Department Of Energy (DOE) Hydrogen Program
2024 Annual Merit Review and Peer Evaluation Meeting

AMR Project ID **TA044**

DOE AWARD DE-EE009252:

SYSTEM DEMONSTRATION FOR SUPPLYING CLEAN, RELIABLE AND AFFORDABLE ELECTRIC POWER TO DATA CENTERS USING HYDROGEN FUEL

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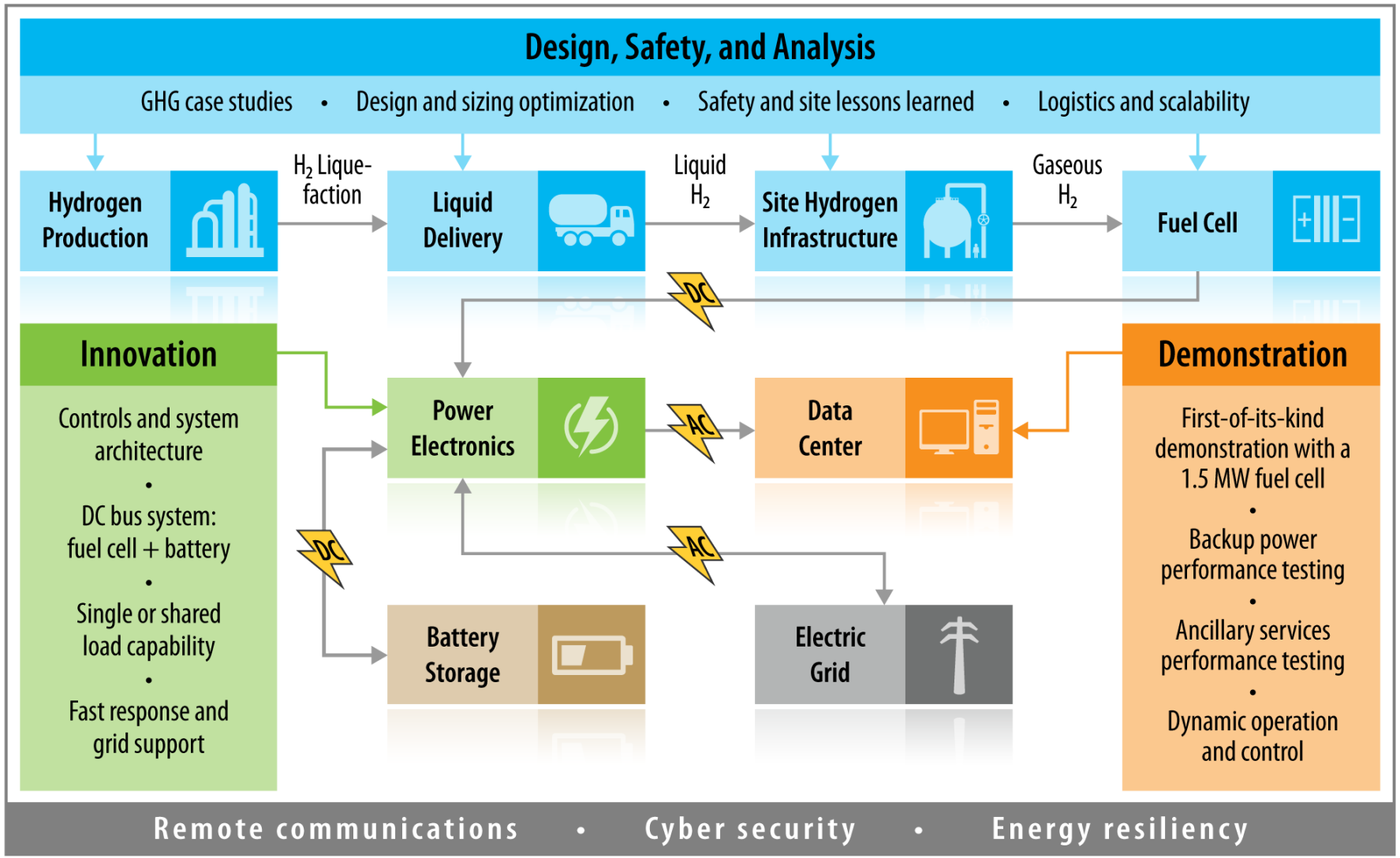
Project goal

Demonstrate 1.5 MW hydrogen fueled data center backup power (Proton Exchange Membrane Fuel Cell, PEMFC)



Overview

Timeline and budget

Effective Date of Award:	10/01/2020
Acknowledged Award in FedConnect:	07/28/2021
Project End Date:	09/30/2024
Total Project Forecast:	$11.9 M
DOE cost share:	$5.6 M
Total cost share:	$6.3 M
Total DOE funds spent*:	$4.7 M
Total cost share funds spent*:	$5.3 M

*As of January 2024

Barriers

- Scaling of PEMFC (multi-MW scale) for data centers
- Hydrogen sourcing, logistics and environmental impacts
- Performance and control for fast response and grid support

