ARIES / Flatirons Facility - Hydrogen System Capability Buildout

PI: Daniel Leighton
Riley Abel
Joshua Martin
Vivek Singh
Tavis Hanna
Jeffrey Mohr
Jacob Thorson
National Renewable Energy Laboratory

AOP WBS #: 7.2.9.9
May 8th, 2024

DOE Hydrogen Program
2024 Annual Merit Review and Peer Evaluation Meeting

Project ID: TA048

Photo from iStock-627281636

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Goal

- Under the “Advanced Research on Integrated Energy Systems” (ARIES) initiative, hydrogen system capabilities including a MW-scale electrolyzer, storage system, and fuel cell generator will be designed and commissioned at NREL’s Flatirons Campus
- This hydrogen infrastructure supports H2@Scale goals by enabling integrated systems R&D to study the science of scaling hydrogen systems
- The system is designed with flexibility to provide a testbed to demonstrate systems integration, grid services, energy storage, direct renewable hydrogen production, and innovative end use applications

Overview

Timeline and Budget

- Project start date: 05/06/2020
- FY23 DOE funding: $0
- FY24 planned DOE funding: $0
- Total DOE funds received to date*: $4,430,145

  * Since the project started

Barriers

- Demonstration of electrolyzer and stationary fuel cell technology under real-world conditions
- Production of hydrogen using directly coupled zero-carbon energy sources
- Hydrogen energy storage and grid stabilization for high-penetration renewable electric grid

