Project Goal

• Under the “Advanced Research on Integrated Energy Systems” (ARIES) initiative, hydrogen system capabilities including a MW-scale electrolyzer, storage system, and MW-scale fuel cell generator will be designed and commissioned at NREL’s Flatirons Campus

• This hydrogen infrastructure will support H2@Scale goals by enabling integrated systems R&D to study the science of scaling for hydrogen energy 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 (e.g. HD transportation, natural gas blending, etc.)
Overview

Timeline and Budget

- Project start date: 05/06/2021
- FY20 DOE funding: $3,671,558
- FY21 planned DOE funding: $328,442
- Total DOE funds received to date*: $4,000,000
  * 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: Daniel Leighton, NREL
Relevance

- This work is a **research capability** for future projects to conduct research in the area of hydrogen generation, energy storage, end-use distribution, and power production at the MW-scale
  - Proving technologies and addressing integration challenges at scale is a critical precursor to deployment and investment nation-wide to reduce greenhouse 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 is also forward-looking support of 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 Equipment
Approach: Hydrogen System Design

1.25 MW PEM Electrolysis

3k PSI H₂ Compression

600 KG Ground Storage

1 MW PEM Fuel Cell

27 hours of 1.25 MW Electrolysis

20 MWh Chemical

10 hours of 1 MW FC

AC or DC Input (integrated grid)

AC or DC Output (integrated grid)
Approach: ARIES Integration

EXISTING
1. Multi-MW Wind Turbines
2. 0.5 MW Solar PV
3. 6.3 MW Controllable Grid
4. 1 MWh Battery

IN PROGRESS
5. 20 MW Controllable Grid
   Temporary Hydrogen Site (MW-Scale Hydrogen Production, Storage, & Power System)
6. Permanent Hydrogen Site (NG/H₂ Blending, HD Vehicle Fueling, etc.)

FUTURE
7. MW-Scale DC Fast-Charging
Approach: Permanent Site Layout
Approach: One-Line
Approach: Hydrogen P&ID
Approach: Hydrogen GMP
• Goal is to build infrastructure to support future hydrogen research at the megawatt scale
  – Initial equipment will be capable of exploring areas including direct renewable hydrogen production (physical wind and solar assets as well as emulation capabilities), energy storage, grid stabilization, and more
  – Site infrastructure is being prepared specifically to support additional future research areas such as natural gas blending, molecule building, high-throughput compression, and heavy-duty vehicle fueling
  – Several project proposals with partners are under-development and additional opportunities are being sought out to support HFTO efforts
Approach: Critical Path Challenges

• Purchasing of major equipment
  – Some of the equipment is nearly first-of-its-kind, making scope determination and contracting difficult
  – Lead times for major systems are 6-10 months
  – **Solution**: Close collaboration with internal contracting specialists to maintain progress toward equipment purchase (most of which is complete)

• Concrete and electrical infrastructure construction timelines are long
  – **Solution**: Temporary connection of equipment at existing site with concrete and electrical infrastructure, with long term plans to move to permanent pad at facility (end of FY22)

• All major equipment arriving around the same time (3-month span)
  – **Solution**: Planning, site preparation, and adequate experienced staff
## Approach: Milestones

<table>
<thead>
<tr>
<th>Milestone Name/Description</th>
<th>End Date</th>
<th>Type</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis, compression, storage tank system purchase orders placed</td>
<td>9/30/2020</td>
<td>Annual Milestone (Regular)</td>
<td>Complete</td>
</tr>
<tr>
<td>Fuel cell system purchase order placed</td>
<td>3/31/2020</td>
<td>Quarterly Progress Measure (Regular)</td>
<td>Mostly complete, contracting for fuel cell system being finalized</td>
</tr>
<tr>
<td>Full system (integrated system of electrolysis, compression, storage, and fuel cell) design and safety reviews complete</td>
<td>3/31/2021</td>
<td>Quarterly Progress Measure (Regular)</td>
<td>Mostly complete, final design and safety reviews pending fuel cell system purchase order</td>
</tr>
<tr>
<td>Fuel cell system balance of plant construction complete</td>
<td>6/30/2021</td>
<td>Quarterly Progress Measure (Regular)</td>
<td>At risk pending fuel cell system purchase order</td>
</tr>
<tr>
<td>Electrolysis, compression, storage, and fuel cell system installed and operational</td>
<td>9/30/2021</td>
<td>Annual Milestone (Regular)</td>
<td>On track for electrolyzer, compressor, and storage tank system; fuel cell system portion at risk due to purchase order delays, but still possible</td>
</tr>
<tr>
<td>Design and develop the dynamic controller for the ARIES Integrated Energy Systems at Scale (IEWS) hydrogen system and integrate with the Controllable Grid Interface (CGI), providing the key mechanism for integration of hydrogen systems into the ARIES platform and virtual emulation environment. Provide a document describing the control system and accompanying virtual assets developed for utilization in integrated systems research.</td>
<td>9/30/2021</td>
<td>Annual Milestone (Regular)</td>
<td>On track, control system design on-going</td>
</tr>
<tr>
<td>Design and construction of additional concrete pad (funded separately by NREL F&amp;I funds already committed) to support future expansion of hydrogen research at Flatirons Campus.</td>
<td>9/30/2022</td>
<td>Annual Milestone (Regular)</td>
<td>On track, design contracting process</td>
</tr>
</tbody>
</table>
Accomplishments and Progress

