NARUC

National Association of Regulatory Utility Commissioners

Long Duration Storage: What's on tap?

October 13, 4:00-5:00 PM ET

Moderator: Hon. Carrie Zalewski, Illinois

Panelists:

Jason Houck, Sr. Manager, Policy and Regulatory Affairs, Form Energy
Michael Purdie, Director of Regulatory Affairs and Markets, National Hydropower Association
Greggory Kresge, Sr. Manager, Utility Engagement and Transportation Electrification – US Energy, World Resources Institute
Dr. Kevin Harrison, Program Manager, National Renewable Energy Laboratory

Opening Remarks

Hon. Carrie Zalewski, IL

Panelists

- **Jason Houck**, Sr. Manager, Policy and Regulatory Affairs, Form Energy
- **Michael Purdie**, Director of Regulatory Affairs and Markets, National Hydropower Association
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- **Dr. Kevin Harrison**, Program Manager, National Renewable Energy Laboratory

BREAKTHROUGH LOW-COST, MULTI-DAY ENERGY STORAGE

NARUC Long Duration Storage Webinar

Jason Houck, Sr. Manager, Policy & Regulatory Affairs

October 13, 2022

Form energy

Energy Storage
For A Better World

Rising to the challenge of climate change with a team that will deliver

LED BY ENERGY STORAGE VETERANS

Decades of cumulative experience in energy storage

- 100's of MW of storage deployed

TESLA ENERGY

A123 SYSTEMS

SUNPOWER FROM MAXEON SOLAR TECHNOLOGIES

24m

NEXTera ENERGY

amsc

Massachusetts Institute of Technology

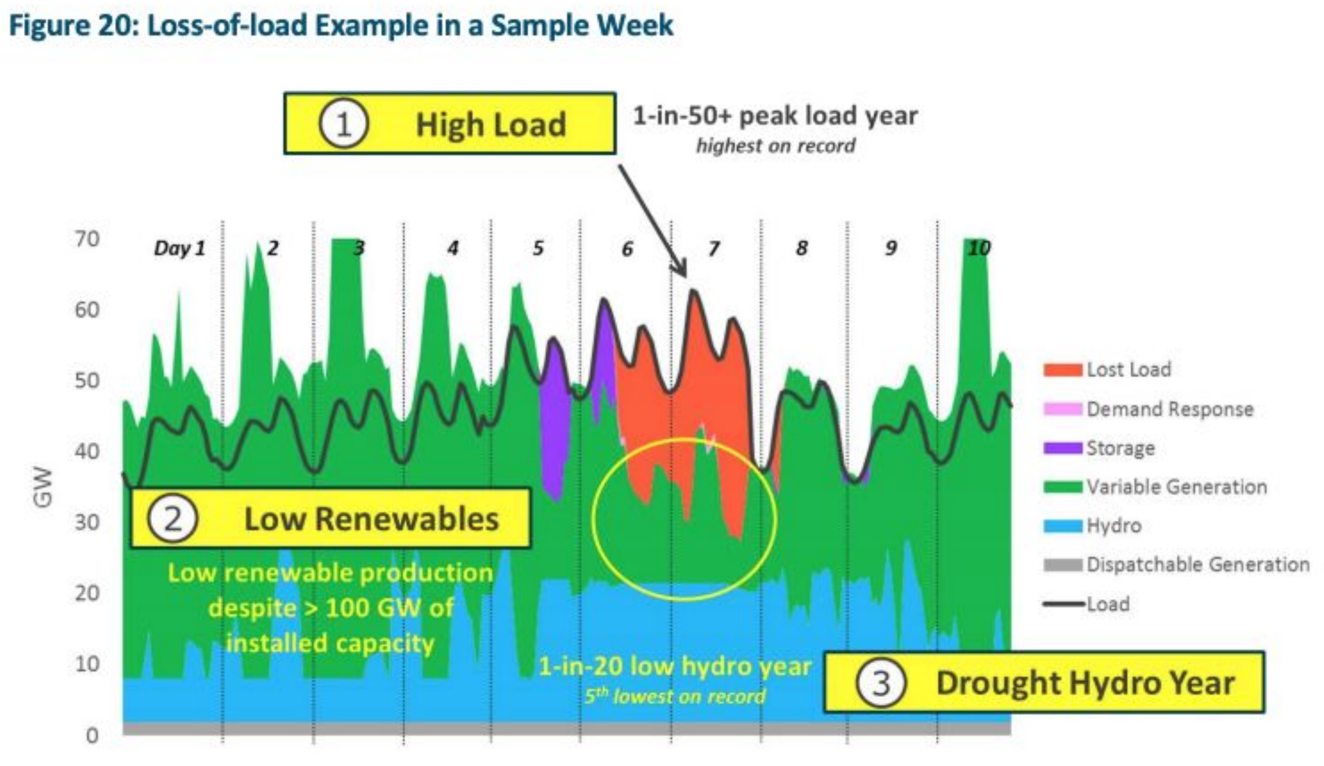
AQUION ENERGY

OUR INVESTORS: LONG-TERM AND IMPACT-FOCUSED

$820M in venture capital from Breakthrough Energy Ventures (BEV), TPG's Climate Rise Fund, Coatue Management, NGP Energy Technology Partners III, ArcelorMittal, Temasek, Energy Impact Partners, Prelude Ventures, MIT's The Engine, Capricorn Investment Group, Eni Next, Macquarie Capital and other long-term, impact oriented investors

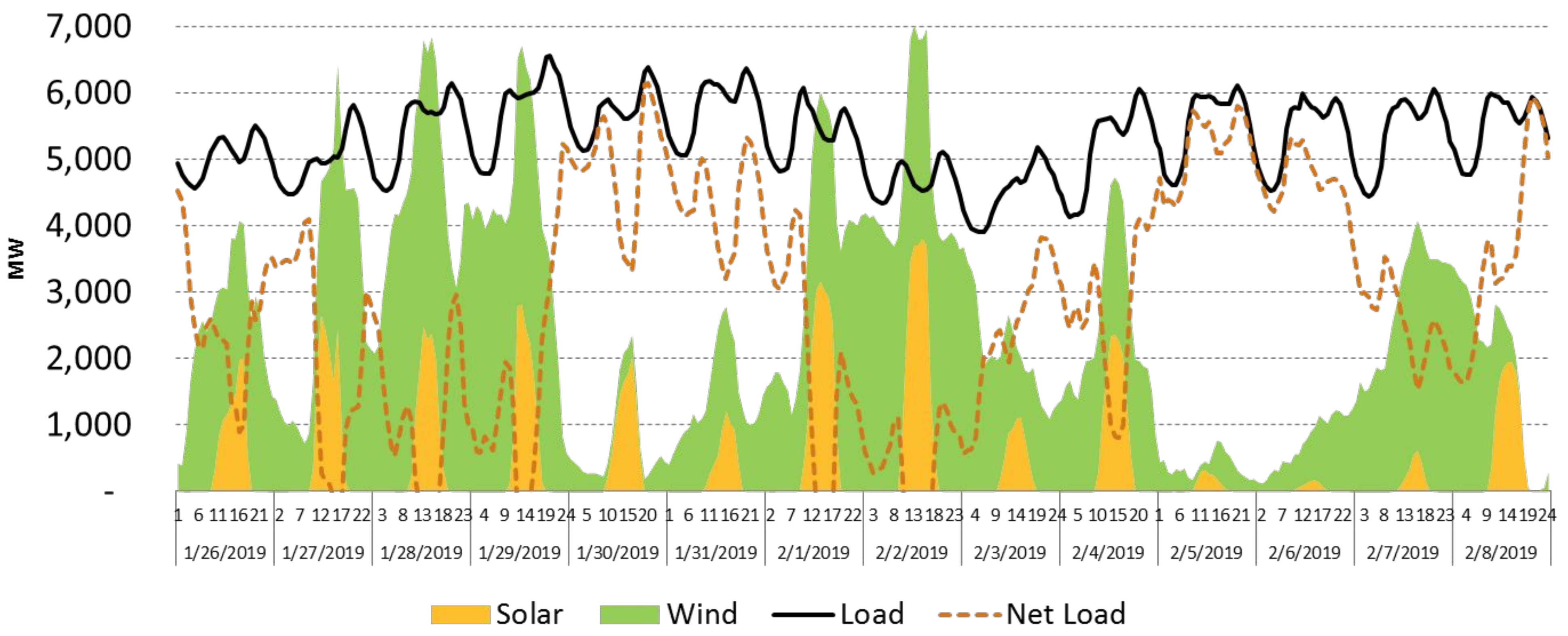
Weather-driven multi-day reliability challenges are widespread

Pacific Northwest Multi-Day Weather Event, 2050



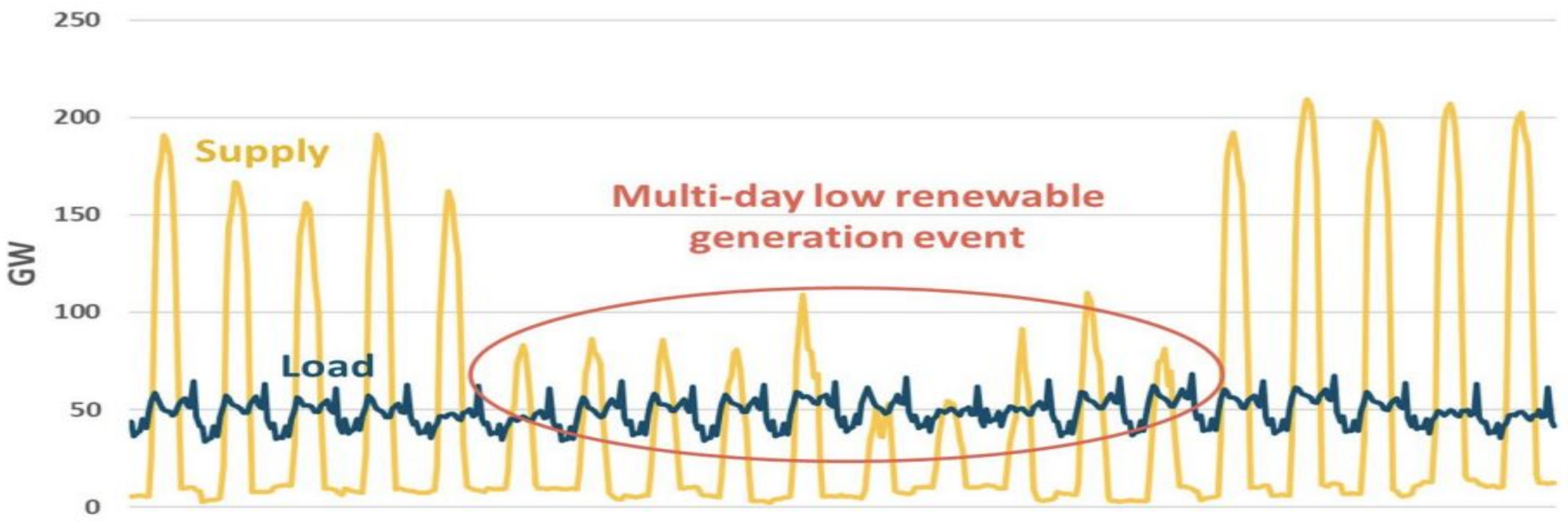
Source: E3, Resource Adequacy in the Pacific Northwest

