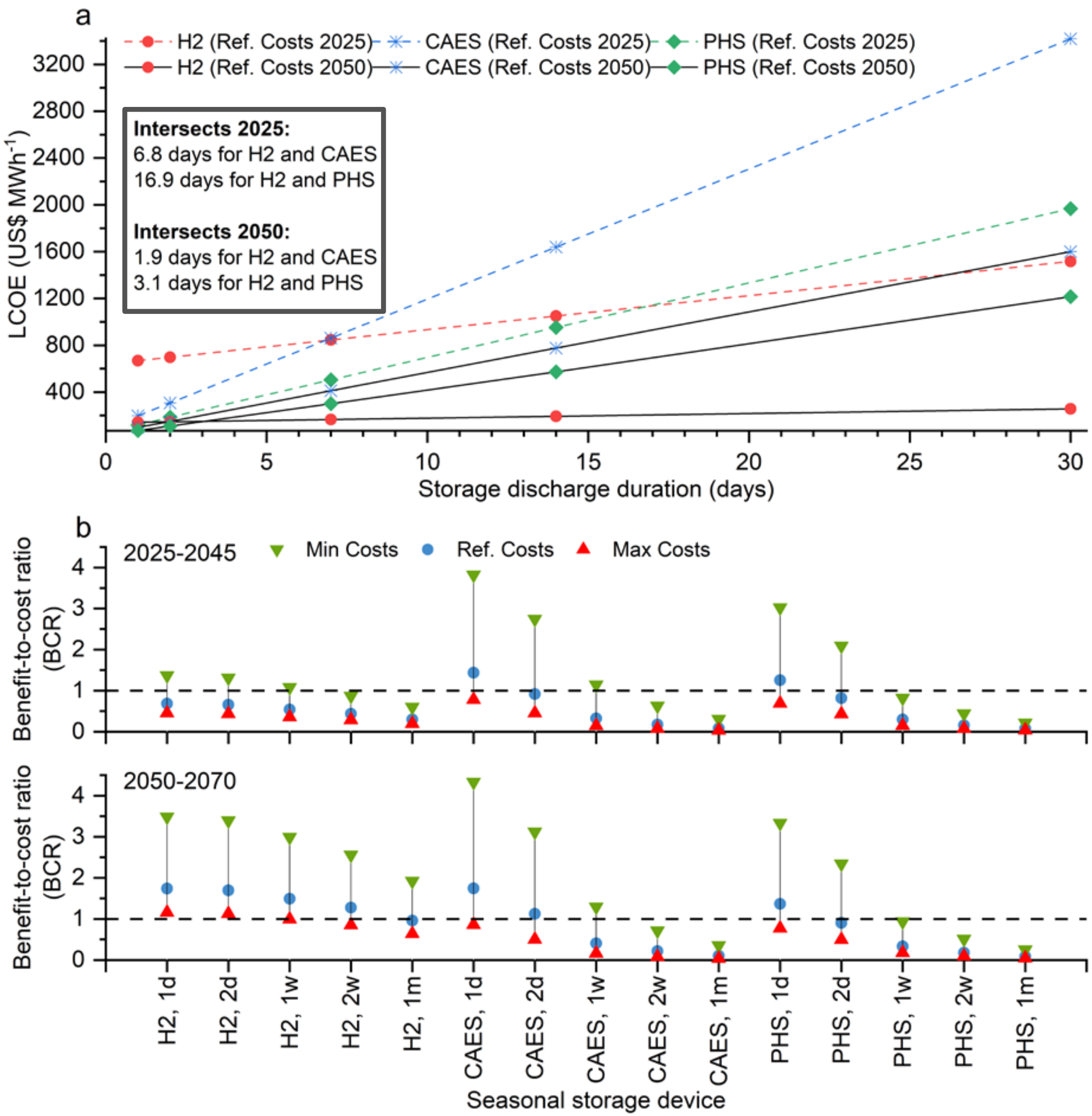
Results: Seasonal Storage Dispatch

End-volume targets for seasonal storage (2050 price-taker results (RODeO)):



Results: LCOE versus BCR

Cost-competitiveness seasonal storage (2025–2045 and 2050–2070 time frames):