• This is a newly awarded project that has been in progress less than one year

• Focus of work so far has been design and procurement of sub-systems (milestone), now waiting long-lead time equipment deliveries for installation and commissioning

• Selection of design drawings (accomplishments) shown in the previous “Approach” slides, with more detailed design work not shown
Accomplishments and Progress: Summary

• Design:
  – Complete: Hydrogen system P&ID, site layout (including setback distances and fire code requirements), high-level electrical system, process hazard analysis (PHA) safety evaluation of storage system, compressor, and gas management panel
  – Partially complete: Integrated cooling system, water storage and supply system, gas management panel design (3D renderings), detailed electrical design drawings, control system and controlled grid interface integration, and electrolyzer system PHA

• Procurement:
  – Ordered: PEM electrolyzer (1.25 MW producing ~22 kg/hr)
  – Ordered: Compressor (electrolyzer output to 3,000 psig storage)
  – Ordered: Type I ground storage vessels (600 kg at 3,000 psig)
  – Ordered: Gas management panel valves (High-flow 1”)
  – Finishing contract: PEM fuel cell generator (1 MW net output)
  – In process: Dry cooling heat exchanger and deionized water storage and delivery system
Accomplishments and Progress: Response to Previous Year Reviewers’ Comments

• This project hadn’t started before last year’s AMR and thus has not been previously reviewed.
Collaboration and Coordination

- This work is directly funded by HFTO with additional funding by NREL
- For the electrolyzer we are working closely with the industry supplier, Nel Hydrogen, on a near first-of-its-kind unit for them
  - The performance data will be valuable for long term product development and will support future joint research opportunities, particularly in the area of closely coupled renewable hydrogen production
- For the fuel cell generator we are developing a CRADA with an industry partner to build and test their first-of-its-kind unit
  - The CRADA will support performance evaluation in a variety of operating applications including renewable grid stabilization and energy storage
  - The findings will support future commercial deployments
Remaining Challenges and Barriers

• Getting the contracts in place for the fuel cell generator is the main challenge for meeting the end of fiscal year operational milestone
  – This is being addressed by working closely with the technical and contracting parties on all sides
• The aggressive schedule for preparation of a new hydrogen capable site, installation of the delivered equipment, and commissioning by the end of the fiscal year will be challenging from a logistics point of view
  – A strong team of experienced researchers and technicians will focus on this large effort
Proposed Future Work

- Finish design, safety evaluation, and procurement of remaining sub-systems in FY21
  - Integrated cooling system, deionized water storage and supply system, gas management panel, electrical system, control system and controlled grid interface integration, and fuel cell generator
- Install and begin commissioning entire hydrogen system in FY21
  - Major FY21 annual milestone
- Wrap up system commissioning, and construct permanent site in FY22
  - Major FY22 annual milestone
- Transition hydrogen capabilities into multiple research projects within the ARIES platform
Summary

- **By the end of FY21 NREL plans to have an operational 1.25 MW PEM electrolyzer, compressor, 600 kg ground storage, and 1 MW PEM AC/DC output fuel cell generator system at the Flatirons campus**

- By the end of FY22 NREL plans to have a permanent hydrogen site installed at the Flatirons campus with infrastructure in place and ready for future research expansion

- 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
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 expected to create a capability that will lead to opportunities for future collaborative work with industry, academia, and other national laboratories
Progress toward DOE Targets or Milestones

• The project is mostly focused on building infrastructure capability to enable future research

• The equipment will help support the “3.6 Technology Validation” sub-task “3.9 Validate large-scale system for grid energy storage that integrates renewable hydrogen generation and storage with fuel cell power generation...”
  — This infrastructure should be able to address this target through direct micro-grid coupling with physical wind and solar assets at the Flatirons campus at the MW-scale through both electrolysis and fuel cell operation with 600 kg of hydrogen energy storage
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
- Controlling **large numbers** (millions to tens of millions) of interconnected devices
- Integrating **multiple diverse technologies** that have not previously worked together
Hydrogen System R&D Opportunities

• Electrolyzer and fuel cell system durability and performance models and scale-up emulation
• Renewable generation hydrogen production control optimization and bulk storage management (actual solar, wind, and DC fast charging assets; simulated hydrokinetic and offshore wind)
• Hydrogen blending with natural gas
• Molecule building (ammonia, renewable NG, etc.)
• Dynamic controllable loads for grid stabilization (electrolyzer and fuel cell – including standardization efforts for grid signal interface)
• HD fueling infrastructure and high-throughput compression
• Multi-modal commercial facility energy and mobility experiments
Energy Calculations

• Electrolyzer:
  – 22.1 kg/hr production @ 1.33 MW total power consumption
  – @ 33.3 kWh/kg this is 55% overall system efficiency
  – @ 600 kg of storage, this is 27 hours of buffer

• Fuel cell:
  – 60 kg/hr consumption @ 1.0 MW net power production
  – @ 33.3 kWh/kg this is 50% overall system efficiency
  – @ 600 kg of storage, this is 10 hours of buffer

• Compressor:
  – 45 kW @ 22.1 kg/hr (435 psig to 3,000 psig)

• Net system AC/AC round trip energy storage efficiency: ~27%