Upper Midwest Multi-Day Weather Event in Winter, 2019



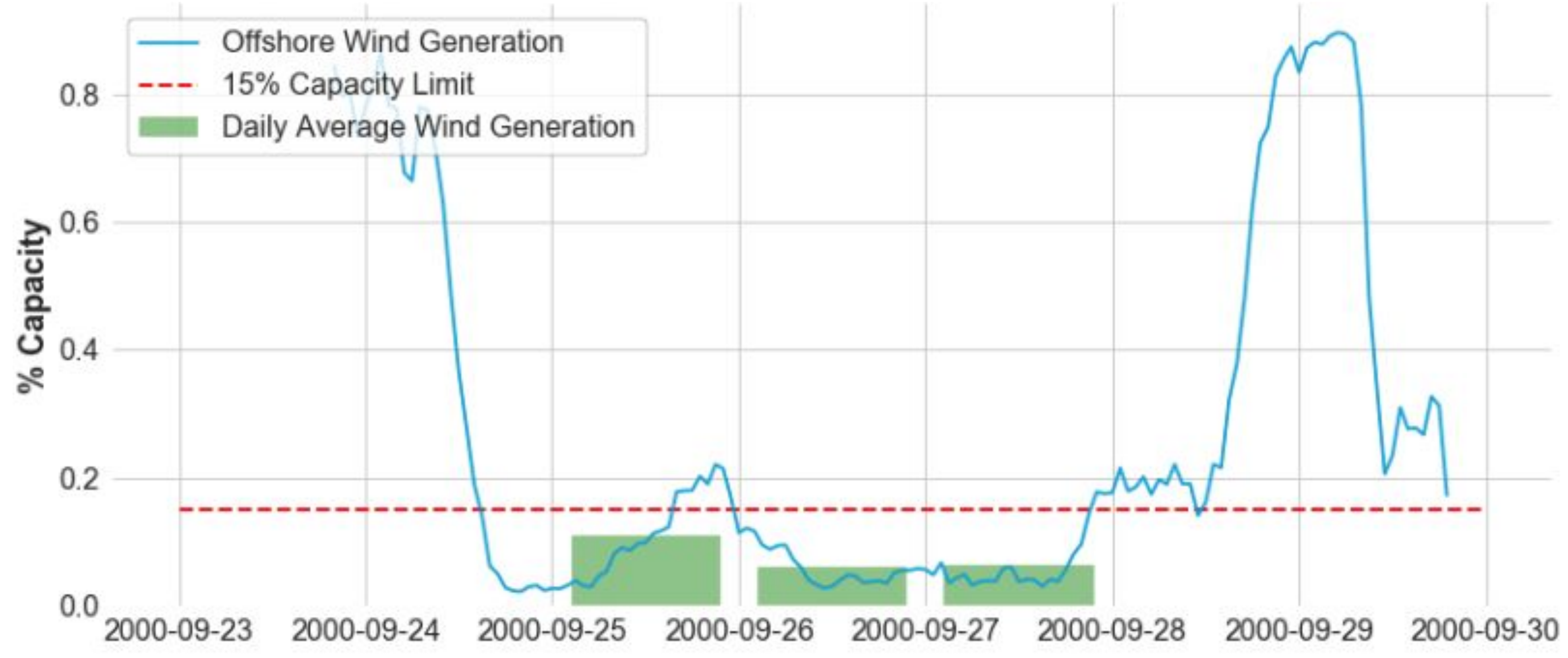
Source: Xcel Energy 2020-2034 Upper Midwest Resource Plan, May 20, 2019 Workshop

California Multi-Day Weather Event in Winter, 2050



Source: E3: Long-Run Resource Adequacy Under Deep Decarbonization

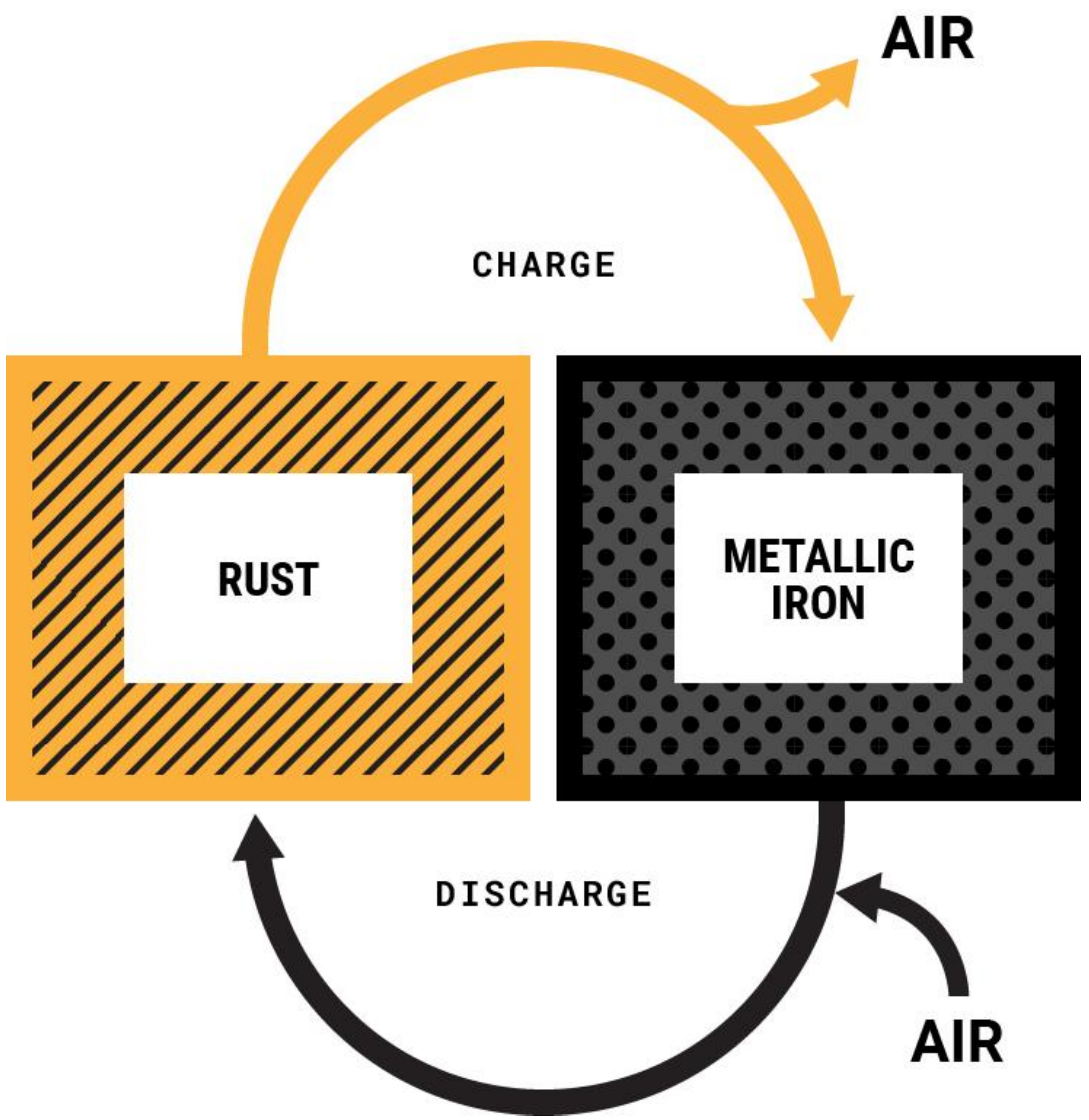
New England Multi-day offshore wind lull, 2000



Source: DNV-GL Analysis of Stochastic Dataset for ISO-NE

Rechargeable iron-air is the best technology for multi-day storage

Reversible Rust Battery



COST
Lowest cost rechargeable battery chemistry.
Chemistry entitlement <$1.00/kWh

SAFETY
No thermal runaway (unlike li-ion)
Non-flammable aqueous electrolyte

SCALE
Iron is the most globally abundant metal
Easily scalable to meet TW demand for storage

DURABILITY
Iron electrode durability proven through decades of life and 1000's of cycles (Fe-Ni)

