INCREASE YOUR H_2IQ

The #H2IQ Hour

Today's Topic:

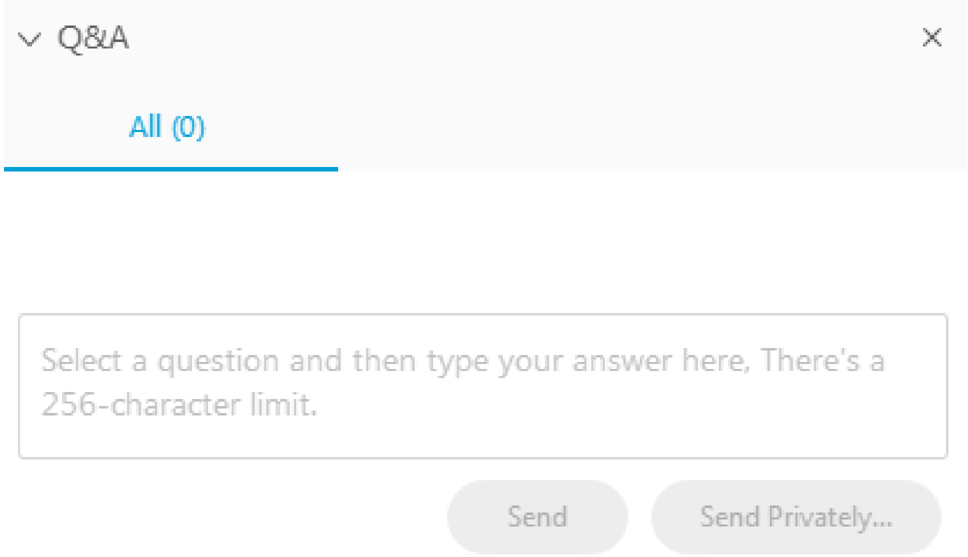
NREL Electrolyzer Grid Integration Study

This presentation is part of the monthly H2IQ hour to highlight research and development activities funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).

INCREASE YOUR H2IQ

The #H2IQ Hour Q&A

Please type your questions into the **Q&A Box**



Electrolyzer Grid Integration Study

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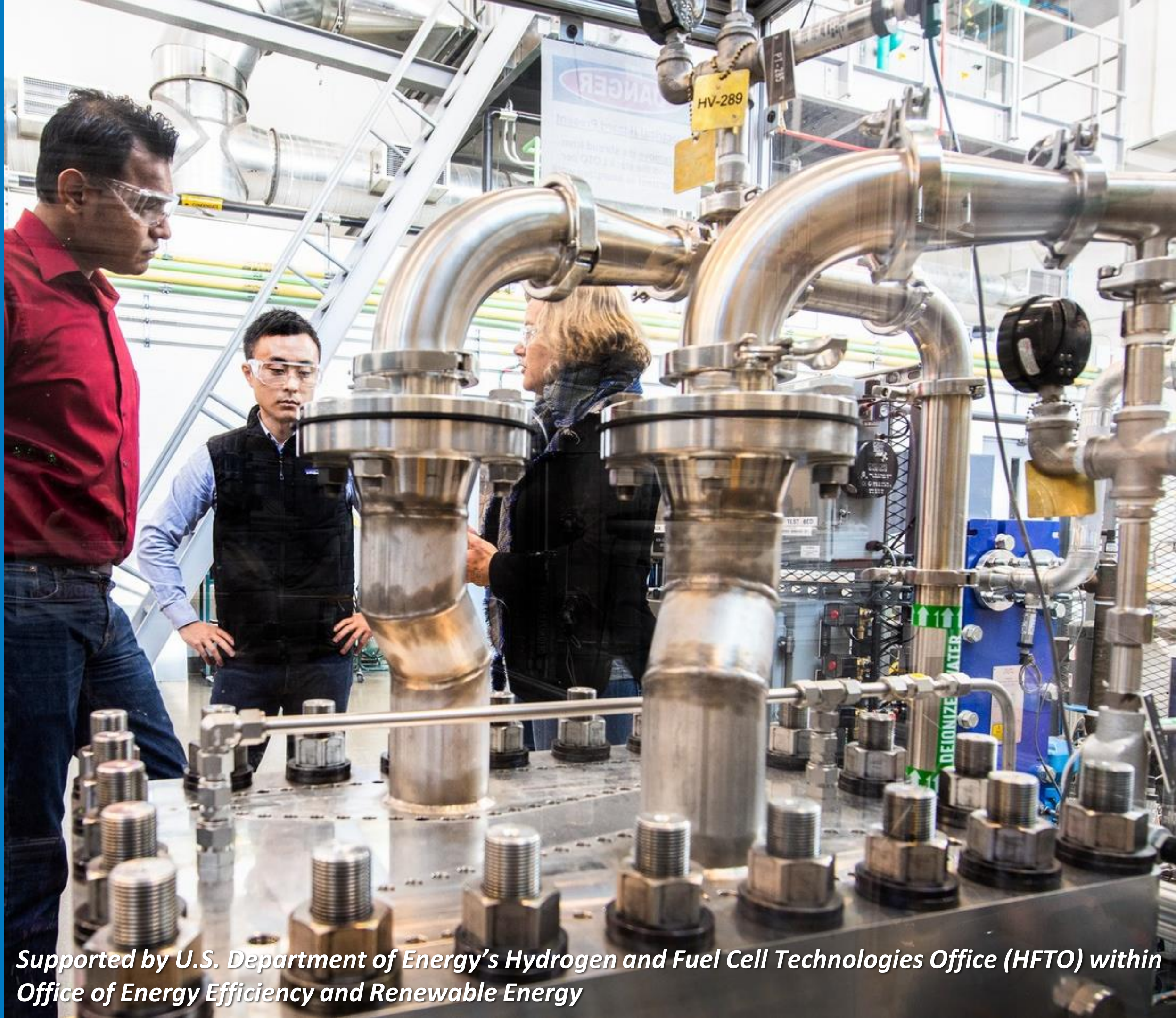
Energy Conversion and Storage Systems Center

Rishabh Jain, Santosh Veda
Power Systems Engineering Center

November 24, 2020
H2IQ Hour Webinar

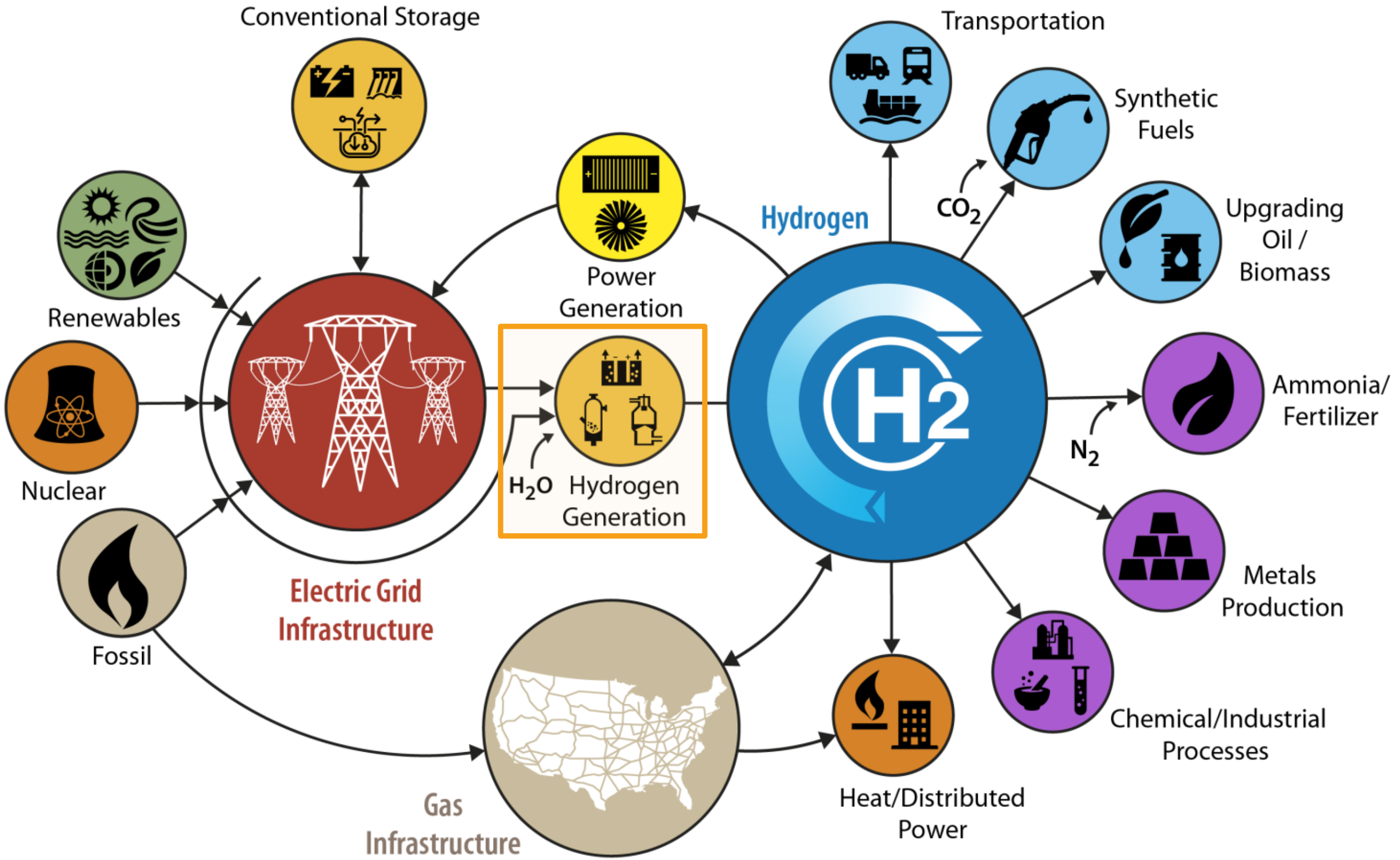
Agenda

- Background and Motivation
- Applications
  - Electrolyzer Characterization
  - Dynamic Electrolyzer Control
  - Integrated Electrolysis and Fast Charge Station
- Advanced Research on Integrated Energy Systems (ARIES) Initiative
- Key Takeaways



Supported by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within Office of Energy Efficiency and Renewable Energy

Grid-Integrated Electrolysis Plays an Important Role in the H2@Scale Vision



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

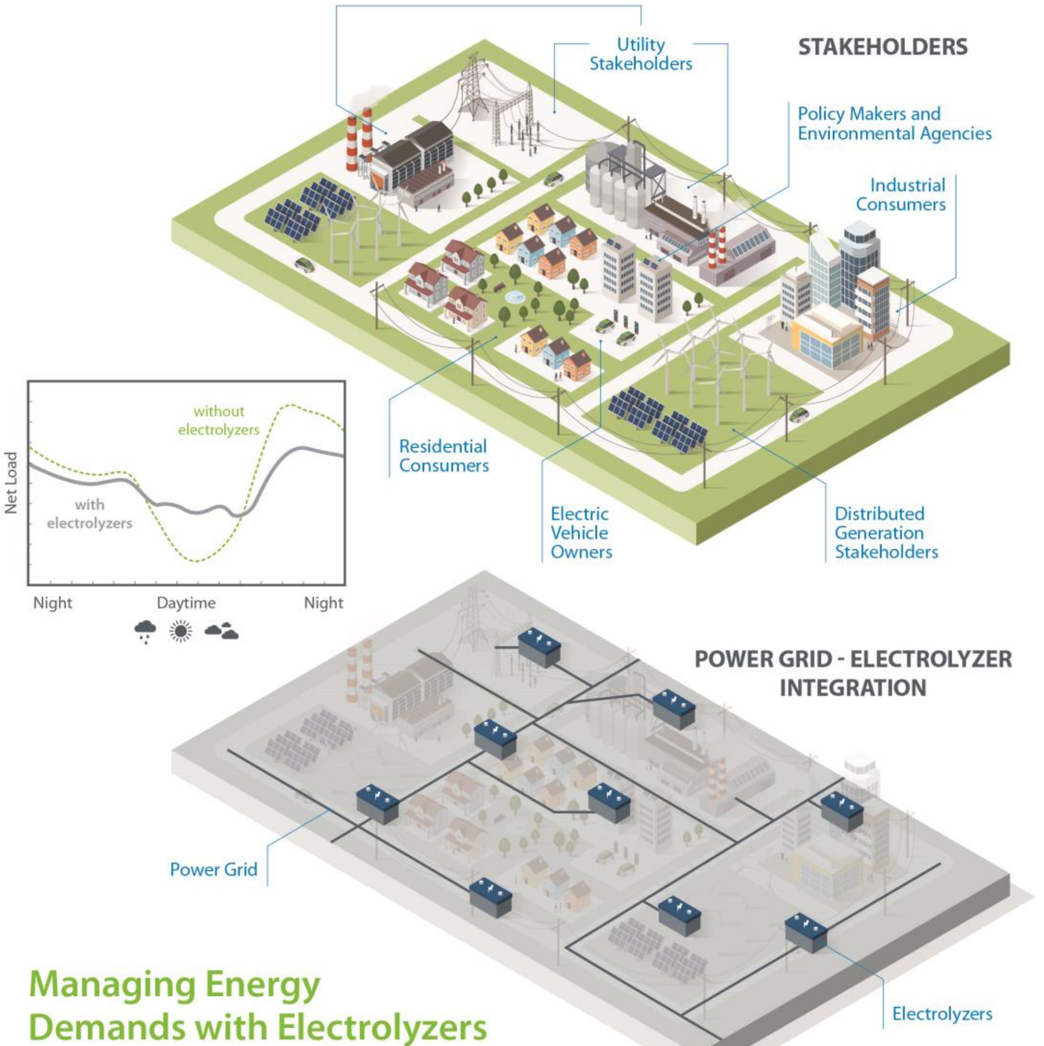
Potential Benefits of Electrolyzer Grid Integration

Reduce energy usage and emissions in end-use applications

- Transportation applications (e.g. HDVs)
- Chemical processes
  (metals refining, fertilizer production)
- Natural gas supplementation
- Combined heat and power with fuel cells

Improve grid performance, reliability, and resiliency

- Stabilize demands for an integrated system
- Avoid curtailment of renewables
- Mitigate voltage/frequency disturbances



M. Koleva, K. Nagasawa, J. Kurtz, "California Hydrogen Integration Report," 2020

High-Level View of ESIF

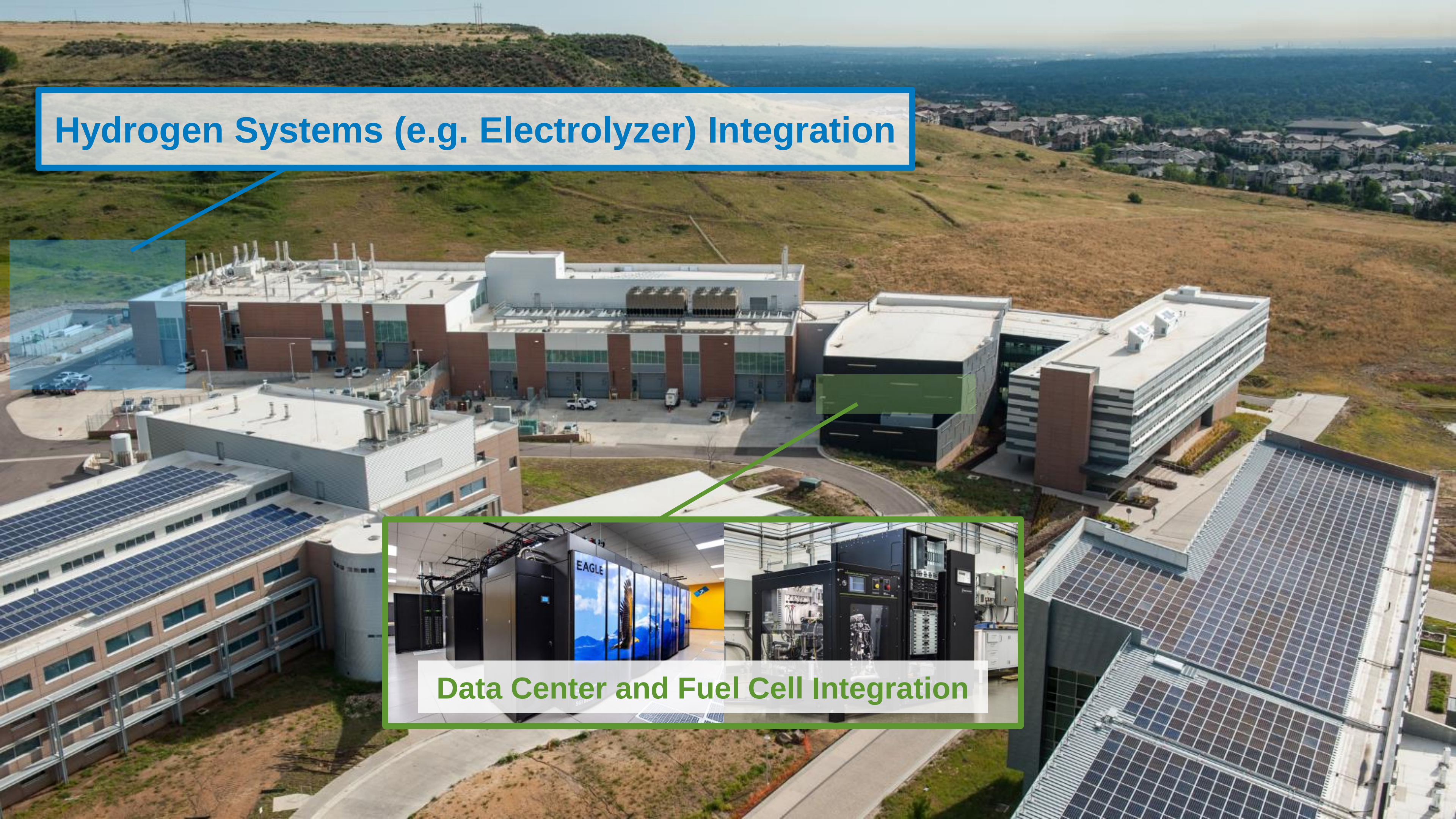
ESIF: Energy Systems Integration Facility