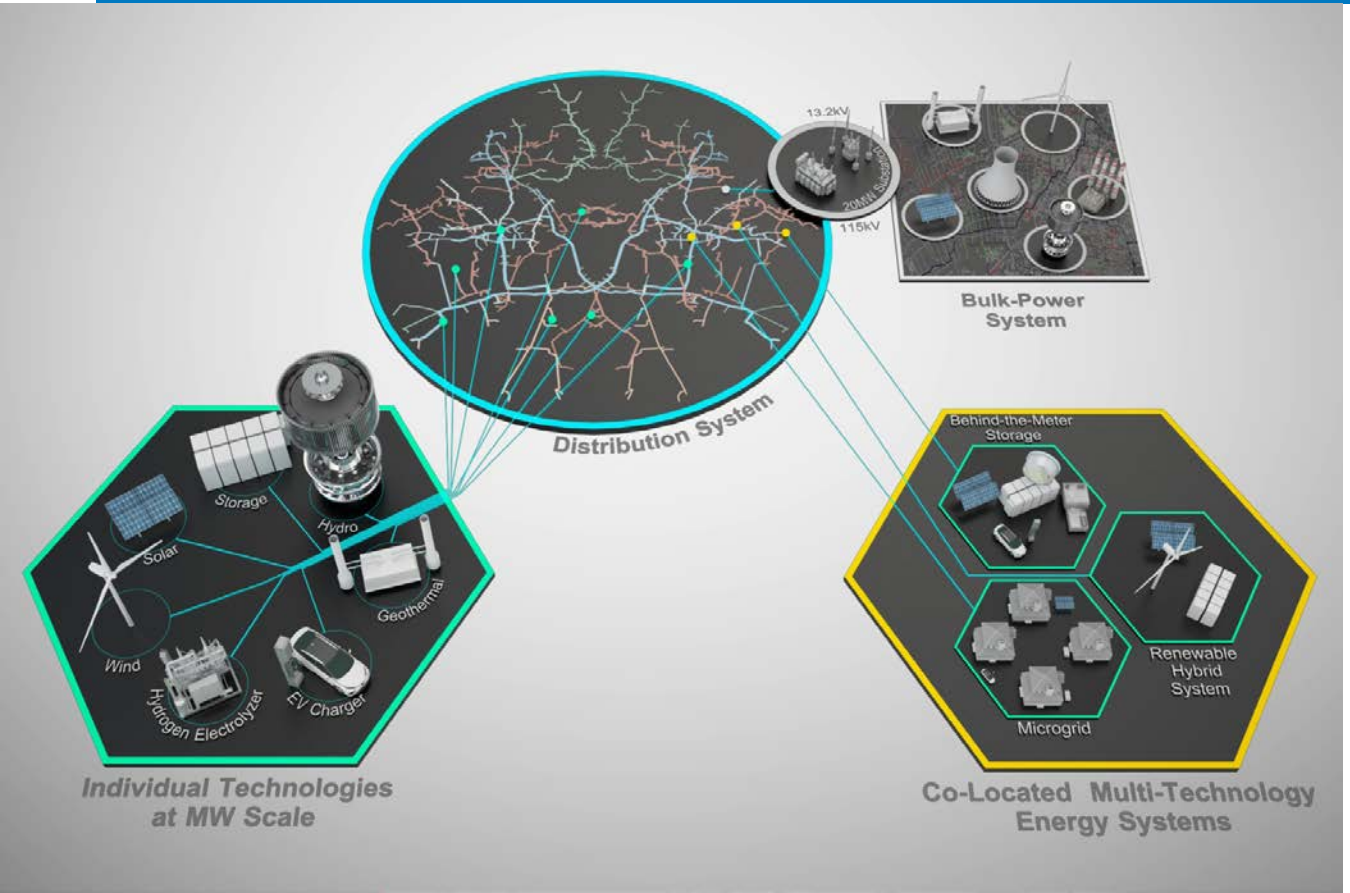
Partners

- Project lead: NREL
- PI: Daniel Leighton

Potential Impact

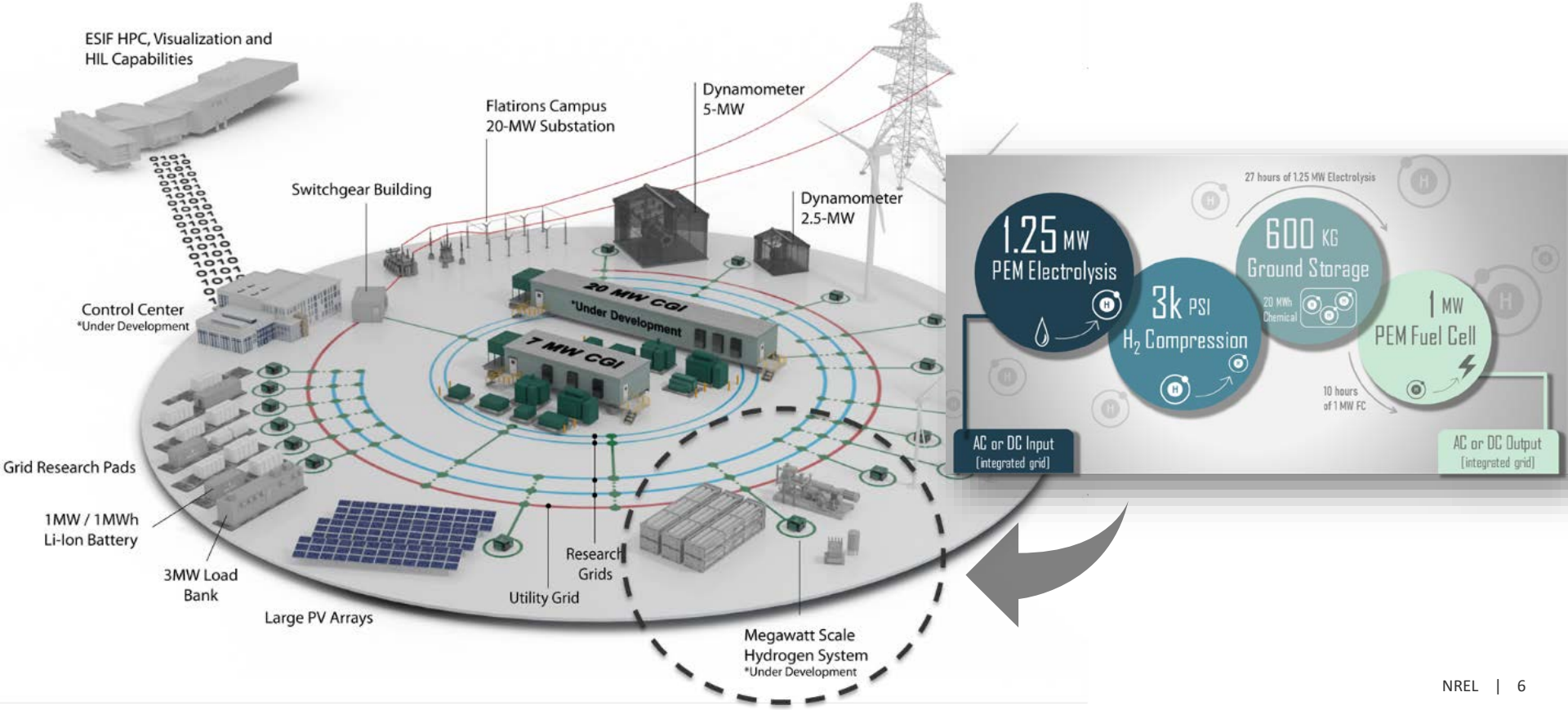
- This project establishes a **research capability** for other projects to conduct MW-scale research on hydrogen generation, energy storage, end-use distribution, and power production topics
  - Proving technologies and addressing integration challenges at scale is a critical precursor to deployment and investment nation-wide to reduce green house gas emissions through the construction of clean U.S. energy infrastructure
  - Key to this is integration of hydrogen as an energy carrying molecule coupled to other technology areas such as wind, solar, energy systems (grid), etc.
