CHANGING WHAT'S POSSIBLE

Duration Addition to electricitY Storage (DAYS)

The why and how of long-duration energy storage

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What's needed to enable LDES

- Technology proven to be cheap and reliable
- Applications (duty cycles)
- Niche / entry markets
- Policy drivers

Objectives of this meeting

- Introduce the DAYS projects
- Learn what's happening from external stakeholders
- Discuss potential early applications and requirements
- Start building a LDES community

Who's here: DAYS, IONICS awardees

Thermal

NREL National Renewable Energy Laboratory
Allied Mineral Products
Purdue University
Greenway Energy
GE Global Research
Power Engineers
Colorado School of Mines — Earth • Energy • Environment

Brayton Energy LLC
MIT Massachusetts Institute of Technology

SwRI Southwest Research Institute

Echogen Power Systems
Solex
TU Wien Technische Universität Wien Vienna University of Technology
Westinghouse
EPRI Electric Power Research Institute

MIT Massachusetts Institute of Technology
NREL National Renewable Energy Laboratory

Antora Energy
Lawrence Berkeley National Laboratory
ASU Arizona State University
NREL National Renewable Energy Laboratory

Michigan State University
ASU Arizona State University
Saudi Aramco Energy Ventures

Electrochemical

form energy
Virginia Tech
MIT Massachusetts Institute of Technology
Sepion Technologies

The University of Tennessee Knoxville
PeroXygen Systems

Primus Power
Columbia University in the City of New York

United Technologies Research Center
MIT Massachusetts Institute of Technology
PennState
Lawrence Berkeley National Laboratory

Mechanical

Quidnet Energy

IONICS

United Technologies Research Center
Harvard University
Advent
University of South Carolina
Berkeley Lab

Washington University in St. Louis
GINER

Who’s here: external stakeholders

Exelon.

Google

Solar Turbines
A Caterpillar Company

Office of the Director of National Intelligence
IARPA
BE THE FUTURE

EPRI ELECTRIC POWER RESEARCH INSTITUTE

conEdison

Hawaiian Electric

Southern Company

NAVIGANT

luxresearch

+VOLTA
ENERGY TECHNOLOGIES

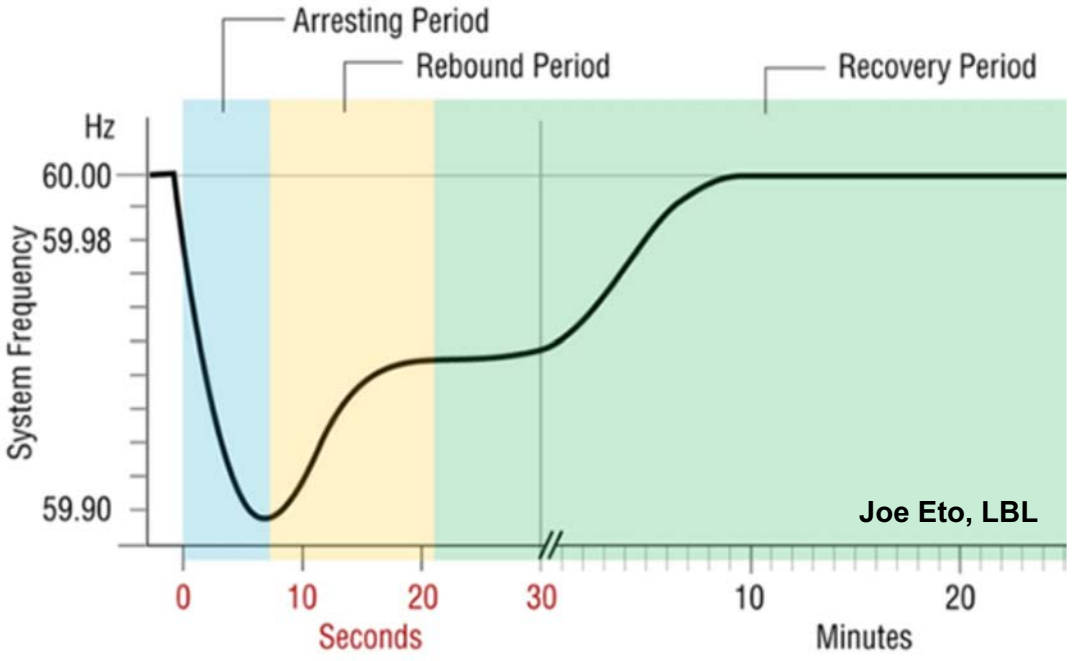
Office of
ELECTRICITY

Outline

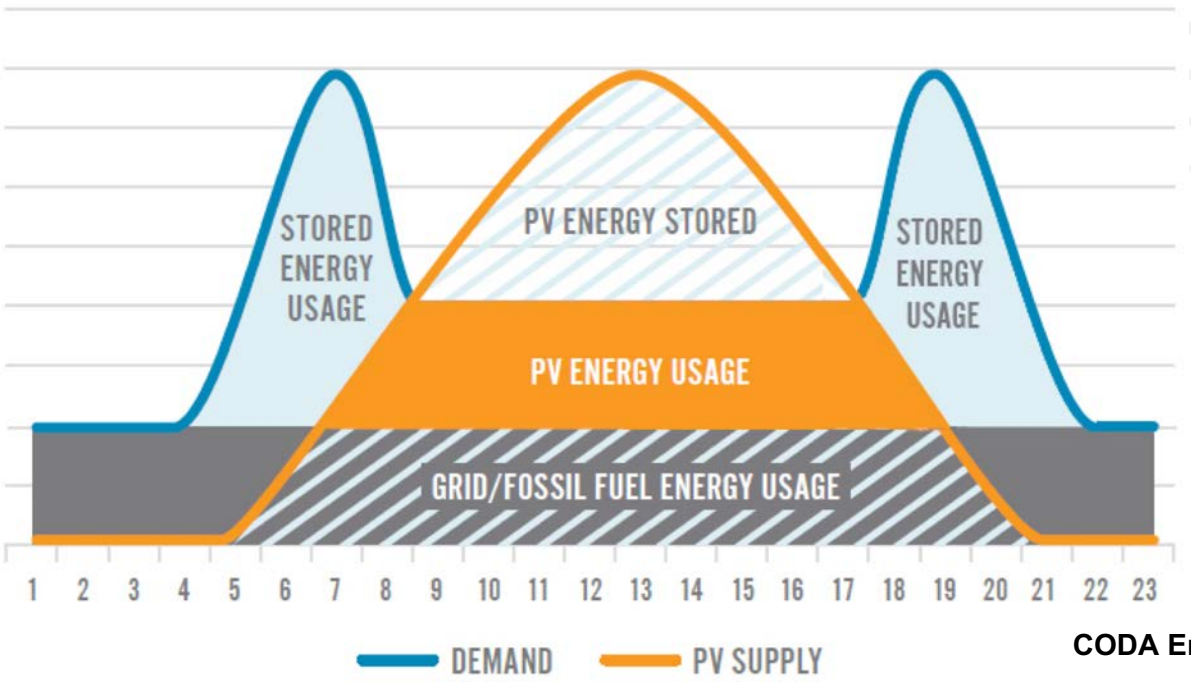
- A brief overview of DAYS
- Potential early applications

