



# DOE HFTO H2IQ Hour: NREL ARIES Flatirons Campus MW-Scale Hydrogen System Research

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July 25, 2024

# NREL at a Glance

## 3,915 Workforce, including:

- 2,913 regular/limited term
- 531 contingent workers
- 223 postdoctoral researchers
- 155 graduate student interns
- 93 undergraduate student interns

—as of 5/15/2024

## World-class research expertise in:

- Renewable Energy
- Sustainable Transportation & Fuels
- Buildings and Industry
- Energy Systems Integration

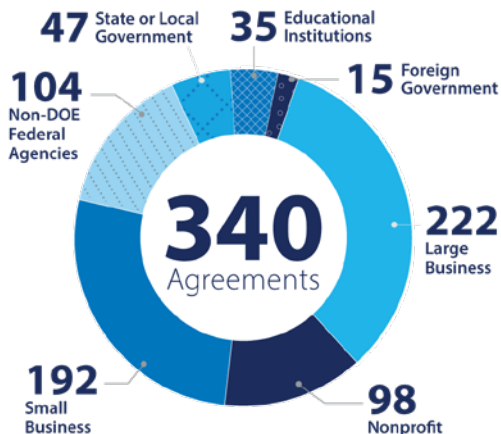
## Partnerships with:

- Industry
- Academia
- Government

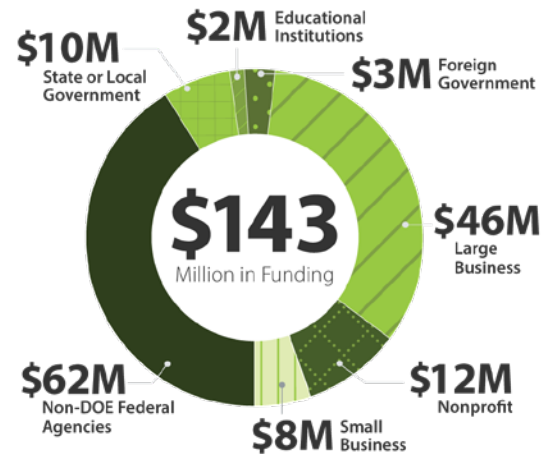
**4 Campuses** operate as living laboratories



## More Than 1,100 Active Partnerships in FY 2023



Agreements by Business Type



Funding by Business Type

## Integrated Energy Pathways



## Electrons to Molecules



## Circular Economy for Energy Materials



**NREL's Vision:**  
A Clean Energy  
Future for the World

Three critical research areas respond to today's energy challenges and provide tomorrow's solutions

# NREL Brings Distinct Capabilities

## Foundational Science

Bench-scale- discovery



Solar Energy Research Facility  
Science and Technology Facility  
Field Test Laboratory Building



## Accelerated Technology Scale-Up

Scaling R&D and Process Engineering



Energy Materials and Processing  
at Scale (Completion 2025)



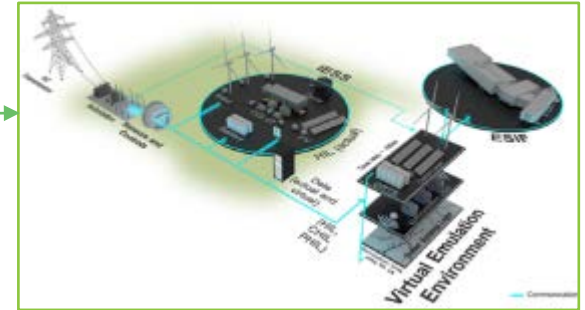
Energy Systems  
Integration Facility



- Carbon-free H<sub>2</sub>
- Products from electrochemical processes and CO<sub>2</sub>
- Advanced Batteries
- PV, Wind, Water Power, Geothermal
- New Buildings and Industrial Materials, Manufacturing and Systems
- Grid and security tech