- This capability will also support additional technology areas relevant to H2@Scale as they mature and need to be evaluated with an integrated MW-scale platform
  - Molecule building, blending with natural gas, heavy-duty vehicle fueling, etc.
  - Supports efforts within the hydrogen industry and other integrated EERE areas

Approach: ARIES Vision



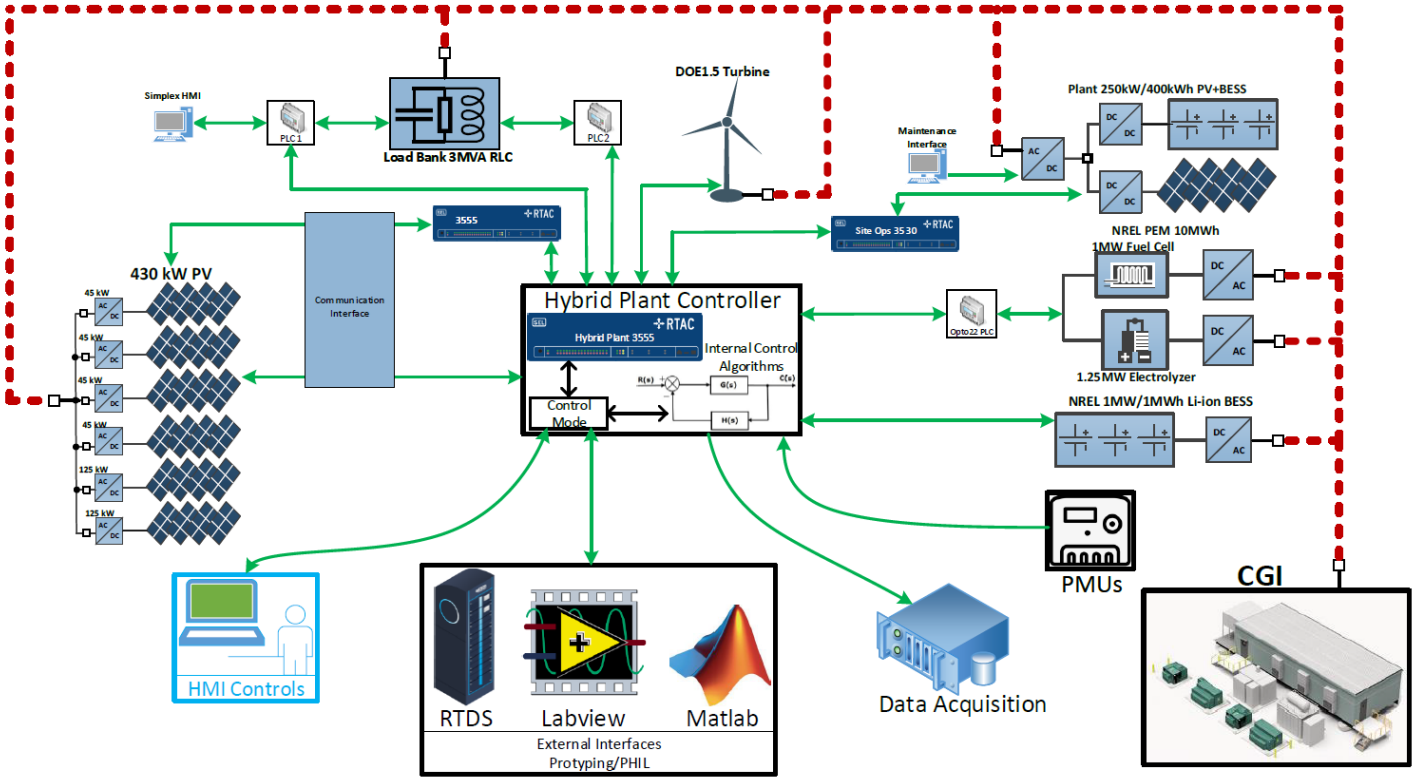
- Highly integrated and configurable
- Integrated energy research with analysis, modeling, and hardware experiments
- Varies in scale (devices, types, sizes up to 20 MW, and beyond virtually)
- Provide a collaborative hands-on experience