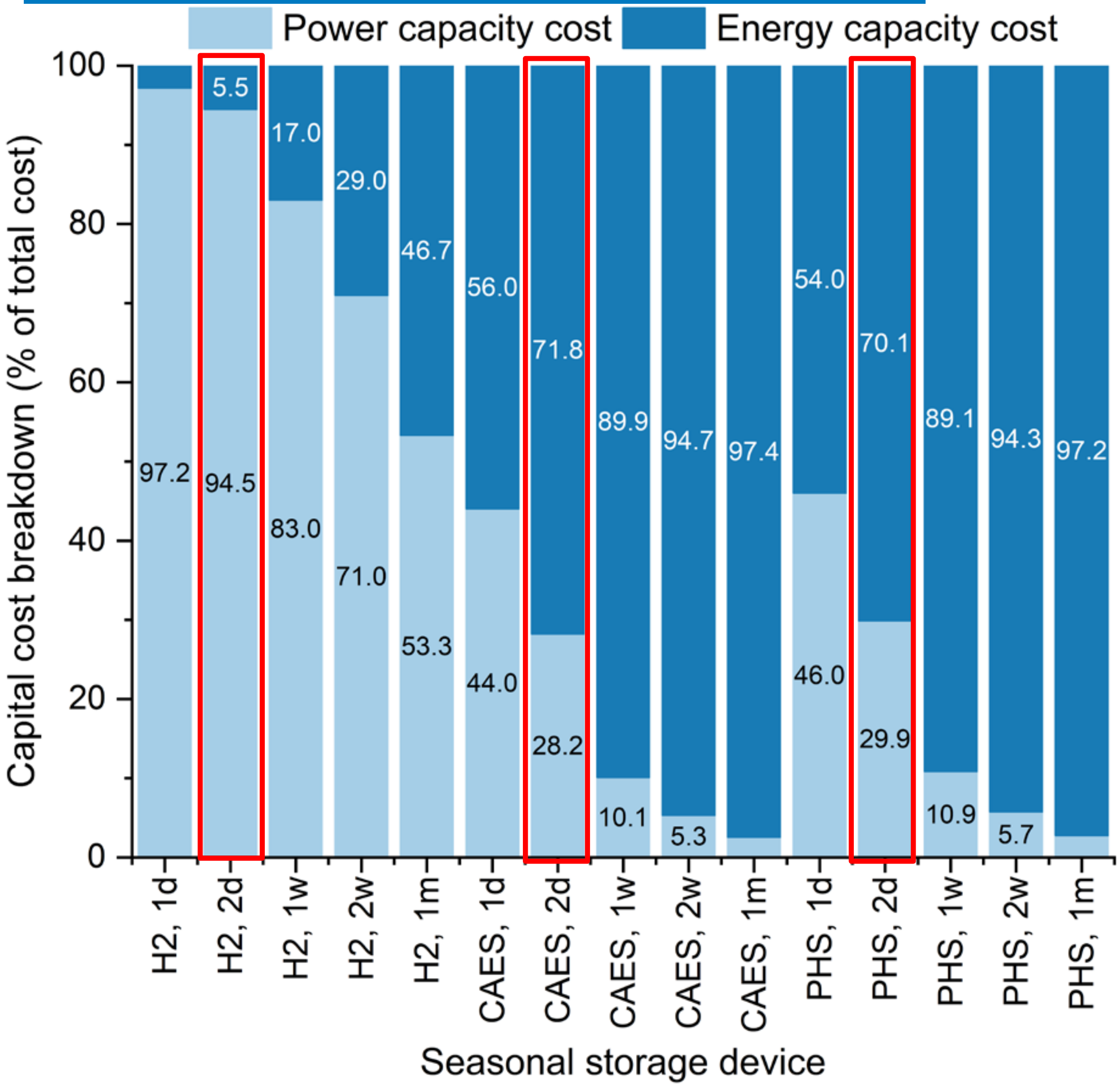


Levelized cost of energy (LCOE): typical cost estimation of storage technologies, i.e., without a corresponding profitability analysis

BCR: more rigorous and accurate reflection of the cost-effectiveness of storage technologies

Results: Capital Cost Breakdown

The role of energy-related capital cost (2050–2070 time frame):