Participants (Funded)
Caterpillar – Prime Contractor (Lead)
National Renewable Energy Laboratory

Participant (Non-Funded)
Microsoft (Demo Site)

Vendors (Funded)
McKinstry, Ballard and Linde

Potential Impact and Relevance

Objective

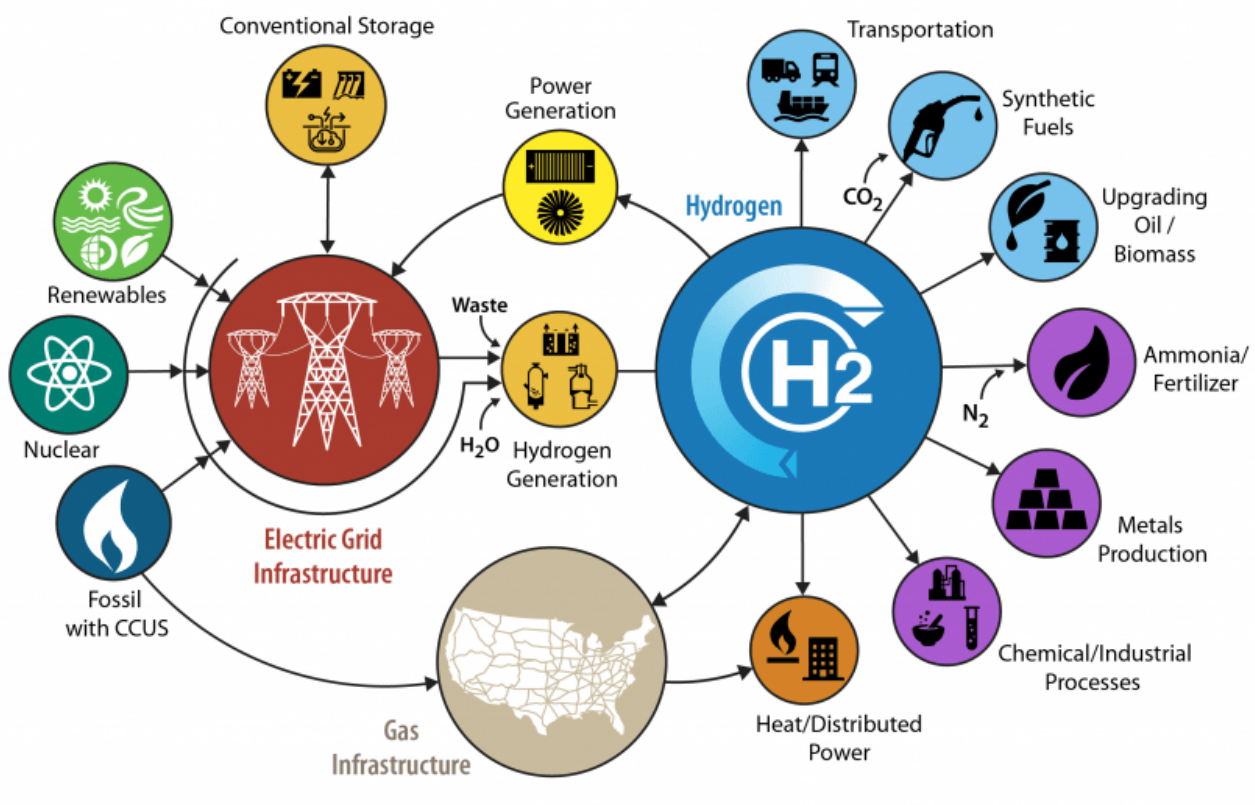
Demonstrate a *first of a kind* megawatt scale stationary fuel cell (FC) to generate electric power and meet the stand-by requirements of a modern data center

Performance targets:

- Full load rating at 1.5 MW (electrical out)
- 48 hours of liquid hydrogen storage