Approach: ARIES Flatirons Grid Equipment



Approach: Hybrid Controller

Hybrid Controls Map

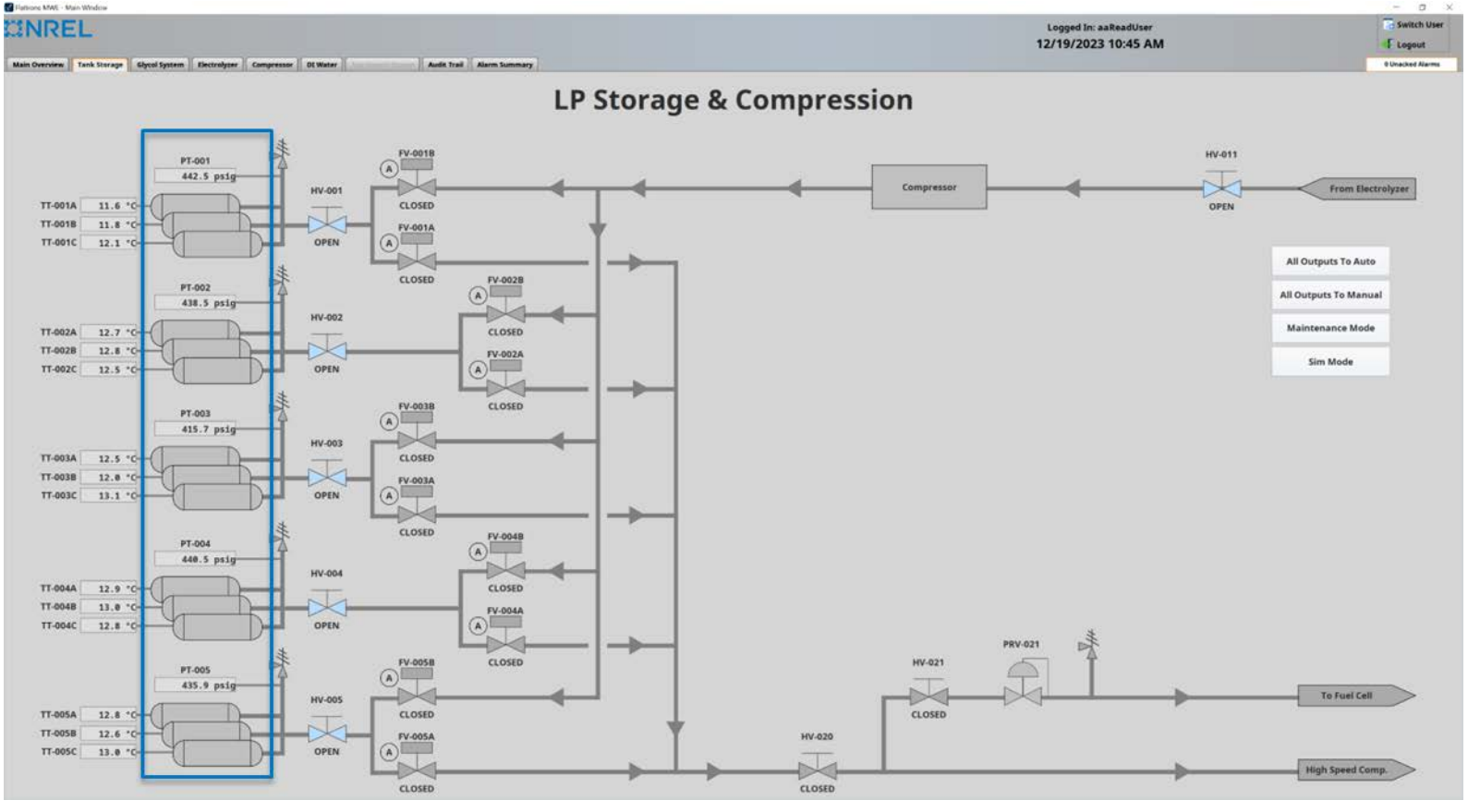


Approach: Safety Planning and Culture

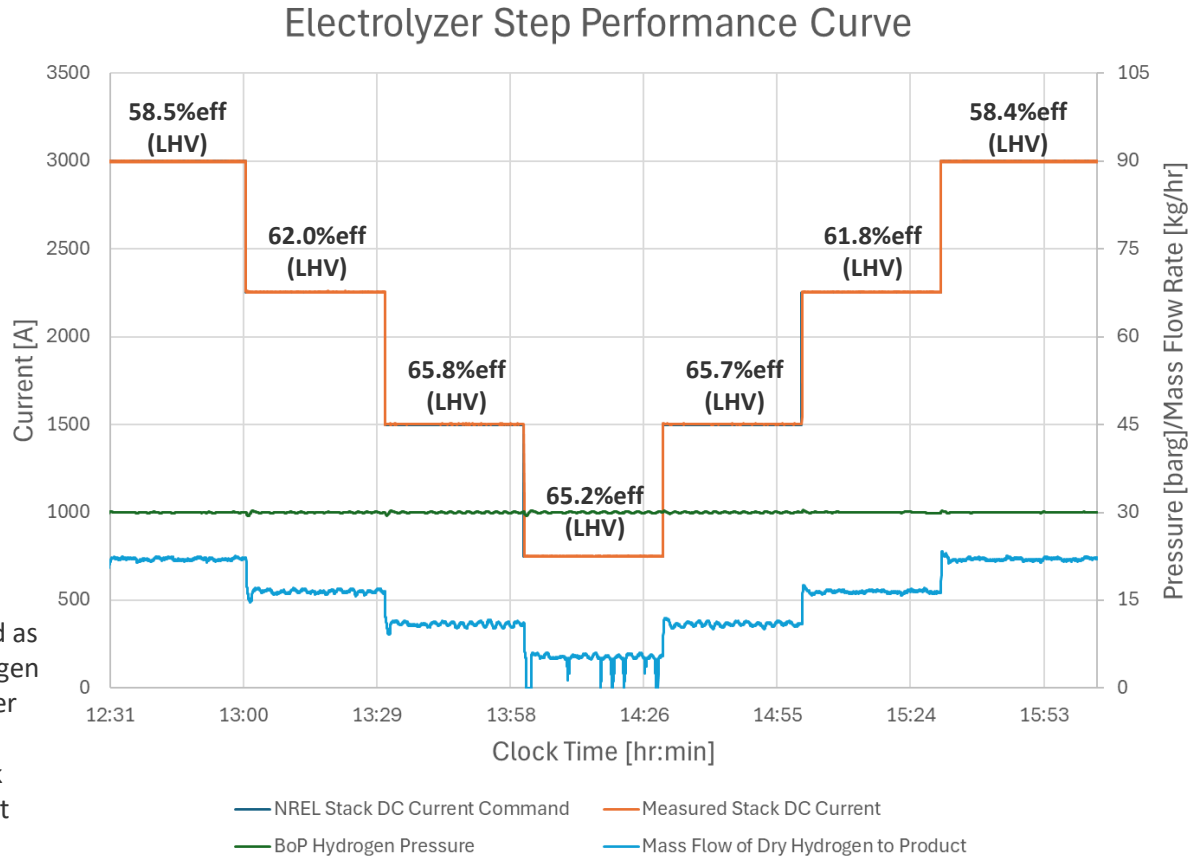
- Project underwent an extensive safety review process prior to construction and commissioning
  - 100's of person-hours completing an extensive, multi-node Process Hazard Analysis (PHA) with relevant NREL subject matter experts (SMEs)
  - NREL "Authorities Having Jurisdiction" (AHJs) were consulted for fire, electrical, and pressure safety
    - Applicable codes and standards were reviewed and approved by AHJs (NFPA 2, NEC, ASME, etc.)
    - Detailed, independent electrical safety inspections were conducted for all equipment and delivered sub-systems, with more than 1,000 person-hours of repairs and modifications made for code compliance
- The best design, construction, and safety practices learned from a decade of experience building and operating hydrogen systems at NREL's main campus were implemented at the Flatirons campus
- Training and requirements for build, operation, and maintenance of the hydrogen systems emphasize:
  - Reviewing the safety hazards of every task, every time
  - Everyone has "Stop Work" authority and the expectation to use it proactively
  - Immediate reporting of safety issues for review by SMEs and dedicated safety professionals
  - Prioritizing personnel safety above all else
- The established safety processes required per NREL's prime contract with the DOE exempted this project from Hydrogen Safety Panel review

Accomplishments and Progress: All Equipment Installed and Integrated

Accomplishments and Progress: Storage System Commissioned to Electrolysis Pressure