Grid-Scale Storage Applications Today

Frequency regulation



Energy shifting



CODA Energy

Examples of other applications:

Reserves

Distribution upgrade deferral

Power quality

Flexible ramping

Demand charge management

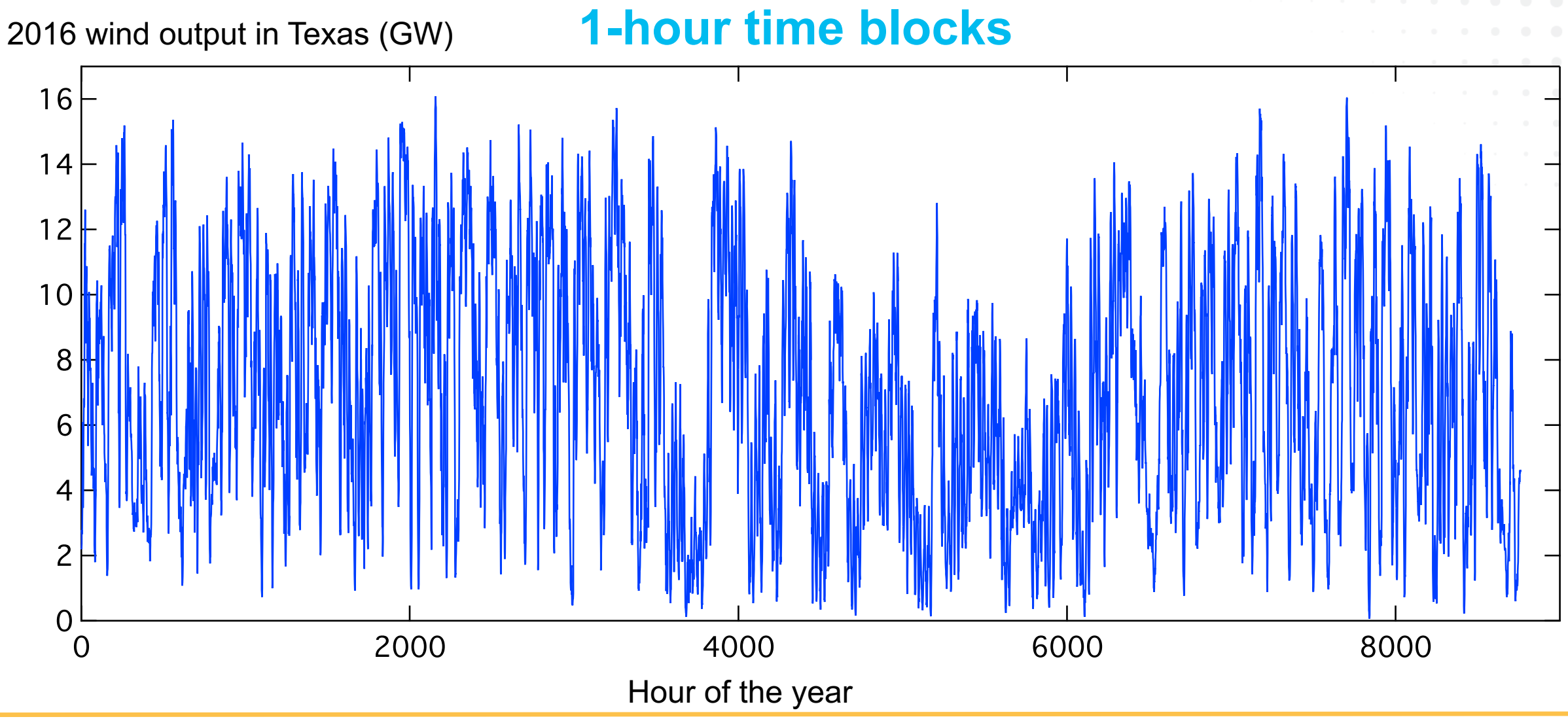
Dispatching variable (and uncertain) renewables