Form Energy’s Modular 100hr Multi-Day Storage System

Cell

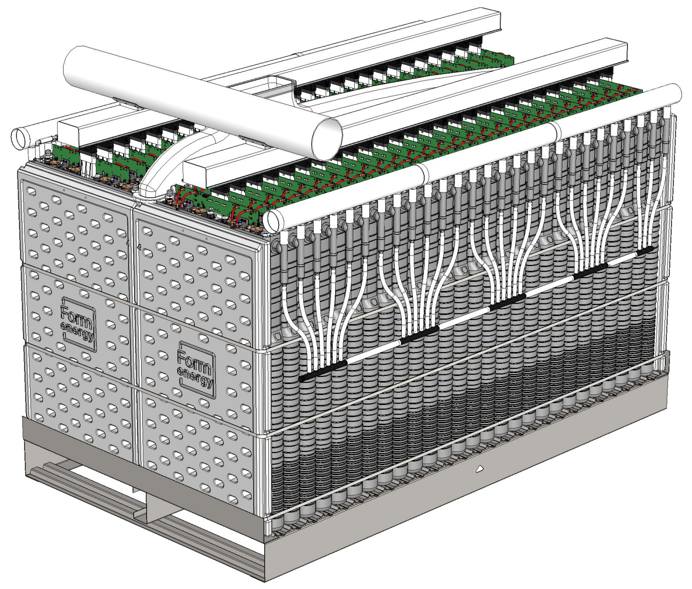
~0.10 kW / 10 kWh

~1m x 60 cm

Electrodes + Electrolyte

Smallest **Electrochemical** Functional Unit

Battery Module



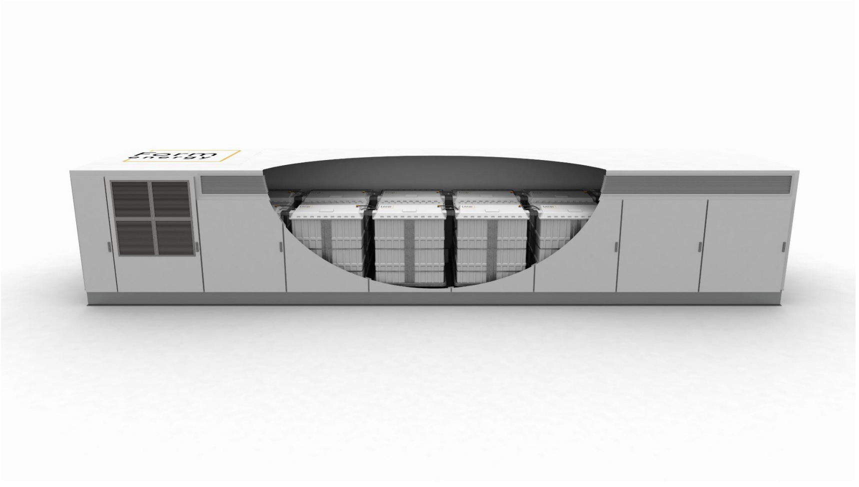
~5 kW / 500 kWh

~2.3 x 1.3 x 1.3m

~50 **Cells**

Smallest Building Block of **DC** Power

Enclosure



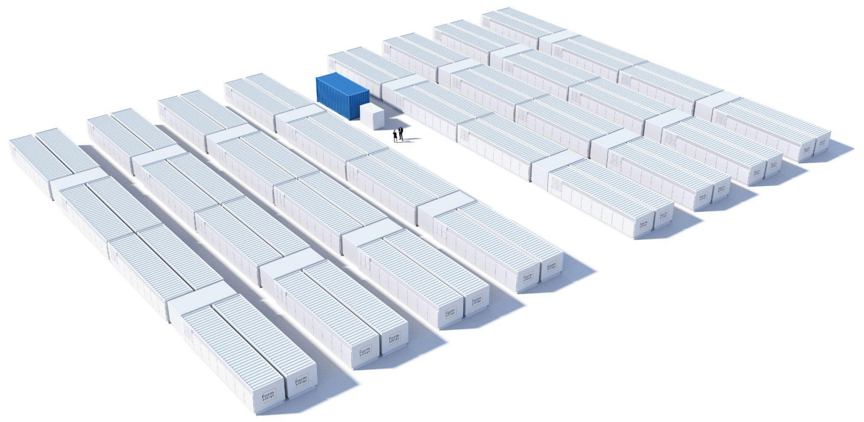
~50 kW

8.6’ x 40’

~10 **Modules**

Product Building Block with **integrated module auxiliary systems**

Power Block



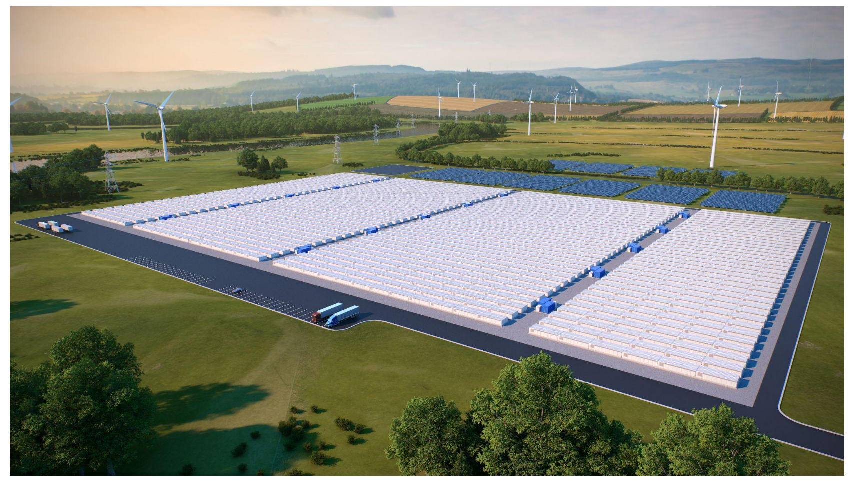
~3.5 MW / 350 MWh

<2 acres

~50 - 100 **Enclosures**

Smallest independent system and **AC Power** building block

System



100+ MW / 10 GWh

50+ acres

10s - 100s of **Power Blocks**

Commercial Intent System

Form Energy's path to transform the global grid

2023/2024
- **Prove Technology at Scale**
- 1-10 MW scale projects
- Demonstrate value in real world environment

2025
- **Initial Commercial Projects**
- 10-100+ MW scale projects
- Demonstrate bankability

2026
- **Full Scale Installations**
- 100+ MW scale projects
- Bankable coal and gas replacement

2030s
- **Deep Decarbonization**
- GW-scale projects
- Meet carbon goals and manage risk

Piloting → Scale-Up → Expansion → Global Transformation

30 years after commercial availability, global lithium-ion manufacturing capacity was 500 GWh/yr in 2020.

Form Energy will exceed that scale before 2030.

GWs of multi-day storage projects deployed by 2030 will enable a lower carbon, more resilient electricity grid

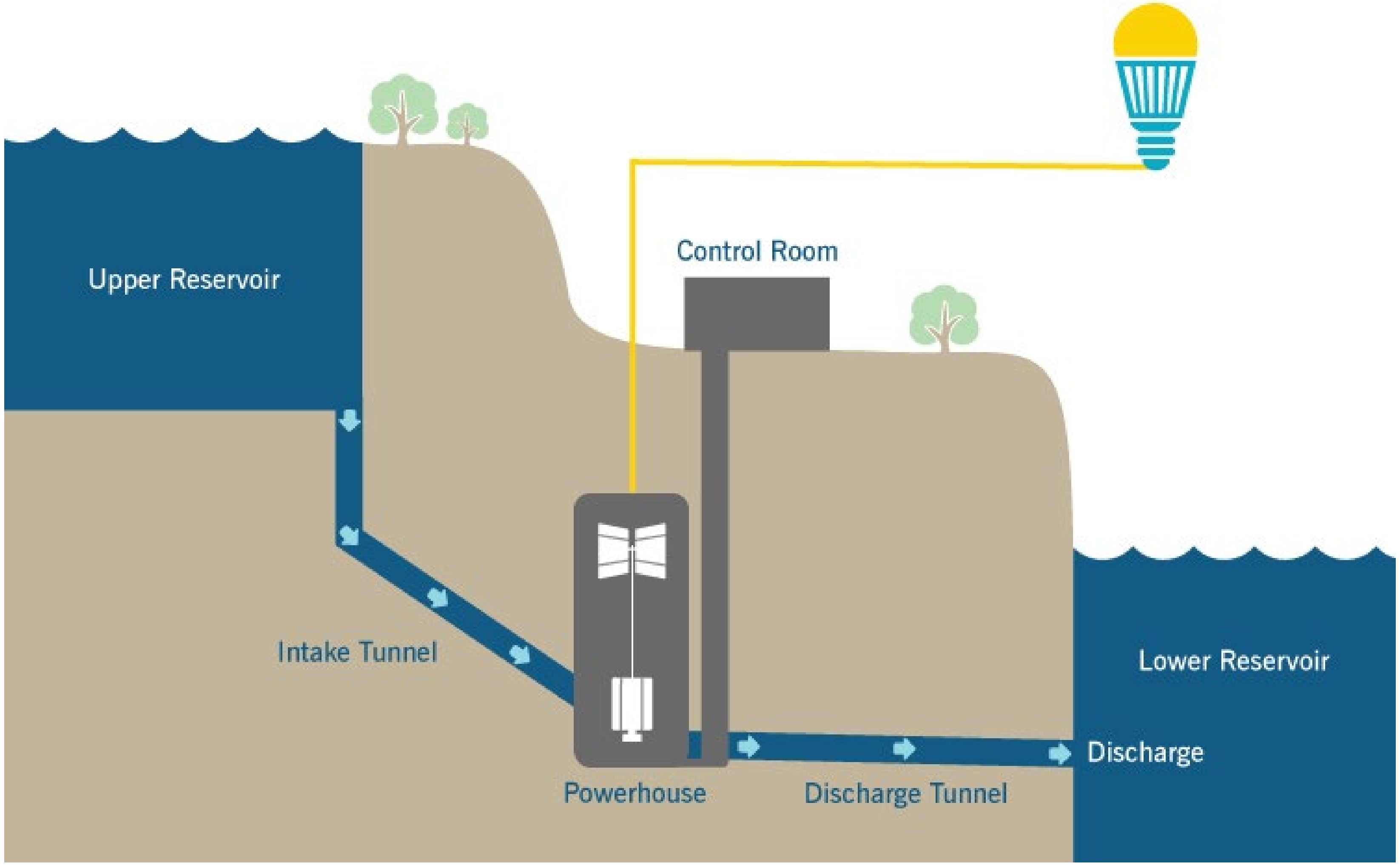
- ✔ Improved grid reliability & resilience
- ✔ Higher renewables penetration
- ✔ Accelerated fossil retirements
- ✔ Lower cost emissions reductions
- ✔ Less congestion and curtailment

National Hydropower Association

NARUC Long Duration Energy Storage Webinar

Pumped Storage Value Proposition

How Do Pumped-Storage Hydro Plants Work?

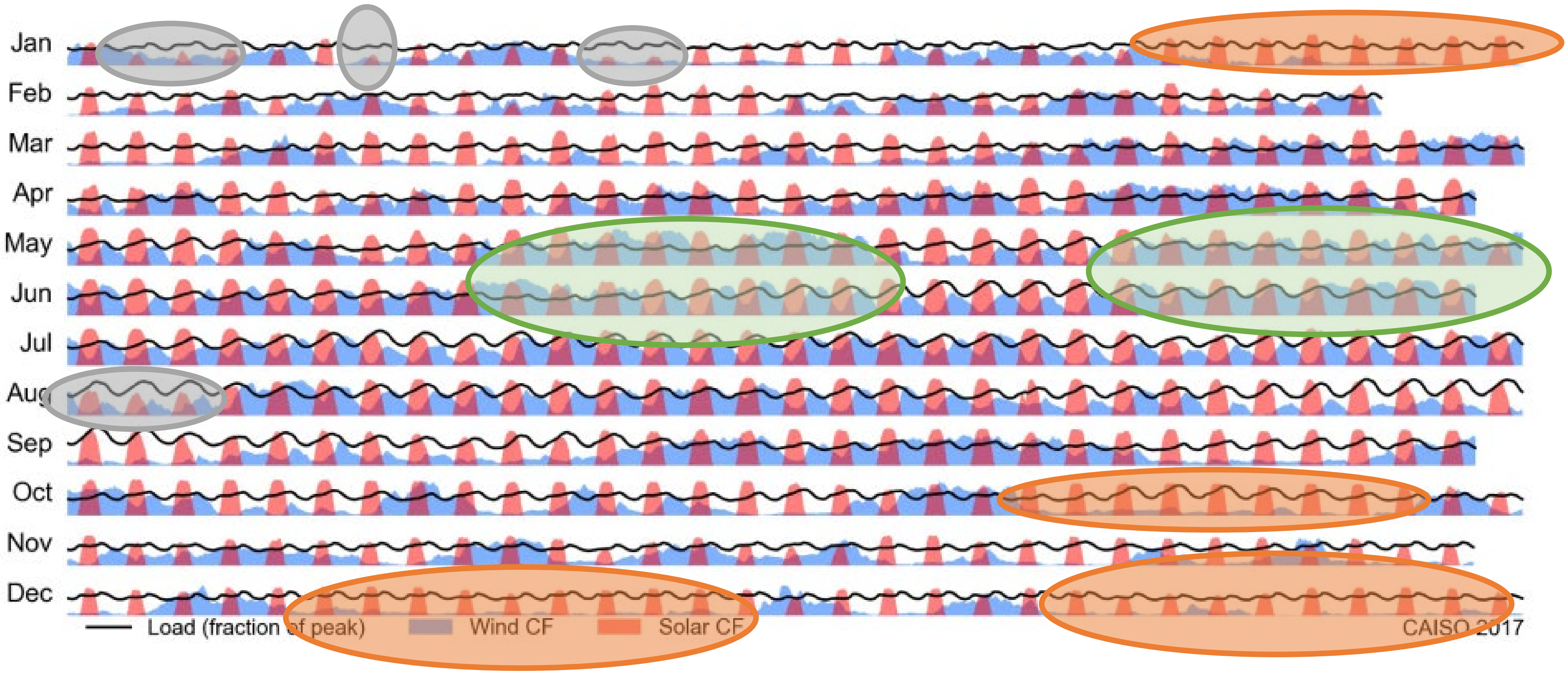


Source: https://www.duke-energy.com/energy-education/how-energy-works/pumped-storage-hydro-plants

The Landscape

- EIA projects the share of electricity from renewables will grow from 21% in 2020 to 42% in 2040.
  - In order to integrate these resources, the system needs flexible capacity that can ramp up and down quickly.
  - As we'll see in the next few slides, long duration storage will be needed.
- Pumped Storage (PSH) has an existing installed capacity approximately 23 gigawatts (GW).
  - Makes up approximately 93% of the electric storage capacity in the U.S.
  - Between 2010-2019, net PSH capacity increased by 1.33 GWs from upgrades at six existing facilities.