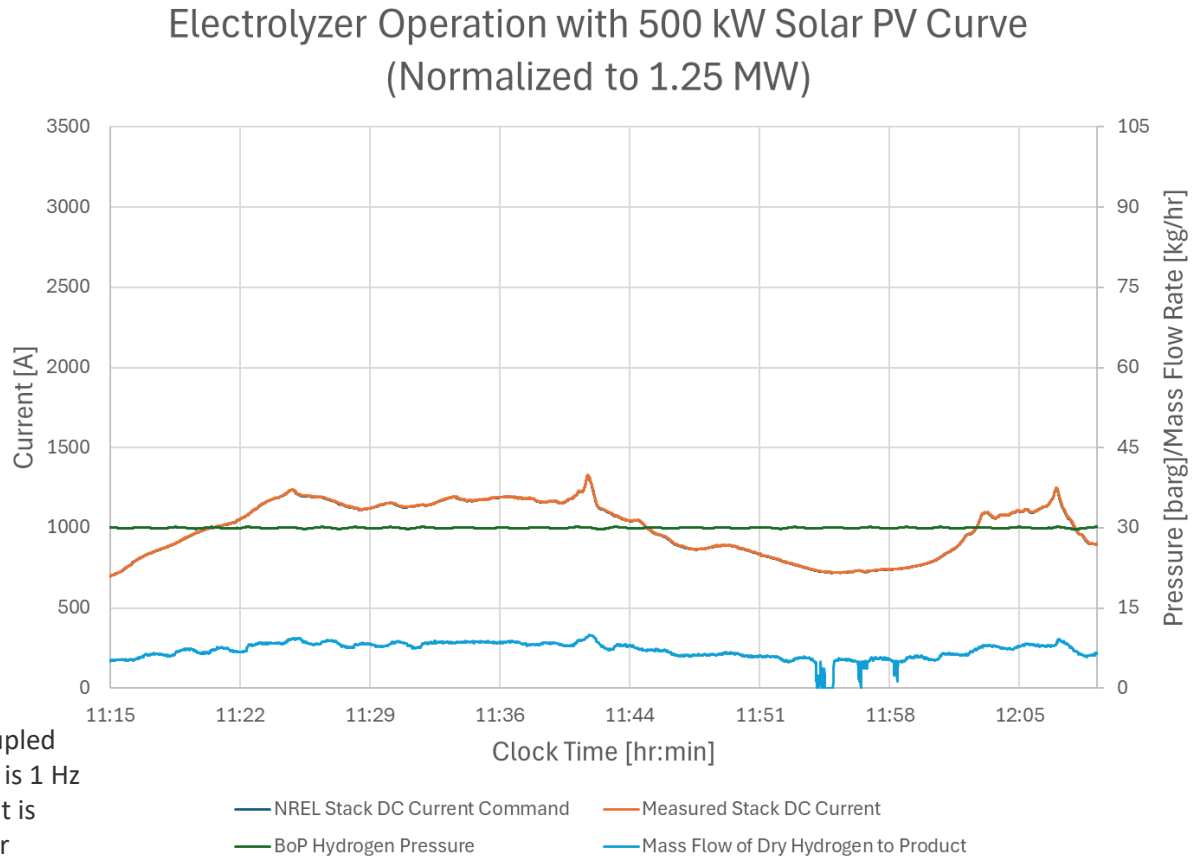


Accomplishments and Progress: Electrolysis System Fully Commissioned



*Note: Efficiencies calculated as measured dry mass of hydrogen output as product times lower heating value of hydrogen divided by DC power to stack (NO parasitic balance of plant power included)

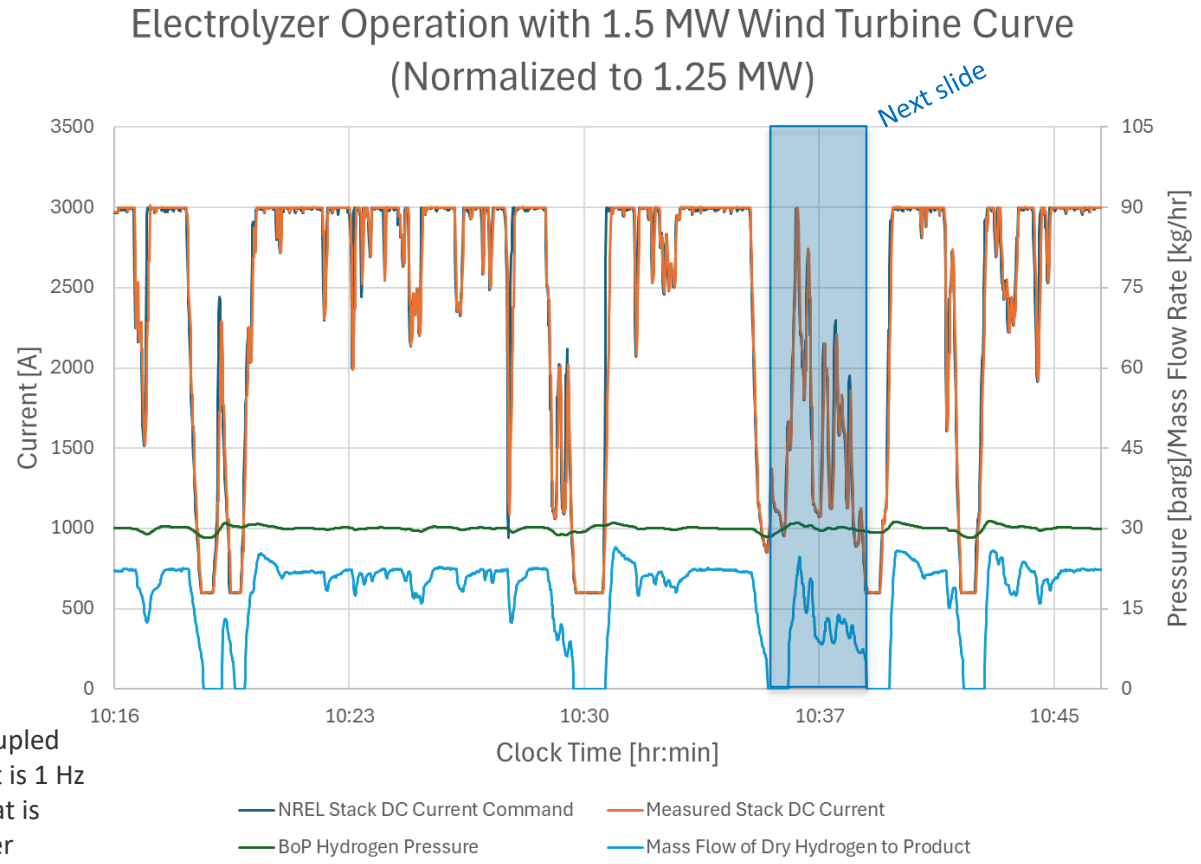
Accomplishments and Progress: Electrolysis System Solar Profile Operation



- 67.0% efficiency (LHV)
- Highly variable (high gain/slew rate) data used from single PV field (near worst case)

*Note: This is NOT direct coupled real time solar production, it is 1 Hz data recorded previously that is prescribed to the electrolyzer