Facility Attributes

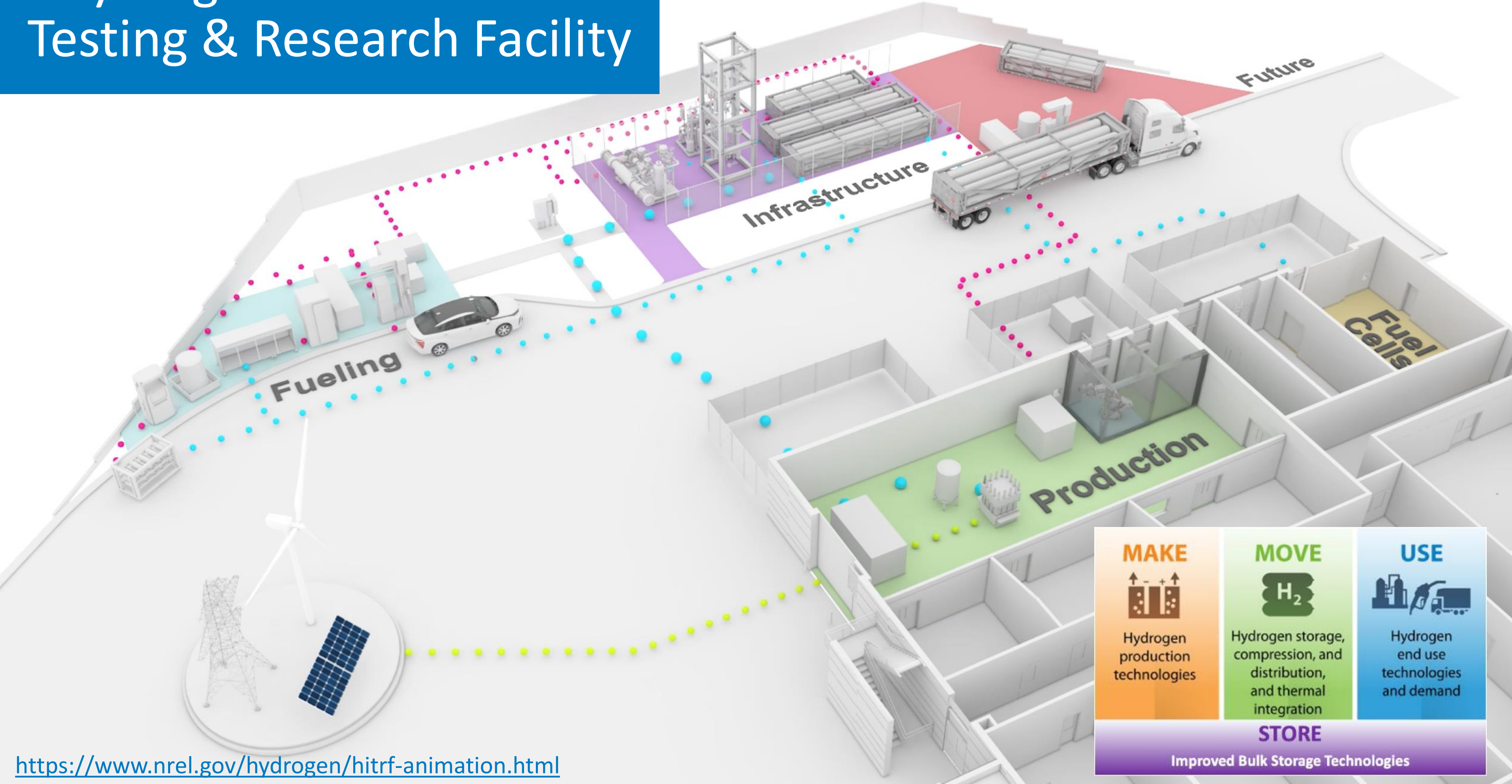
- Designated Technology User Facility with $36 million F&I Budget
- 8 Petaflop HPC, data center, and visualization room
- **Hydrogen system & chemistry labs**
  - Production, Compression, Storage, Dispensing
- **Integrated Labs**
  - REDB, Thermal, Modeling/RTS, Outdoor Test Areas, Fixed Equipment, Flatirons Campus

Key Research Enablers

- **Hardware and controls experimentation**
- **Power Hardware-in-the-Loop (PHIL)**
- Fundamental science for energy materials
- Modeling and simulation
- Data analytics and visualization
- Education and training

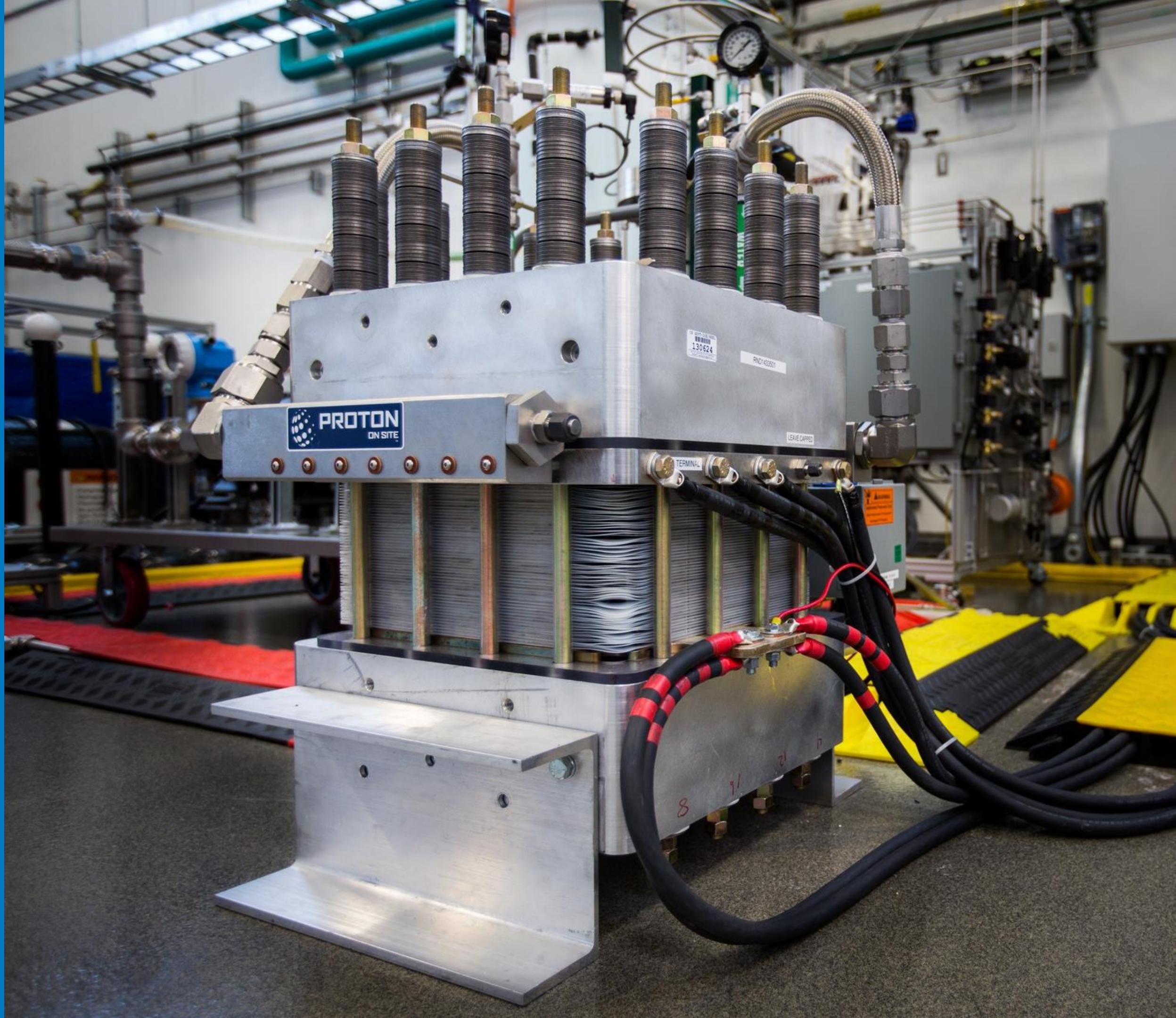

Hydrogen Systems (e.g. Electrolyzer) Integration
EAGLE
Data Center and Fuel Cell Integration

Hydrogen Infrastructure Testing & Research Facility



https://www.nrel.gov/hydrogen/hitrf-animation.html

Electrolyzer Characterization



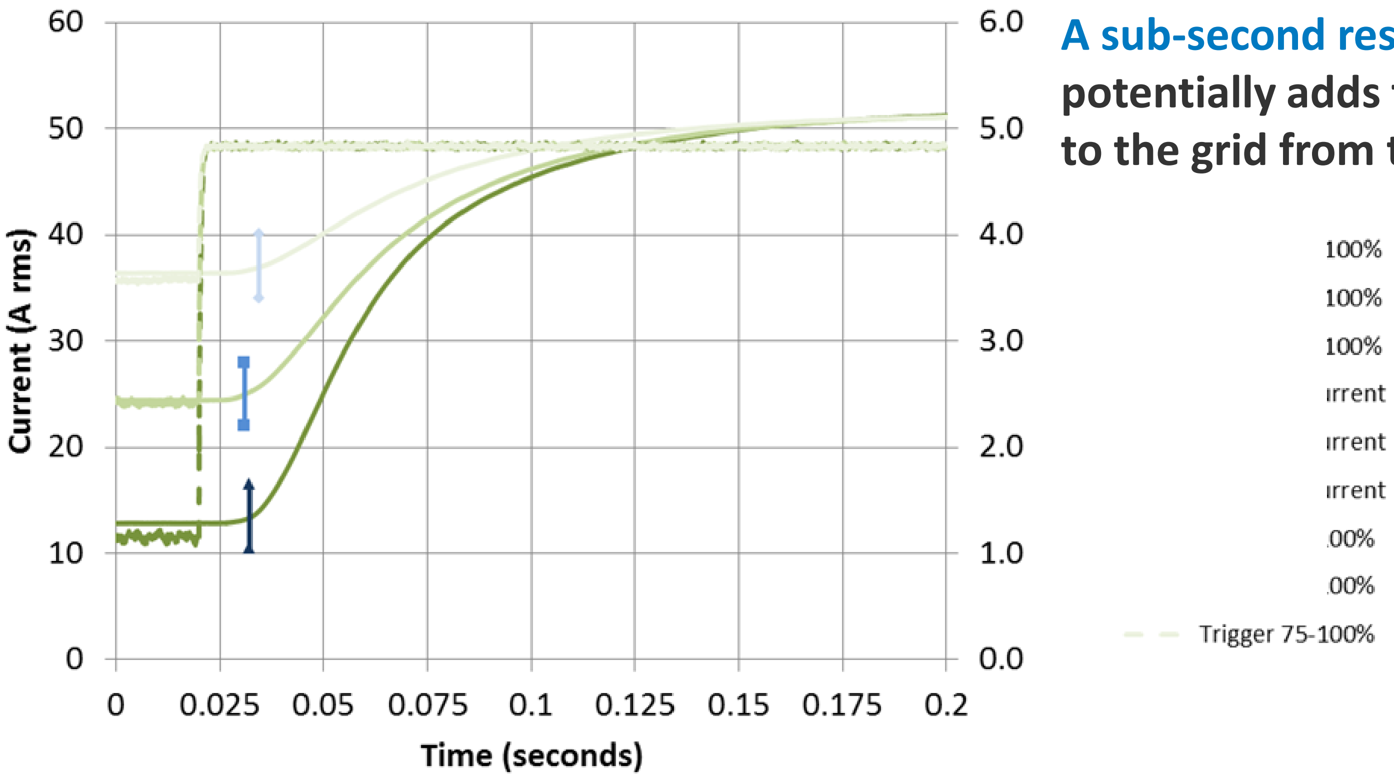
Electrolyzer Grid Integration R&D Timeline

	FY15–FY16	FY17	FY18	FY19	FY20
Objective	Identify highest potential integration opportunities and build HIL capabilities with remote control	Develop communication and controls and demonstrate fast-acting electrolyzer response	Verify communication and controls with traditional grid and high renewable penetration	Validate grid modeling with renewables and nuclear and validate mitigated disturbances	Evaluate the ability of electolyzers to stabilize integrated station power demands
Modeling	Utility distribution grid, electrolyzer characterization, economic potential	Front-end control	Multiple distribution grid networks with renewables	Bulk and distribution grids with renewables, nuclear generation	Integrated station with multiple demands (and renewables)
Systems Analysis	Demand response, ancillary services, reverse power flow, grid fault transient dampening with electrolyzer	Frequency and voltage support with grid faults, refined economic analysis	Different renewable penetrations, rate structures for a production costs	Validated bulk and distribution models, improved hydrogen production model	Geographical effects on economic trade-offs for demand and energy charges
ESIF	40 kW PEM electrolyzer, 120 kW PEM electrolyzer via RTDS, verified sub-second response, and validated communication INL-NREL	500 hours of electrolyzer operation, validated response time for grid faults, and characterized electrolyzer efficiency	225 kW PEM electrolzyer, operated with multiple PV production profiles, validated avoidance of curtailed renewable energy	Validated electrolyzer control with bulk and distribution grids, refined power set-point control	750 kW PEM electrolyzer, integrated station control

ESIF: Energy Systems Integration Facility

System-Level Response Time for the PEM Electrolyzer: Ramp-Up

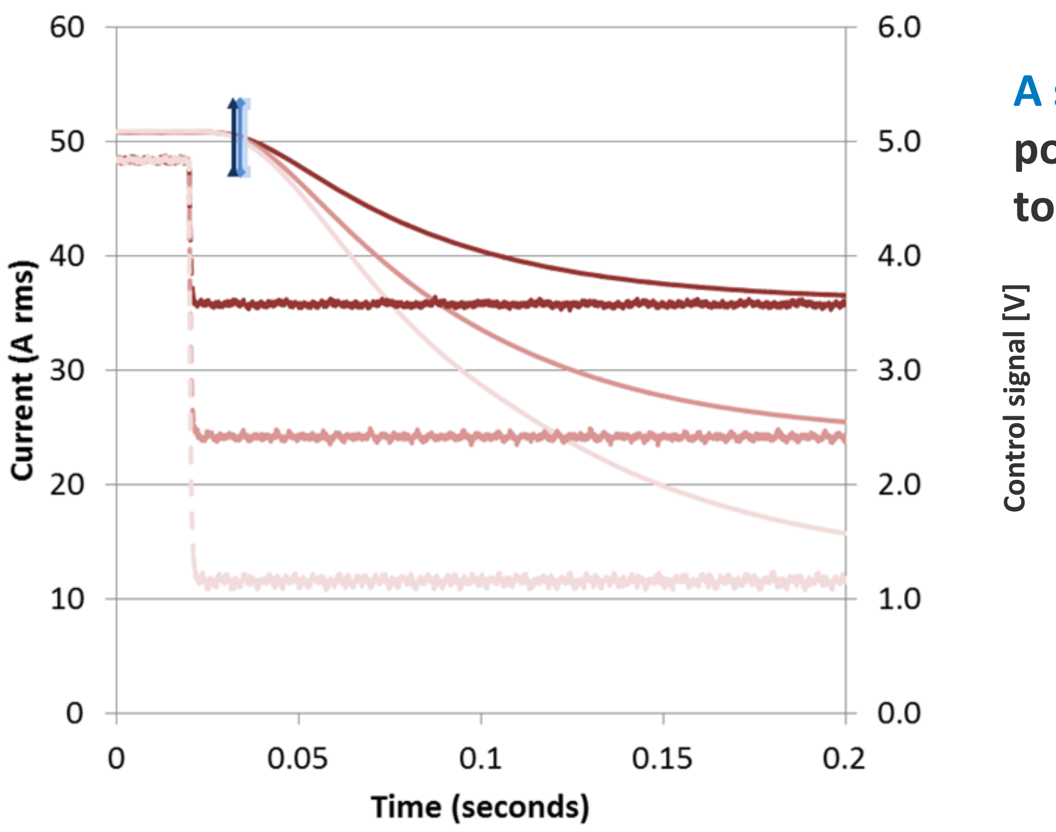
PEM: Proton Exchange Membrane



A sub-second response time potentially adds flexibility and stability to the grid from the demand side.