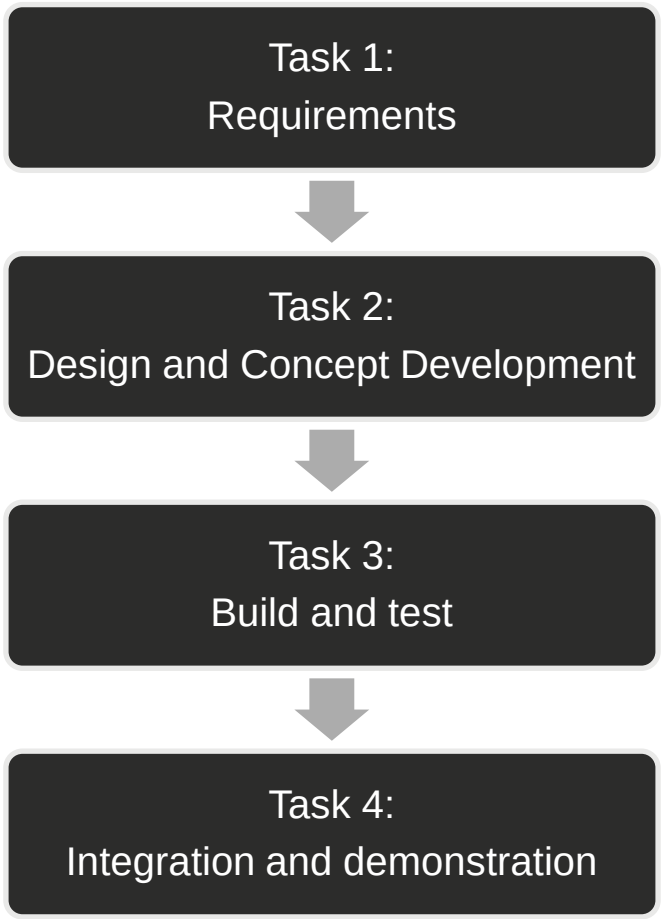
Relevant DOE goals

- System development and integration
- Commercial readiness assessment
- Reduce Greenhouse Gas (GHG) emissions
- Technology validation



Technology Acceleration: Integrated Clean Energy Systems
Document requirements, progress and identify gaps (scaling of PEMFC, integration, technology, and sourcing)

Approach: Project Phases and Selected Milestones/Subtasks



- ✓ Requirements document
- ✓ Fuel cell market opportunity

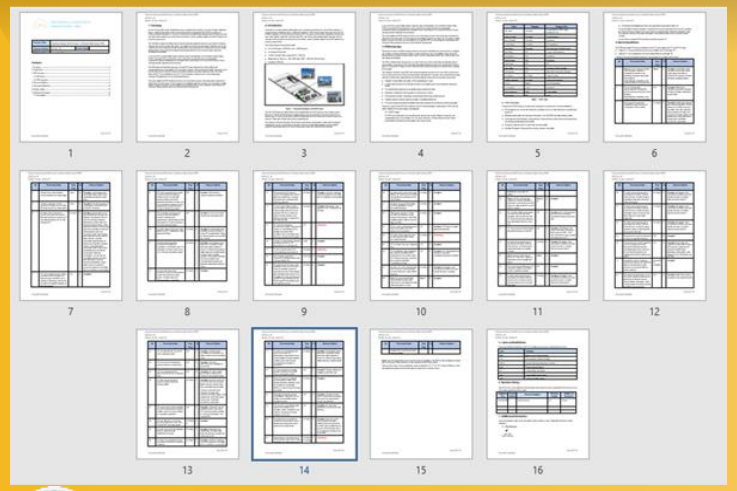
- ✓ System component sizing
- ✓ Component performance simulation

- ✓ Controls development
- ✓ Site safety acceptance
- ✓ Fuel cell factory acceptance tests

- ✓ Construction complete
- ✓ Commission and debug
- ✓ Performance testing

Approach: Safety Planning and Culture

Participation from all including Hydrogen Safety Panel input



- Hydrogen Safety Plan submitted and revised
- Process Hazard Analysis (PHA)
- Pre-Startup Safety Review (PSSR)
- Zero incidents
- Training: in person and online
- Safe Job Procedures created
- Lessons learned documented
- Dedicated onsite safety person