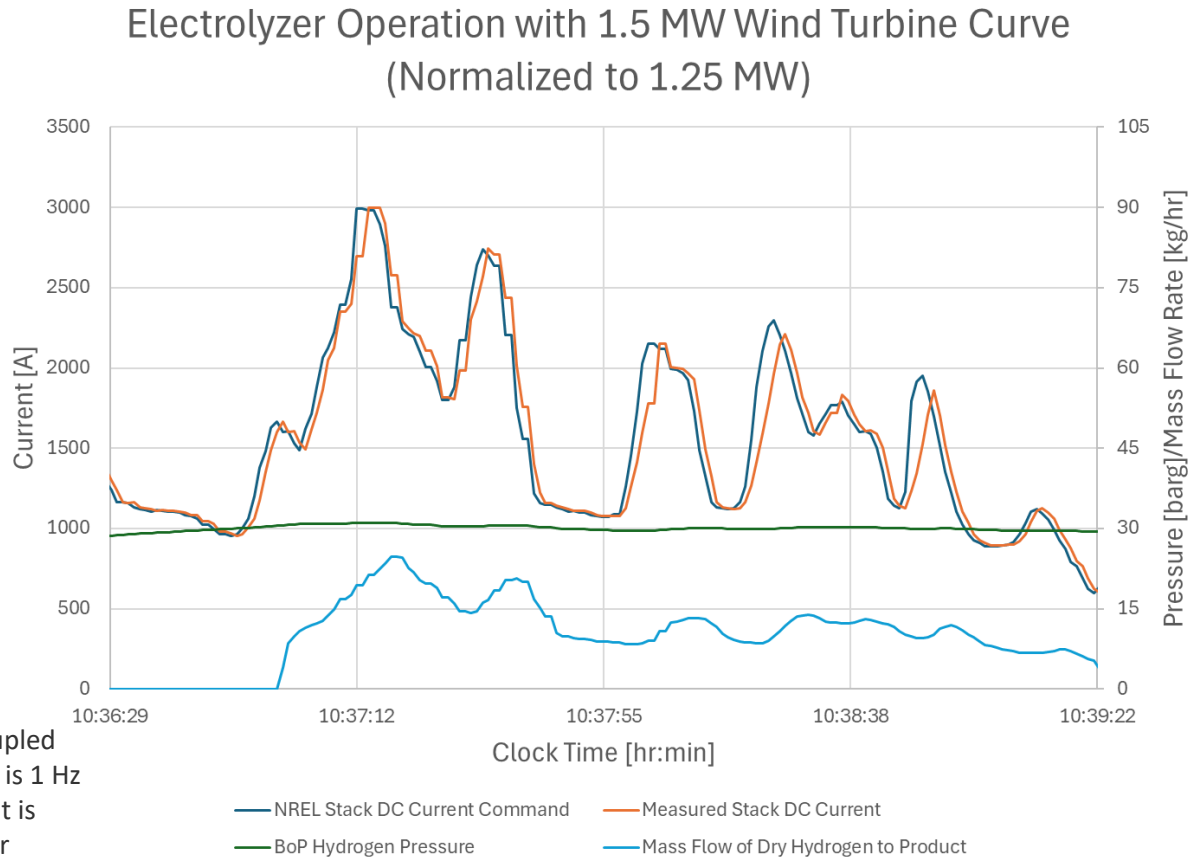
Accomplishments and Progress: Electrolysis System Wind Profile Operation



- 58.4% efficiency (LHV)
- Highly variable (high gain/slew rate) data used from single turbine (near worst case)

*Note: This is NOT direct coupled real time wind production, it is 1 Hz data recorded previously that is prescribed to the electrolyzer

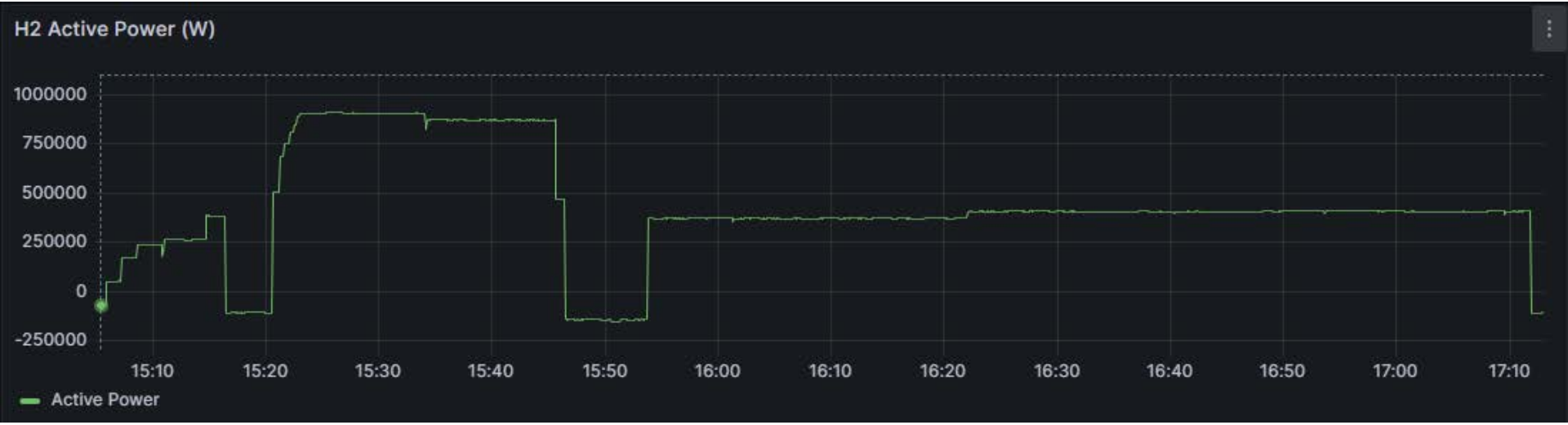
Accomplishments and Progress: Electrolysis System Wind Profile Operation



- Up to 573A offset during gain period (~3 seconds)
- Up to 250A offset during slew period (~1 second)

*Note: This is NOT direct coupled real time wind production, it is 1 Hz data recorded previously that is prescribed to the electrolyzer

Accomplishments and Progress: Fuel Cell System Produced 1 MWe and >1 MWhe AC Output