## Systems

R&D with Industry Partners

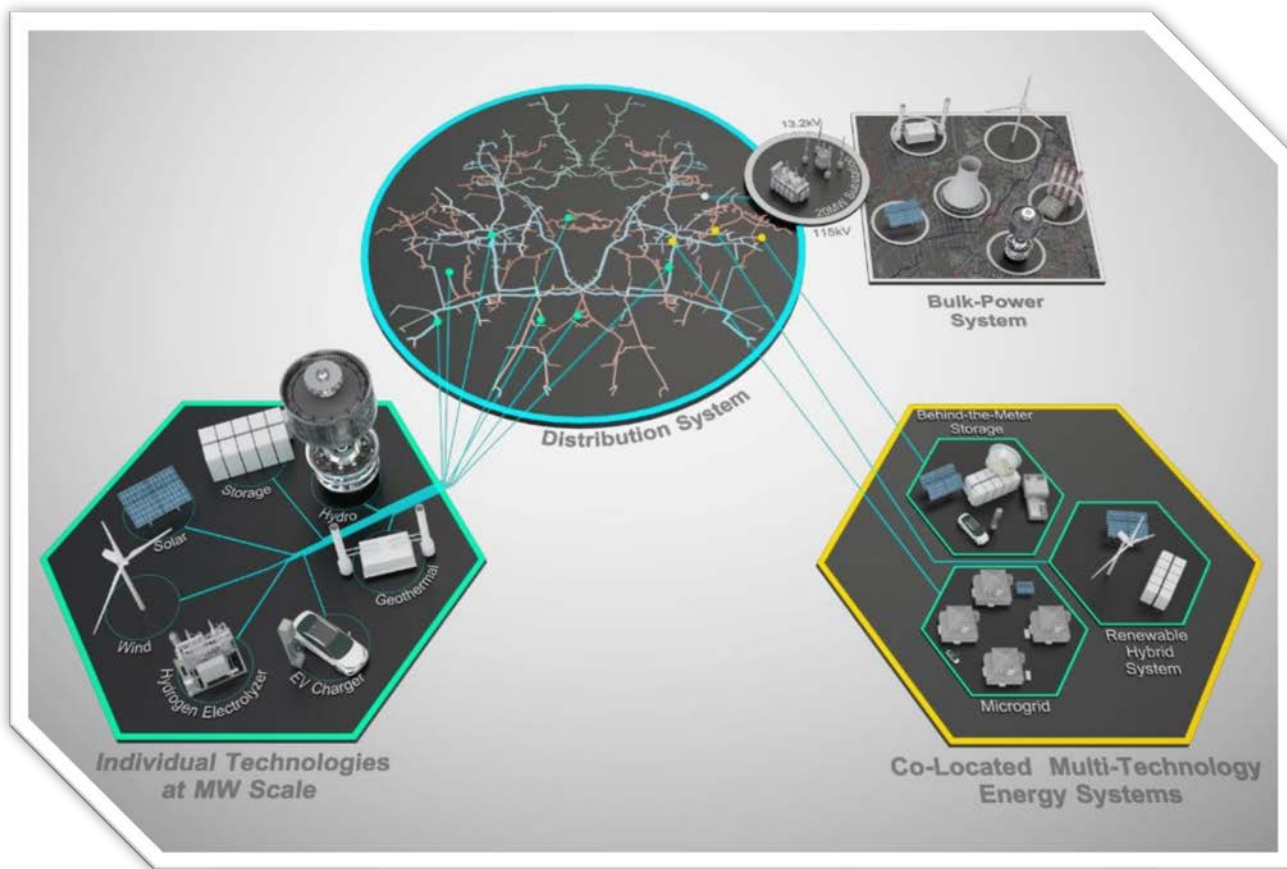


Advanced Research on  
Integrated Energy Systems

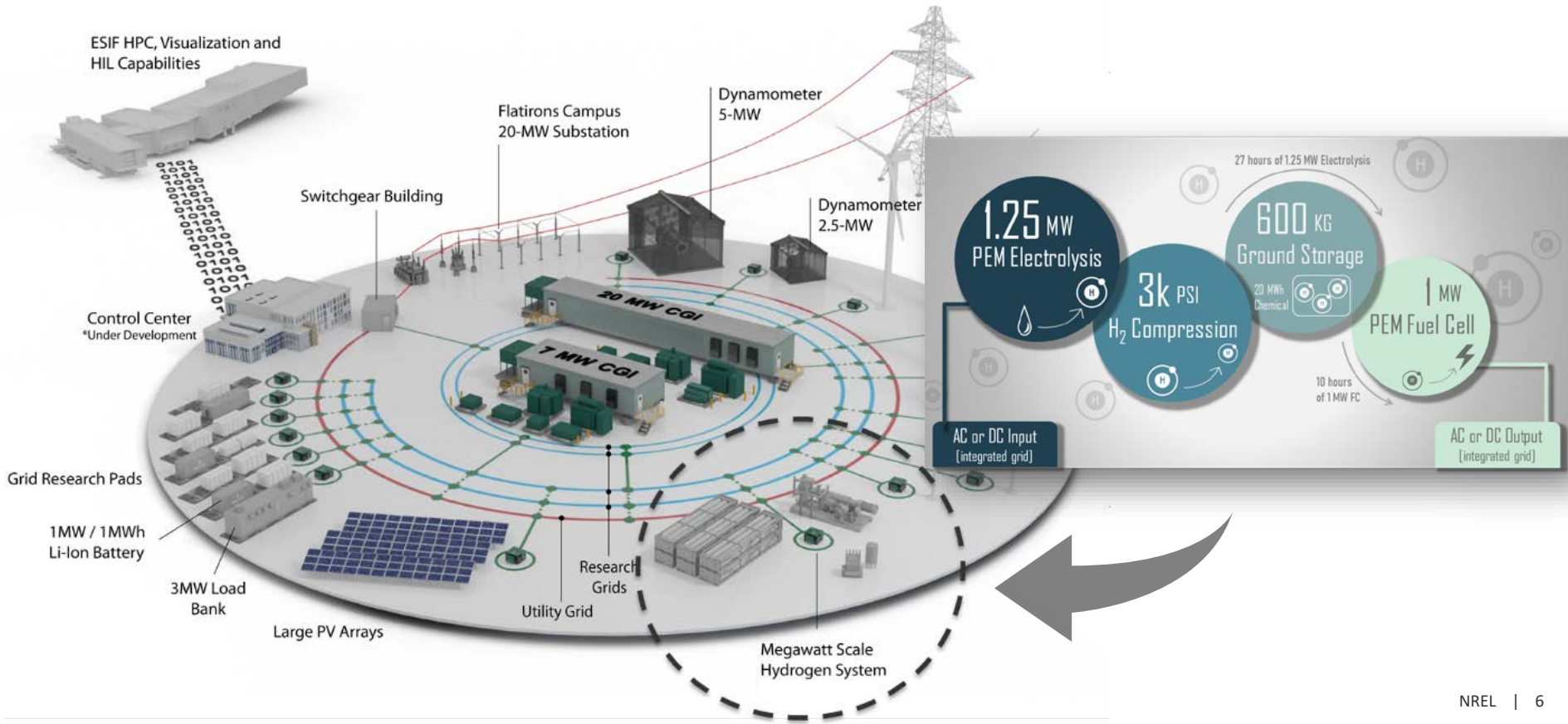
## Markets

High-Performance Computing, Simulation, and Visualization

# Advanced Research on Integrated Energy Systems (ARIES) Vision

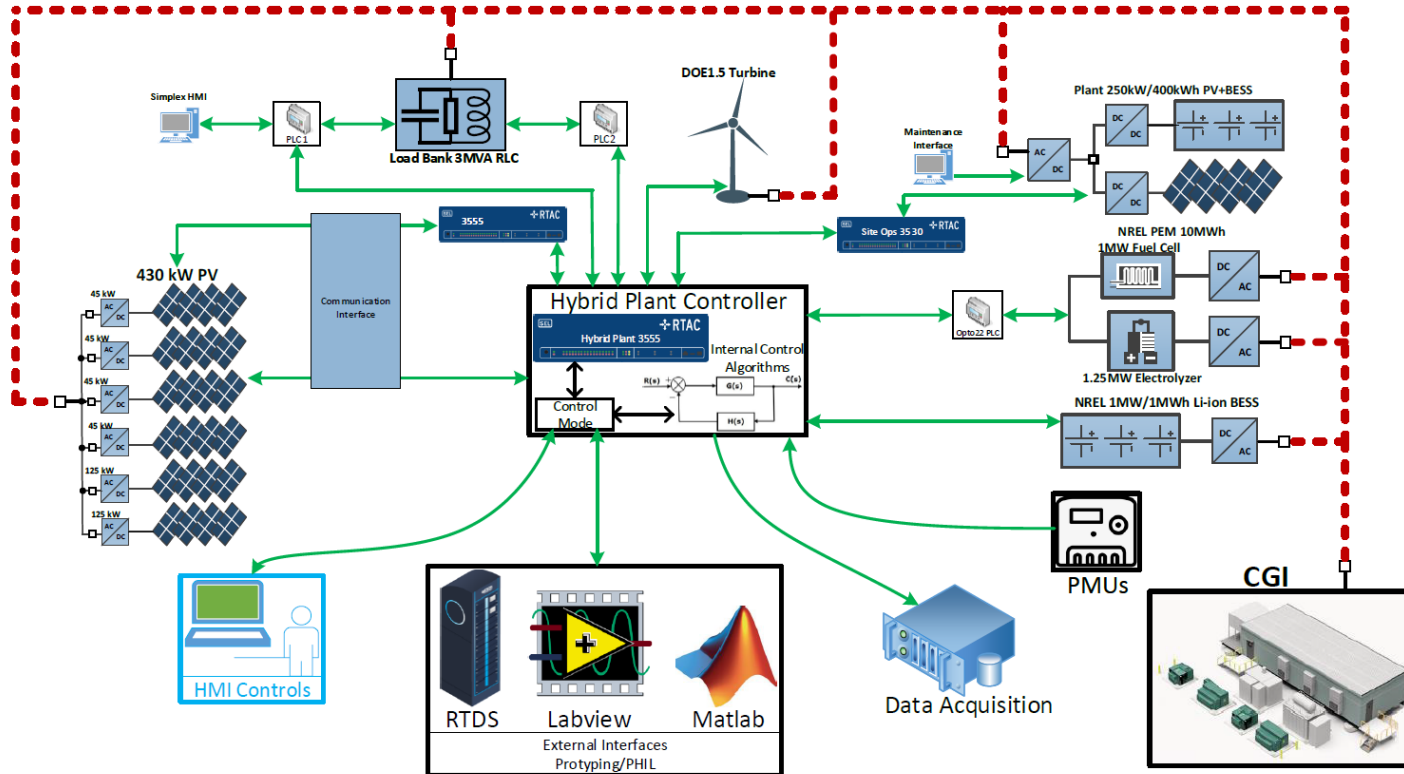


# ARIES Flatirons Campus Grid Equipment



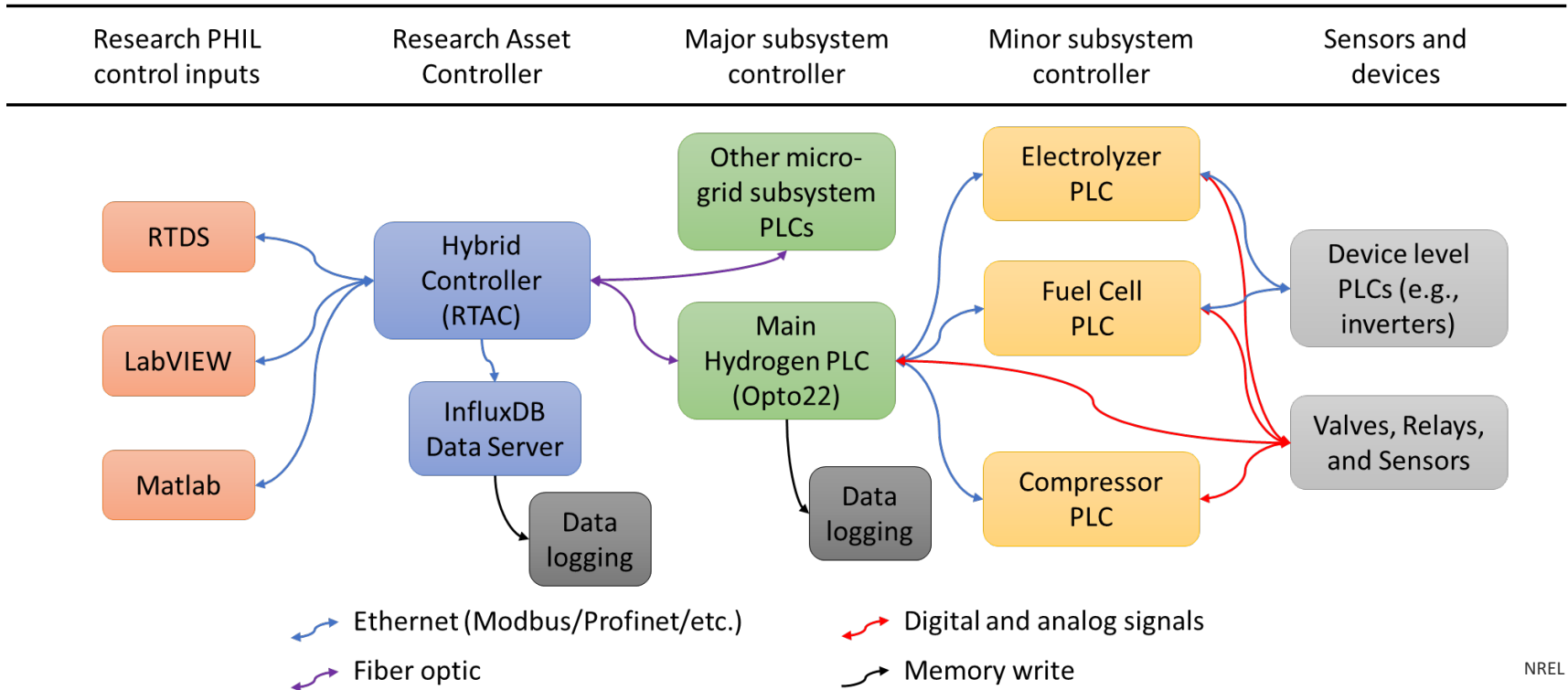