J. Eichman, K. Harrison, M. Peters, "Novel Electrolyzer Applications: Providing More Than Just Hydrogen," NREL Technical Report, 2014

System-Level Response Time for the PEM Electrolyzer: Ramp-Down



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Dynamic Electrolyzer Control

Distribution and Transmission Grid Applications

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ESIF: Energy Systems Integration Facility

Distribution Grid Application

DER: Distributed Energy Resource

High-level summary; Does not captures all aspects.

Objectives

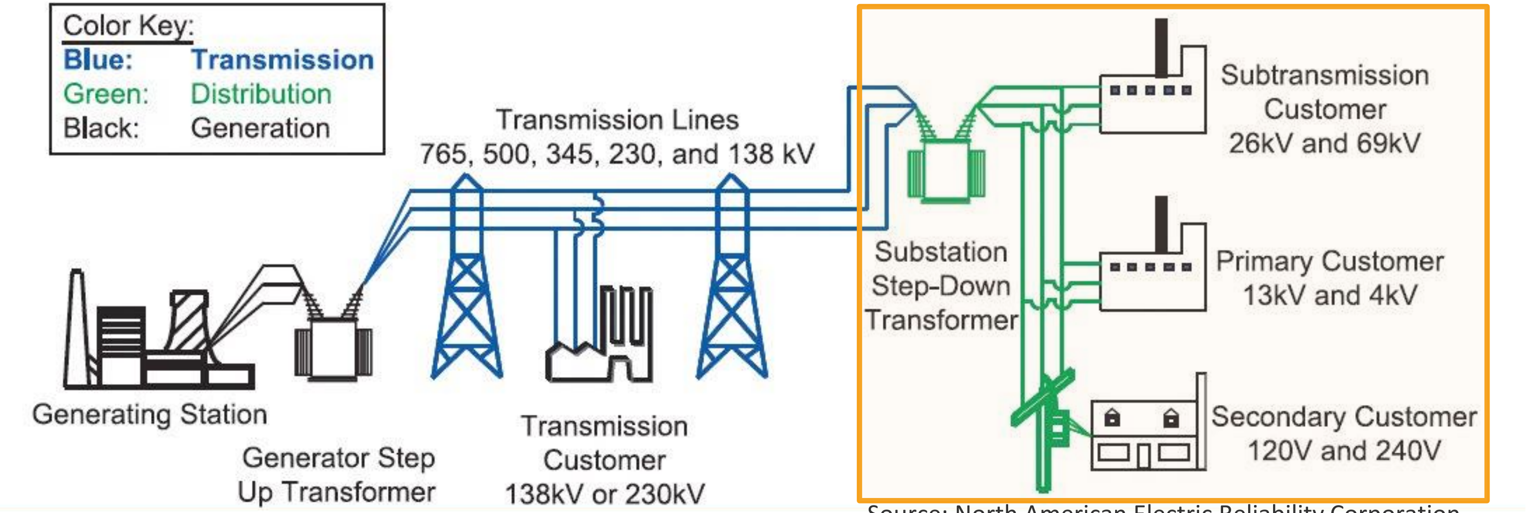
Maintain power quality

- Voltage regulation
- DER integration

Approaches

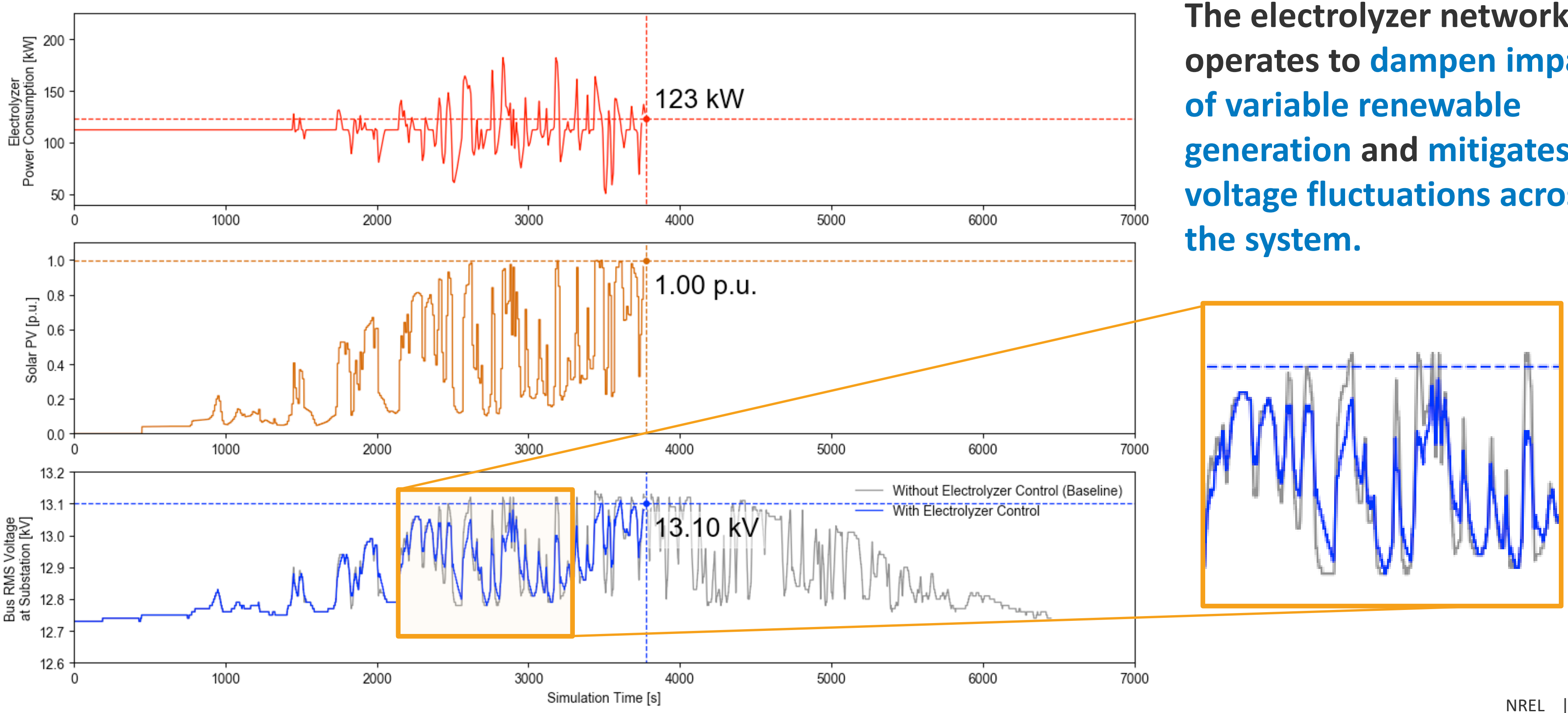
Regulate voltage and/or power ramps

- Tap changers (traditional)
- Network of electrolyzers



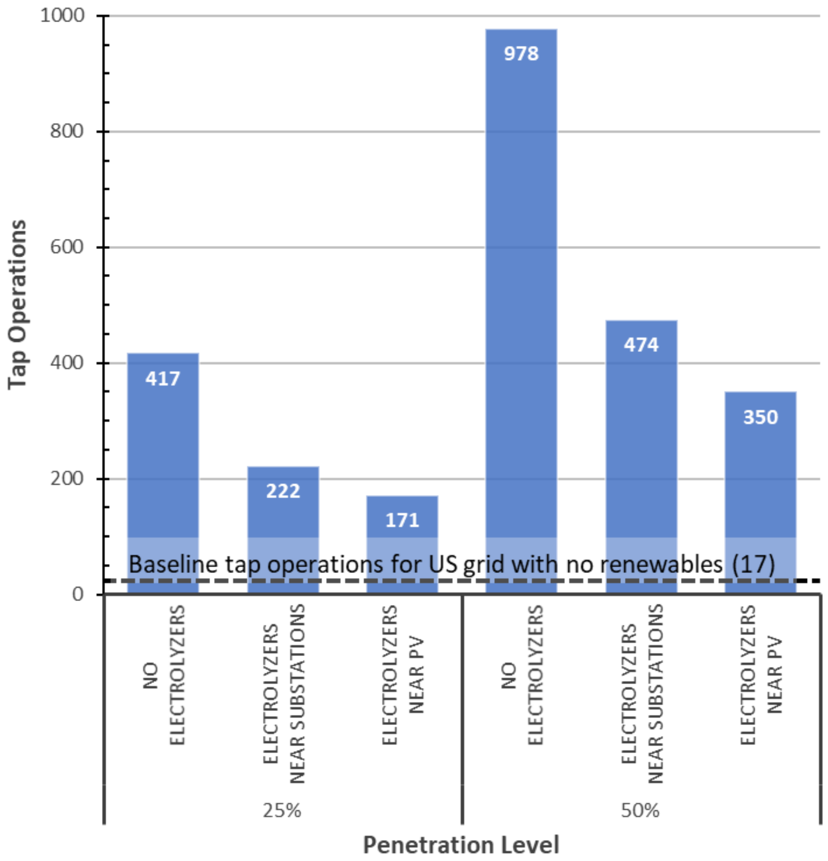
Source: North American Electric Reliability Corporation

Effects of Variable Renewables on Electrolyzer Operation



The electrolyzer network operates to dampen impacts of variable renewable generation and mitigates voltage fluctuations across the system.

Reduced Tap Operations



Adding electrolyzers on the grid helps reduce wear and tear of tap changers and cost burdens of maintaining grid reliability.

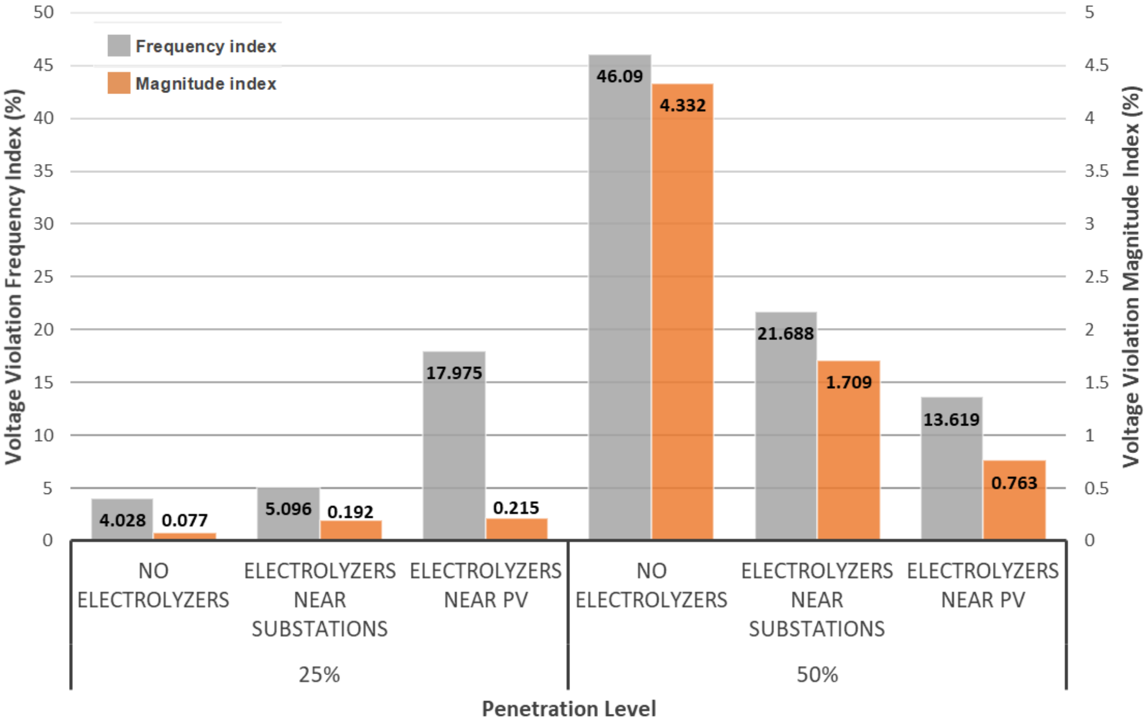
Renewable penetration levels

- 25%
- 50%

Electrolzyer deployment scenarios

- No electrolyzers
- Electrolyzers near substations
- Electrolyzers near PV

Mitigated Voltage Disturbances in Count & Magnitude



In the high renewable penetration scenario, locating electrolyzers near the renewable generation source mitigates voltage disturbances more effectively.

Electrolyzer location was not optimized.

Transmission Grid Application

High-level summary; Not captures all aspects.