Accomplishments and Progress

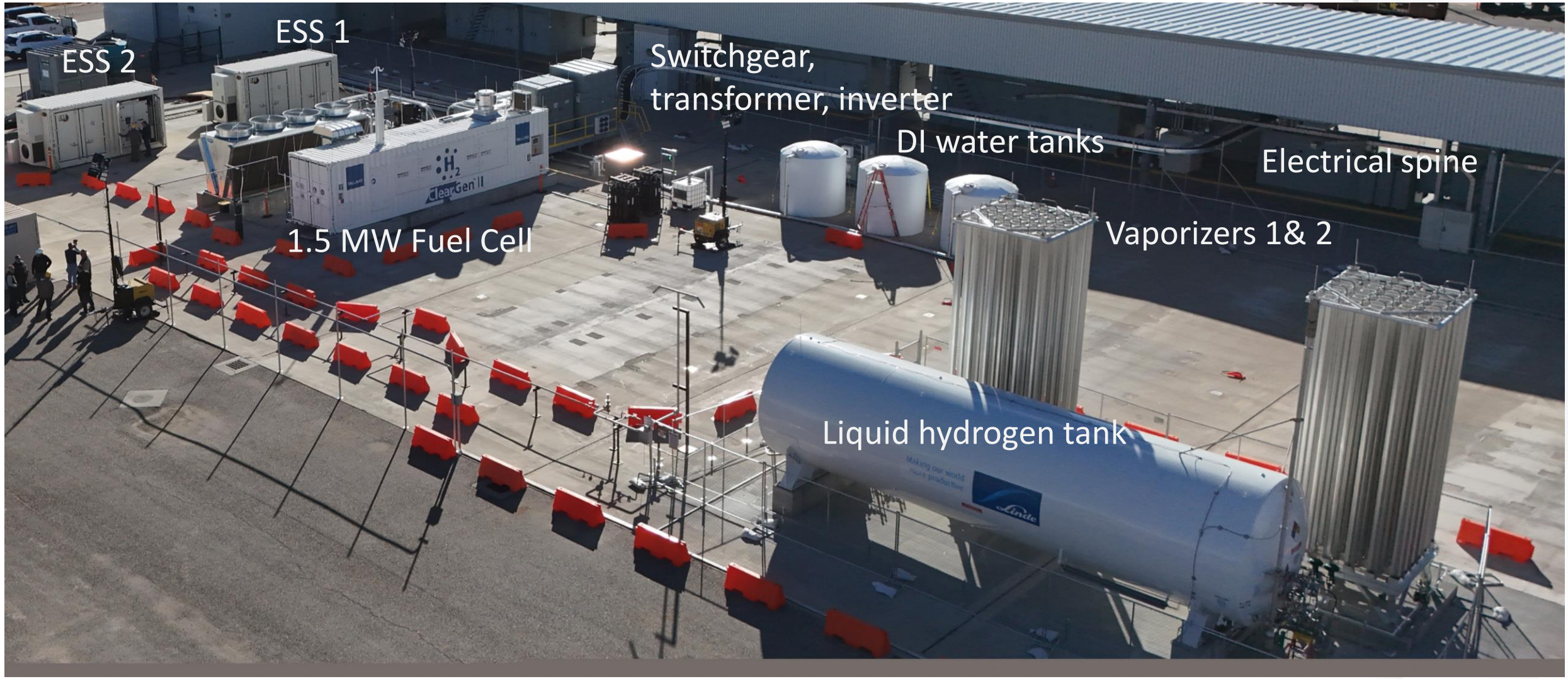
All subtasks completed

Subtasks	Description	Month from start
1.1	Customer requirements	3
1.2	Fuel cell market opportunity, value proposition and regulations	4
2.1	Component performance simulation and testing	9
2.2	Determination of controls strategies	9
2.3	System component sizing - fuel cell & balance of plant, H2 storage, power supply equipment	9
2.4	Cyber security remote access capability assessment	36
2.5	Site layout design and permitting	12
3.1	Detailed design & layout of the system and related infrastructure	15
3.2	Bill of material and parts procurement	18
3.3	Build and internal bench tests	23
3.4	Controls development	23
3.5	Sub-system acceptance testing	27
3.6	Site preparation	30
3.7	Greenhouse Gas Emissions Analysis	21
4.1	System installation, commissioning, debug	33
4.2	Demo and data collection	35
4.3	Final report	36
4.4	Decomission of the system	36

Completed In progress Not started

Accomplishments and Progress

Installed, commissioned and debugged



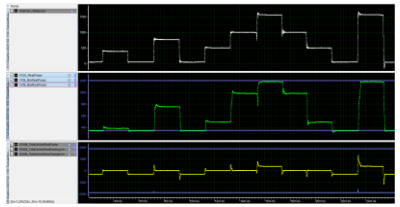
Accomplishments and Progress

Systems integration and controls

MMC-S Dispatches ESS and Fuel Cell to maintain

- Fuel Cell Min/Max
- Utility Min/Max
- ESS Target SOC

MMC-S Offsets ESS Voltage and Frequency to assist in Grid Syncing



Fuel Cell and Inverter

PGS1260 (x2)

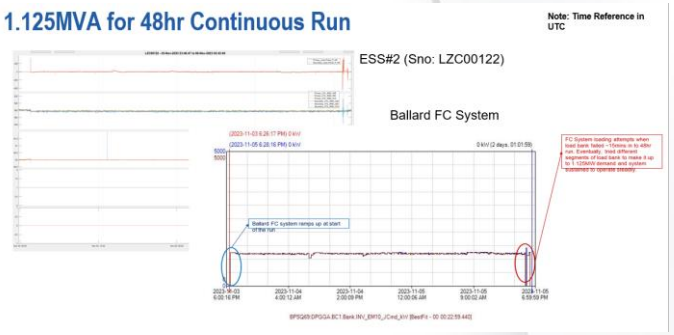
Microgrid Master Controller (MMC-S)

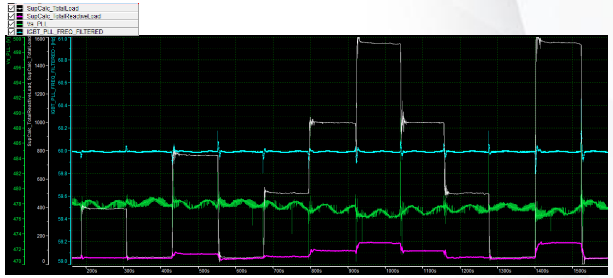
Protective Relay

Accomplishments and Progress

- Software checks complete for various modes of operation
- Transient load steps conform to ISO 8528-5 G3 spec requirements
- Demonstrated capability to sustain a backup power event
    - 48hr continuous run @75%load