# Medium Voltage Grid Hybrid Controller

## Hybrid Controls Map



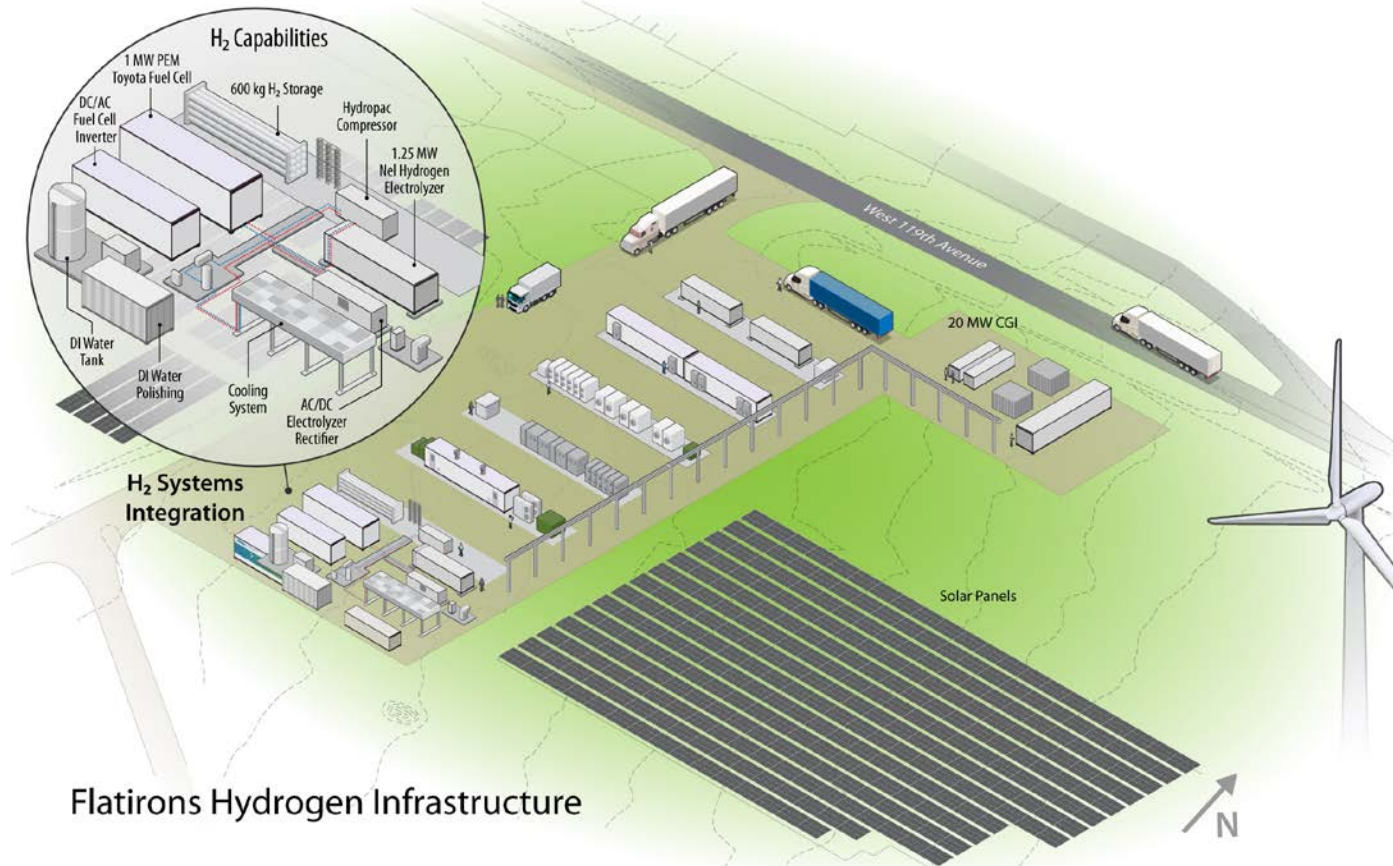
# Controls Architecture

## Hydrogen System Signal Flow

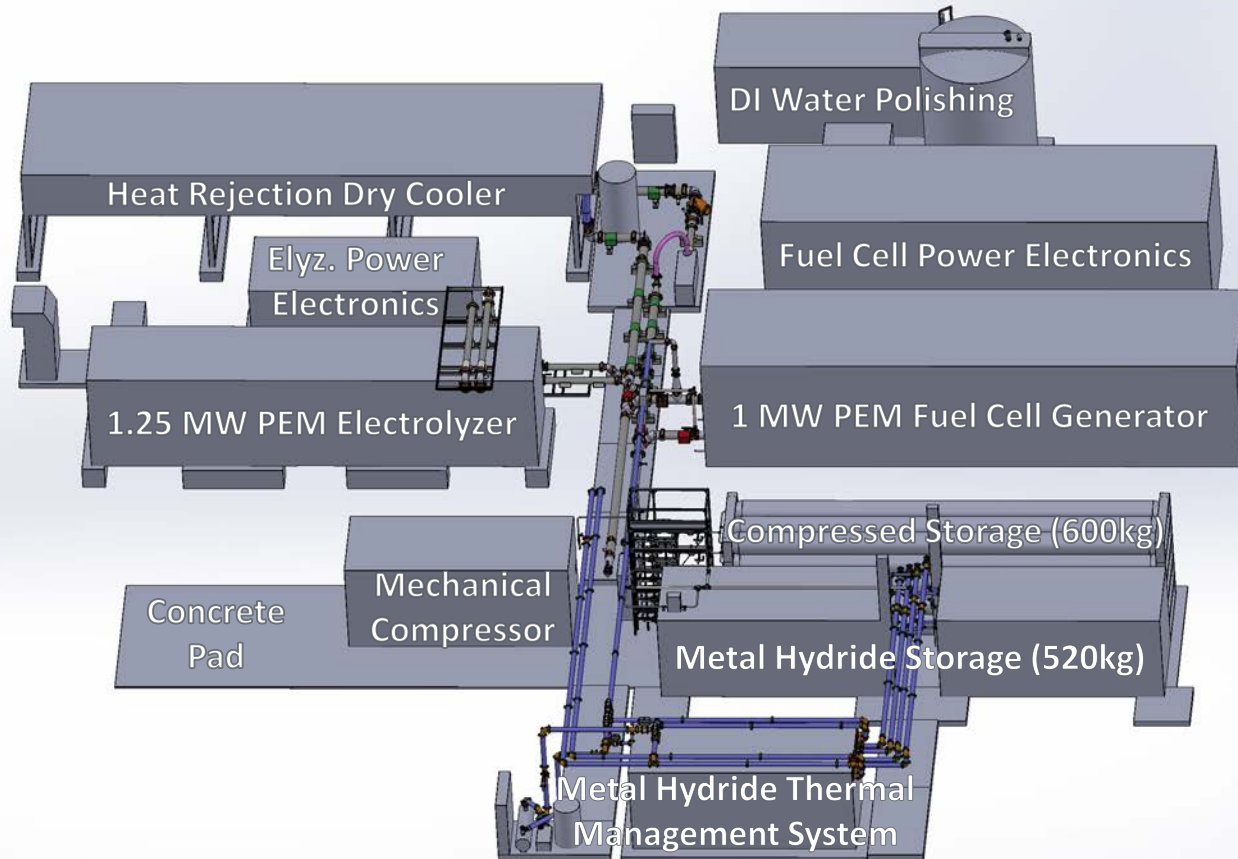




# Flatirons Campus Site



# Existing Flatirons Campus Hydrogen System Layout

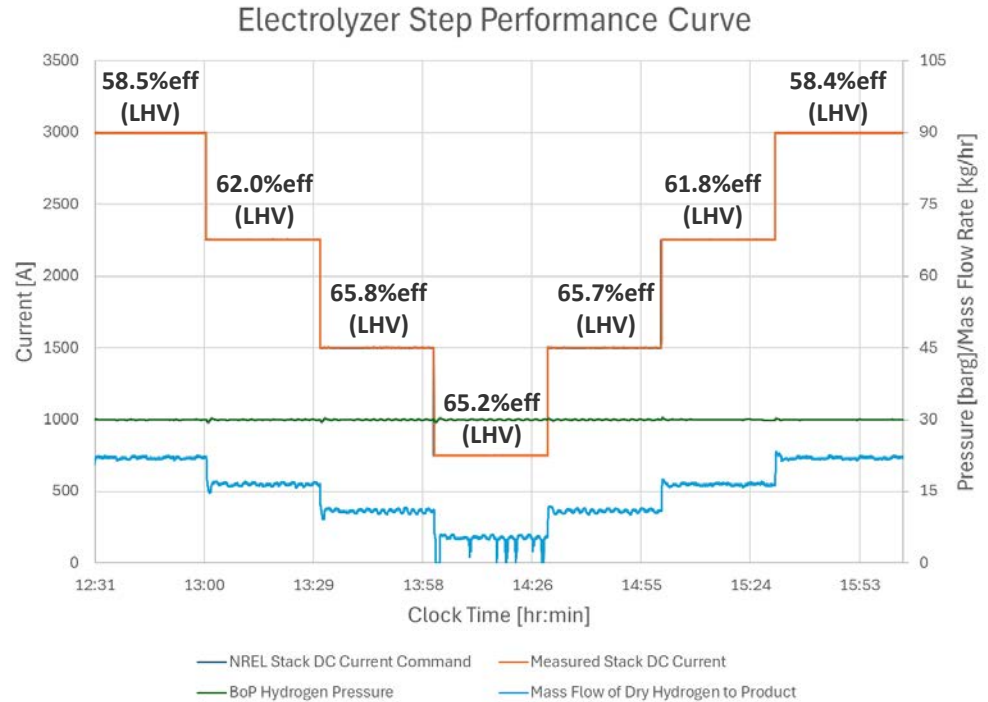


# Flatirons Campus Hydrogen System Today



**Future Hydrogen  
Site Construction  
(inc. MMW LTE)**