California Wind and Solar Generation fo Each Day of 2017, CA Installed Capacity, 2019



Source: Reflections on the Energy Transition: "A Collection of Testimonies by Ernest J. Moniz." June 2021.

Emissions Intensity

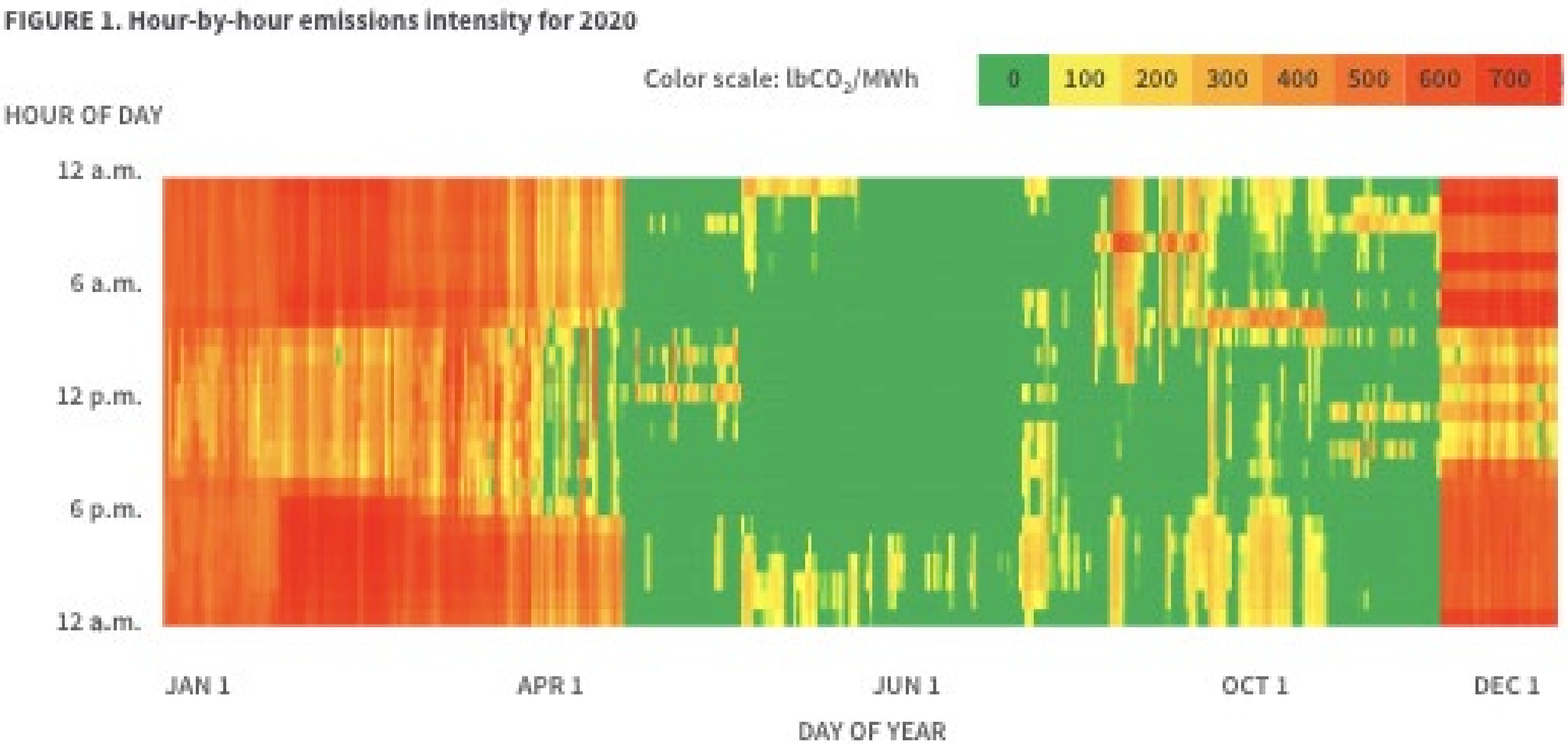


Image credit: Peninsula Clean Energy (2022), Our Path to 24/7 Renewable Energy by 2025.
https://www.peninsulacleanenergy.com/our-path-to-24-7-renewable-power-by-2025/

Evolving Operations

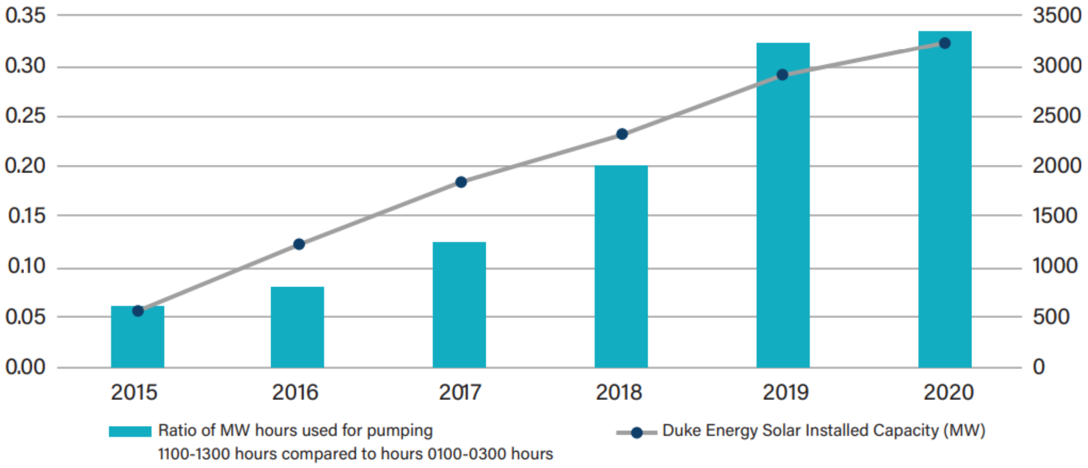


Figure 4. Jocassee and Bad Creek PSH ratio of pumping GWH daytime and nighttime.

Source: NHA's 2021 Pumped Storage Report. Available at https://www.hydro.org/wp-content/uploads/2021/09/2021-Pumped-Storage-Report-NHA.pdf

Evolving Operations

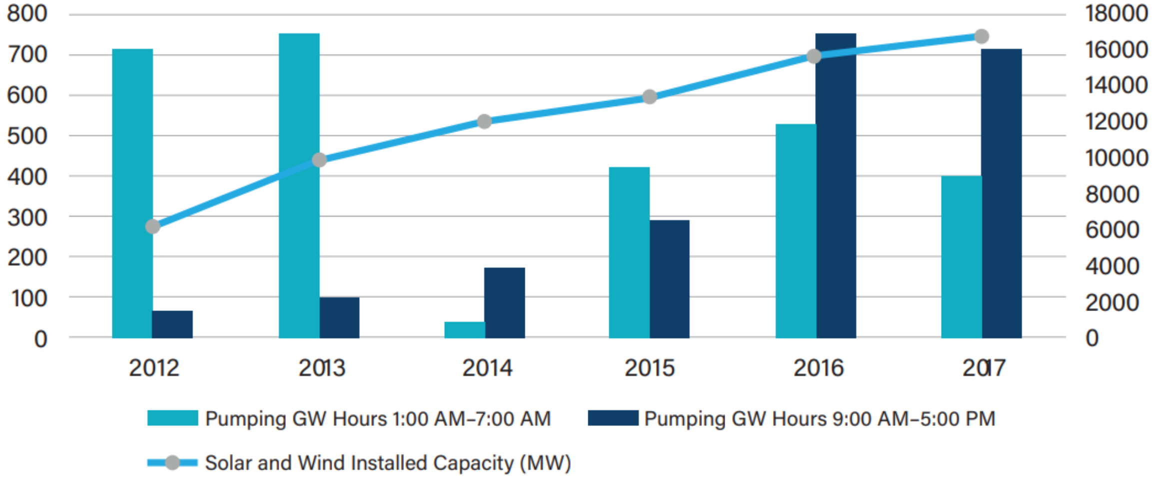


Figure 3. Helms PSH ratio of pumping nighttime and daytime hours with solar and wind overlay.
Source: PG&E, as filed with DOE April 2018 and California Energy Commission.