Objectives

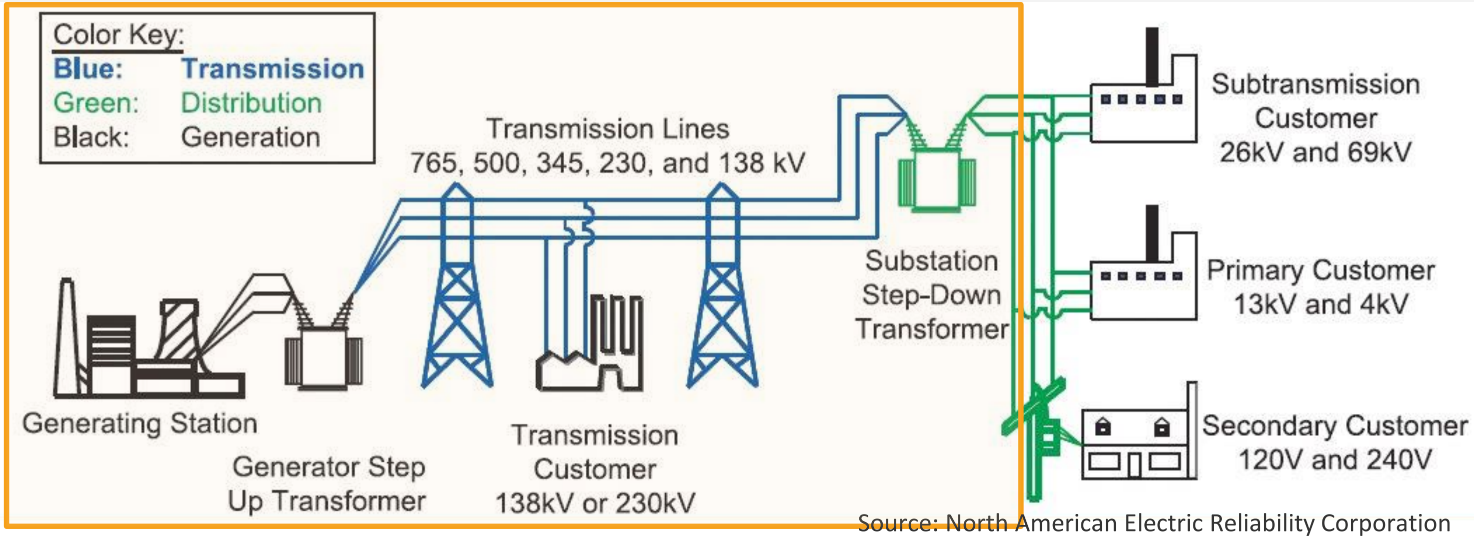
Maintain system balancing

- Frequency regulation
- System inertia support

Approaches

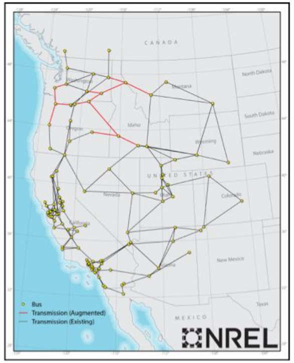
Regulate equipment power exchange

- Generation reserves (traditional)
- Network of electrolyzers

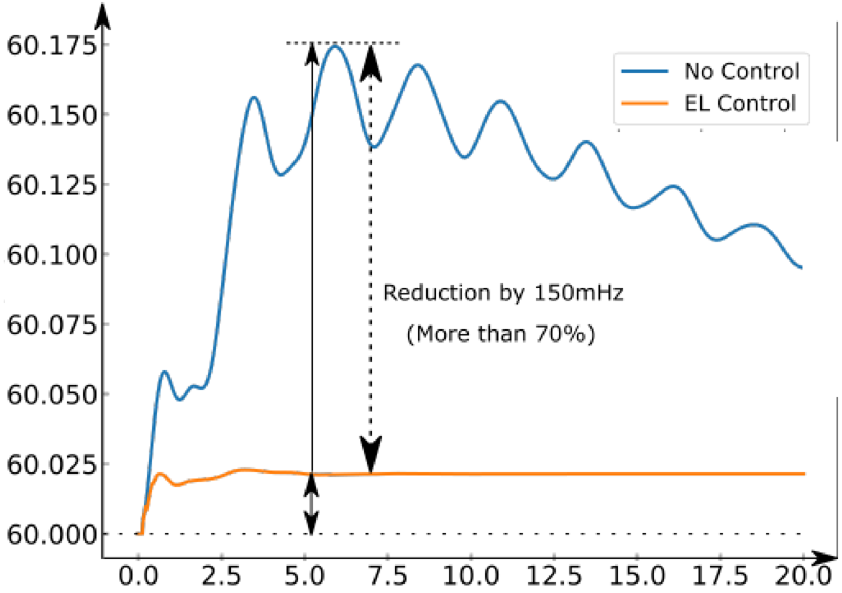


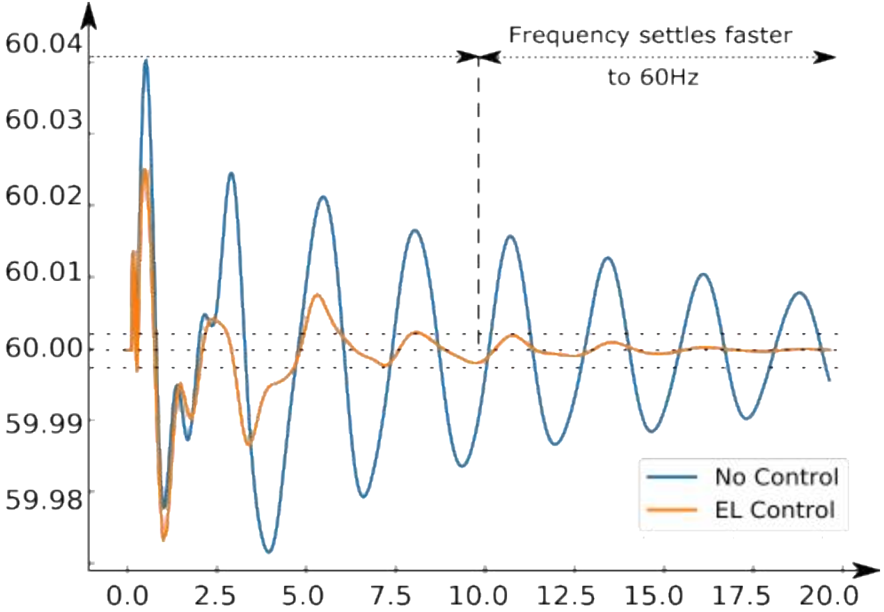
Source: North American Electric Reliability Corporation

Impacts of Electrolyzers on the Bulk Grid



The electrolyzers dispersed on the bulk grid reduced frequency deviations, and the frequency settling time was about ~50% less compared to the case without the electrolyzer network.





Integrated Electrolysis and Fast Charge Station

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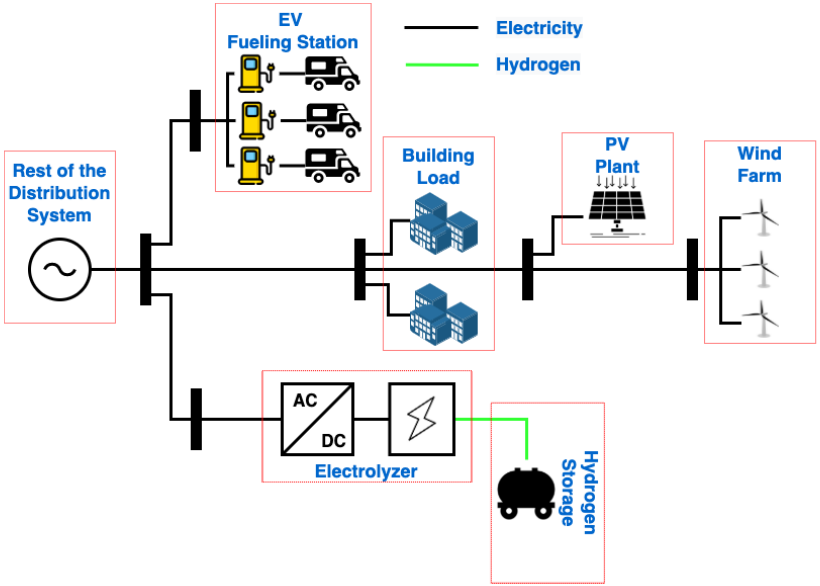
ESIF: Energy Systems Integration Facility

Basic Concept of an Integrated Fueling Station

- Scalable real-time control test-bed with electrolyzers, EV charging station, building load, and distributed energy resources (PV, Wind)

- Active demand management in conjunction with a reduced grid model and optimization routine

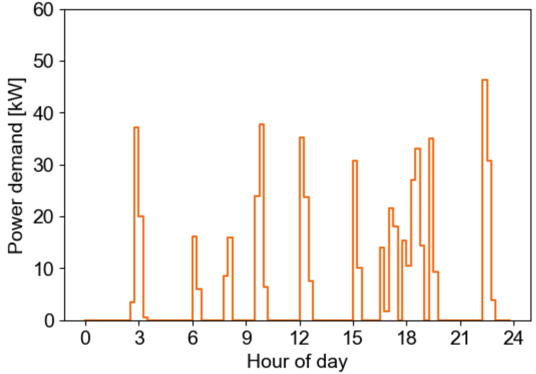
- Modularity to configure other assets for a variety of test cases

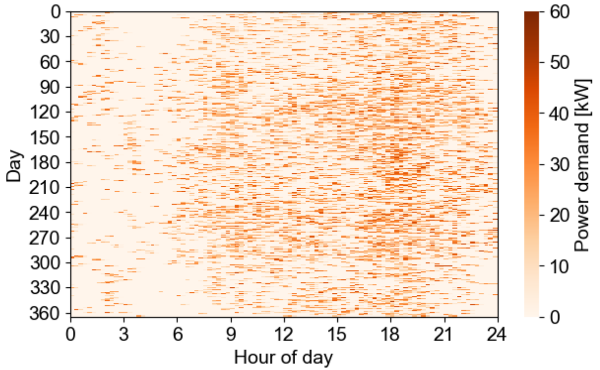


BEV Charging Profiles for the Low and High Deployment Scenario

Low Deployment Scenario

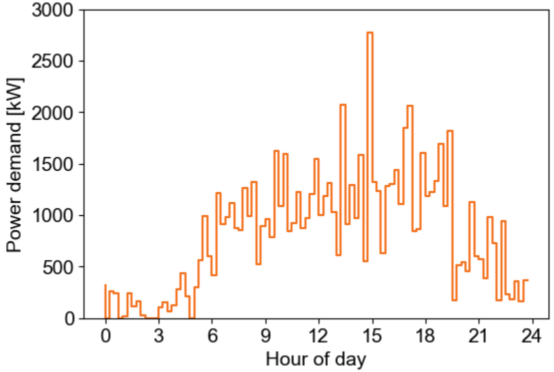
- 1 plug rated at 50 kW
- Current fast chargers

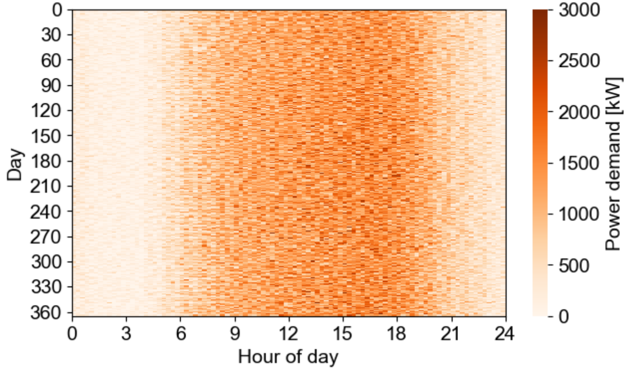




High Deployment Scenario

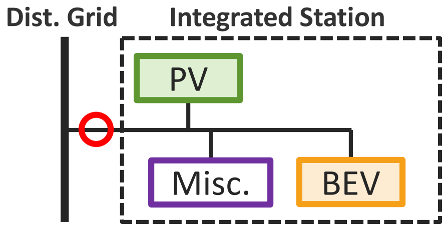
- 20 plugs rated at 400 kW each
- Upper bound of high-power DCFC station operation



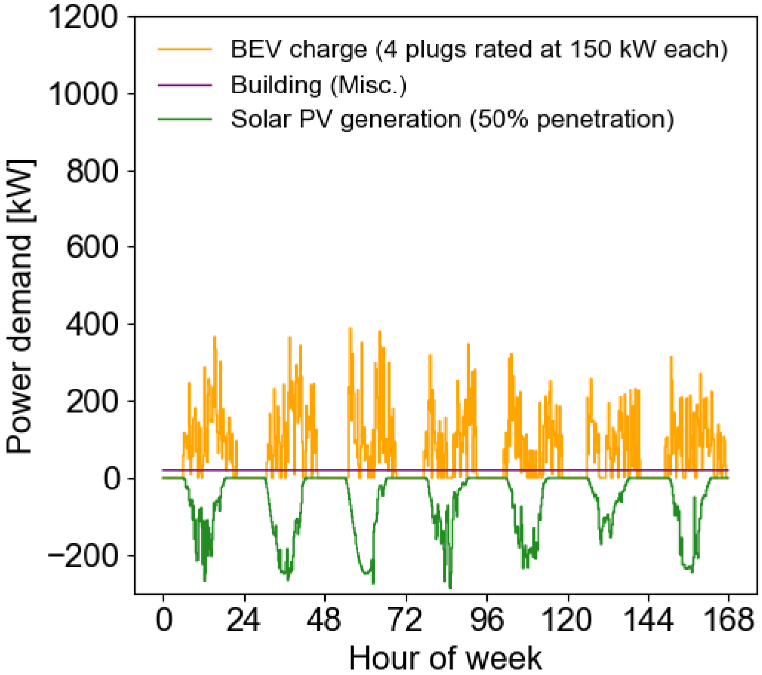


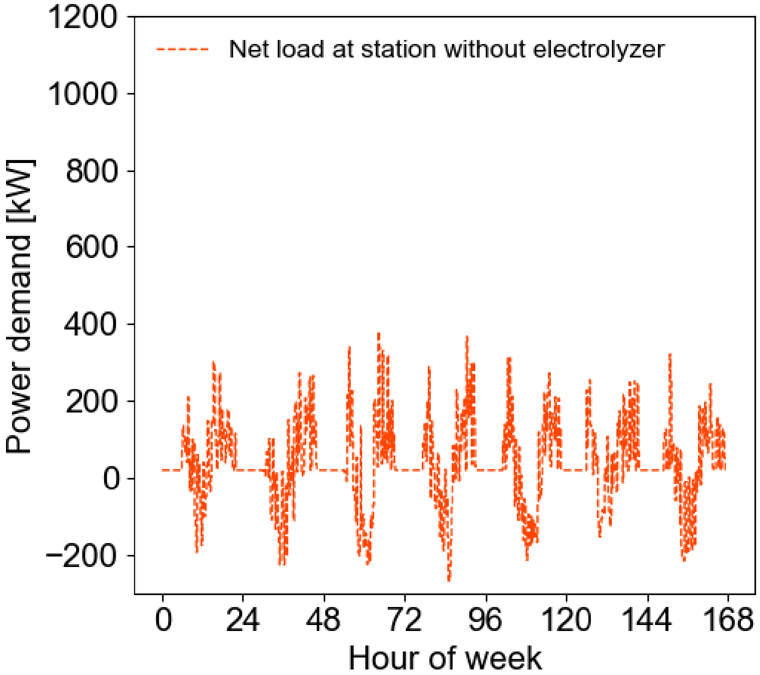
M. Muratori, et al., “Technology solutions to mitigate electricity cost for electric vehicle DC fast charging,” Applied Energy, 2019

Effect of PV Generation on Net Load

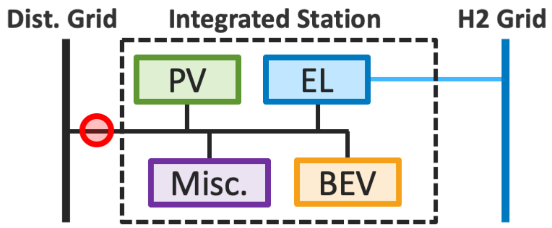


Integrating solar PV with the BEV station reduces some of intermittent high-power demands, but the utility still sees fluctuations.

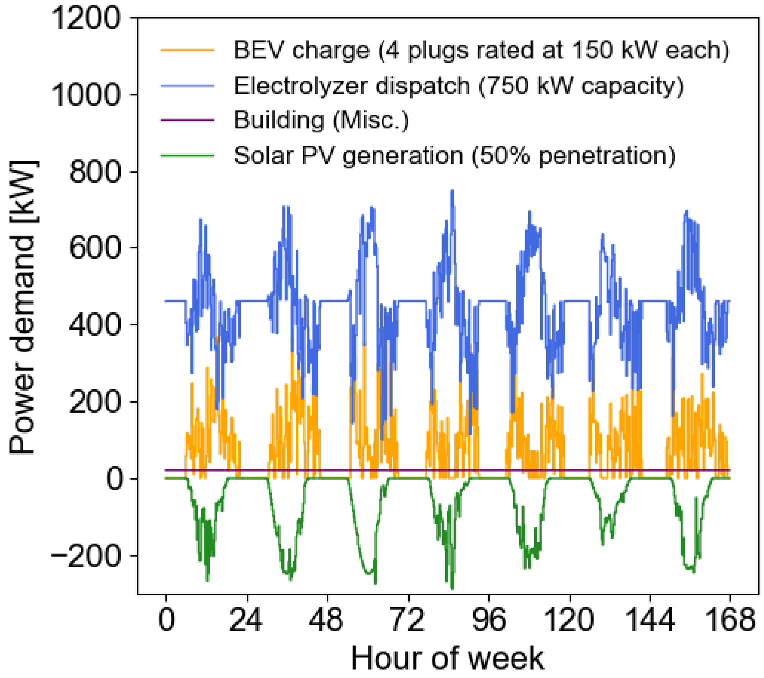




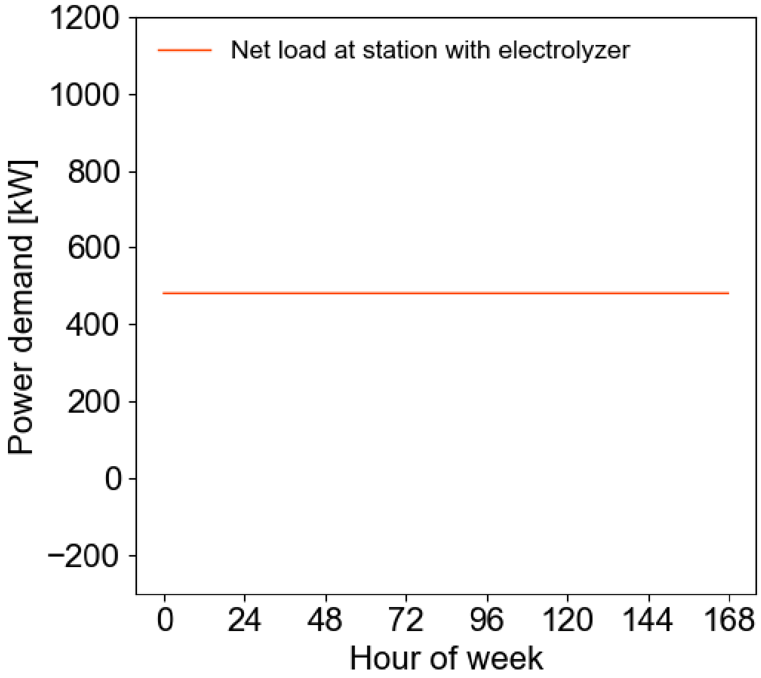
Effect of Electrolzyer Control on Net Load



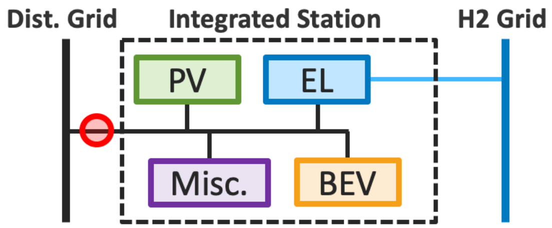
The integrated station with the electrolyzer stabilizes demand fluctuations, and the utility just sees the constant power demand.