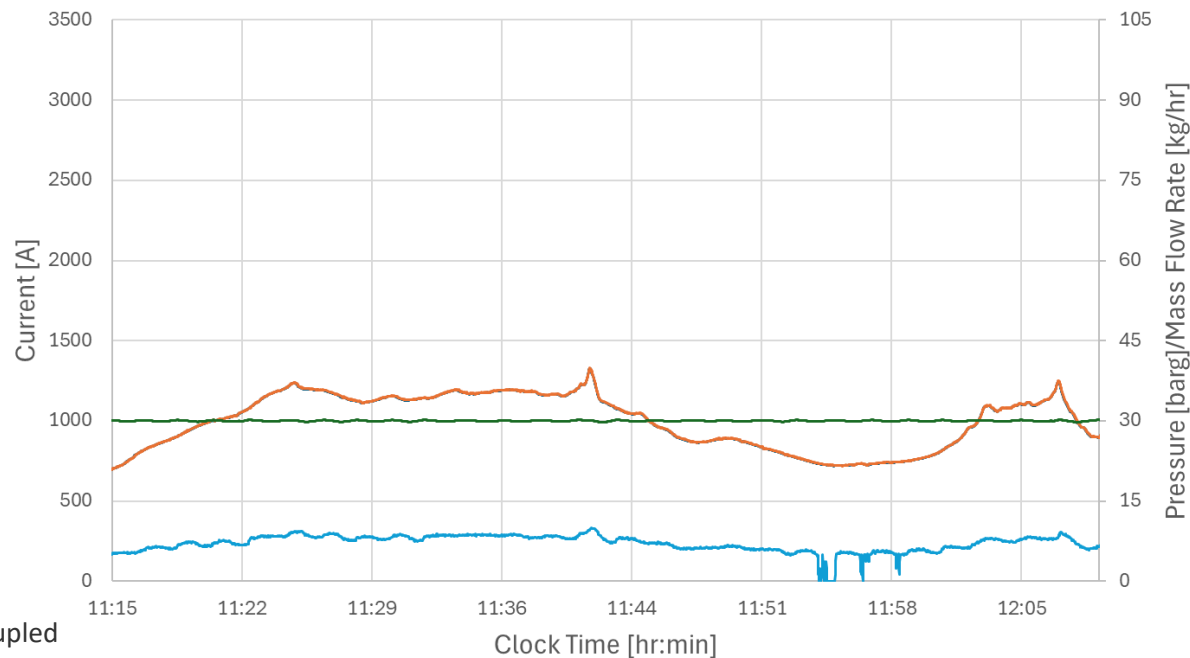
# Electrolyzer Steady State Efficiency



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

# Electrolyzer Operated on Solar PV Profile

Electrolyzer Operation with 500 kW Solar PV Curve  
(Normalized to 1.25 MW)



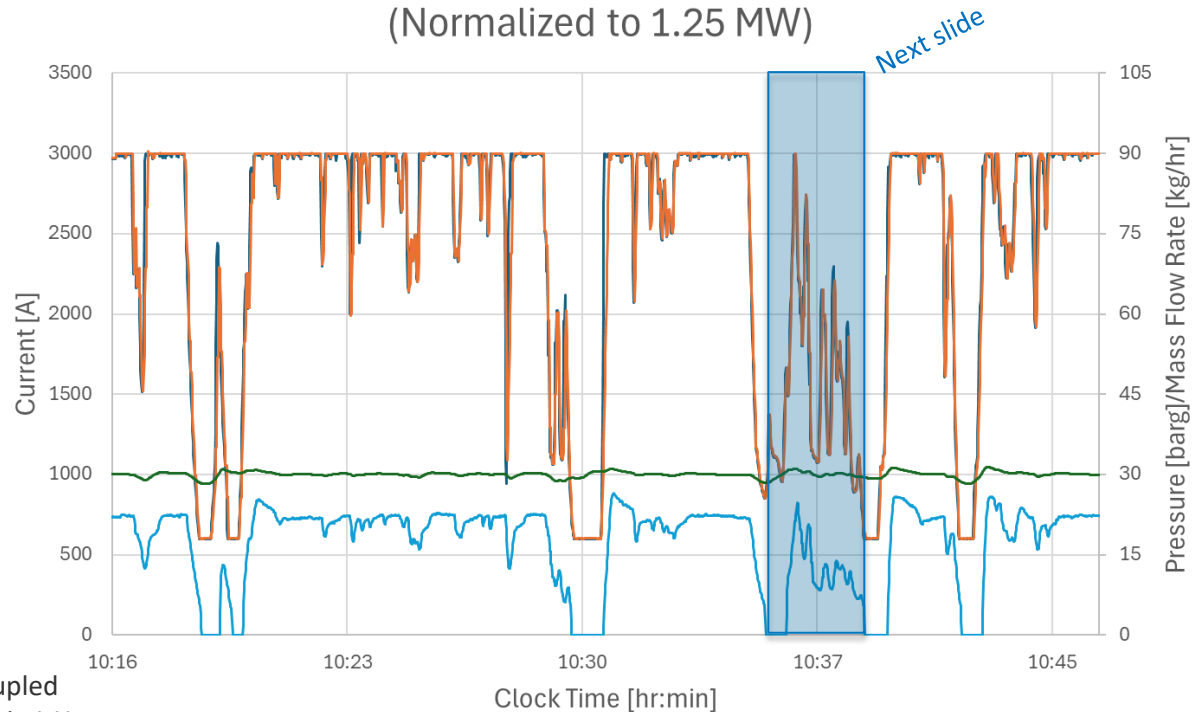
- 67.0% efficiency (LHV)
- Highly variable (high gain/slew rate) data used from single PV field (near worst case)

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