What will it take…

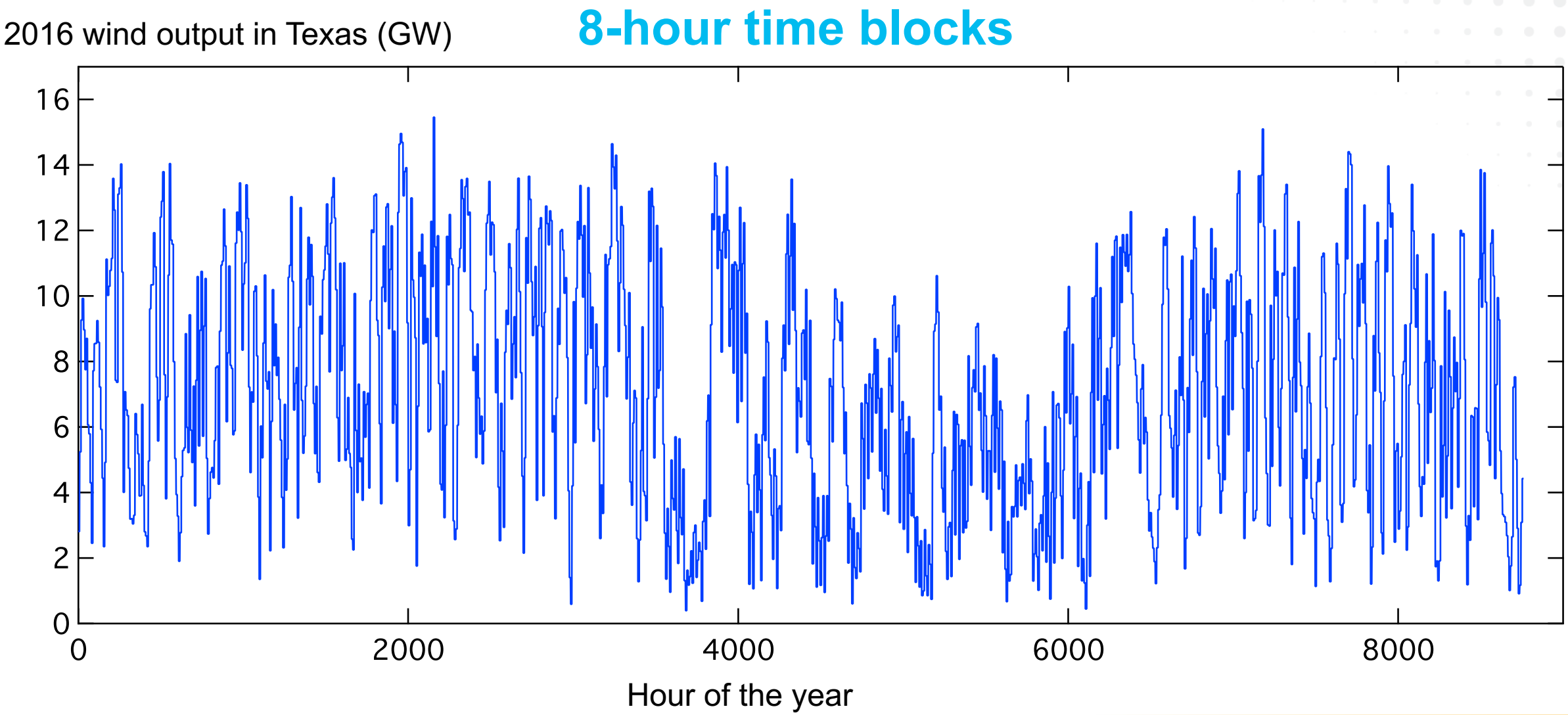
To make the availability of this:

Look more like this:

Example: variability of wind in Texas



Example: variability of wind in Texas



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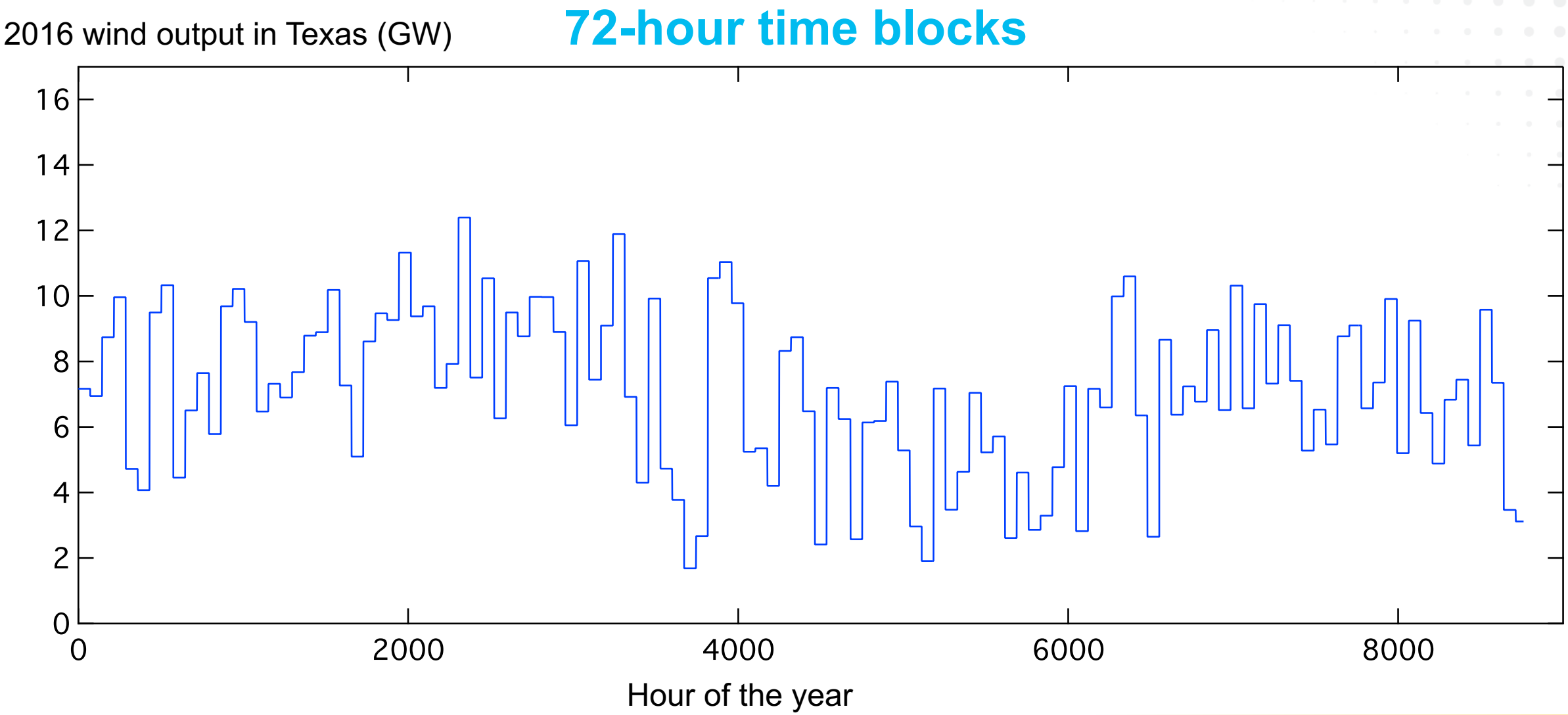