Simplified scenario (constant net load).

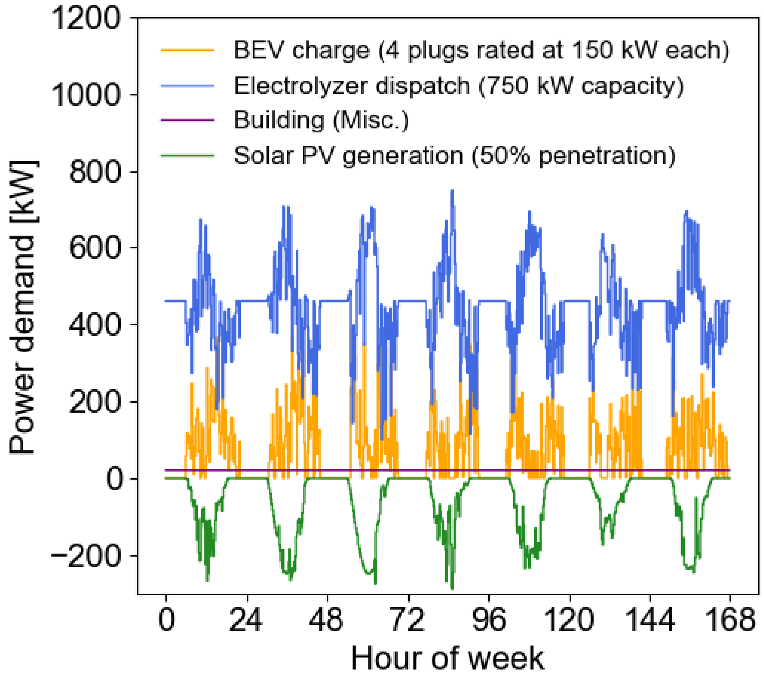


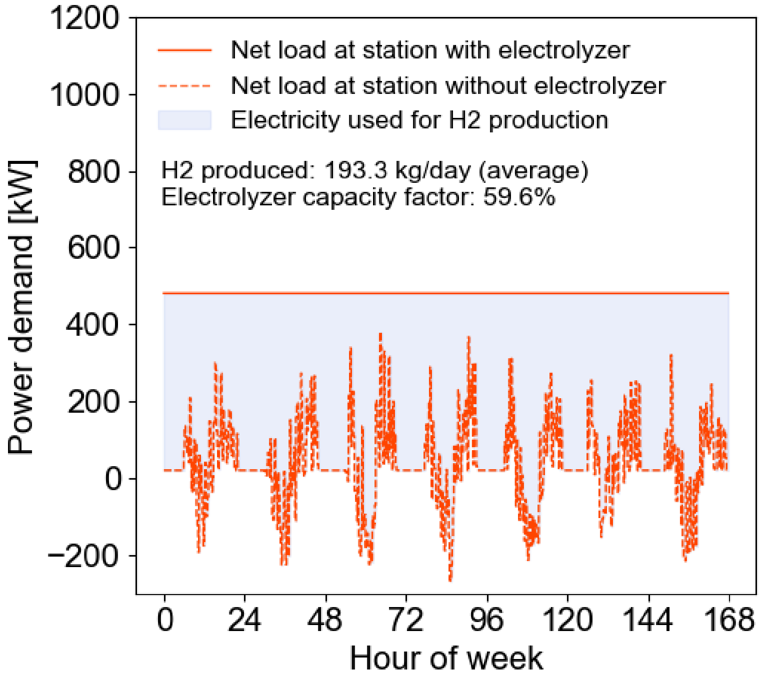
Effect of Electrolzyer Control on Net Load



The integrated station with the electrolyzer stabilizes demand fluctuations while producing valuable hydrogen, and the utility just sees the constant power demand.

Simplified scenario (constant net load).

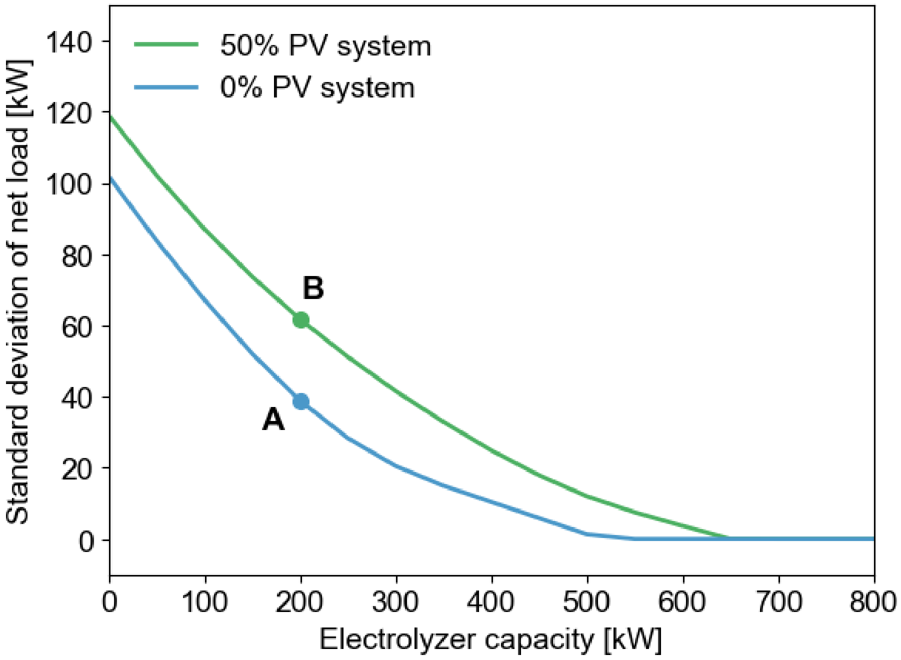


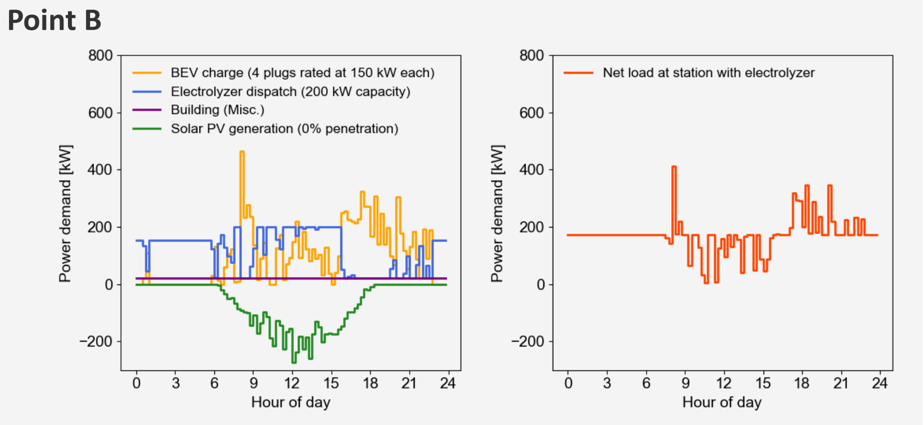


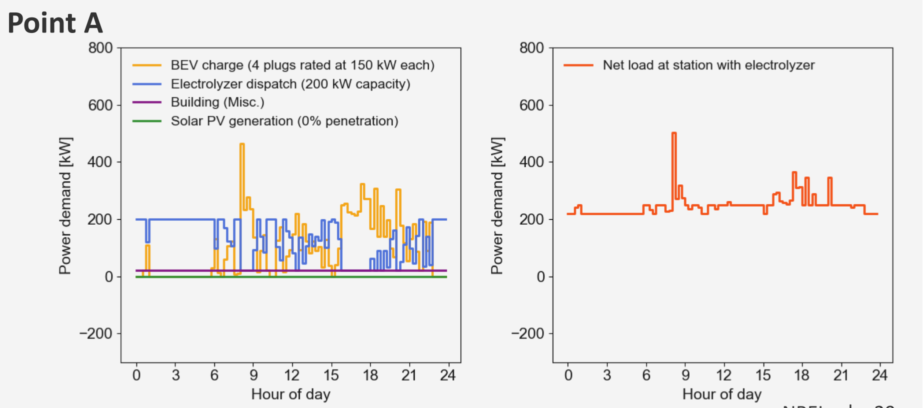
Impact of Electrolyzer Sizing on Station Net Load Stability

Electrolyzer sizing is important; the under-sized electrolyzer creates a variable net load.

Moderate BEV Deployment Scenario: 4 plugs rated at 150 kW each







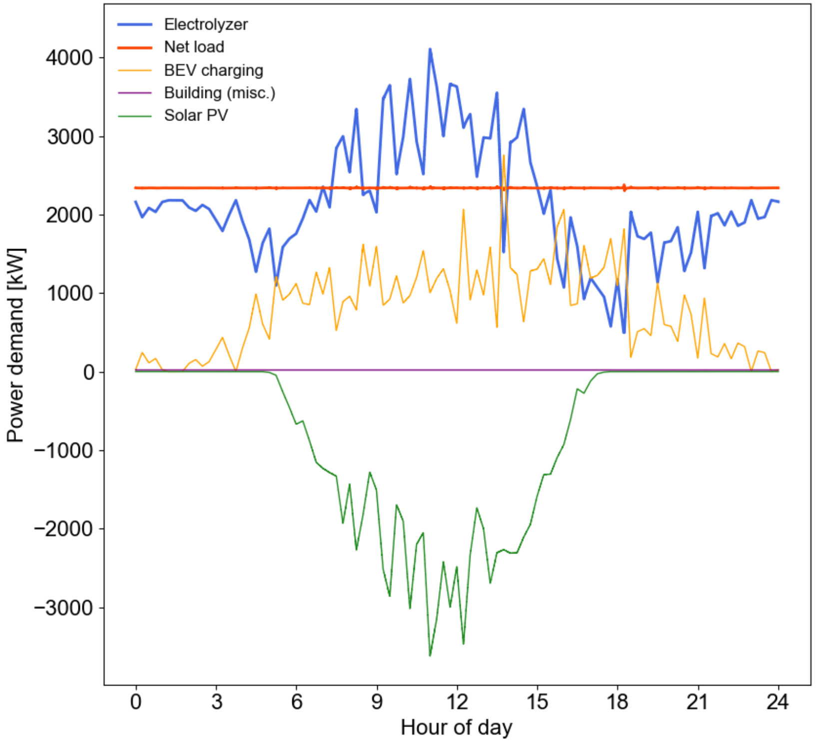
Test Cases for Real-Time Simulation

The grid modeling tool RSCAD was used to analyze grid dynamics as well as to develop control algorithms. This tool is capable of real-time simulation and hardware validation.

Test ID	BEV Charging Scenario	Building Load [kW]	PV Capacity [kW]	Electrolyzer Capacity [kW]
1	Low: 1-plug rated at 50 kW	20	0	Optimal: 60
2	Low: 1-plug rated at 50 kW	20	0	Undersized: 30
3	Low: 1-plug rated at 50 kW	20	0	Oversized: 90
4	Low: 1-plug rated at 50 kW	20	25	Optimal: 80
5	Low: 1-plug rated at 50 kW	20	25	Undersized: 40
6	Low: 1-plug rated at 50 kW	20	25	Oversized: 120
7	Mod: 4-plug rated at 150 kW each	20	0	Optimal: 550
8	Mod: 4-plug rated at 150 kW each	20	0	Undersized (w/o PV)
9	Mod: 4-plug rated at 150 kW each	20	0	Oversized (w/o PV)
10	Mod: 4-plug rated at 150 kW each	20	300	Optimal: 650
11	Mod: 4-plug rated at 150 kW each	20	300	Undersized: 325
12	Mod: 4-plug rated at 150 kW each	20	300	Oversized: 975
13	High: 20-plug rated at 400 kW each	20	0	Optimal: 3100
14	High: 20-plug rated at 400 kW each	20	0	Undersized: 1550
15	High: 20-plug rated at 400 kW each	20	0	Oversized: 4650
16	High: 20-plug rated at 400 kW each	20	4000	Optimal: 4950
17	High: 20-plug rated at 400 kW each	20	4000	Undersized: 2475
18	High: 20-plug rated at 400 kW each	20	4000	Oversized: 7425

Real-Time Simulation Results: Optimally-Sized Electrolyzer

The controller developed for this study follows the power setpoints of the electrolyzer system, resulting in a relatively constant net load.