— NREL Stack DC Current Command    — Measured Stack DC Current  
— BoP Hydrogen Pressure            — Mass Flow of Dry Hydrogen to Product

# Electrolyzer Operated on Wind Turbine Profile

Electrolyzer Operation with 1.5 MW Wind Turbine Curve  
(Normalized to 1.25 MW)



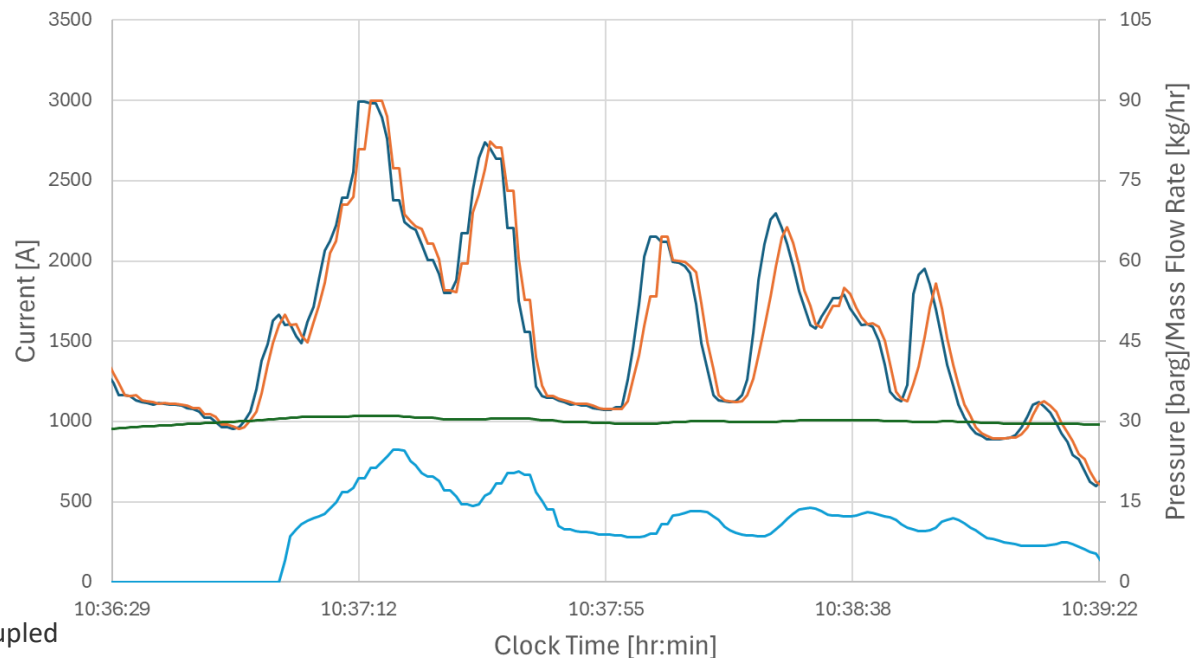
- 58.4% efficiency (LHV)
- Highly variable (high gain/slew rate) data used from single turbine (near worst case)