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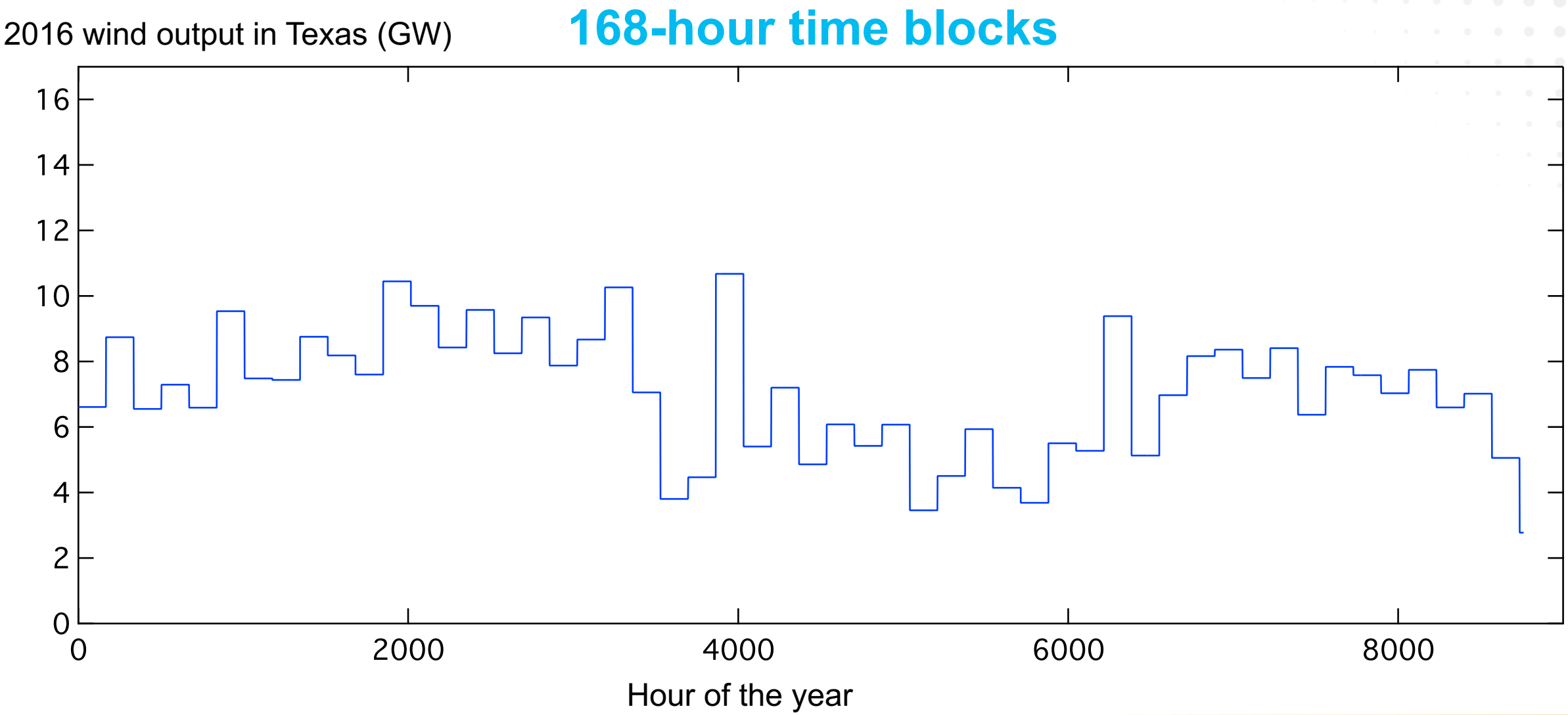
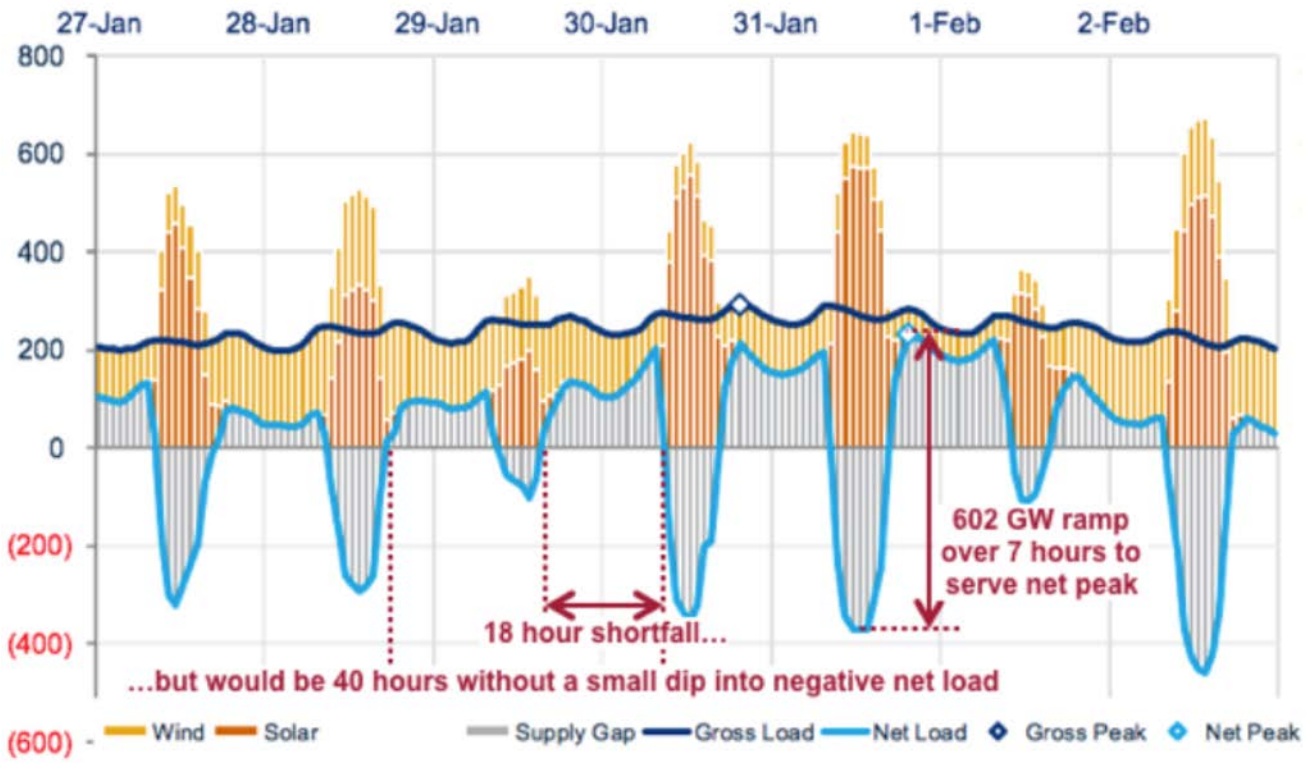