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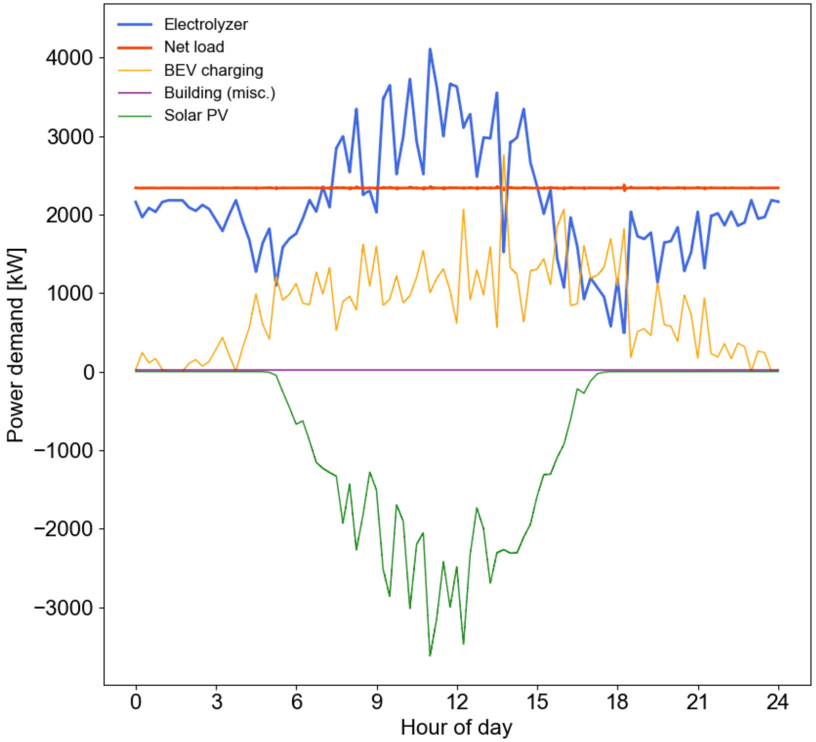
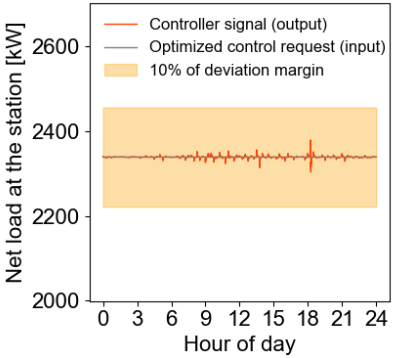
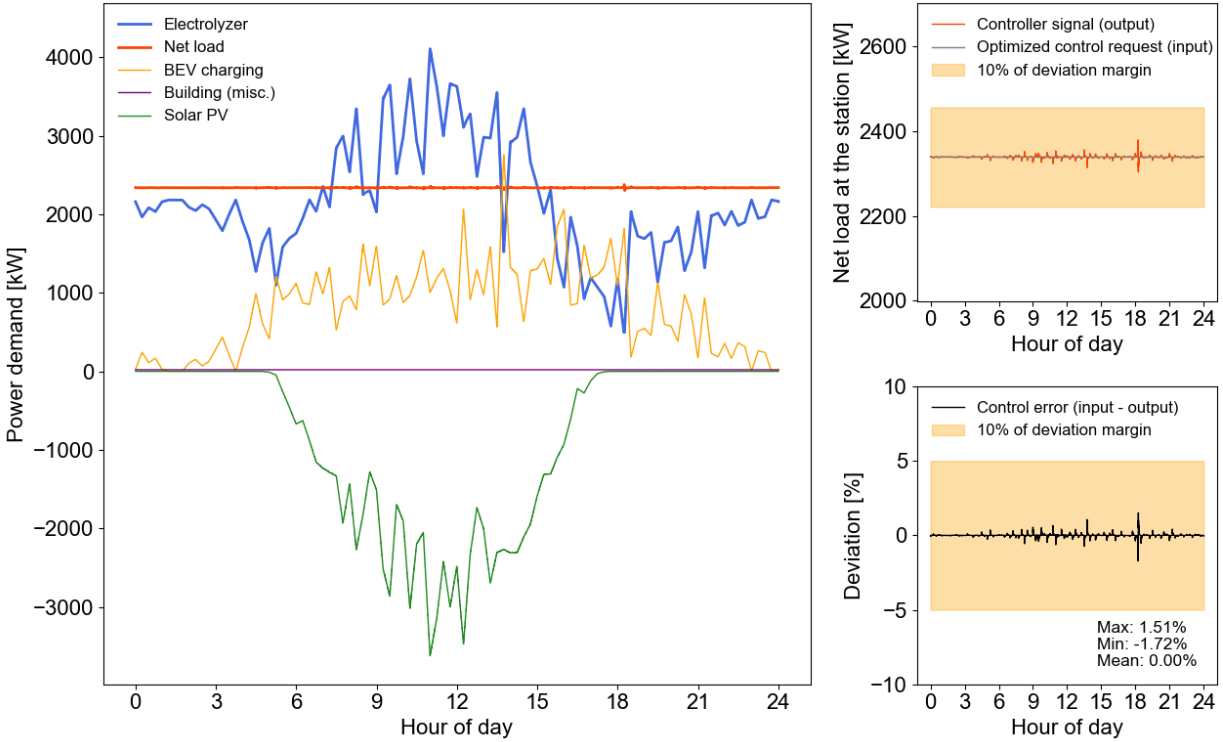




Real-Time Simulation Results: Optimally-Sized Electrolyzer

The controller performance was within 3% across the BEV deployment and PV penetration scenarios if the electrolyzer was sized adequately.



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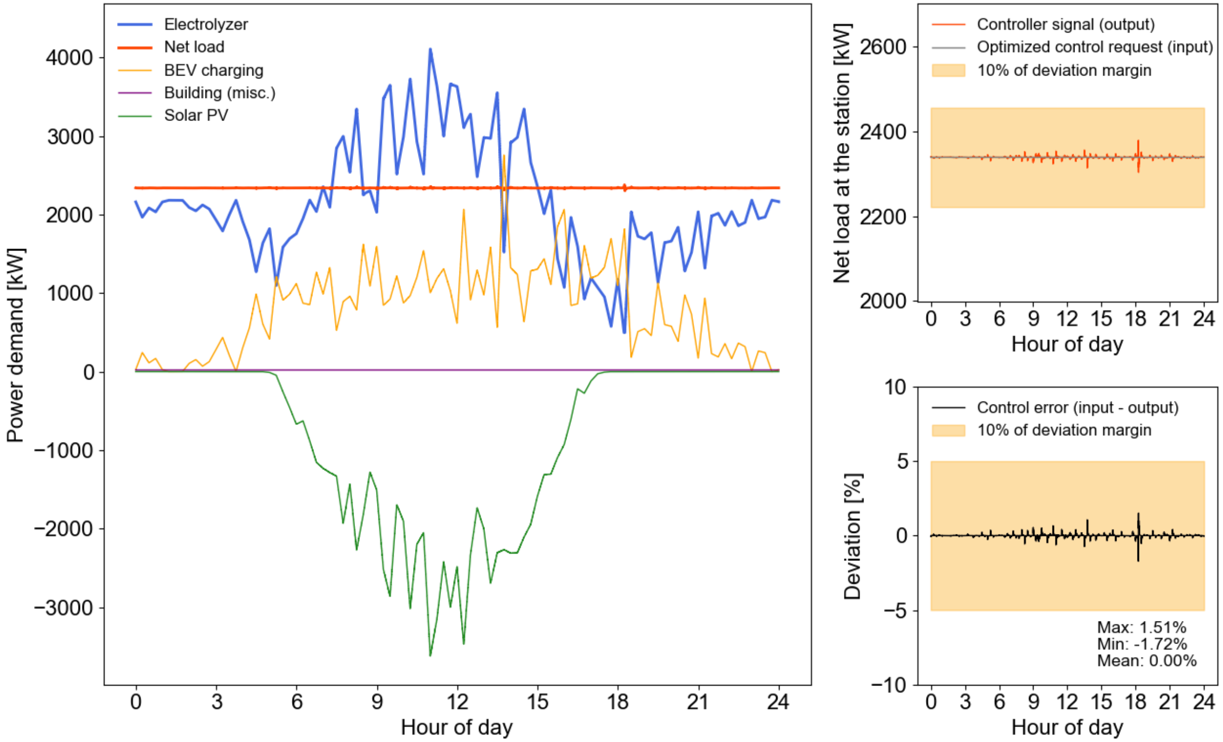
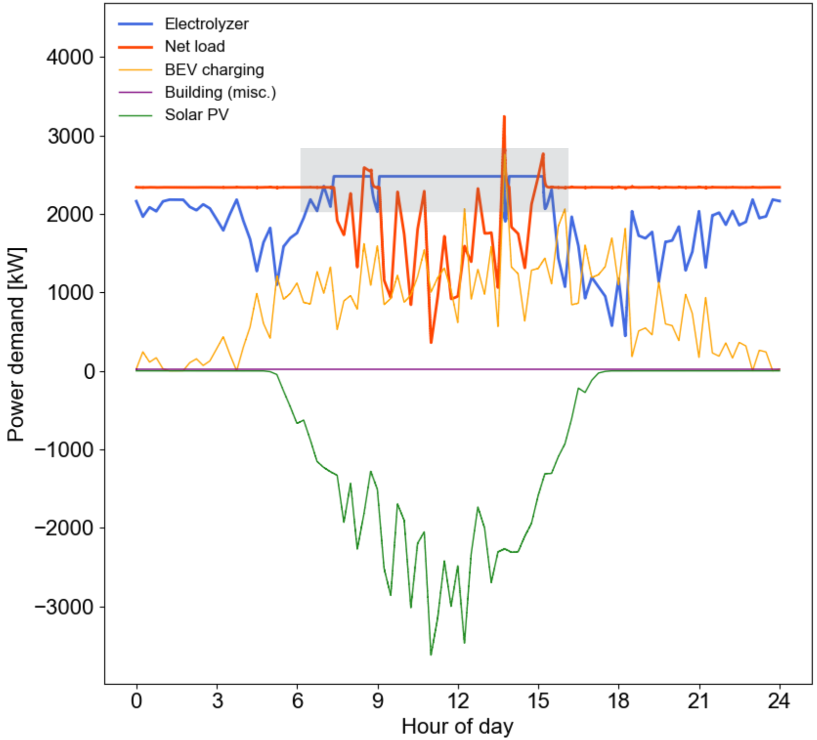
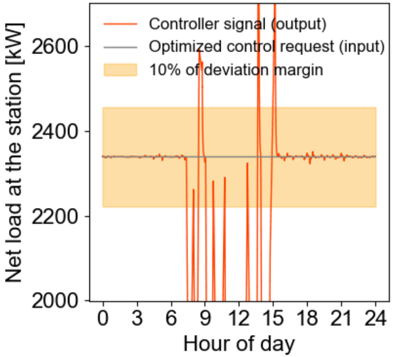
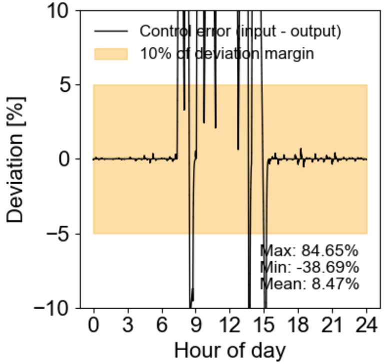


Real-Time Simulation Results: Under-Sized Electrolyzer

The electrolyzer reaches the maximum capacity during the day, resulting in a significant deviation from the optimal control request.

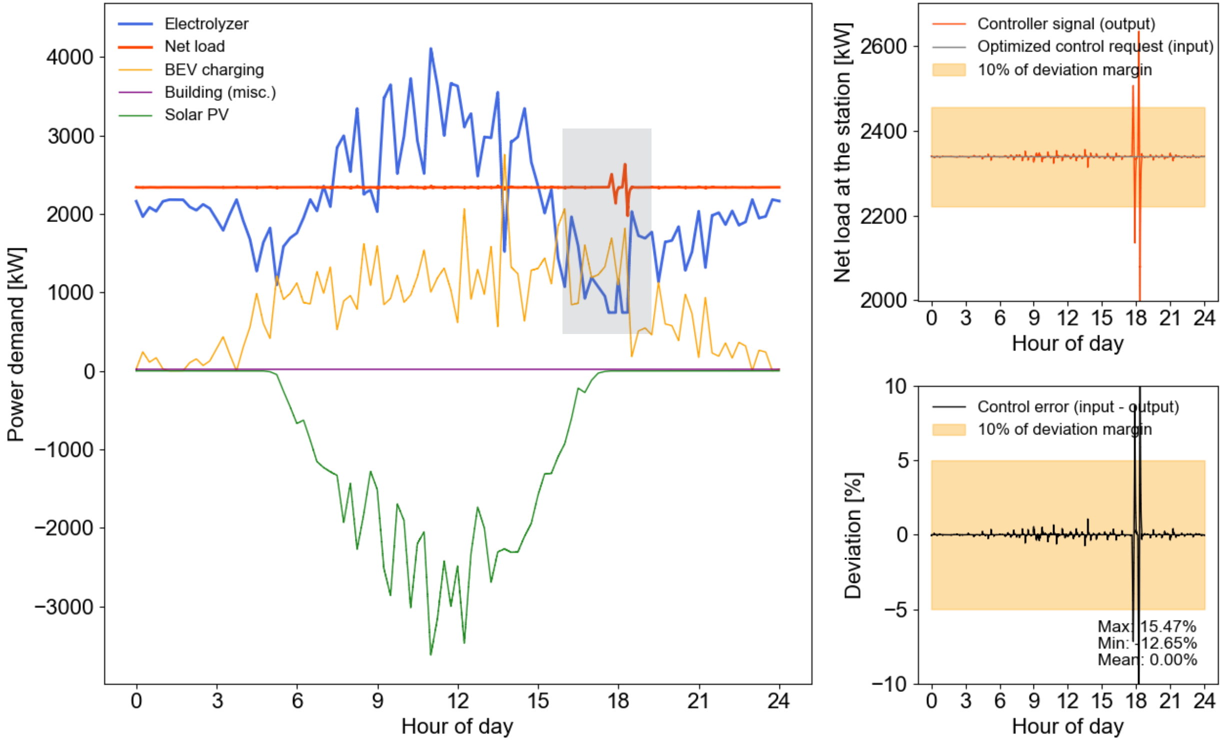




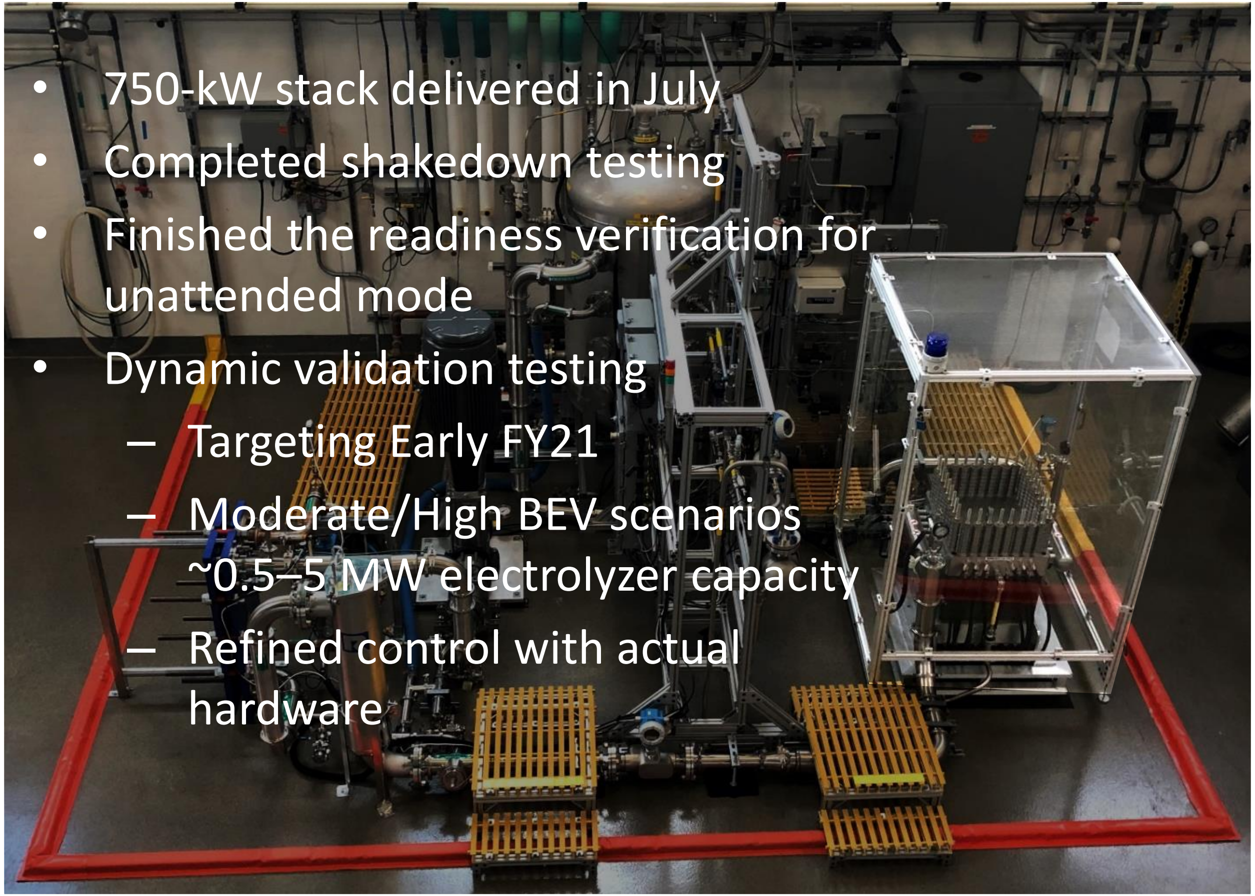


Real-Time Simulation Results: Over-Sized Electrolyzer

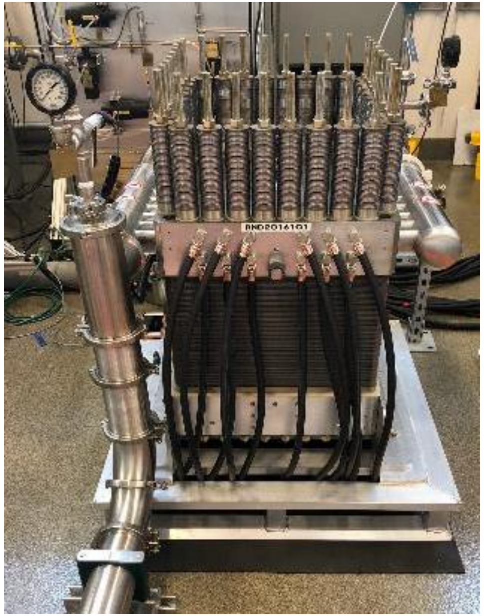
The over-sized electrolyzer requires a higher minimum operating load, causing limitations to the electrolyzer's ramp-down response.