Source: Courtright Reservoir, the upper reservoir for Pacific Gas & Electric's Helms Power Plant. Photo credit USFWS at http://www.fs.usda.gov/detail/sierra/recreation/?cid=stelprdb5245570

Source: NHA's 2021 Pumped Storage Report. Available at https://www.hydro.org/wp-content/uploads/2021/09/2021-Pumped-Storage-Report-NHA.pdf

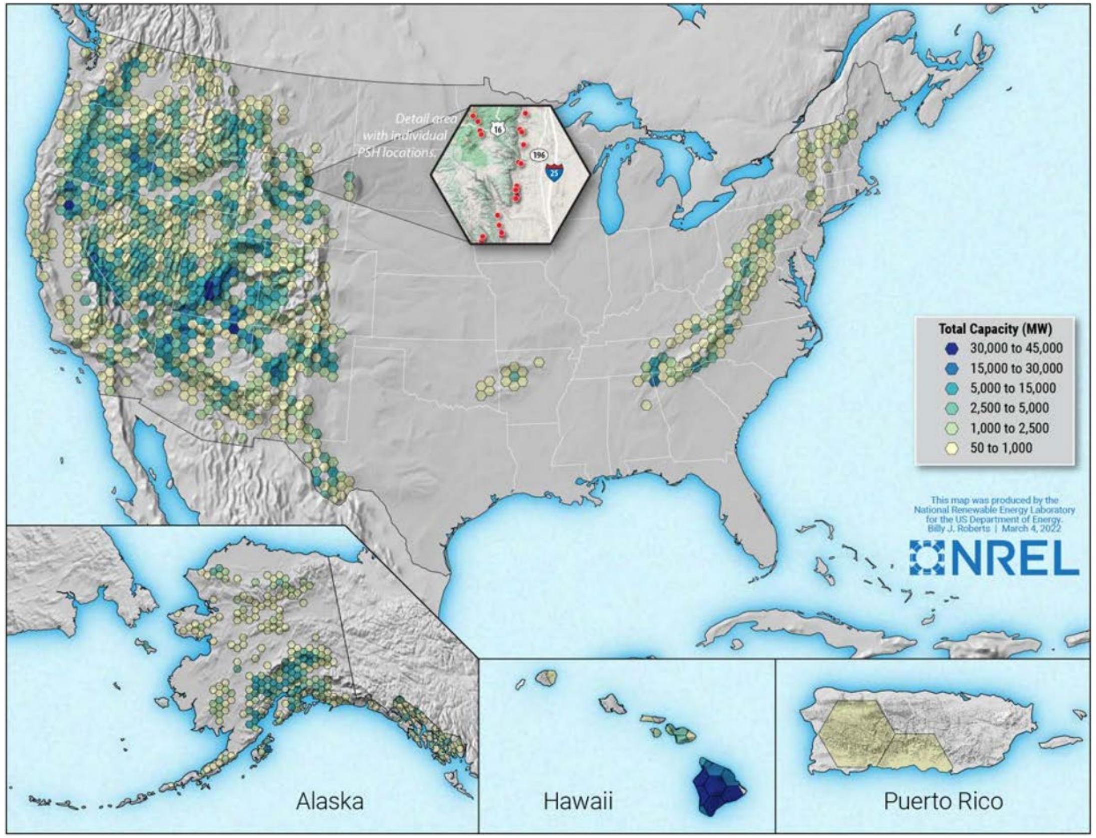
Future PSH Development and Challenges

- According to the Department of Energy, Levelized Cost of Storage ($/MWh) for PSH can run between $121-$209/MWh.
- Three projects totaling 1.8 GWs have received a FERC license.
- Approximately 40 other applicants have received preliminary permits.
- Challenges to development of new PSH include lengthy licensing process and long lead times for development.

Source: A Review of Technology Innovations for Pumped Storage Hydropower (April 2022).
Available at https://publications.anl.gov/anlpubs/2022/05/175341.pdf

Technical Potential

- The United States still has 35 TWh of unused, cost-competitive, closed-loop PSH potential outside legislatively protected wilderness.
- Much of this potential is provided by the terrain in the American West.



Source: Closed-Loop Pumped Storage Hydropower Resource Assessment for the United States (May 2022).
Available at [Closed-Loop Pumped Storage Hydropower Resource Assessment for the United States. Final Report on HydroWIRES Project D1: Improving Hydropower and PSH Representations in Capacity Expansion Models (nrel.gov)]

Thank You!

Michael Purdie
Michael@hydro.org

WORLD RESOURCES INSTITUTE

VEHICLE-TO-EVERYTHING TECHNOLOGY & LONG DURATION STORAGE APPLICATIONS

WRI Electric School Bus Initiative

Photo: Byronv2, fl

Why Electrify the U.S. school bus fleet?

Electrification can accelerate decarbonization while bringing direct, tangible benefits to every community

- **Improved health** and cognitive outcomes for children
- **Cleaner air**, especially in high-pollution corridors and communities of color
- **Reduced operating expenses** for school districts
- **New jobs** in green manufacturing
- A **tipping point** for MHD + electrification
- Enhanced **resiliency** and **renewables integration** with V2G

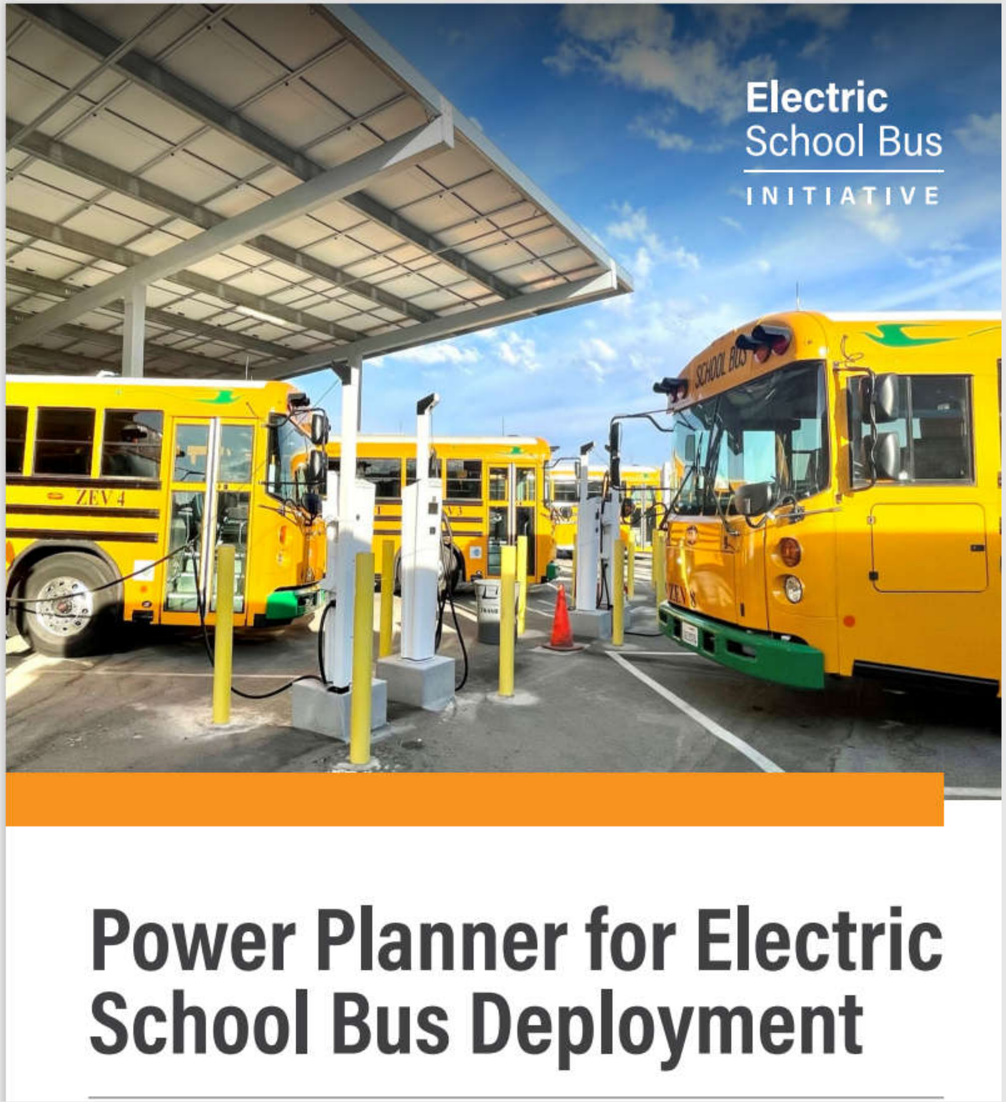
Our vision involves multiple stakeholders

Goal: **An Equitable Transition to Electric School Buses**

Pillar 1	Pillar 2	Pillar 3	Pillar 4	Pillar 5
School Districts	**Manufacturers**	**Utilities**	**Federal & State Policymakers**	**Local Communities**

Foundation: **Equity, Communications, Engagement**

Proactive utility engagement for electric school bus deployment

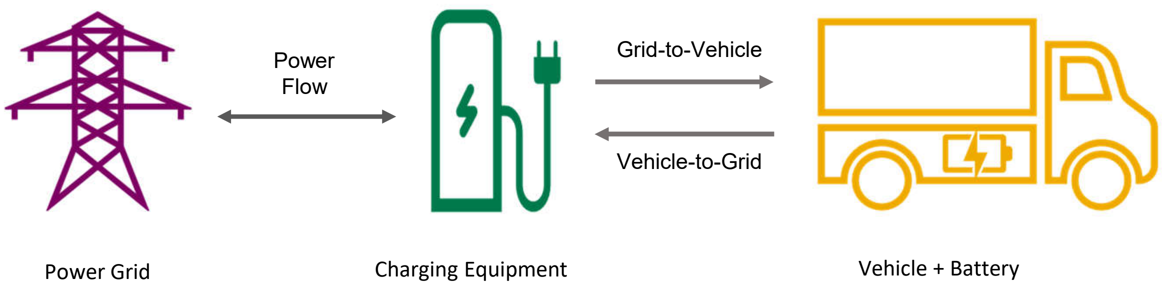


What is V2X?

- Vehicle-to-Everything (V2X): All encompassing where stored energy in the vehicle is discharged for some benefit. This is the preferred term. This is often mistaken for V2G

What is V2G?

- Vehicle-to-grid (V2G) is a technology that allows power stored in electric vehicle batteries to be pushed back on to the electric grid where the electrons mix with those from other generating sources



TYPES OF CHARGING TECHNOLOGIES

- **Vehicle-to-Everything (V2X): All encompassing where stored energy in the vehicle is discharged for some benefit.**