FMEA ID	Test Description	Necessity	Test Details
191323	Software Verification Check	Microgrid - Modes of Operation	Basic software communication checks. Load acceptance tests detailed in Sequence of Operations.
193155	1.125MVA- 48-hour Demonstration	Data Center Back Up Operation Cycle	Simulate Backup Power event for datacenter application (48hr Continuous Run)
193970	Transient Performance Test	Transient capability	ISO 8528-5 Reciprocation IC Engines Load spec. for genset operations 25% Block load steps, 100% Unloading, Microsoft load script
193952	Durability Tests	Durability Assessment	Operation for durability/reliability assessment - run 148 hrs. in total at minimum per agreed budget/timeline constraints

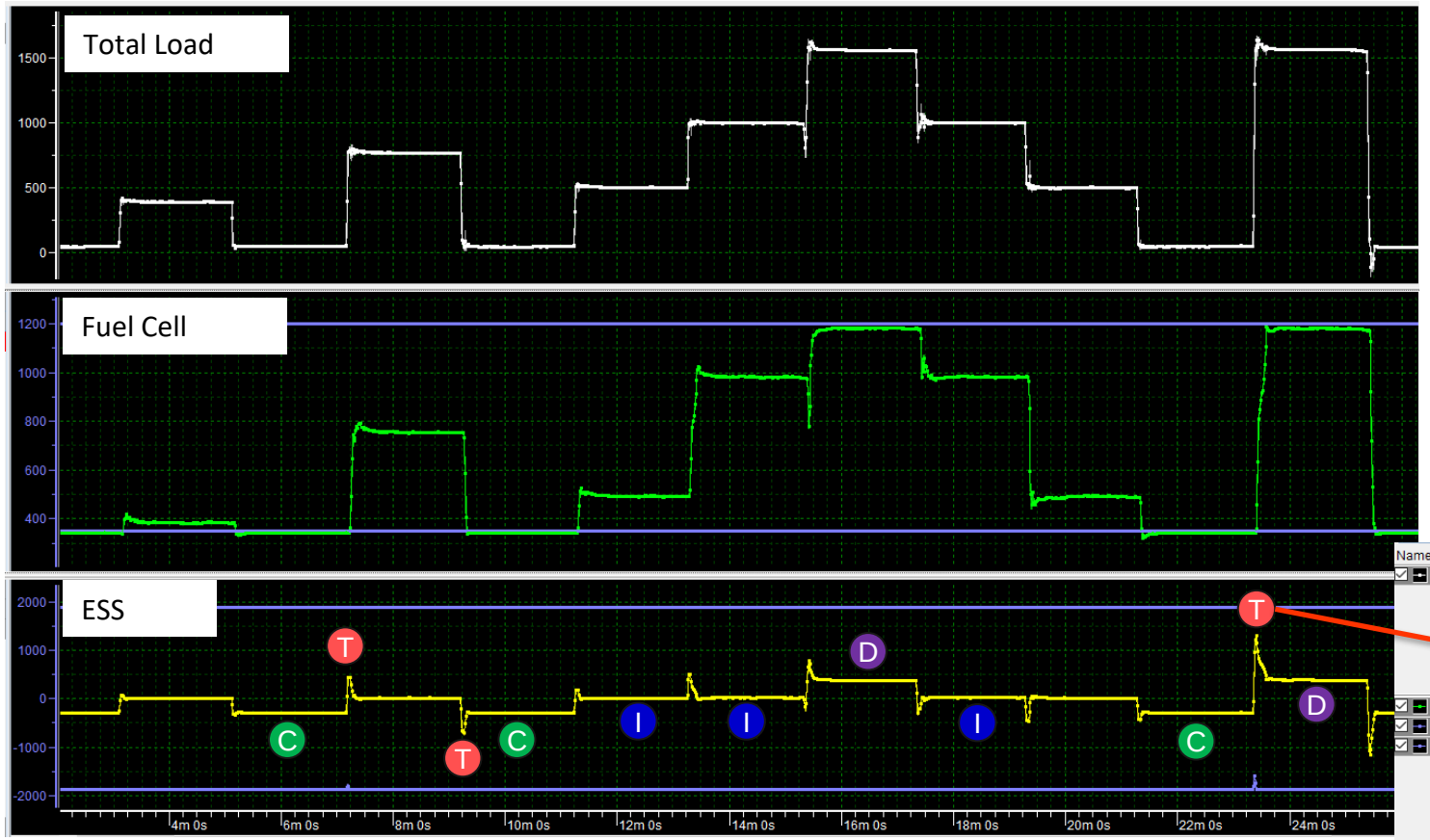




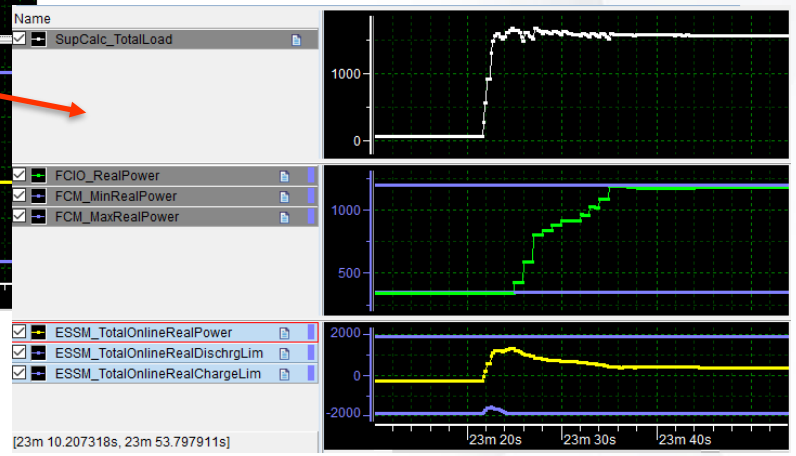
Step	Load Value	Load Value	Total Load	Load Step				Steady State Variance	
#	kW	kVar	%	Freq. Var.	Freq. Rec. Time	Volt Var.	Volt Rec. Time	Frequency	Voltage
1	426	43	28.55%	-0.11667%	2.7	-0.83333%	0.4	-0.0133%	-0.41667%
2	54	39	4.933%	0.191079%	2.2	0.630252%	0.5	-0.02667%	-0.41667%
3	790	84	52.933%	-0.27316%	2.9	-0.83507%	0.4	-0.02667%	-0.625%
4	56	39	4.533%	0.509395%	2.8	1.594211%	0.59	-0.0133%	-0.41667%
5	514	64	34.533%	-0.62113%	3	-2.07039%	0.6	-0.02667%	-0.41667%
6	1008	105	67.533%	0.065212%	2.7	-0.42283%	0.5	-0.0133%	-0.41667%
7	1578	151	105.667%	0.116071%	4	-0.21231%	0.7	-0.0133%	-0.625%
8	1001	92	67%	0.313793%	5.8	4.042553%	2.1	-0.0133%	-0.625%
9	497	57	33.333%	-0.05324%	3.1	-2.04409%	0.6	-0.0133%	-0.41667%
10	44	37	3.8%	0.16312%	3	1.25261%	0.8	-0.0133%	-0.625%
11	1562	152	104.6%	-0.33833%	2.9	-1.875%	1.61	-0.02667%	-0.625%
12	41	43	3.933%	0.76833%	3.5	-1.875%	1.2	-0.0133%	-0.41667%