Dynamic Validation Testing Is Scheduled in Early FY21



- 750-kW stack delivered in July
- Completed shakedown testing
- Finished the readiness verification for unattended mode
- Dynamic validation testing
  - Targeting Early FY21
  - Moderate/High BEV scenarios ~0.5–5 MW electrolyzer capacity
  - Refined control with actual hardware



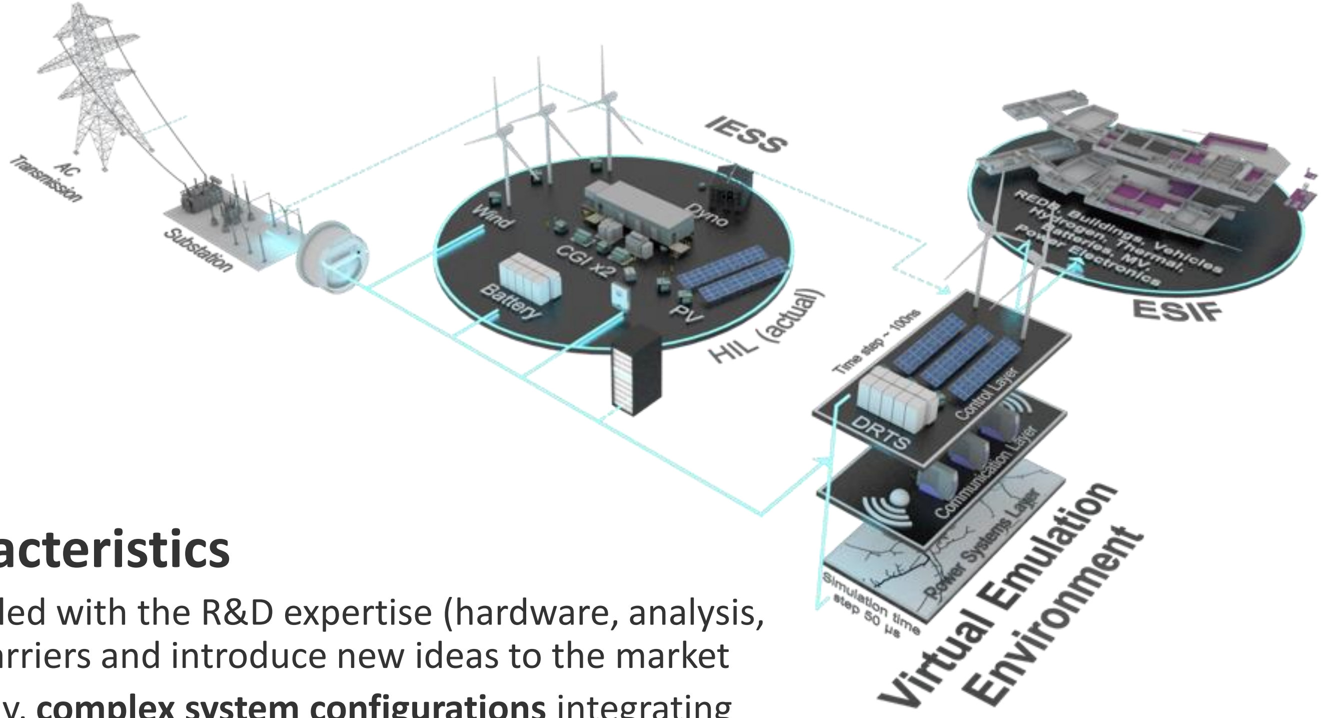
About ARIES

ARIES: Advanced Research on Integrated Energy Systems

ARIES

ARIES is a research platform designed to de-risk, optimize, and secure current energy systems and to provide insight into the design and operation of future energy systems. It will address the fundamental challenges of:

- Variability in the **physical size** of new energy technologies being added to energy system
- Securely controlling **large numbers** (millions to tens of millions) of interconnected devices
- Integrating **multiple diverse technologies** that have not previously worked together



ARIES

Differentiating Characteristics

- **Infrastructure at scale**, coupled with the R&D expertise (hardware, analysis, and modeling), to remove barriers and introduce new ideas to the market
- **Flexibility** to investigate many, **complex system configurations** integrating real devices and protocols
- An **entire system** (generation, demand, and storage) perspective in a **real-world** context for future energy systems
- **Partnerships** to increase impact and accelerate innovation

NREL’s Integrated Capabilities for ARIES

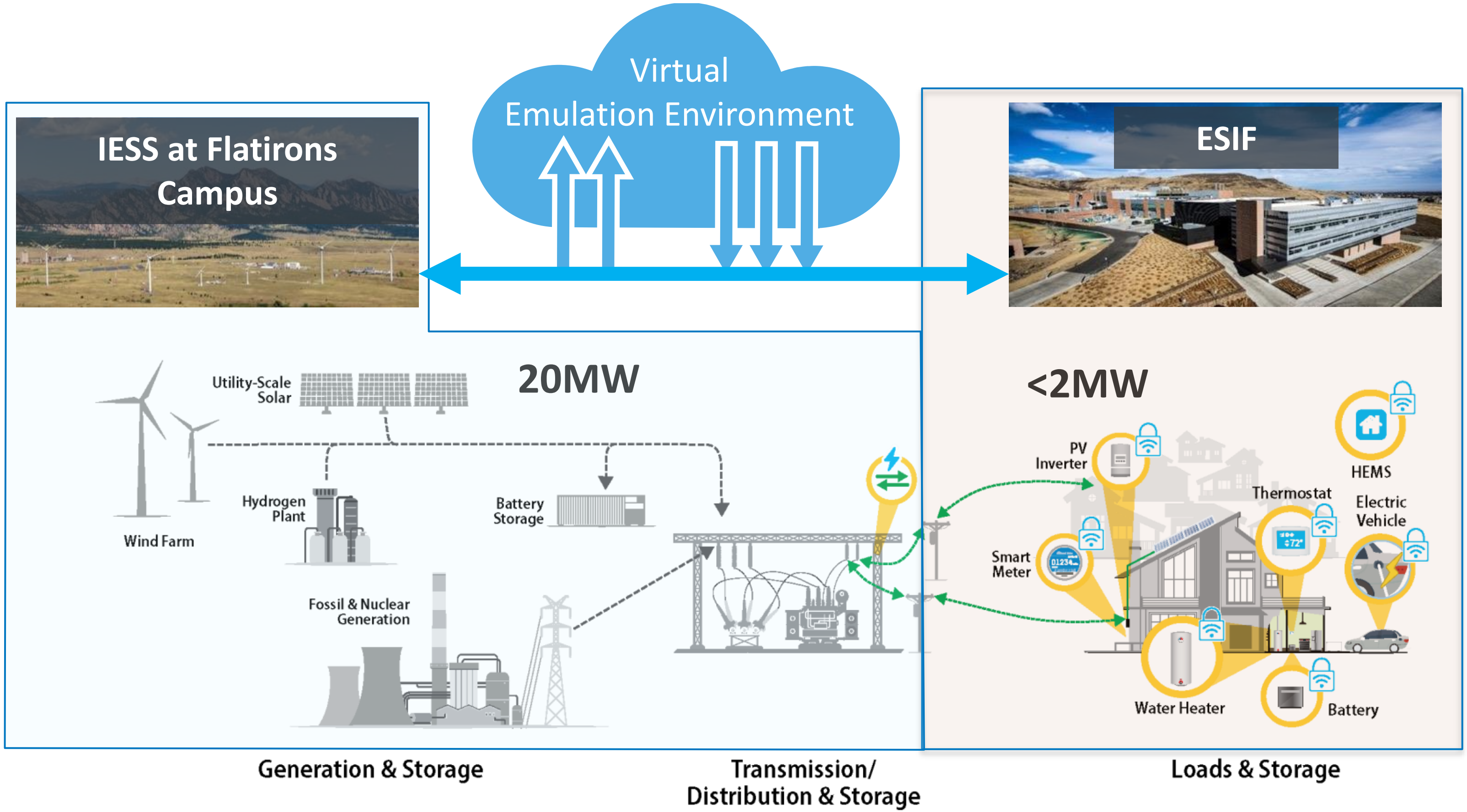
Energy Systems Integration Facility (ESIF)

Designated assets at the ESIF will be dedicated to the new joint research capability

Integrated Energy Systems at Scale (IESS)

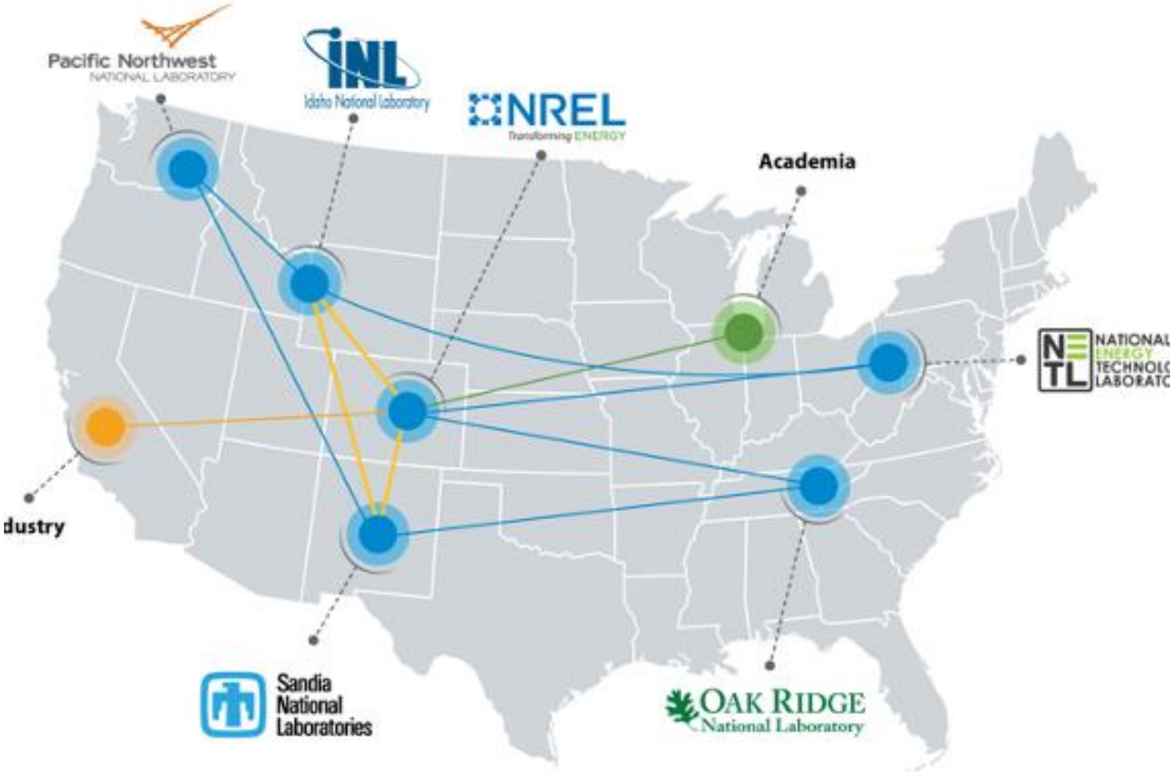
Designated assets at the Flatirons Campus will be dedicated to the new joint research capability

ARIES Research Platform – At-Scale

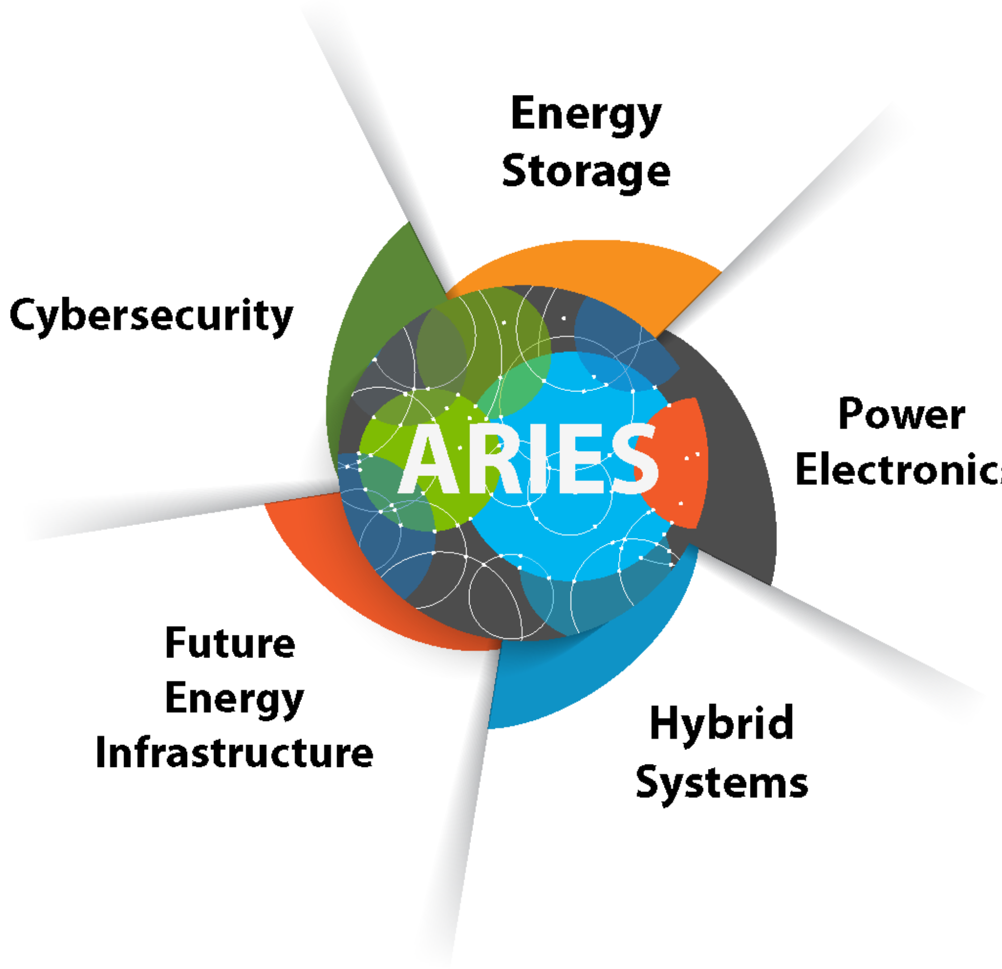


ARIES Advances Research Across the DOE Lab Complex

- ARIES has **complementary objectives with several strategic investments** across DOE's lab portfolio.
- The interconnected nature of the ARIES platform **enables significant opportunities to coordinate these research capabilities** to advance DOE's mission.
- NREL is in **active discussions with PNNL (GSL wholistic energy storage validation), ORNL (sensor development, prototyping, and packaging), INL (high temperature electrolyzer and nuclear operational data), and Sandia (distributed system integration)** to identify opportunities and first-of-its-kind research.