V2X: Bidirectional Charging Inludes -

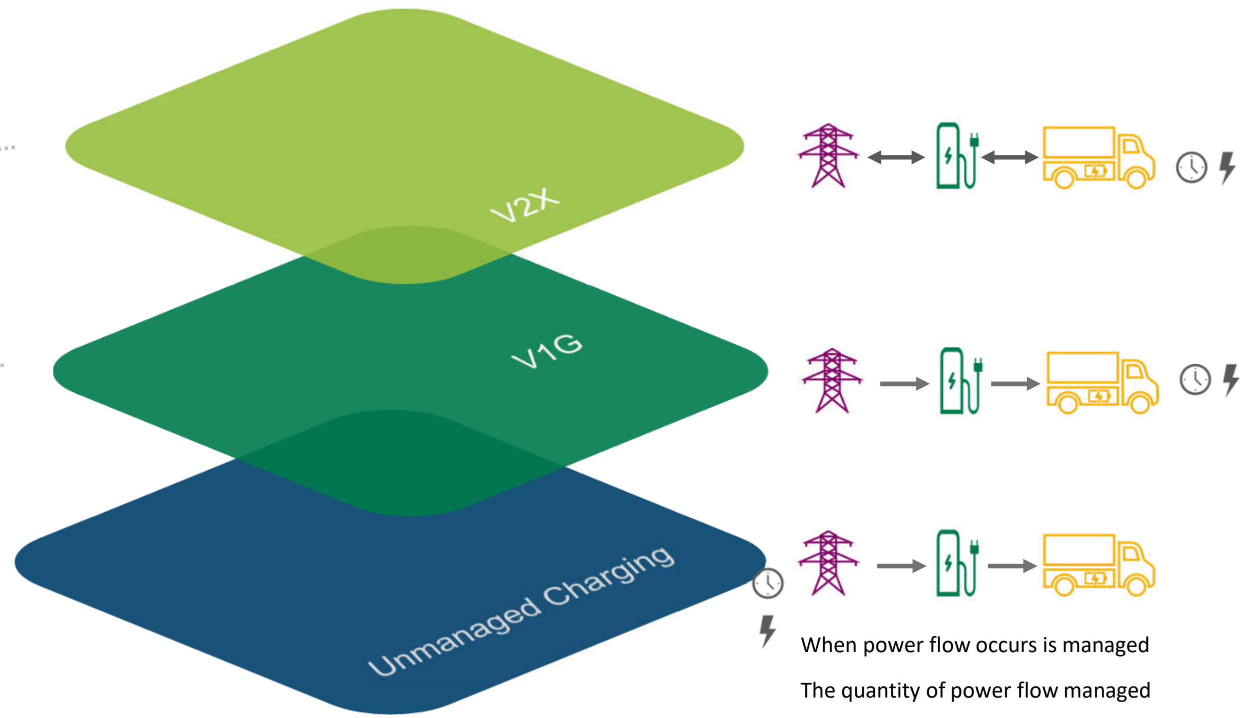
•Vehicle-to-Grid (V2G): Stored energy in the vehicle is discharged back through facility infrastructure (reverse power flow) pass the meter onto the grid to mix with other electrons from other sources/facilities
•Vehicle grid integration (VGI): Where charging and discharging of the vehicle is done in coordination with grid demand to work as a grid asset.
•Vehicle-to-Building (V2B): Stored energy in the vehicle is discharged to the facility/building only
•Vehicle-to-Load (V2L): Stored Energy in the vehicle is discharged to some load that requires electricity to operate

V1G: Managed charging

Electricity flows from grid to vehicle. The time at which charging occurs and/or the quantity of power used to charge are managed to benefit the grid.

Unmanaged Charging

Vehicles are plugged in to a charger and electricity flows from the grid to vehicle at the greatest power capable. EVs charge without regard for the impact charging has on the electric grid.



School Buses & V2X

Electric school buses are well-suited to support V2X

Predictable operational schedules

Large battery capacity

Benefits for school districts

Benefits of V2X

Grid Flexibility & Emergency Preparedness

- V2X services provide grid operators with an on-demand source of power that can provide a range of services. Vehicles can also provide back-up power and mobile power supplies in emergencies.

Decarbonization: Support Renewables

- V2X allows vehicles to absorb renewable energy generation when it is abundant and release that energy when it is not.

Compensation: Lowers Total Cost of Ownership (TCO)

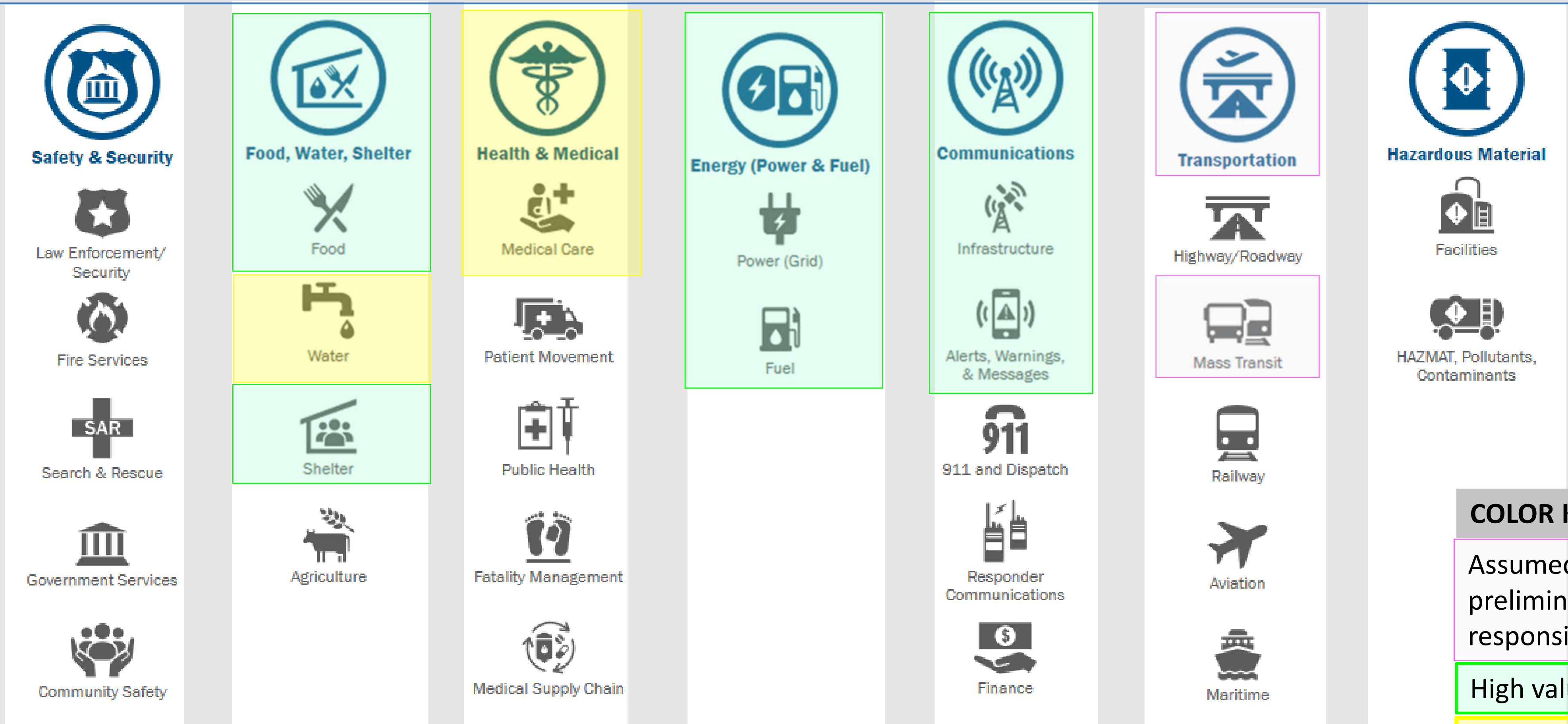
- V2X can generate value by providing services to the grid where vehicle operators are compensated.

V2X Applications

- Energy stored in the batteries of electric school buses can support a range of services and functions
- Some of the most common services include:
  - Demand Charge Mitigation
  - Microgrid/Site Power
  - Demand response
  - Frequency regulation
  - Energy arbitrage
  - Energy arbitrage in support of renewables
  - Emergency preparedness and response

Source: Uddin et al. 2017

Disaster RESPONSE OPPORTUNITIES FOR ESB



COLOR KEY

- Assumed preliminary responsibility
- High value add
- Supplementary value add

WRI would use this in engaging with schools to identify resiliency needs for potential FEMA Mitigation Funding grants

https://www.fema.gov/sites/default/files/2020-08/fema_mitigation-action-portfolio-support-document_08-01-2020_0.pdf

What is a Mutual Aid Agreement?

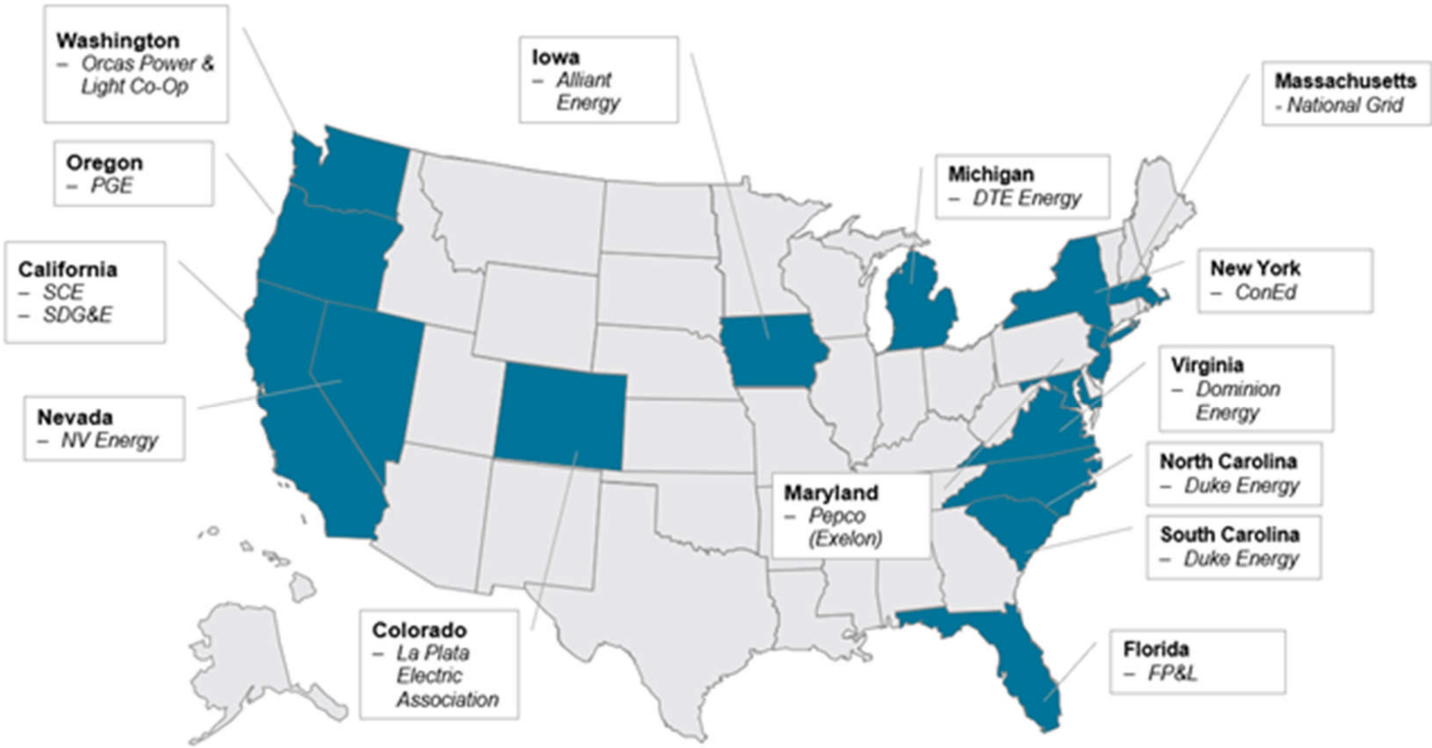
Mutual aid agreements establish the terms under which one party provides resources—personnel, teams, facilities, equipment, and supplies—to another party.