Another viewpoint: integrating renewables with the grid

Aggregate footprint at 50% wind & 50% solar

Load, generation, and imbalances (GW)

Peak (MW)			ICAP (MW)			Consecutive hours	
Gross Load	Net Load	Peak Reduction	Solar	Wind	Battery	(-) net load	(+) net load
292,559	231,549	61,010	575,190	193,722	277,858	9	18



- Wood Mackenzie report on 2019 polar vortex
- Examined grid conditions if capacity was 50% solar and 50% wind
- For solar to provide relief for low wind: 18-40 hours of storage

https://pv-magazine-usa.com/2019/02/12/wood-mackenzie-looks-at-the-polar-vortex-and-100-renewable-energy/

Digging deeper: levelized cost of storage (LCOS)

$$LCOS(\$ \cdot kWh^{-1} \cdot cycle^{-1}) = \left[\left(\frac{1}{\eta_{RTE}} - 1\right) P_c \sum_{t=1}^{T} \frac{n_c(t)}{(1+r)^t} + \sum_{t=1}^{T} \frac{O\&M(t)}{(1+r)^t} + \left(\frac{C_E}{\eta_D} + \frac{C_P}{d}\right)\right] * \left[\sum_{t=1}^{T} \frac{n_c(t)}{(1+r)^t}\right]^{-1}$$

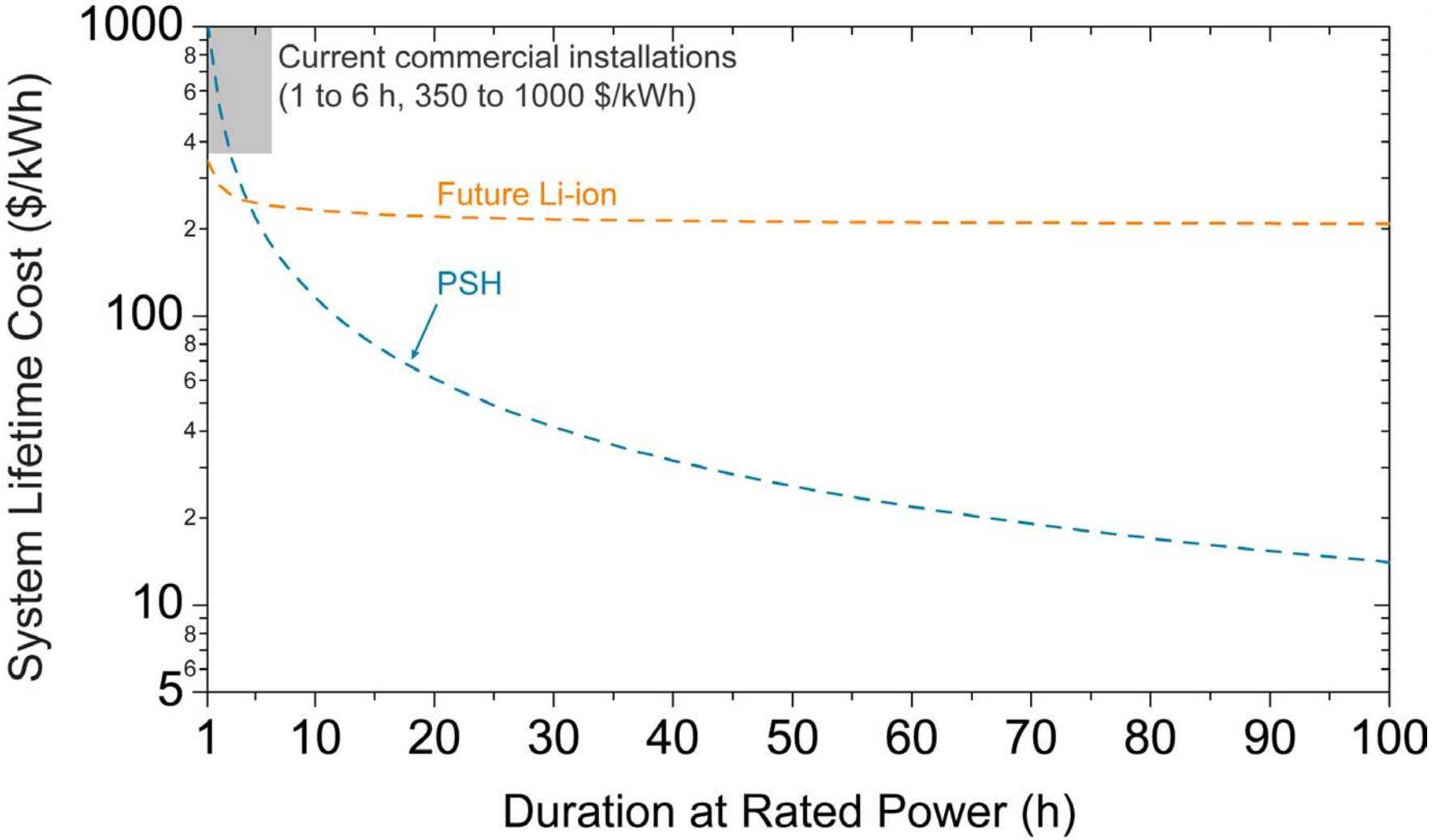
Primarily application-dependent parameters

- P_c – input electricity price in $/kWh
- d – duration of storage at rated power in hours
- n_c – number of equivalent full cycles