Accomplishments and Progress

Dispatch strategy

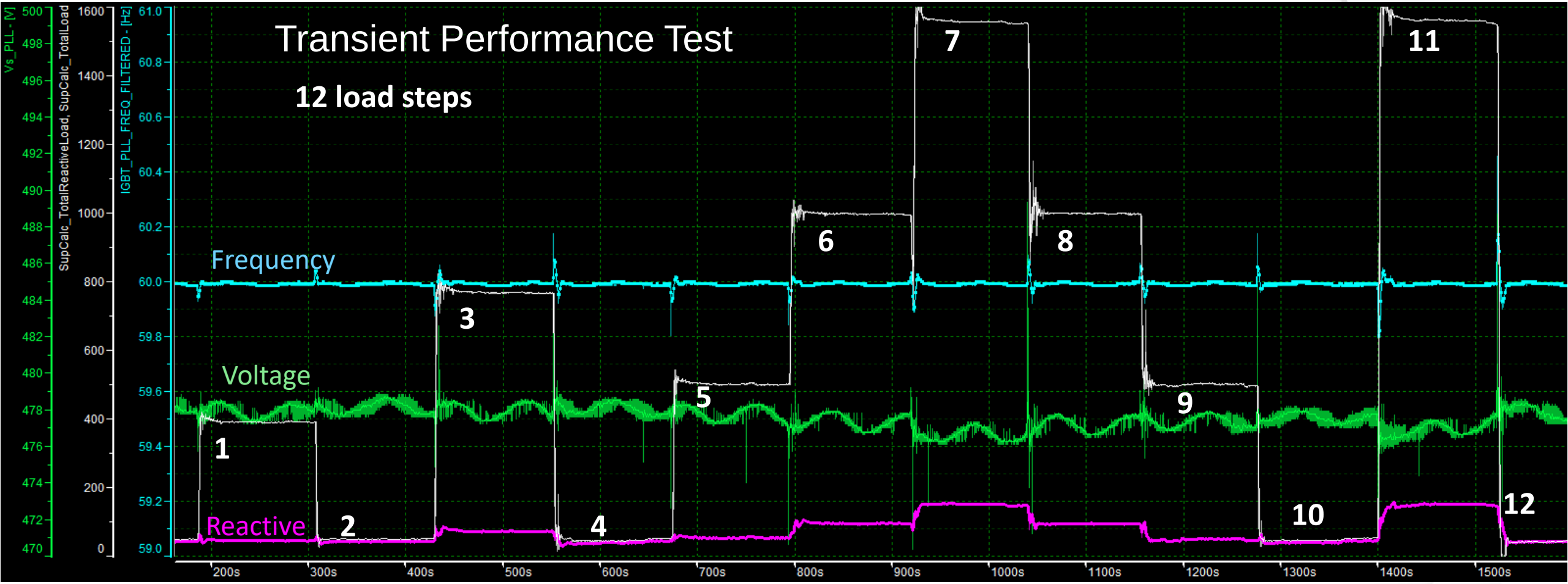


- **Transient Assist**: ESS takes initial transient load. Load then transfers to FCPS
- **Steady State Charge**: ESS charges steady state to keep FCPS at desired min power.
- **Steady State Discharge**: ESS discharges steady state to keep FCPS at desired max power.
- **ESS Idle**: ESS idles when site load is between FCPS min and FCPS max