- V2X MAA template produced from - National Incident Management System - Guideline for Mutual Aid (fema.gov)
- MAAs can apply to specific emergency scenarios and will vary in scope (interstate, intrastate, local emergencies)
- MAA examples
  - CA – Disaster and Civil Defense Master MAA
  - CO – Pueblo County Fire Protection MAA
  - NJ – Hazardous Materials MAA
  - Texas – Public Water Utilities MAA

In Development: V2X Disaster Response White Paper

- Want a prescriptive white paper – a "recipe" that describes the equipment needed and steps to follow for establishing a V2X-ESB system to provide emergency back-up power services
- Hoping to identify a partner school district to conduct a real-world microgrid ESB project specifically focused on V2B and building load isolation for shelter services
  - Potential Project Team:
    - WRI ESBI
    - Utility
    - Priority Outreach School District
    - Bidirectional Charger Mfrs.
    - Bus Mfrs.
    - Partner NGOs
    - Gov. Agencies - DOE, FEMA, NEMA

3 Design Considerations for ESB V2G Programs



Map of Utility V2G Electric School Bus Pilot Programs [3 Design Considerations for Electric School Bus Vehicle-to-Grid Programs | World Resources Institute (wri.org)]

WORLD RESOURCES INSTITUTE

1. Equity First

Does the Program Prioritize an Equity-First Approach when Selecting Partners and Locations?

Electric school buses with V2G technologies offer an opportunity to advance an equity-driven agenda given the air quality, health and resiliency benefits that may be amplified in underserved communities where residents face higher levels of pollution and are more susceptible to climate change impacts. Several proposed or deployed V2G utility programs have focused on underserved communities, identified through indicators such as the number of students eligible for free and reduced lunches or average family income.

2. Supportive Rates

Does the Program Consider New Rates to Enable School Bus Electrification and V2G Applications?

Using electricity for powering buses typically results in significant cost savings compared to relying on diesel fuels. However, specific electricity rate designs, which can vary widely across the U.S., influence the economics of electric school buses and can be particularly important if using V2G applications. Electricity rate structures can influence when buses are charged or when it makes sense to discharge electricity. In some cases, districts may face higher costs for charging during peak usage periods. Or they may face higher demand charges if their overall power usage increases during a specific hour (or, sometimes, a 15-minute interval) during a month.

3. Community Resilience

Does the Program Help Drive Community Resilience?

Electric school buses could play a role in disaster recovery and response by providing electricity during hurricanes, fires, floods and other emergencies. With climate change, natural disasters are becoming more frequent and more intense. By 2030, floods will affect more than 145 million people, including many who live in coastal areas of the United States. During extreme weather and other emergencies, interconnected infrastructure systems can fail due to power outages that stop core community operations and expose the most vulnerable residents to disproportionately high risk.

Thank you

Please contact Gregg Kresge at

Gregg.Kresge @wri.org

Electrons-to-Molecules

Electrolytic H_2 as a Pathway for Renewable Fuel Production, Energy Storage, & Waste-to-Energy Applications

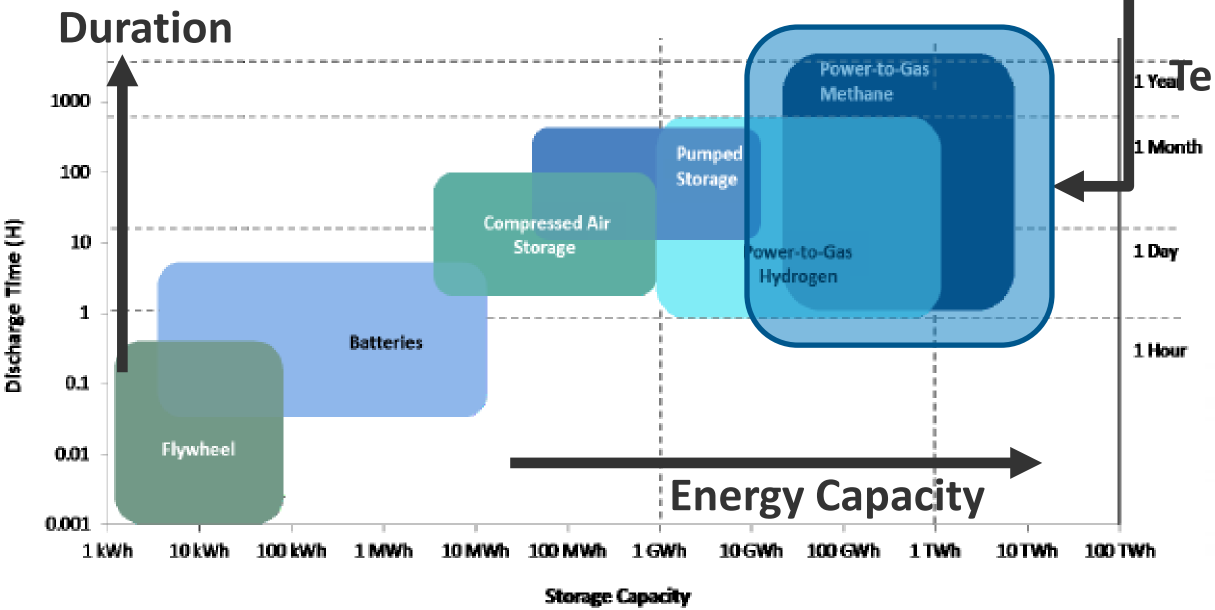
Nancy Dowe, Kevin Harrison, and Claire Victor

October 13th, 2022

NARUC Long Duration Storage Webinar

NREL Transforming ENERGY | 45Th anniversary

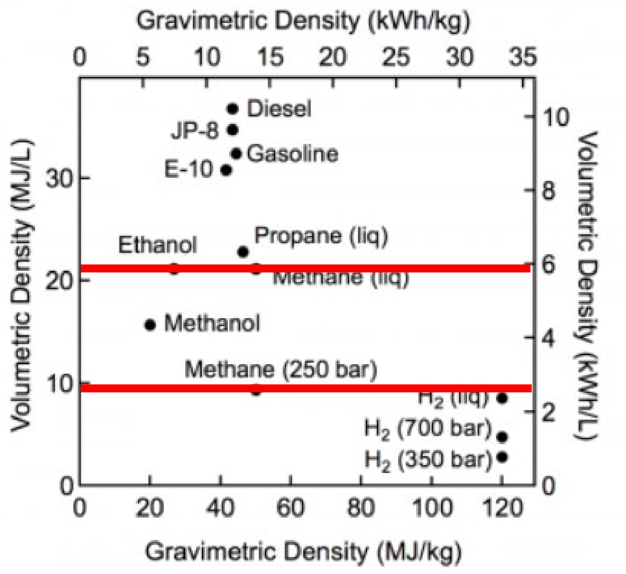
Energy Storage: Electrons-to-Molecules



Highest Energy Density

Terawatt-hour-scale energy storage in the existing NG Network

- **For example, 1 TW-h requires 25,000 10MW batteries (4 hr)**

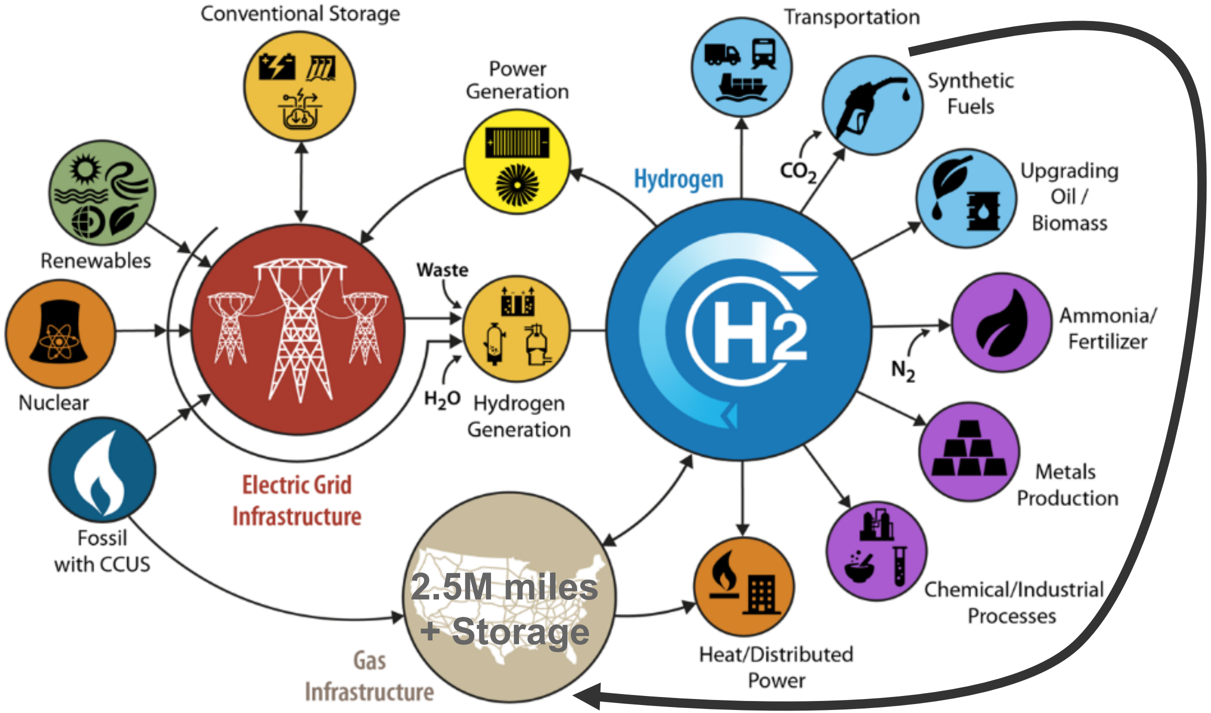


https://www.energy.gov/eere/fuelcells/hydrogen-storage

Over 130 billion cubic feet of natural gas storage capacity exists in Southern California.