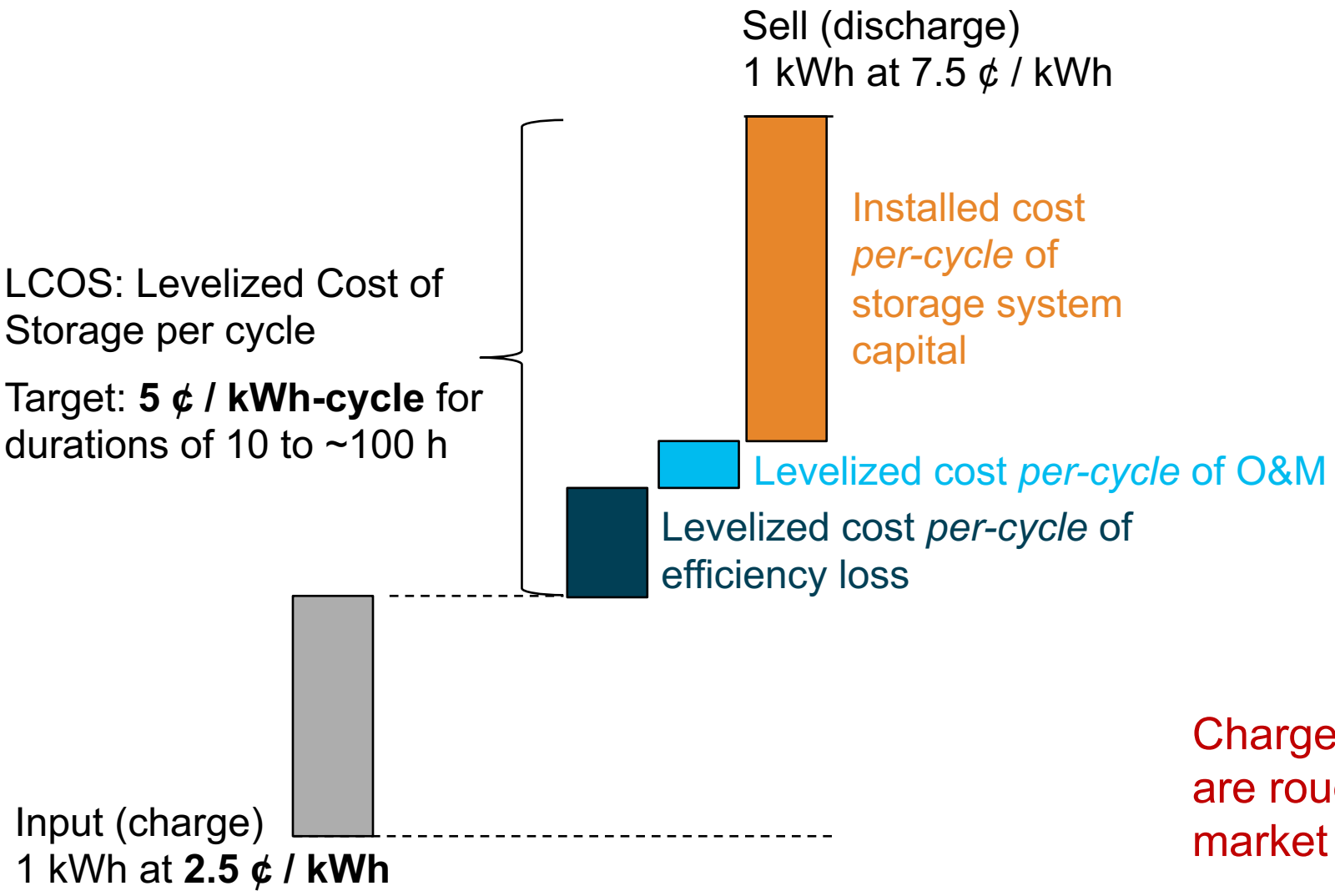
Primarily technology-dependent parameters

- η_{RTE} – round-trip efficiency of storage (AC basis)
- η_D – discharge efficiency of storage (AC basis)
- $O\&M$ – fixed and variable operations and maintenance cost (including component replacements)
- C_E – installed marginal capital cost of energy in $/kWh
- C_P – installed marginal capital cost of power in $/kW