ARIES Research Areas

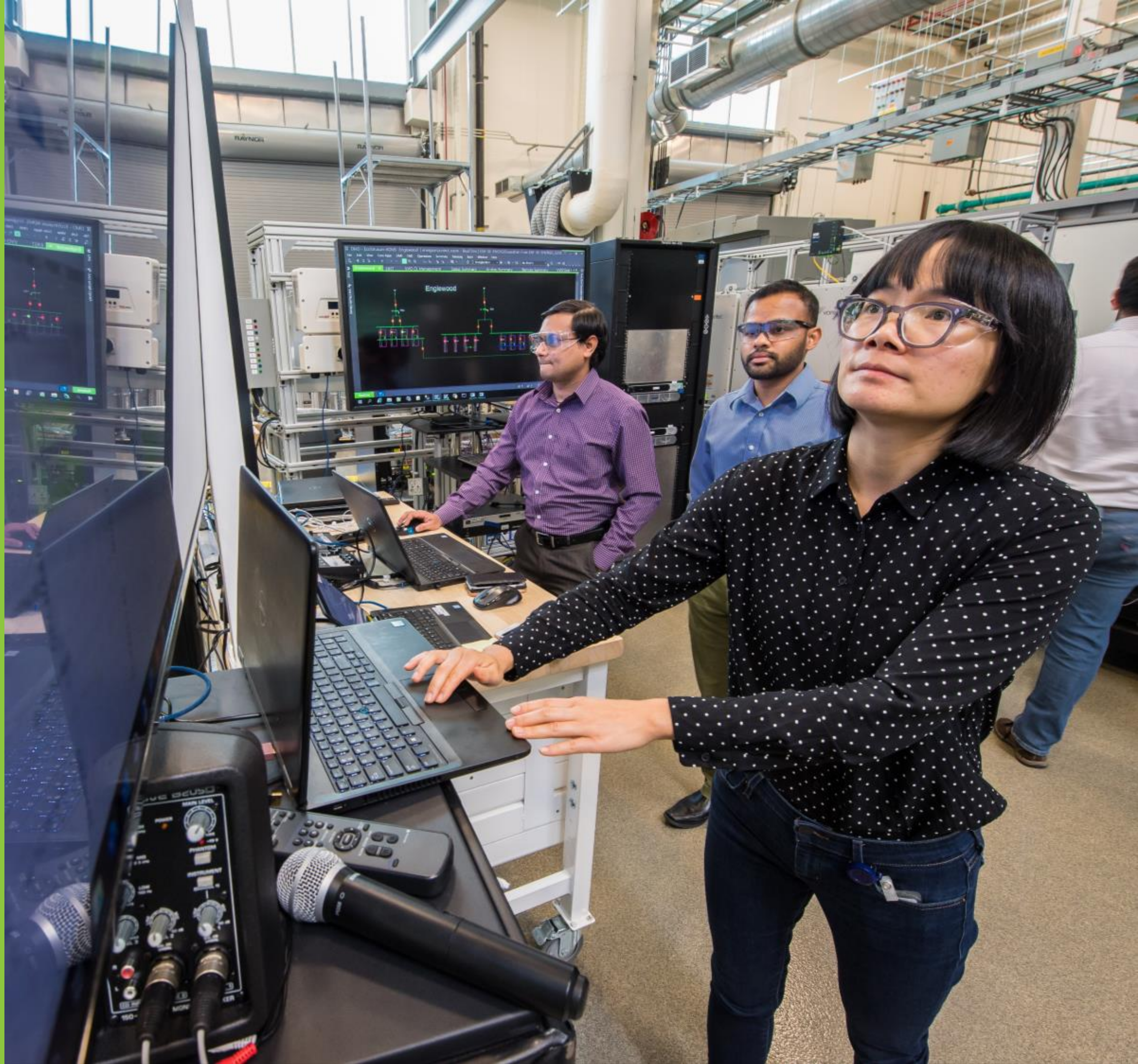


A Focus on Energy Storage Challenges

- Purpose driven integration and controls for flexibility and security
- Accelerating diverse technologies (e.g., electrochemical, molecular, thermal, and mechanical storage)
- Balancing for various size and timescales

A Focus on Advancing Power Electronics

- Grid operation at high-levels of power electronic interfaced generation and load
- Real-world proving grounds
- Develop and validate new power electronic technologies

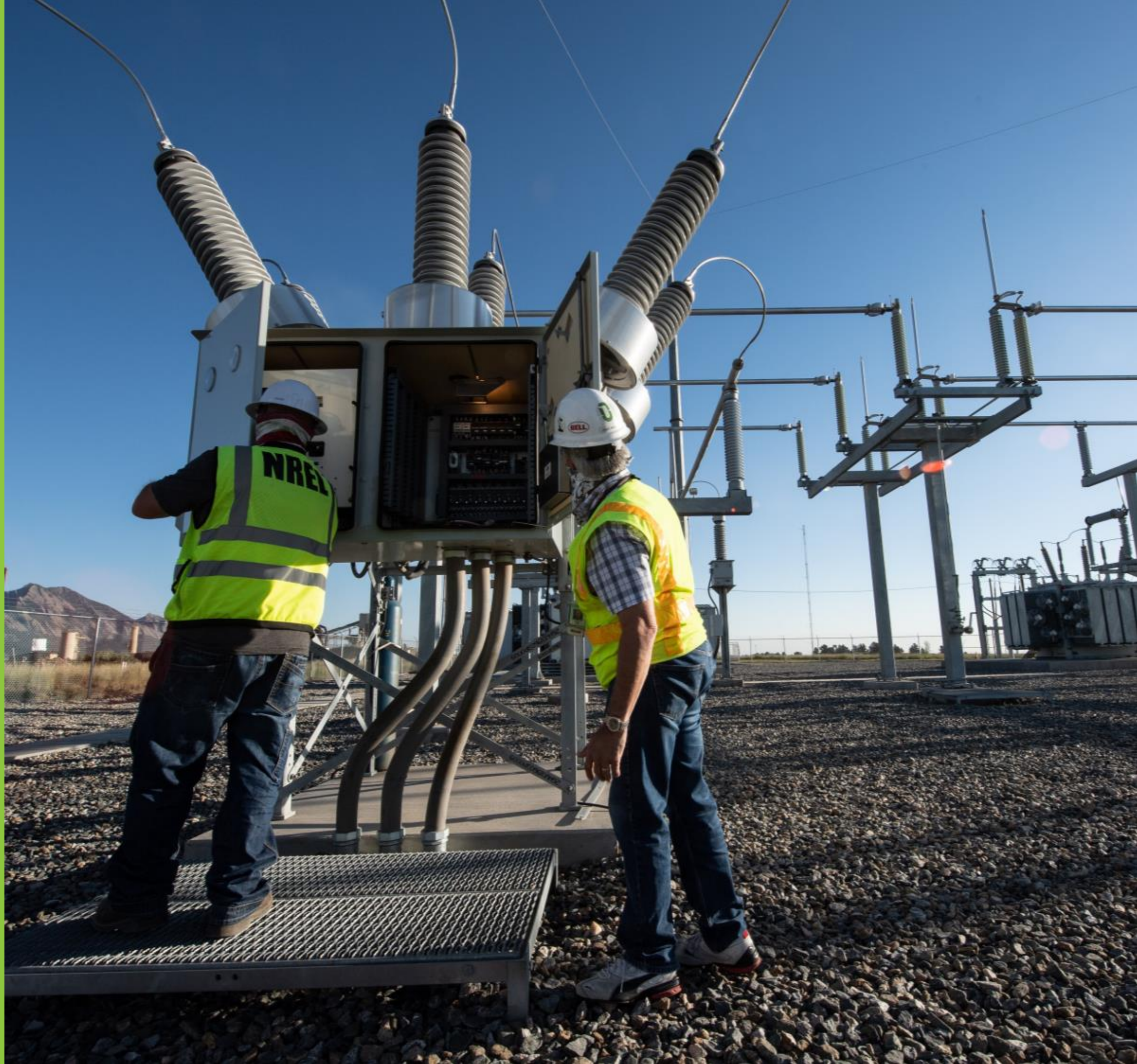


A Focus on Hybridization Opportunities

- Optimizing dynamic controls of diverse technologies
- Understanding the interdependencies and effects
- Quantifying hybridization benefits

A Focus on Future Energy Infrastructure Needs

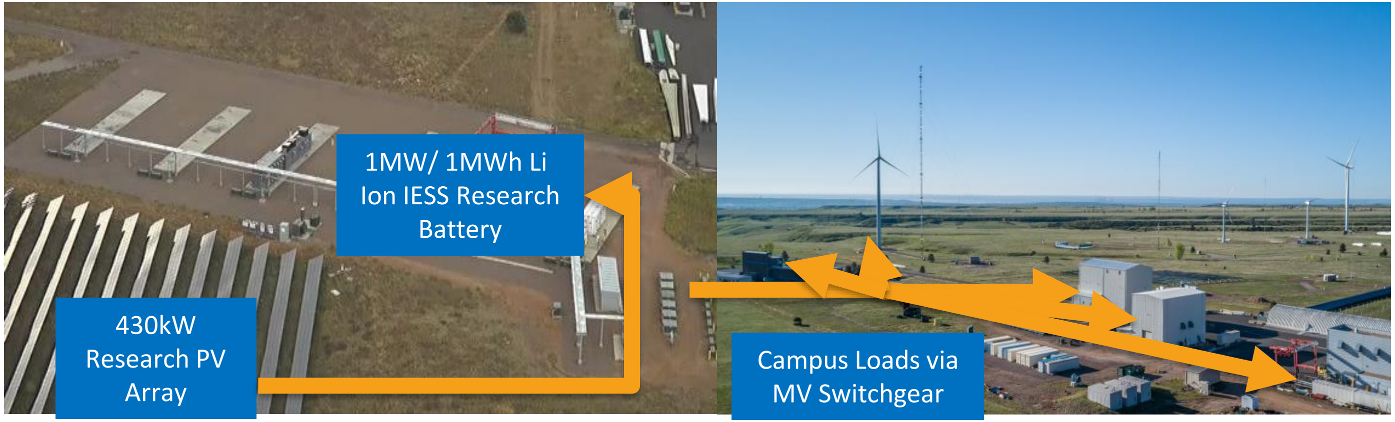
- Protection for highly connected systems
- Advanced system-level operations
- Controls for operational efficiency and stability



A Focus on Cybersecurity

- Proactive defense and automated response
- Improved situational awareness
- Secure communication innovation

Current ARIES Microgrid Capability



ARIES microgrid
(at Flatirons Campus, Subsequent Wind/PV/storage operation)

Key Research Relevance: Innovation is necessary for the rapidly evolving grid because **protection** equipment and schemes are designed for the legacy grid.

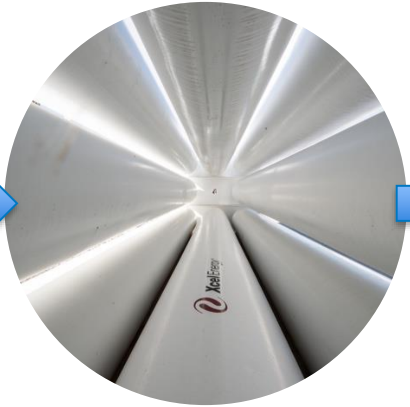
Initiated a black start ARIES microgrid with renewable generation and storage to power critical building systems after a substation failure in September 2020.

Planned Hydrogen Infrastructure at IESS

1.25 MW Electrolysis

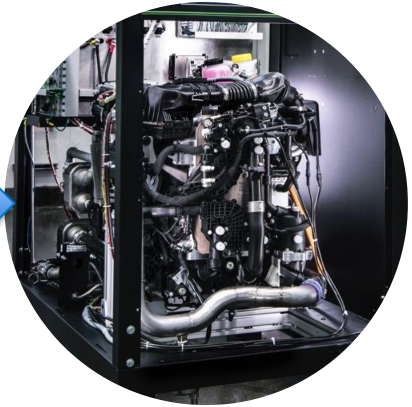
3,000 psig H_2 Compression

600 kg (20 MWh*) H_2 Ground Storage



27 hrs of 1.25 MW Electrolysis Buffer
40 hrs of 0.25 MW Fuel Cell Buffer

0.25 MW Fuel Cell**



AC or DC Input (Integrated Grid)

AC or DC Output (Integrated Grid)

*Chemical
**Net output includes BOP

Key Takeaways

- A sub-second response time of electrolyzers potentially adds flexibility and stability to the grid from the demand side
- Integrating electrolyzer systems in the grid helps improve grid performance, reliability, and resiliency
  - Reduces the number of tap operations (voltage levels)
  - Decreases the frequency deviation; shortens the frequency settling time
  - Mitigates the intermittent BEV fast charging demand
- ARIES initiative addresses the fundamental challenges how to scale up the physical size of integrated energy systems

Thank You

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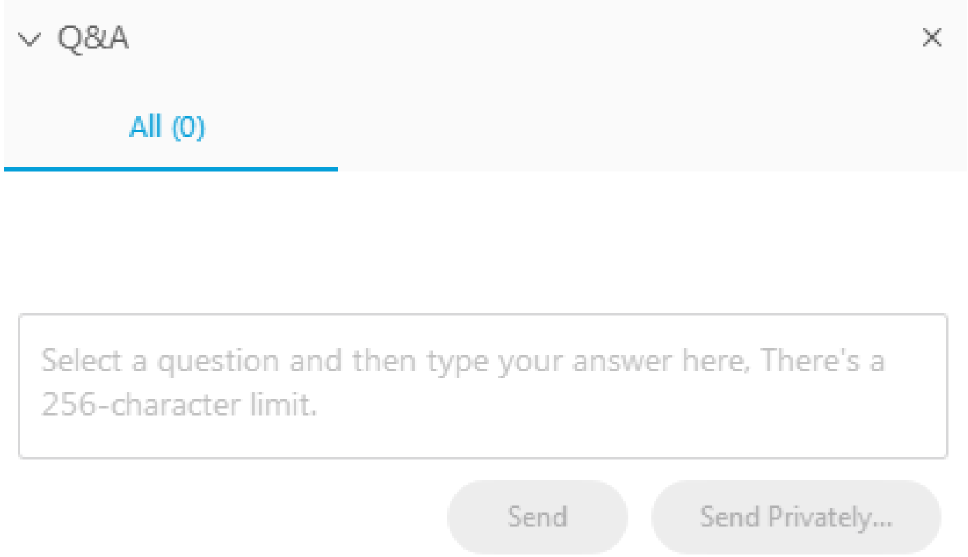
NREL Transforming ENERGY

The #H2IQ Hour Q&A

Please type your questions into the **Q&A Box**



The #H2IQ Hour

Thank you for your participation!

Learn more:

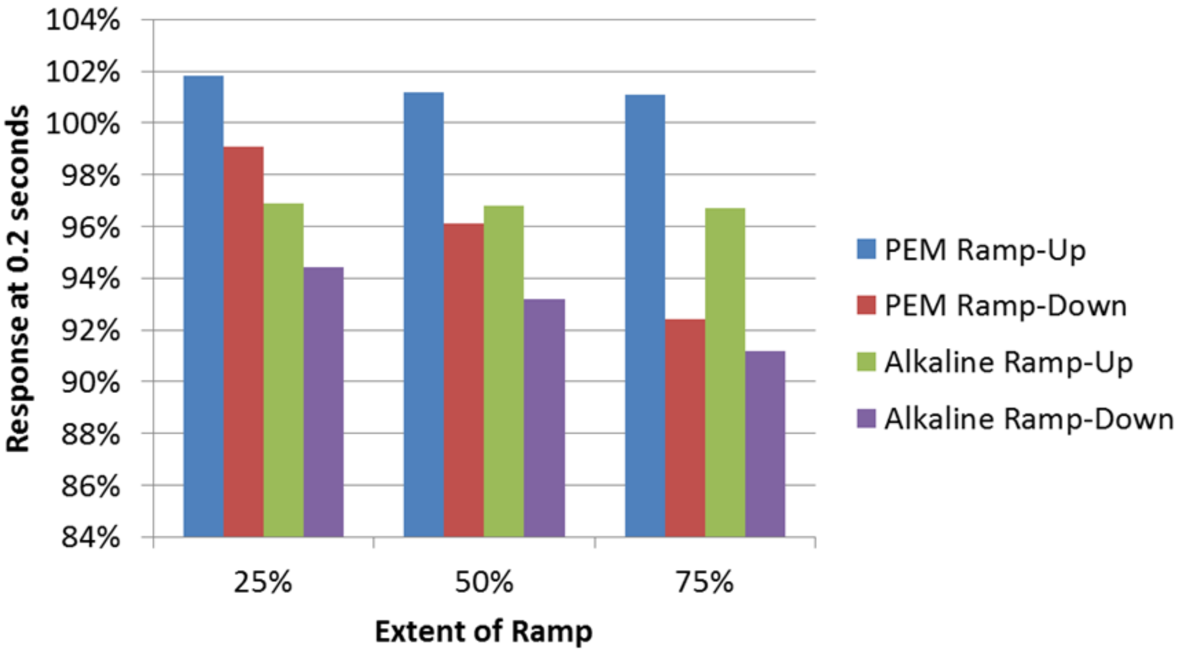
energy.gov/fuelcells
hydrogen.energy.gov

Additional Material

System-Level Response Time for PEM and Alkaline Electrolyzers

PEM: Proton Exchange Membrane

A sub-second response time of the PEM electrolyzer potentially adds flexibility and stability to the grid from the demand side.



J. Eichman, K. Harrison, M. Peters, "Novel Electrolyzer Applications: Providing More Than Just Hydrogen," NREL Technical Report, 2014