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

— NREL Stack DC Current Command    — Measured Stack DC Current  
— BoP Hydrogen Pressure            — Mass Flow of Dry Hydrogen to Product

# Electrolyzer Operated on Wind Turbine Profile

## Electrolyzer Operation with 1.5 MW Wind Turbine Curve (Normalized to 1.25 MW)



- 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

— NREL Stack DC Current Command — Measured Stack DC Current  
— BoP Hydrogen Pressure — Mass Flow of Dry Hydrogen to Product

# Fuel Cell Generator Performance

- 48.7% efficiency at 100 kW-AC
- 52.4% efficiency at 250 kW-AC
- 48.4% efficiency at 1 MW-AC

\*Note: These are NOT stack efficiency numbers, but are instead complete generator efficiencies calculated as AC power output from inverter divided by dry mass of hydrogen discharged from tanks times lower heating value (LHV) of hydrogen. They include ALL parasitic balance of plant loads such as compressor, pump, fan, lighting, and control power, as well as conversion losses



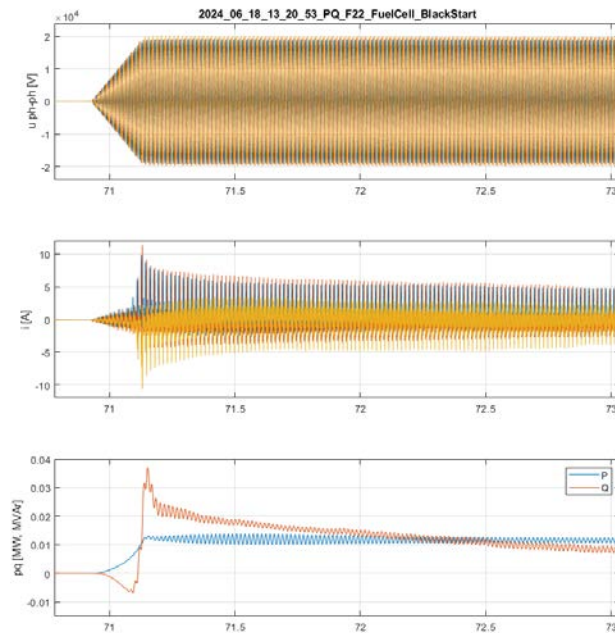
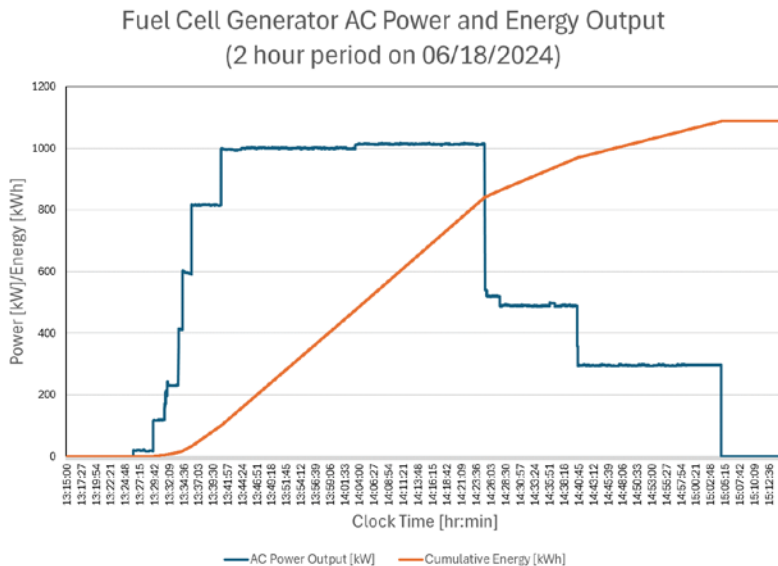
Photo by Daniel Leighton, NREL

- 28.3% round trip energy storage efficiency at full power (electrons to electrolysis molecule production, molecular storage, back to grid electrons via fuel cell generator)
- 35.1% round trip energy storage efficiency at low power (solar PV electrolysis case and 25% fuel cell)



# Fuel Cell Generator Black Start/Grid Forming

- 6+ MVA of transformers black started on 13.2kV grid in 200 ms with maximum inrush current of 12 A
- Peak output power of 1.016 MWe-AC, with 1.088 MWe-AC of energy produced
- 64.4 kg of hydrogen consumed, which is 50.7% AC-LHV efficiency
- Maximum Frequency/Power (F/P) droop of 1.4% during step changes



MV Grid 50 kHz data of black start voltage, current, real and reactive power (from top to bottom) versus time in seconds – Courtesy of: Przemyslaw Koralewicz

# ARIES Research Projects Underway

*We're collecting data with industry partners to answer questions on the suitability of current commercial PEM electrolysis and fuel cell technology for larger scale deployments*