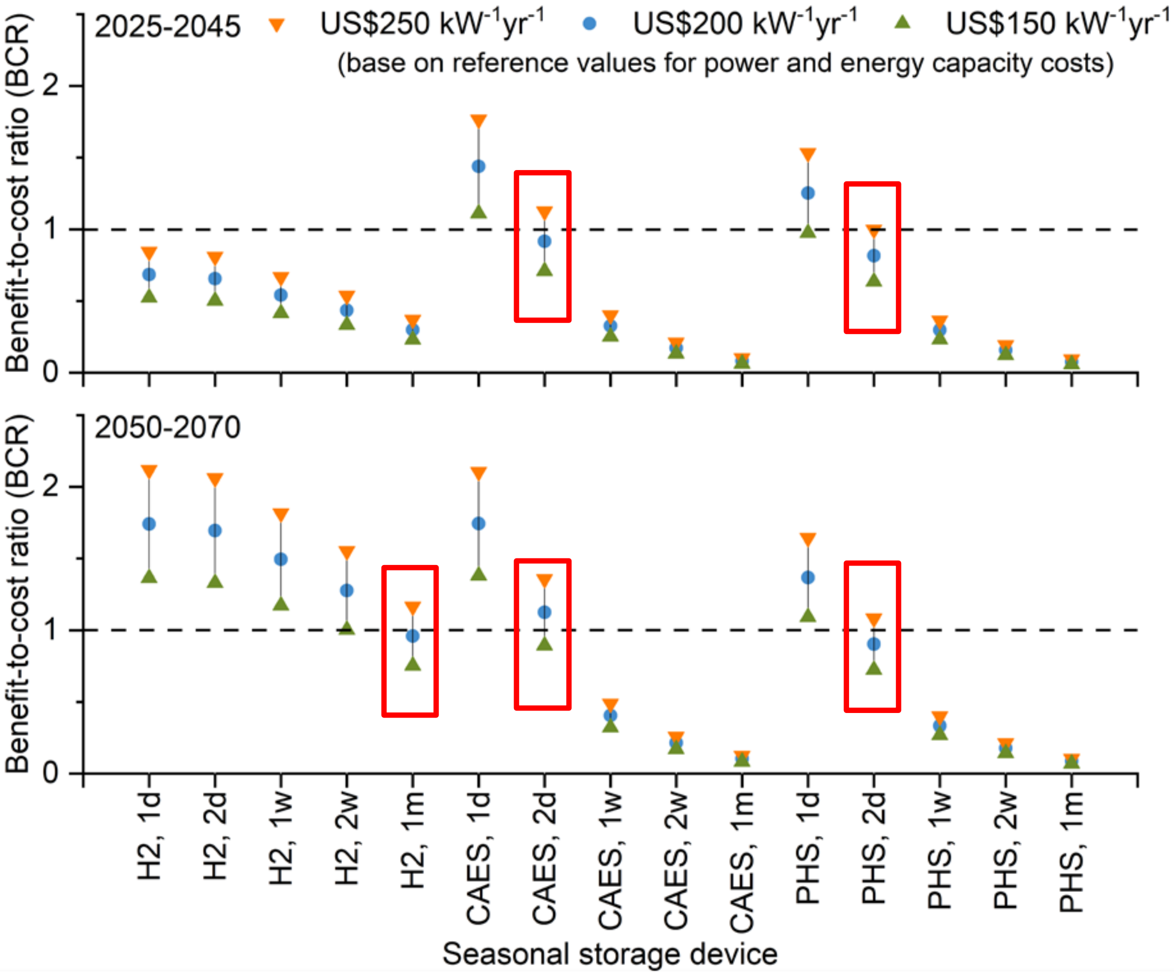


Why hydrogen?

The energy capacity capital cost of hydrogen storage is less than that of CAES and PHS.

Results: The Effects of Capacity Value

Sensitivity of BCR metric to avoided capacity cost of peaking generators:



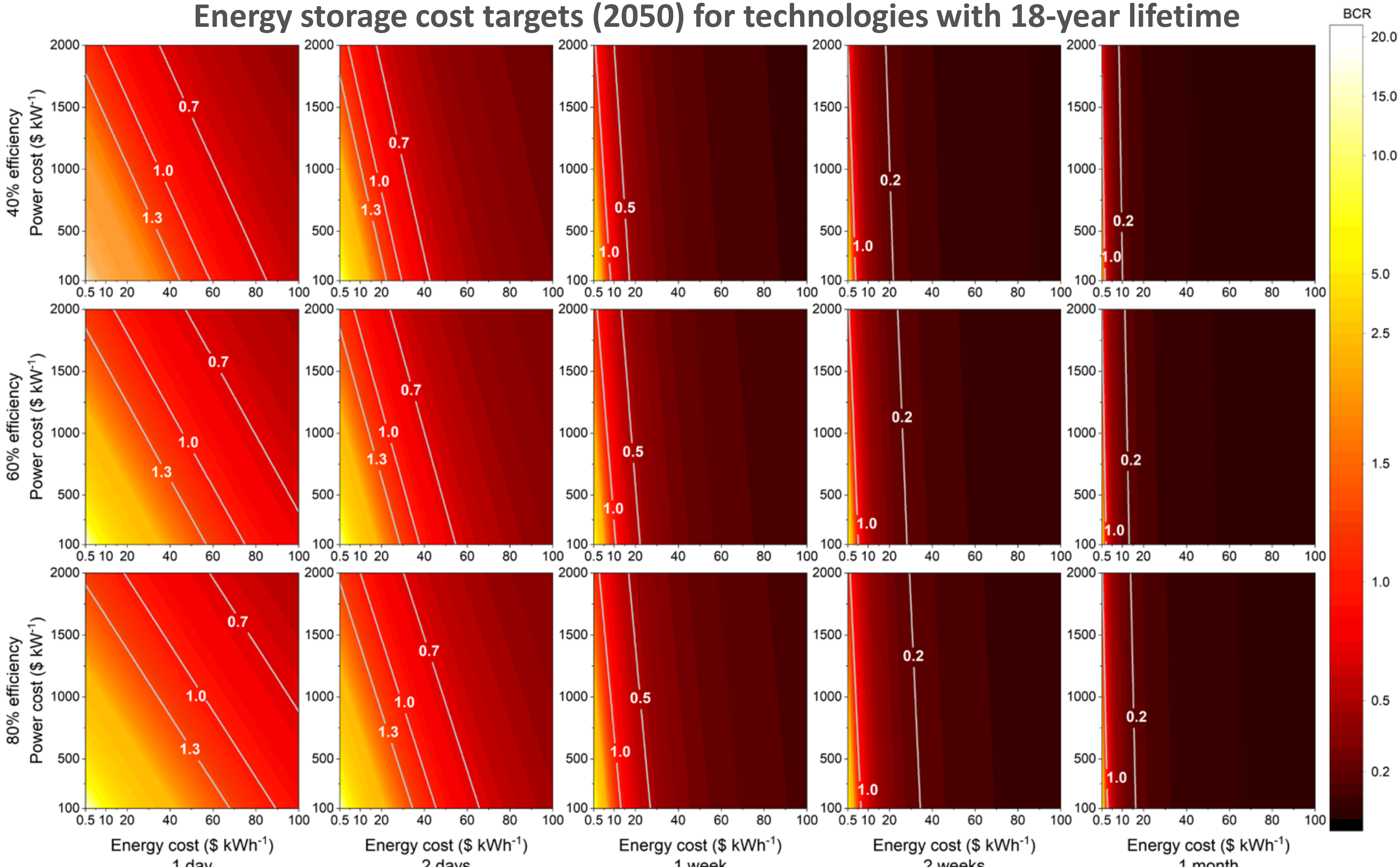
Hydrogen storage is uneconomical for the 2025–2045 operation window and cost-effective with up to 2 weeks of discharge duration for the 2050–2070 time frame, regardless of the assumed capacity value.

- The value of a given seasonal storage device is driven mostly by its capacity value (its ability to replace fossil-based peaking generators), e.g., capacity value ranges from 76%–93.4%, depending on the time frames.

Results: Power- and Energy-Related Cost Targets

These results allow for a quick economic assessment of storage across a wide range of technology cost and performance parameters.