Impact of capex for power and for energy



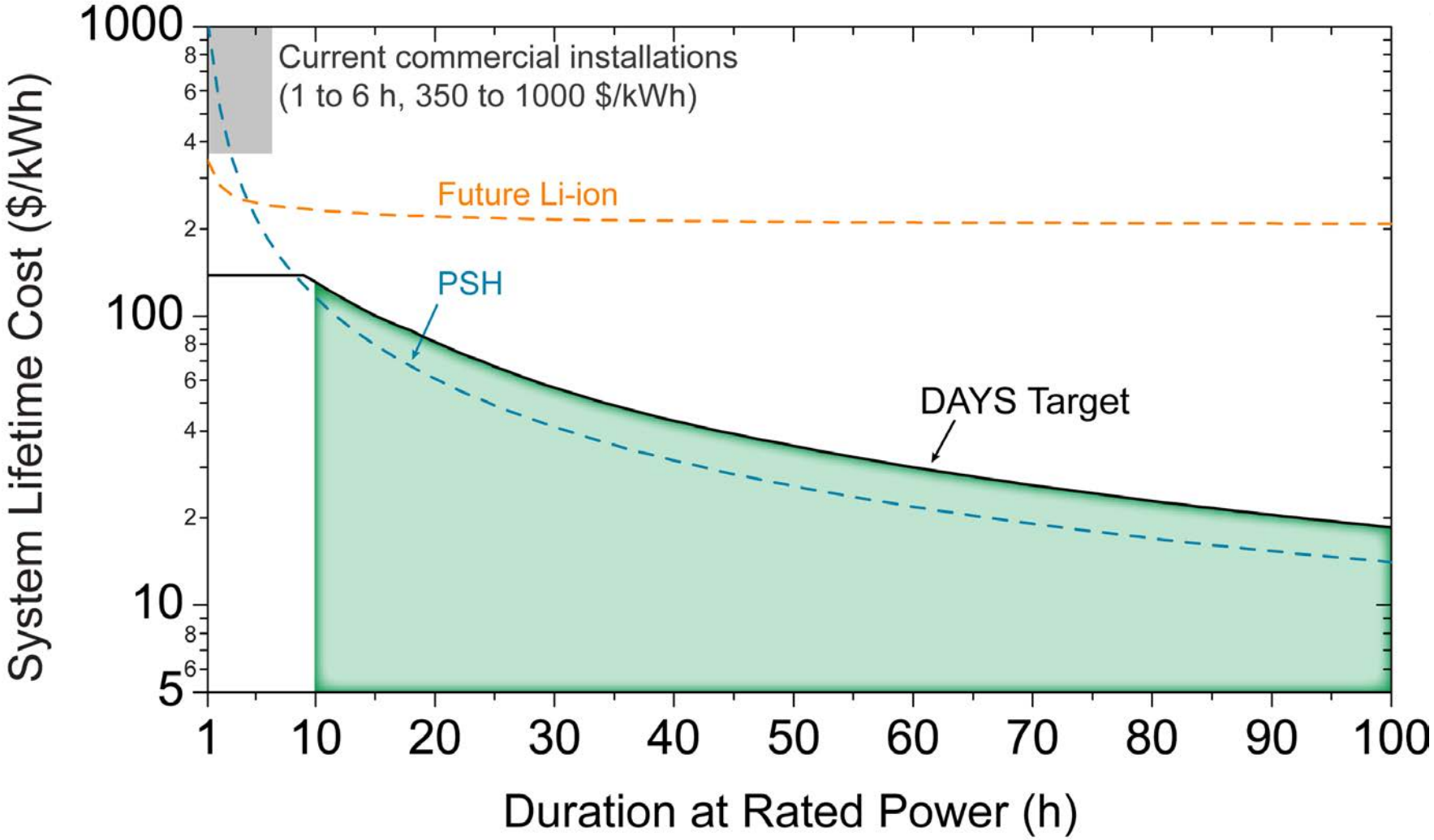
The DAYS cost target



Charge/discharge prices are rough estimates; not market projections

Capital discounted at 10% over project life (20 years).

DAYS cost-duration target



The DAYS innovations

Thermal

- Fluidized bed heat exchanger
- Thermochemical Mg-Mn-O bed
- Reversible turbomachine
- Full loop controls system
- Supercritical CO_2 cycle

Electrochemical

- Aqueous sulfur
- Zr-Br_2 membrane-less, single tank
- Reversible fuel cell for H_2O_2
- Sulfur-manganese flow battery

Geomechanical

- Elastic strain in underground rocks

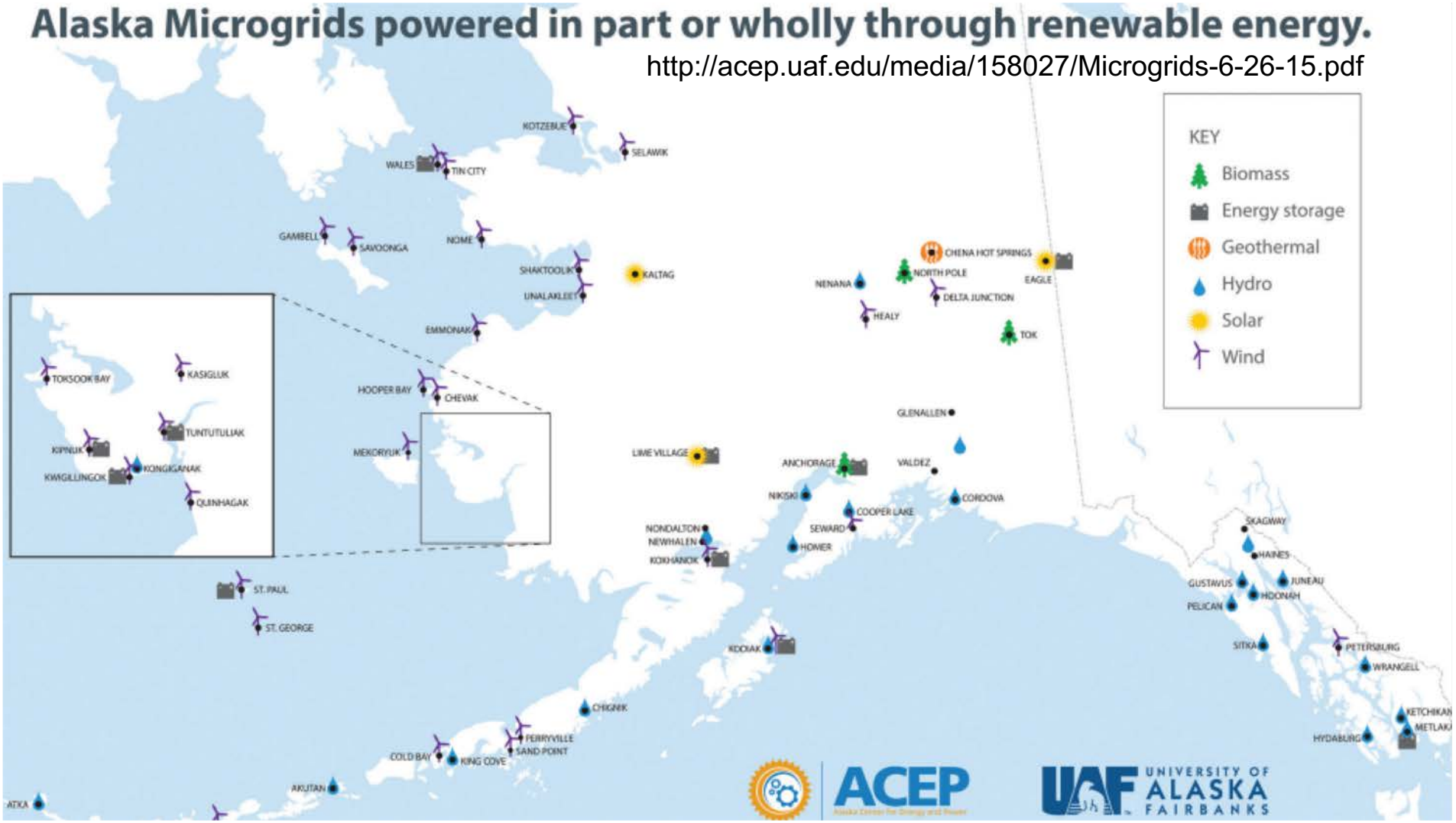
Thermophotovoltaic

- High efficiency, stable over time

Outline

- A brief overview of DAYS
- **Potential early applications**

Islands and remote areas



- No contiguous grid
- Rural electricity: $0.60-$1.20/kWh
- Lots of renewable resources, including RoR hydro and pumped hydro
- Large seasonal variations
- Consisting diesel genset alternatives

Related presentation: Vladimir Shvets (Hawaiian Electric Co.)