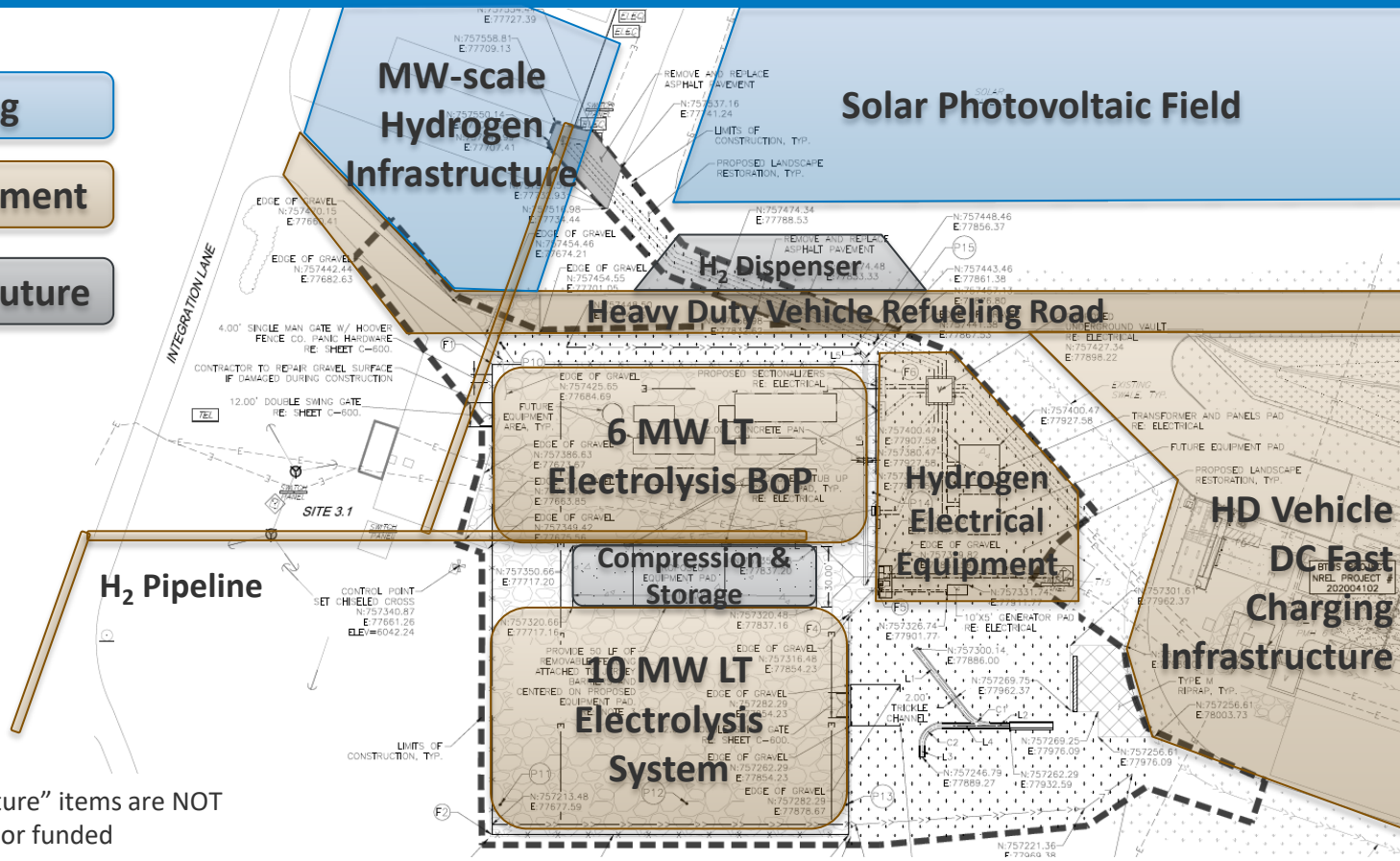
- **GKN & SoCalGas CRADA:** High Efficacy Validation of Hydride Mega Tanks at the ARIES Lab
- **EPRI CRADA:** Hydrogen Production, Grid Integration, and Scaling for the Future
- **GE & Nel Hydrogen CRADA:** Optimal Wind Turbine Design for H<sub>2</sub> Production
- **EPRI/GTI (et al.) CRADA:** Next Generation Hydrogen Leak Detection--Smart Distributed Monitoring for Unintended Hydrogen Releases
- Multiple other DOE funded projects (Flexpower, Leak Rate Quantification, etc.)
- Multiple direct-funded industry projects

# Site Infrastructure Plans: Existing, Funded, and Proposed

Existing

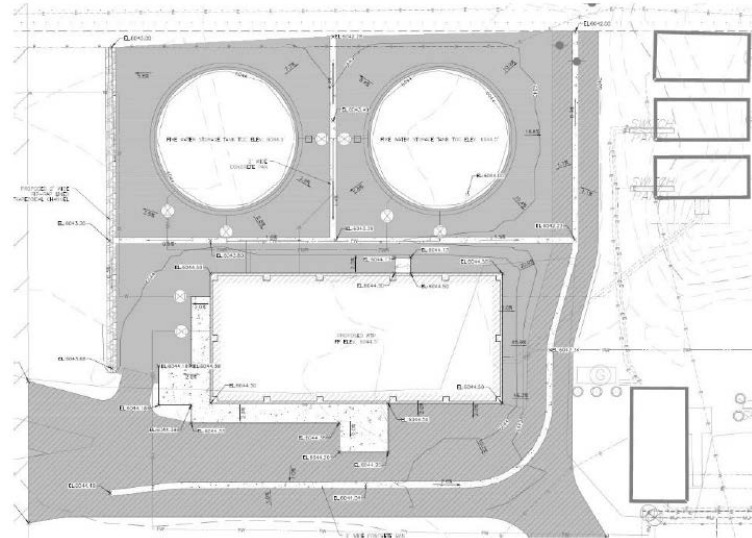
In development

Potential Future



\*Note: "Potential Future" items are NOT currently committed or funded

# Campus Water Supply Infrastructure Upgrades



Planned water tanks and treatment plant locations

- Infrastructure investment being made to develop water main from reservoir, treatment facility, storage system, and supply lines to equipment (including hydrogen site)
- Design complete
- Awaiting Colorado State approval of water treatment process to proceed with construction bidding

# MMW LTE Research Capability

Industry Partner Delivers  
(maximum sizes):

10MW Full System

6MW PEM or LA  
Stack with Core Bop

6MW PEM Stack  
or 2MW LA Stack

## Balance of System

- Physical space/site and safety/code controls
- Transformer to substation electrical infrastructure
- 480 V auxiliary electrical
- Thermal management
- DI water supply
- Hydrogen gas management and interconnection
- Hydrogen flaring