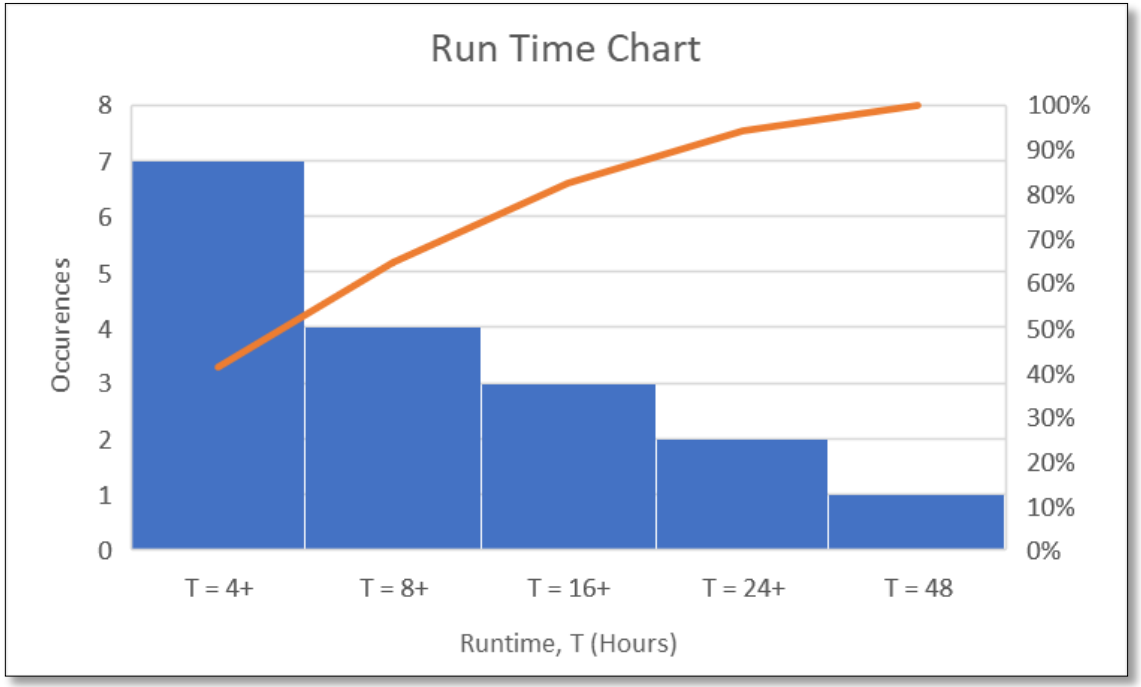
Accomplishments and Progress

Each load step met ISO8528 G3 standards

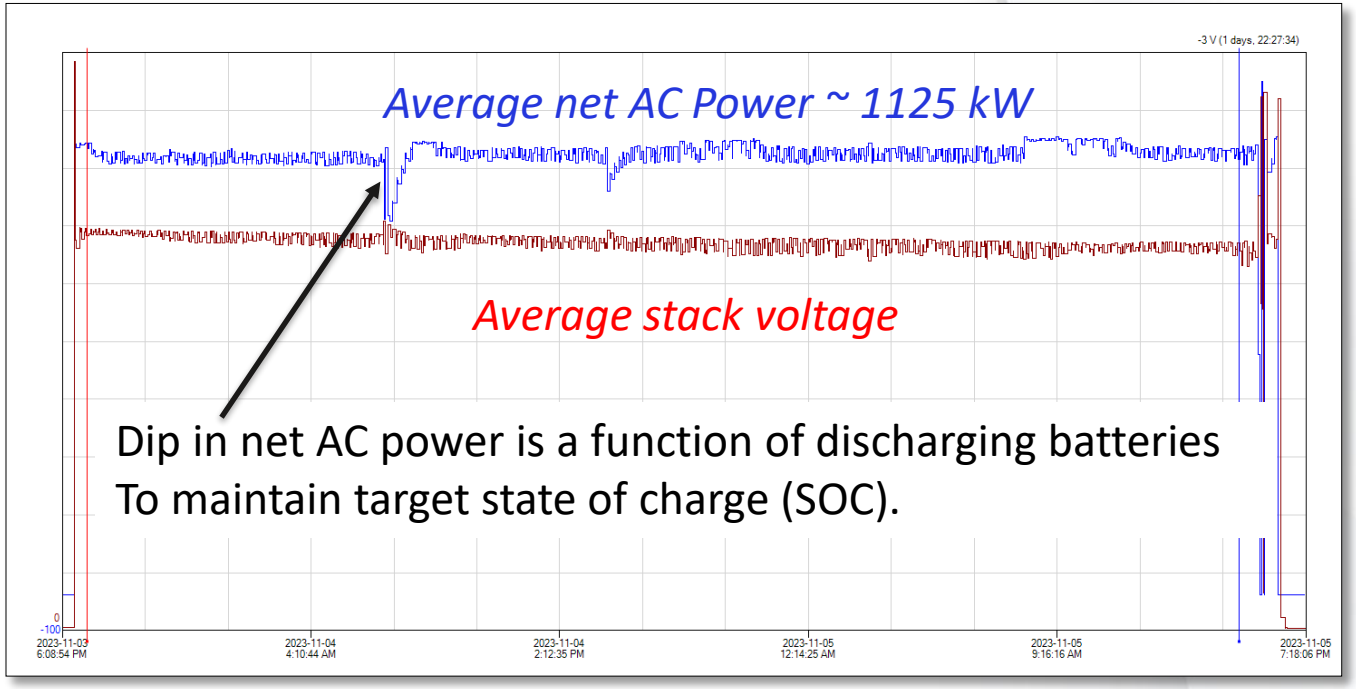


Accomplishments and Progress

83 operational cycles with power export from fuel cell for 153.3 run hours



Cumulative run data during demonstration. (Subtask 4.2).



48 hour run chart: Nov 3 – 5, 2023.

Responses to Previous Year Reviewer's Comments

Comments	Response
"Unfortunately, this project will not accomplish much as it is currently designed. …, the electrical power will be sent to an onsite load bank. It is unclear what Microsoft really gains from this at all."	This project is valuable to Microsoft and the industry. This is a first-time demonstration with liquid hydrogen and a MW-scale fuel cell at a data center. The same steps to proof a diesel genset was applied to this technology.
"This project seems to be focused entirely on technical aspects, without much, if any, economic analysis, so there is a bit of a weakness…"	The technoeconomic analysis was presented at the 2022 AMR comparing different backup power sources. Available in backup slides.
"There is very little time allotted for the actual demonstration of the PEMFC system (two months), which is a major lost learning opportunity for the DOE Hydrogen Program."	The amount of running time for this demo is equivalent to a diesel genset at a data center anywhere between 1 and 15 years, depending on outages and monthly checks.
It is not clear why a "supply of deionized (DI) water for fuel cell" is needed.	Most of the water is recovered, and DI water is supplied to make up for the dry conditions that may be present
"The system that is (sort of) being demonstrated here is capable of doing nothing more than replacing diesel gensets."	The solution presented here is a 1.5 MW fuel cell + battery microgrid capable of many modes of operation including backup power.