Transmission and distribution projects


Fish and Wildlife Service

"D"

- Utilities pursuing "non-wires" deferral projects
- Current RFP for Orange & Rockland Utilities
  - System reliability and load relief
  - 17 MW of load relief for 24 hours
  - Traditional solution: upgrade to two 35 MVA transformers

"T"

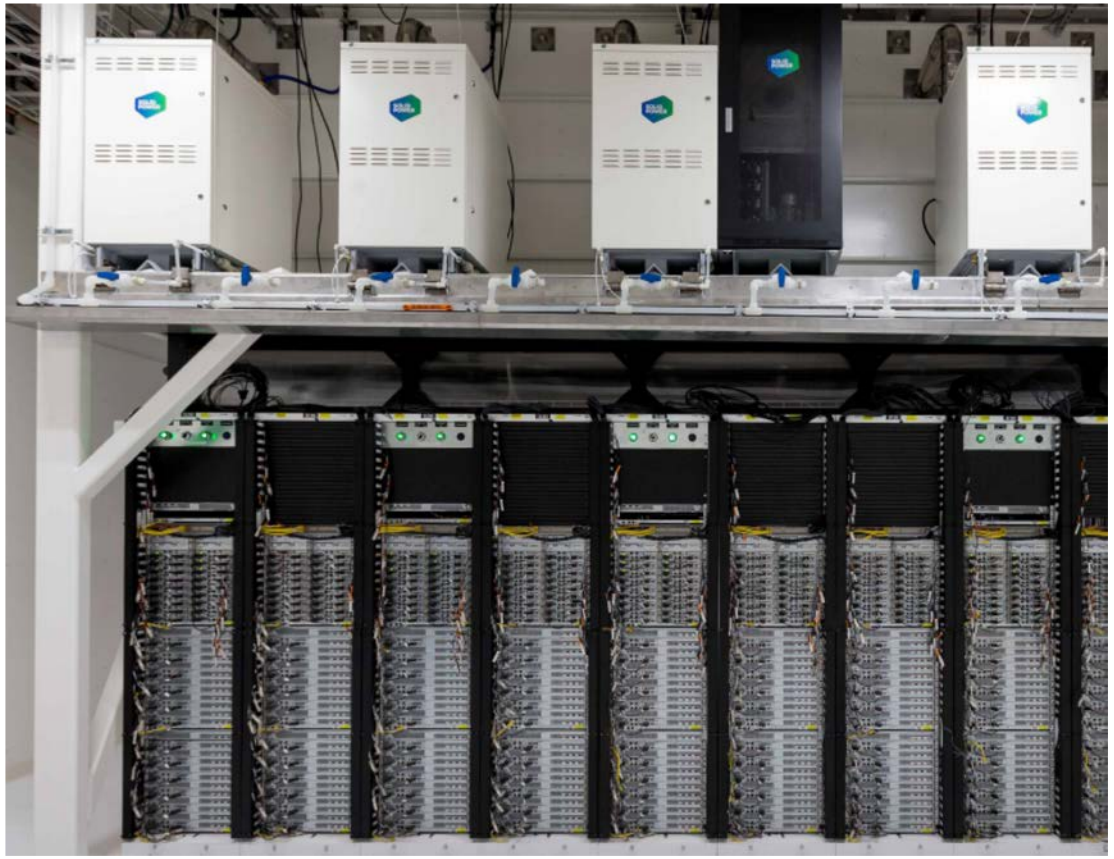
UTILITY DIVE

Brattle: Electrification could drive $600B in transmission spending by 2050

Related presentations: Jason Burwen (Energy Storage Association), Matt Arnold (Enel Green Power)

https://www.utilitydive.com/news/brattle-electrification-could-drive-600b-in-transmission-spending-by-2050/550010/

Data centers, critical infrastructure



Synergy Research, 2017

- Data traffic is doubling every 2-3 years
- Data centers today consume 200 TWh worldwide
- By 2030: 8% of global electricity demand
- 45% of data centers are in the U.S.
- Backup power now: uninterruptible power supply, diesel generators

Could long-duration storage replace diesel gensets at critical sites such as data centers?

https://www.pjm.com/-/media/about-pjm/exploring-tomorrows-grid/advanced-tech.ashx

Thinking about duty cycles

Y. Shi, et al., *IEEE Trans. Power Sys.* 33, 2882-2894 (2017)

How Big Batteries at Data Centers Could Replace Power Plants

Battery systems intended as backups may help companies like Microsoft increasingly employ renewable energy

By Benjamin Storrow, E&E News on July 19, 2018

- Univ. of WA study: 11% decrease in annual energy bill from peak shaving
- Additional revenue from frequency regulation
- Microsoft: worked with PJM and Eaton on frequency regulation with a data center

What's the duty cycle for a long-duration system?

Long-duration storage is an enabling technology

Google

Moving toward 24x7 Carbon-Free Energy at Google Data Centers: Progress and Insights

2. **A diverse portfolio of carbon-free energy sources — whether variable or dispatchable — can have a greater impact than a single variable source.** In the absence of long-duration energy storage, a single source of renewable energy is generally not sufficient to provide a 24x7, 100% match with a data center's load.

https://storage.googleapis.com/gweb-sustainability.appspot.com/pdf/24x7-carbon-free-energy-data-centers.pdf

Summary

- The onus right now is on the technology community (us)
- There are entry markets
- Longer-term picture: unclear, but policy will follow technology

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