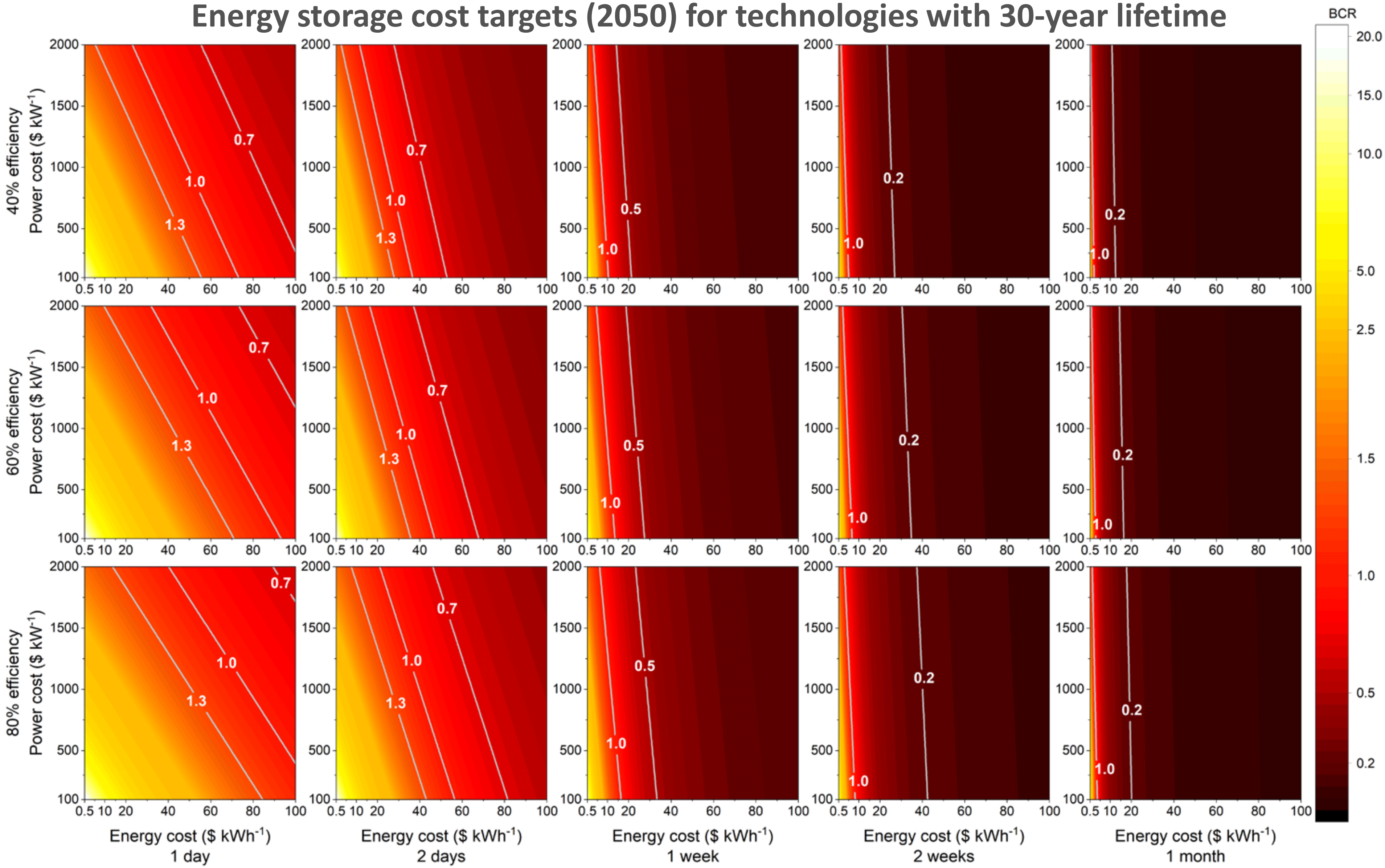
Energy storage cost targets (2050) for technologies with 18-year lifetime



Results: Power- and Energy-Related Cost Targets

These results allow for a quick economic assessment of storage across a wide range of technology cost and performance parameters.