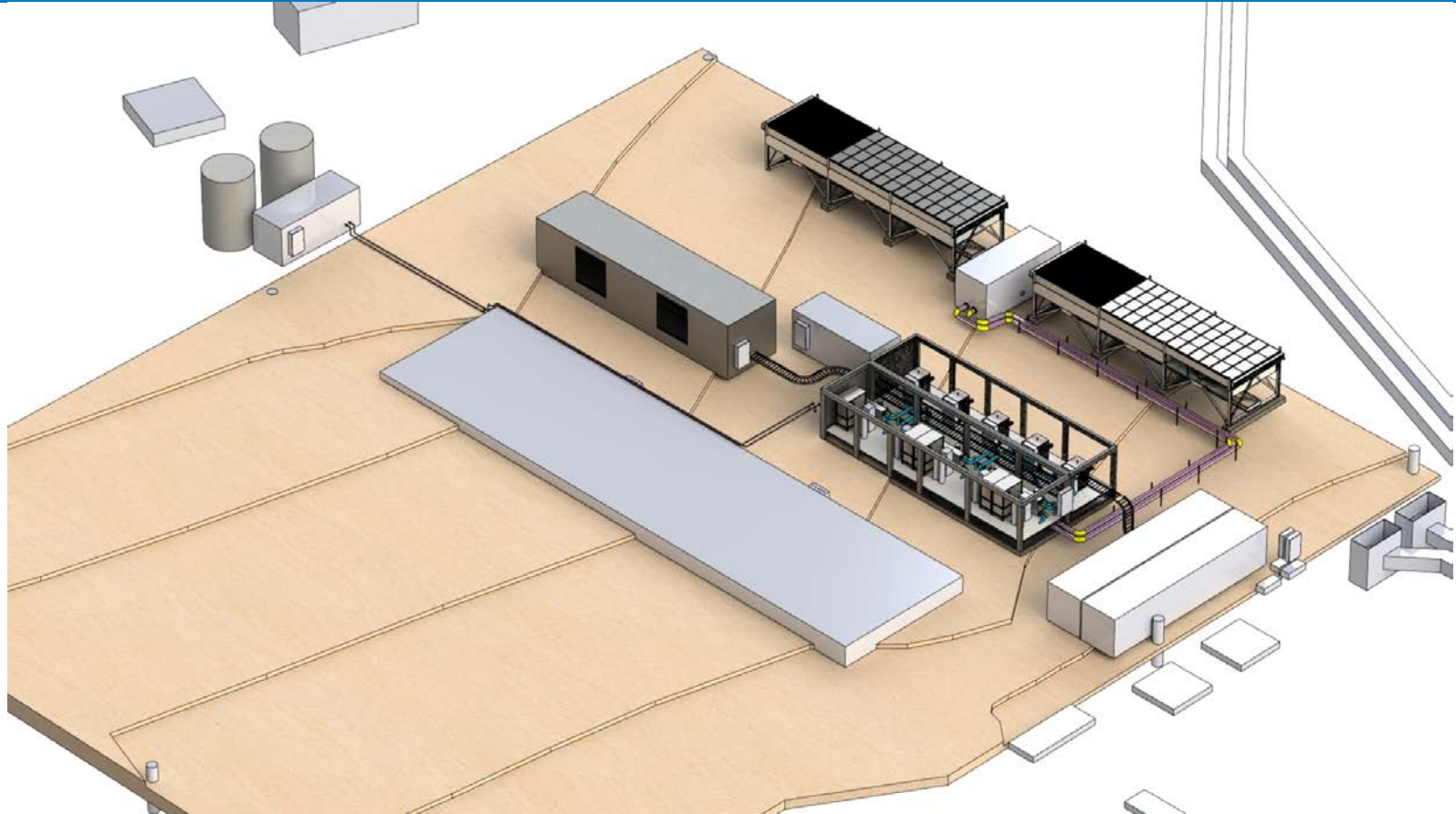
## Full Balance of Plant

- DC rectifiers
- DC interconnection infrastructure
- Hydrogen drying

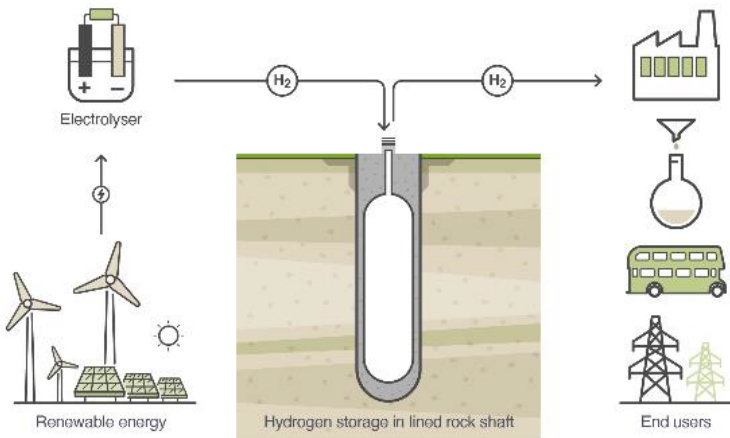
## Core Balance of Plant

- Weatherproof and thermally controlled containerization for stacks
- DI water pumps
- Separator tanks
- Process cooling heat exchangers
- Sensors (cell voltage monitoring, etc.)

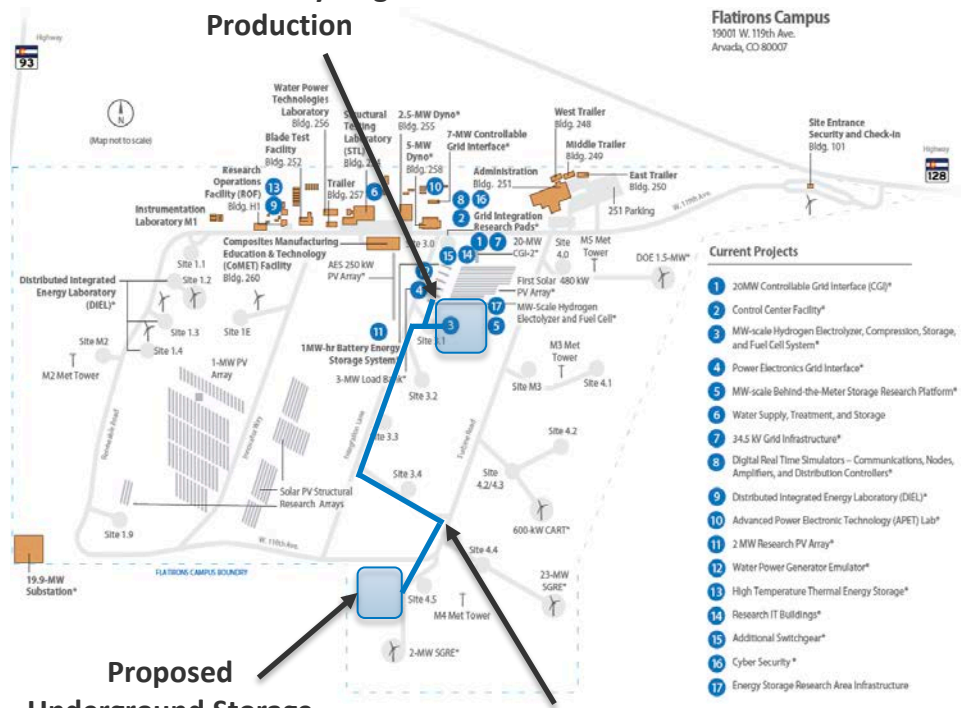
# Future MMW LTE Site Layout



# 10-ton Underground H<sub>2</sub> Storage Capability



## Renewable Hydrogen Production



**Flatirons Campus**  
19001 W. 119th Ave.  
Arvada, CO 80007

- Current Projects**
- 1 20MW Controllable Grid Interface (CGI)\*
  - 2 Control Center Facility\*
  - 3 MW-scale Hydrogen Electrolyzer, Compression, Storage, and Fuel Cell System\*
  - 4 Power Electronics Grid Interface\*
  - 5 MW-scale Behind-the-Meter Storage Research Platform\*
  - 6 Water Supply, Treatment, and Storage
  - 7 34.5 kW Grid Infrastructure\*
  - 8 Digital Real Time Simulators – Communications, Nodes, Amplifiers, and Distribution Controllers\*
  - 9 Distributed Integrated Energy Laboratory (DIEL)\*
  - 10 Advanced Power Electronic Technology (APET) Lab\*
  - 11 2 MW Research PV Array\*
  - 12 Water Power Generator Emulator\*
  - 13 High Temperature Thermal Energy Storage\*
  - 14 Research IT Buildings\*
  - 15 Additional Switchgear\*
  - 16 Cyber Security\*
  - 17 Energy Storage Research Area Infrastructure

**Proposed Underground Storage**

**Proposed Campus Hydrogen Pipeline**

# Potential Future Capabilities

- Heavy-duty vehicle fueling station
- H<sub>2</sub> power systems (fuel cells, engines, turbines)
- Molecule building (ammonia, green steel, methanol, etc.)
- Direct DC integration of H<sub>2</sub> technologies with renewables
- Liquefaction and/or liquid hydrogen storage
- Natural gas blending



A satellite view of Earth at night, showing the curvature of the planet and the glowing lights of cities and continents. The sun is visible on the left horizon, creating a bright glow and lens flare effect.

# Thank You

[www.nrel.gov](http://www.nrel.gov)

NREL/PR-5700-90601

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 the 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.

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