Fuel cells idle to generation, manual step up slowly

Fuel cells to idle to discuss results

Fuel cells ramped to >1 MWe AC to transformer for >22 minutes

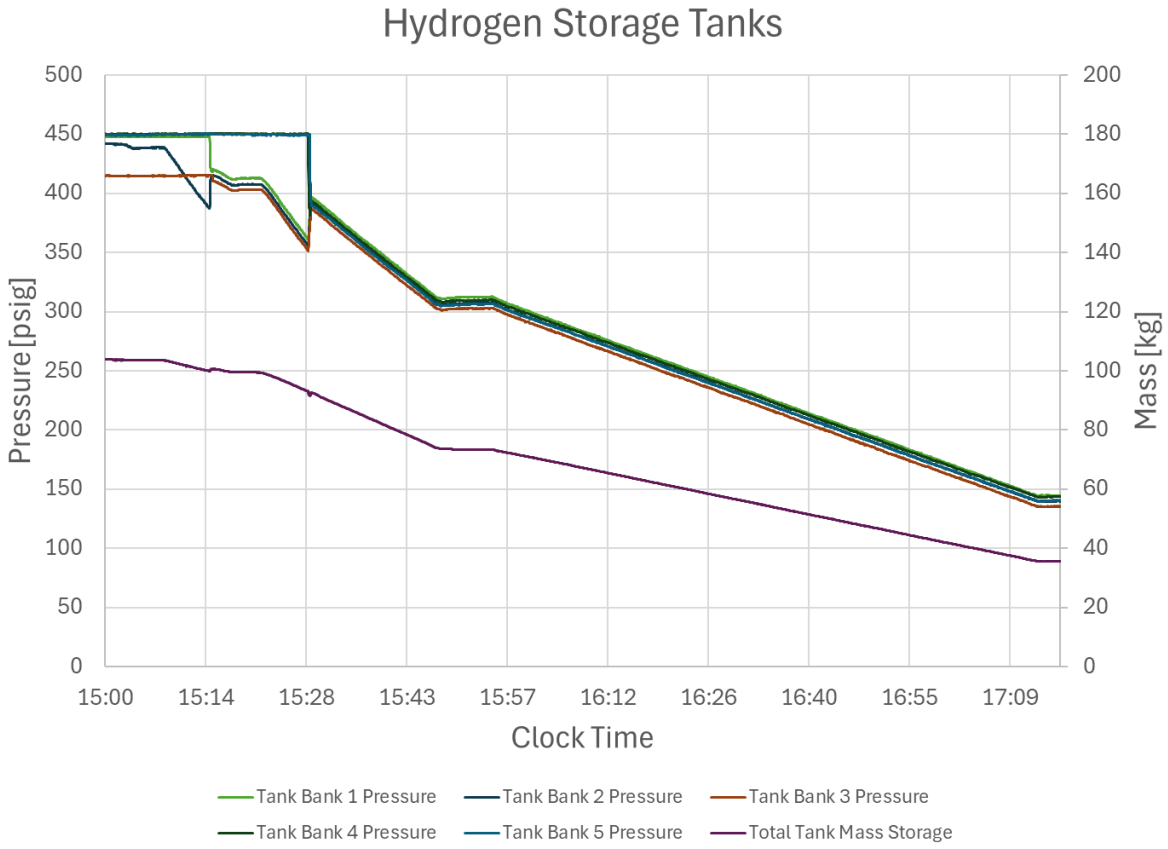
Fuel cells set to idle due to high temperature on one of them to discuss (filter clog diagnosed and fixed later)

Fuel cells run at >0.5 MWe for >77min

Fuel cell off, parasitic load of site ~100 kW

Notes:
- Plot is net power of entire hydrogen site, including loads unrelated to Fuel Cell system
- Fuel cell system in grid-following mode

Accomplishments and Progress: Fuel Cell System Consumed 68.4 kg of Hydrogen (~50% efficiency)



Accomplishments and Progress: Fuel Cell System

- Subsequent all day run with “sweep” of constant power levels:
  - 10% Power (~100 kWAC out) efficiency of 48.7%
  - 25% Power (~250 kWAC out) efficiency of 52.4%
  - 100% Power (~1 MWAC out) efficiency of 48.4%
- Efficiencies calculated as AC power out divided by measured mass of hydrogen consumed times lower heating value (LHV) of hydrogen
  - Fuel cell parasitic balance of plant and power electronics conversion efficiencies included
  - Parasitic power of thermal heat rejection system (shared with electrolyzer) NOT included
- Resulting round trip energy storage efficiency at 100% power for PEM electrolyzer and PEM fuel cell systems is approximately 28.3%
  - Round trip efficiency would be higher for variable renewable and variable load profiles (average powers lower than 100%)
  - 35.1% round trip efficiency for solar PV electrolysis and 25% power fuel cell cases shown above

Accomplishments and Progress: Summary

- Completed fuel cell generator electrical installation, integration, and modifications
- Electrolyzer commissioned to produce dry (<5ppm H_2O) hydrogen gas up to full 1.25 MWe power
- Storage tank and gas management panel commissioned up to full electrolysis pressure (30 bar)
- Compressor system repaired and ready for commissioning
- Electrolyzer operated successfully using prescribed, dynamic renewable power profiles taken from NREL solar PV and wind turbine data sets (as well as partner data sets)
- Fuel cell system commissioned and operational up to full 1 MWe AC power output
- Multiple research projects with industry partners underway using newly established research capability

Response to 2023 Reviewers' Comments

- *Numerous comments on a weakness being a lack of onsite water, the drawbacks of trucking in deionized water, lack of waste stream management, and suggestions for water recovery from the fuel cell system*
  - Deionized water deliveries do not create a waste stream at the campus (current configuration)
  - The water system is built to recover and treat condensate from the fuel cell system to feed back to the electrolyzer
  - Agreements have been secured for long-term water rights in a reservoir several miles away
  - 100% design completed for pipeline upgrade and campus water treatment facility (factors in consumption of electrolysis)
  - State permit approval process for water treatment system underway
  - The electrolyzer has a deionization system installed to make use of this future potable water source (currently bypassed and *will* require additional waste stream management when active)
- *Numerous comments noting lack of partnerships listed, suggesting increased engagement with utilities, other DOE program offices, and other industry partners*
  - The initial infrastructure investment was for design, procurement, and installation of equipment only, no research
  - Use of the equipment is now targeted for research partnerships, of which there are more than 10 unique partners on numerous projects currently funded (please see numerous other AMR presentations), and many more in the works, including utilities and other DOE program offices. The development and leadership of the projects using this capability extends across multiple technology groups within NREL to ensure integration with multiple DOE program offices.
  - Please reach out if there is interest in partnering!

Response to 2023 Reviewers' Comments

- *Redundancy in the system is not clear, which may be a source of risk for companies and project teams considering the campus*
  - It is true that the system has not been designed with redundancy as a key characteristic as may be done in some commercial applications. The cost trade-offs made for this research asset led to a system that does not have inherent redundancy. The impact is minimized through significant on-site engineering expertise and close relationships with sub-system suppliers.
- *Additional information on how projects will be managed, including management of data and privacy issues, and how to coordinate multiple projects reliant on the same infrastructure*
  - NREL has an established electronic system and staff to schedule, track, and cost the use of infrastructure, per asset, per project. There is management engagement in approval of new opportunities to evaluate strategic mission alignment. These two items combine to ensure equitable management and access for use of infrastructure and de-conflict overlapping demand.
  - NREL has established organizational practices for management of data and protected information. The level of access and protection depends on the specifics of the project contract and the funding source.
- *A hydrogen liquefaction capability and liquid hydrogen storage are recommended*
  - The broader development of infrastructure at the campus includes space and setback distances that could accommodate a future liquefaction and storage system without significant modification
- *A summary report of construction and installation cost and lessons learned would be valuable*
  - Agreed. This is something we plan to develop.