The project team should consider extending the demonstration period and connecting the system to the data center.	The team worked on finding post demo sites and made inquiries including potential data center sites.

Collaboration and coordination

Participant	Role
Caterpillar Inc.	Lead responsible for overall project, requirements, system integration, controls development, installation and demonstration.
Microsoft	Host of demonstration site, data center requirements
Ballard	Supplier for 1.5 MW fuel cell. Support for installation of fuel cell at site, commissioning and tests
National Renewable Energy Laboratory (NREL)	Hydrogen safety, Technoeconomic Analyses, GHG impacts
Linde	Liquid hydrogen equipment and supply for demonstration
McKinstry	Design layout, site preparation and installation, decommissioning

Remaining challenges and barriers

- Project completed

Proposed Future Work

- Project end date: 30th September 2024
- Disposition and deployment* 1.5 MW fuel cell at a suitable site

- *Any proposed future work is subject to change based on funding levels.

Summary

- Safe and successful demonstration of a MW scale fuel cell at a live data center with liquid hydrogen
- 1.5 MW fuel cell + battery microgrid provides applicability beyond standby
- Increased resiliency, lower carbon intensity, integrated system

Over 83 cycles with power export exceeding 4 hours/run at an altitude of 6086 ft (1855 m) in challenging conditions

Operation in freezing conditions

Acknowledgements

- Financial support from DOE EERE Fuel Cell Technology Office (DE-EE0009252)
- Program Manager: Pete Devlin
- Hydrogen Safety Panel
- Caterpillar
- Ballard Power Systems
- National Renewable Energy Laboratory (NREL)
- McKinstry and Linde