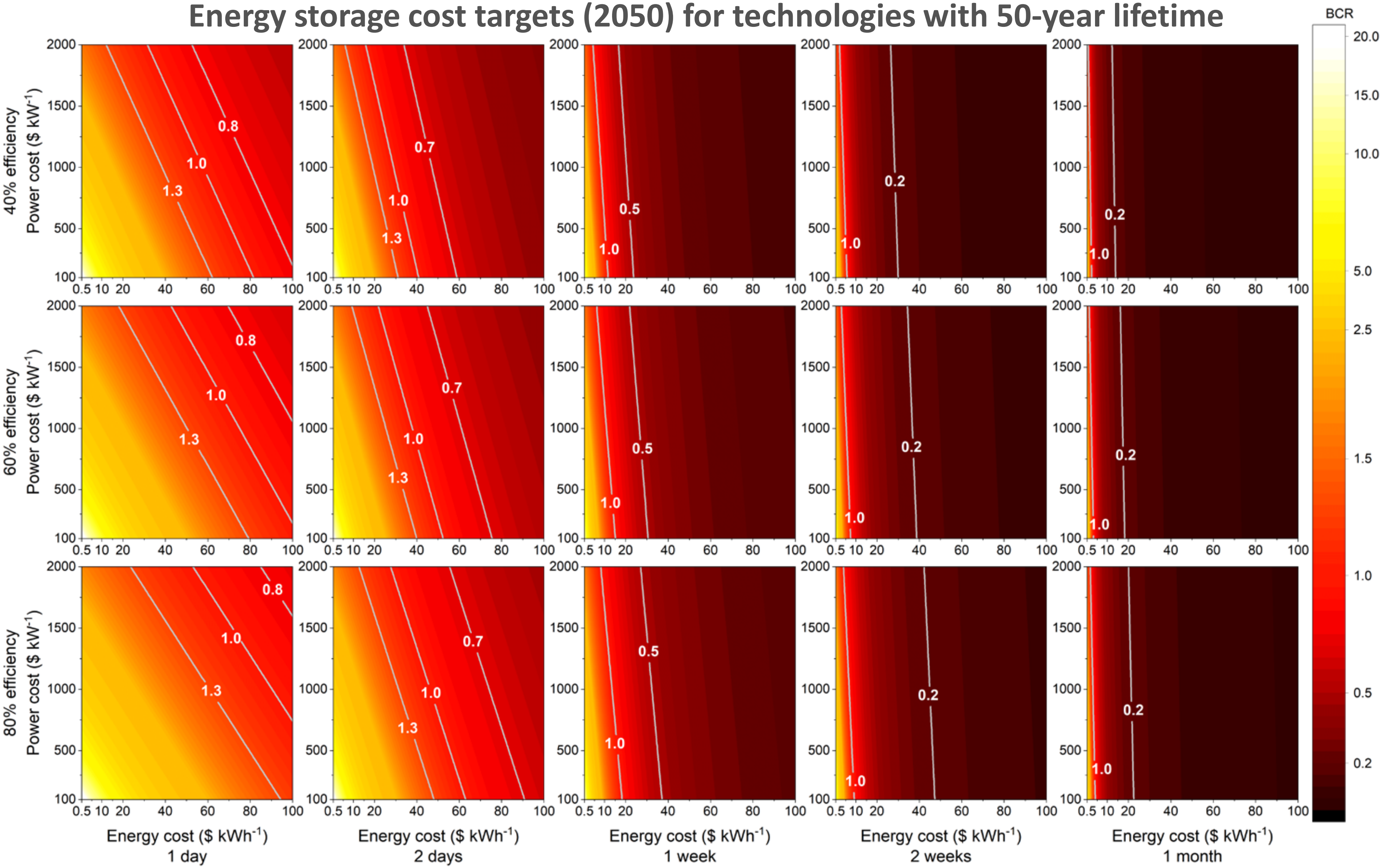
Energy storage cost targets (2050) for technologies with 30-year lifetime



Results: Power- and Energy-Related Cost Targets

These results allow for a quick economic assessment of storage across a wide range of technology cost and performance parameters.

Energy storage cost targets (2050) for technologies with 50-year lifetime



Conclusions

Hydrogen seasonal energy storage could be cost-competitive.

- Electrolysis-based hydrogen production and storage could improve the operation of the electric grid while integrating a variety of disparate systems, including the transportation, agricultural, industrial, and residential sectors.
- Hydrogen, which is a storage technology with relatively low energy-related capacity cost, could play an important role in achieving 100% carbon-free or renewable power systems.
- Hydrogen storage with up to 1 week of discharge duration could be cost-effective in the near future if power and energy capacity capital costs are equal to or less than ~U.S. \$1507 kW^{-1} and ~U.S. \$1.8 kWh^{-1} by 2025, respectively.
- Based on projected power and energy capacity capital costs for 2050, hydrogen storage with up to 2 weeks of discharge duration is expected to be cost-effective in future power systems.

Thank you!

www.nrel.gov

NREL/PR-5D00-78296

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Office of Strategic Programs and Fuel Cell Technology Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL Transforming ENERGY