Collaboration and Coordination

- Close collaboration with Nel and Toyota to commission the sub-systems that NREL purchased, including feedback on performance, requirements, and use cases
- Multiple funded projects are currently leveraging this capability, including the following CRADAs:
  - EPRI: Hydrogen production, grid integration, and scaling for the future
  - GE and Nel Hydrogen: Optimization of wind turbines for hydrogen electrolysis
  - GKN and SoCal Gas: Metal hydride tank R&D coupled with electrolysis and fuel cell systems
  - EPRI/GTI (et al.): Next Generation Hydrogen Leak Detection--Smart Distributed Monitoring for Unintended Hydrogen Releases
- Multiple industry direct-funded projects are underway currently, with more in various negotiation stages
- Additional interest in using this infrastructure to conduct joint research is welcome!

Remaining Challenges and Barriers

- Transition fully to research operation of the equipment (end of this project)
- Continue stewarding and building upon the investment made to ensure continued relevance to answering national level energy challenges

Proposed Future Work

- Complete commissioning of the compressor system
- Store renewably generated hydrogen for longer than a week and demonstrate resiliency by using fuel cell generator to *grid-form* the Flatirons research grid, producing 1 MWh of electrical energy
- Use the newly commissioned MW-scale Flatirons ARIES hydrogen RD&D capability to produce unique experimental data sets for at least four separate projects related to clean hydrogen, including dynamic response, in support of the Hydrogen Shot goal to ultimately meet $2/kg and $1/kg hydrogen cost goals.
- Directly AC grid couple wind turbine and solar PV with electrolysis

Note: Any proposed future work is subject to change based on funding levels

Summary

- Commissioning of all equipment is complete less the compressor and grid-forming functionality of fuel cell generator
- Research is underway with industry partners via CRADAs and directly funded projects
- This infrastructure will support future research projects under the ARIES umbrella, specifically in the areas of energy storage, direct hydrogen production coupling with renewables, grid stabilization, electrons to molecules, heavy duty transportation, and other innovative end uses

Thank You

www.nrel.gov

NREL/PR-5700-89231

Contact:
daniel.leighton@nrel.gov

This work was authored 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 Hydrogen and Fuel Cell Technologies 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.

Technical Backup and Additional Information

Technology Transfer Activities

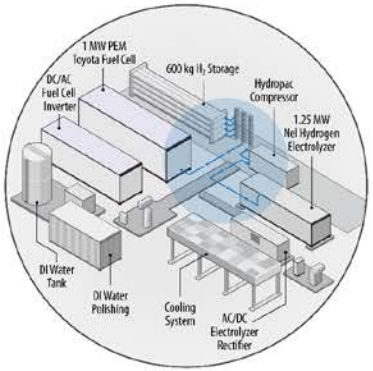
- No patent, licensing, or technology transfer is planned as a part of this funded work
- The work funded is creating a capability that supports multiple future collaborative research projects with industry, academia, and other national laboratories

Special Recognitions and Awards

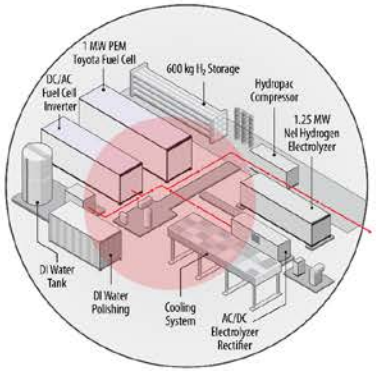
2023 NREL Presidents Team Award:
Riley Abel, Tavis Hanna, Daniel Leighton, Josh Martin, Jeff Mohr, Jake Thorson

Outstanding achievement on commissioning of H_2 electrolyzer and hardware including contributions to implementing the ARIES integrated hydrogen MW+ research system and navigating new partnerships with suppliers and cross-discipline researchers. The team is recognized for their efforts that have put NREL at the forefront of technology and demonstrated first of its kind capabilities for highly integrated hydrogen systems.

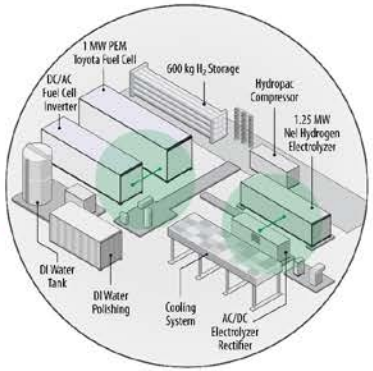
Technical Backup Slide: Systems Integration



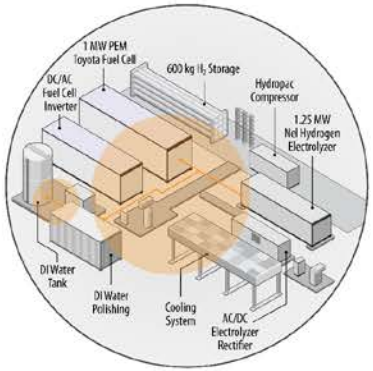
Hydrogen Connections



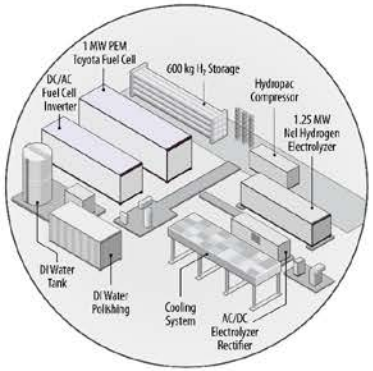
13.2 kW Grid Connections



DC Connections



DI Water Connections



System Map