To put this in perspective, this is enough to supply all of the gas-fired generation in the region for more than two months.
- SoCalGas

H_2@Scale Initiative



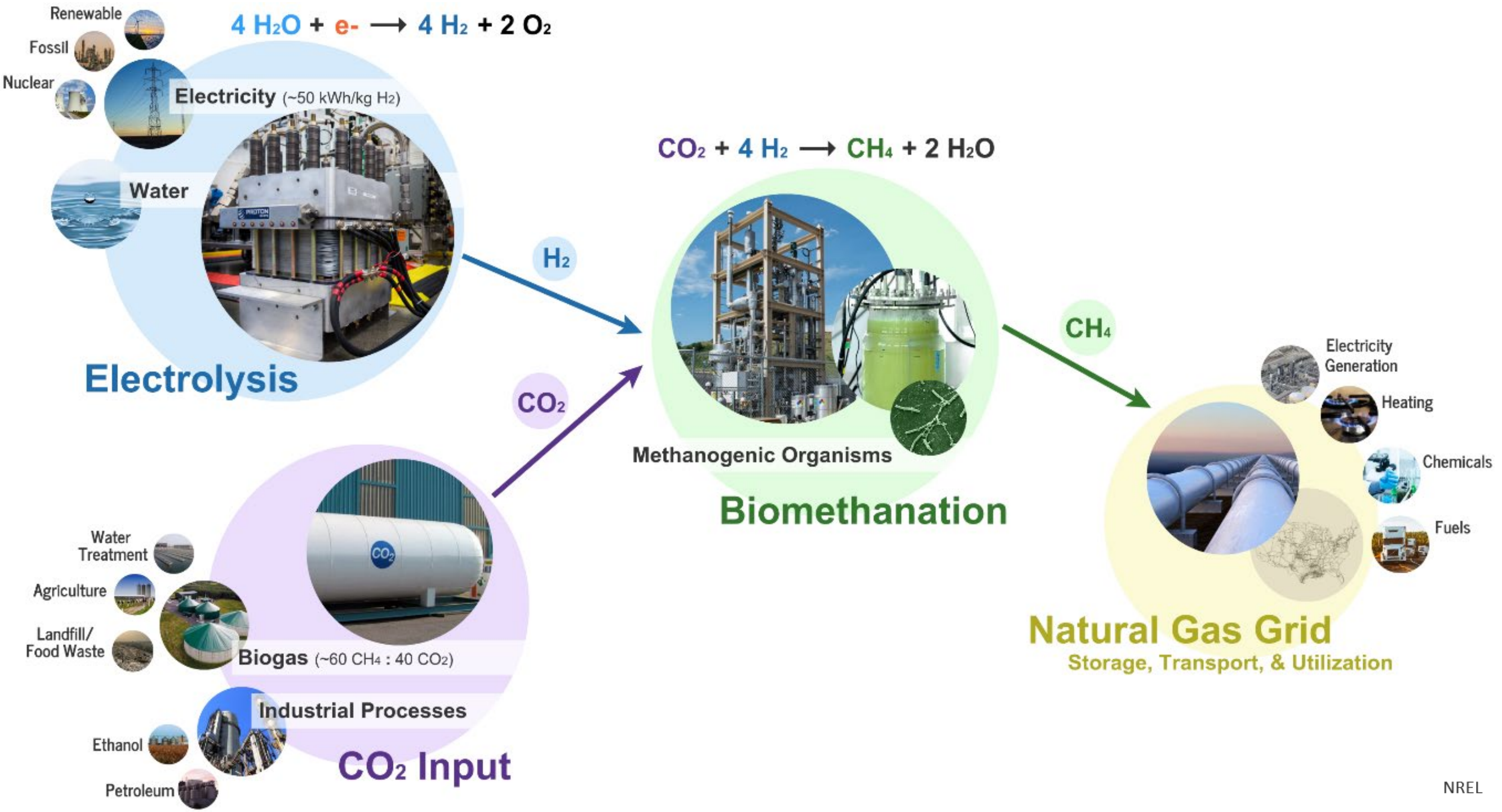
Benefits of Renewable H_2

- Enables higher penetration of renewable electricity
- Electrolyzer can provide grid services
- H_2 is used in many aspects of our energy system
- O_2 is a byproduct
- Growing transportation sector
- Reduces fossil fuel consumption
- Scale-able, non-toxic, low temperature process

10 MM tons H_2 /year in U.S.

https://www.energy.gov/eere/fuelcells/h2scale

TECHNOLOGY OVERVIEW



AD > H2 > Biomethanation

Anaerobic Digester

Mesophilic (30°C – 38°C) or thermophilic (49°C – 57°C)

Heat

$50\ Nm^3/h\ CO_2$ (from Biogas)

$75\ Nm^3/h\ CH_4$ (from Biogas)

Biomethanation, 60°C

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O + \text{Heat}$$

carbon dioxide, hydrogen, methane, water

Synthetic Biomethane $50\ Nm^3/h$

Organic Biomethane $75\ Nm^3/h$

Natural Gas grid

160 kW, 60°C Heat

H_2 Production, 60 – 80°C

1MW, ~20kg/hr

80% efficient (HHV)

50 – 55 kWh / kg H_2 @Scale

9L per kg H_2 Electrolysis only

$200\ Nm^3/h\ H_2$

$400\ Nm^3/h\ O_2$

200 kW, 60°C Heat

KEY ENABLERS

1

Low-cost, Low-carbon Electricity

Select renewable technologies (e.g., utility scale solar PV and wind) are cost-competitive with conventional generation technologies when considering unsubsidized levelized cost of electricity

2

Waste-to-Energy

Biomethanation via the 13,500+ potential biogas and other CO_2 sources can increase RNG production by ~70% over gas separation technologies (e.g., membranes, amine)

3

Carbon Markets

	Federal RFS	CA LCFS
Manure	**D3** $19.93/mmbtu	-250 CI $61.98/mmbtu
Food Waste	- -	0 CI $15.54/mmbtu -25 CI $20.18/mmbtu
Wastewater	**D3** $19.93/mmbtu	
Landfill	**D3** $19.93/mmbtu	45 CI $7.18/mmbtu

Examples of Federal and state carbon markets support RNG and other fuel production

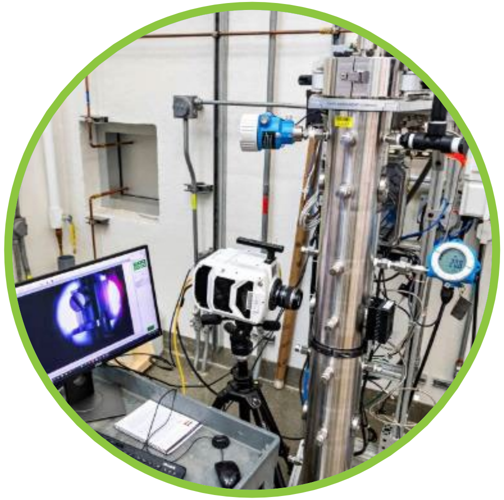
4

Long-duration Energy Storage

In addition to its high energy density, methane has high storage capacity for long-duration energy storage

The existing NG Network alone has Terawatt-hour-scale energy storage capacity via underground geological and pipelines

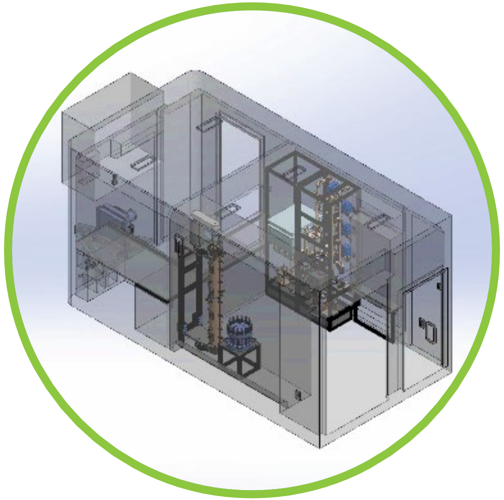
CURRENT PROJECTS



EL/Bioreactor Integration

SoCalGas, BETO, HFTO, & University of Chicago

Close-coupling of electrolyzer and bioreactor to advance IP, advancing water management techniques, and improving hydrogen mass transfer with advanced gas mixing



Biopower

BETO, Electrochaea, & SoCalGas

Producing pipeline quality RNG from Biomethanation via 20L bioreactor on a mobile RD&D platform and collaborating with ANL to investigate CI from dairies with TEA/LCA

Peaks Renewables

BETO, SoCalGas, Electrochaea, Plug, & CDM Smith

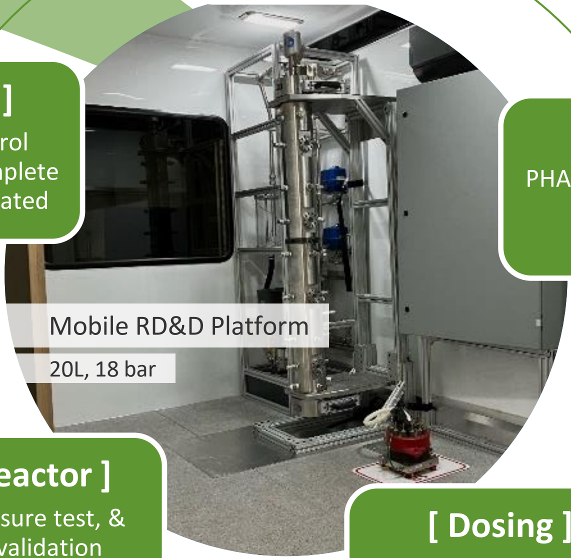
Summit Utilities/Peaks Renewables to deploy biomethanation at a diary digester, integration with renewable electricity & hydrogen production

ACCOMPLISHMENTS

[Operations]
Installed, commissioned, & operated 700L , 18 bar reactor for 300+ hours

[Mobile RD&D]
3D model & control room fabrication complete

[Controls]
Power and control system design complete & installation initiated



[Thermal]
PHA, fabrication, & leak test complete

[Bioreactor]
PHA, pressure test, & sensor validation complete

[Dosing]
Design, PHA, & part specification complete

2021 Patent Applications

Application No. 17/261,473

Improving capital and operating costs of the electrolyzer

- 5-10% EL capital cost reduction
- 3-5% EL system efficiency improvement
- Advancement of operational safety via elimination of dissolved H_2 at EL anode

Application No. 17/397,665

Using stack current for H_2 mass flow and gas ratio control

- Enhancement of mixed gas ratio control
- Improvement of H_2 mass transfer
- Elimination of H_2 mass flowmeter and flow control valve

PATH FORWARD

Cost & Efficiency

De-risk two-step biomethanation process by improving cost and efficiency

Decarbonization

Complete pathway certification for waste-to-energy feedstocks, and GHG reduction at pilot-scale installations

H_2 Gas Mass Transfer

Investigate gas sparger designs and conduct bubble analyses with high-speed imaging

Water Management

Improve water removal in the gas phase of the bioreactor to maintain organisms & nutrients

Thermal Management

Recycle waste heat from electrolyzer and bioreactor for downstream processes

Thank You

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Panelists

- **Jason Houck**, Sr. Manager, Policy and Regulatory Affairs, Form Energy
- **Michael Purdie**, Director of Regulatory Affairs and Markets, National Hydropower Association
- **Greggory Kresge**, Sr. Manager, Utility Engagement and Transportation Electrification – US Energy, World Resources Institute
- **Dr. Kevin Harrison**, Program Manager, National Renewable Energy Laboratory

SAVE THE DATE: Monday, January 30, 4-5 PM EST

Long Duration Storage Virtual Site Visit

Join AEE institute and Form Energy for a virtual tour of Form Energy's state-of-the art lab facilities. Get a behind-the-scenes look at how Form Energy is ramping up to produce its low-cost, 100-hour iron-air batteries.

Form Energy's CTO, William Woodford, will discuss the development of Form's groundbreaking iron-air technology and Form's plan to rapidly scale manufacturing capacity. Form Energy's CEO, Mateo Jaramillo, and Nidhi Thakar, VP of Policy and Regulatory Affairs, will host a Q&A in the latter half of the program.

Invitations coming soon! Contact Sophie Watterson (swatterson@aee.net) with any questions.

Upcoming

- NARUC Annual Meeting & Education Conference in New Orleans, November 13-16, 2022
- Check www.naruc.org/cpi for information on upcoming activities

Thank you!

Visit www.naruc.org/cpi for additional resources