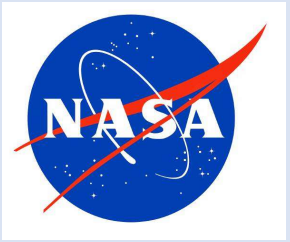
U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

24th FECM/NETL Spring R&D Project Review Meeting
April 25, 2024

Aris Energy Solutions – DE-FE0031978
Dan Connors, COO

Modular Fuel Cells Providing Resiliency to Data Centers and Other Critical Power Users



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Modular Fuel Cells Providing Resiliency to Data Centers and Other Critical Power Users

Acknowledgements

- Dr. Jai-woh Kim, DoE Senior Program Manager
- Ryan Miller, DoE Contracting Officer

Tasks 2 & 3 at the National Energy Technology Laboratory Morgantown, West Virginia

- Dr. Harry Abernathy, National Energy Technology Laboratory (NETL)
  - Serves as technical portfolio lead for solid oxide fuel cell research.
  - Manages budget and technical direction of site support contract.
- Dr. Jian "Jay" Liu, National Energy Technology Laboratory (NETL)
  - Research Physical Scientist
  - Performs the on-site testing of SolydEra BlueGEN SOFC systems installed at NETL.

Four (4) BG-0 1.5kW Fuel Cells – 6 kW Total

Original project budget modified - $800,000 redirected to NETL

Objective: "Stress test" the BlueGen's ability to reliably disconnect from the grid into "Island Mode" and then reliably "Load Follow" critical loads on the Year 1 6kW Quad product

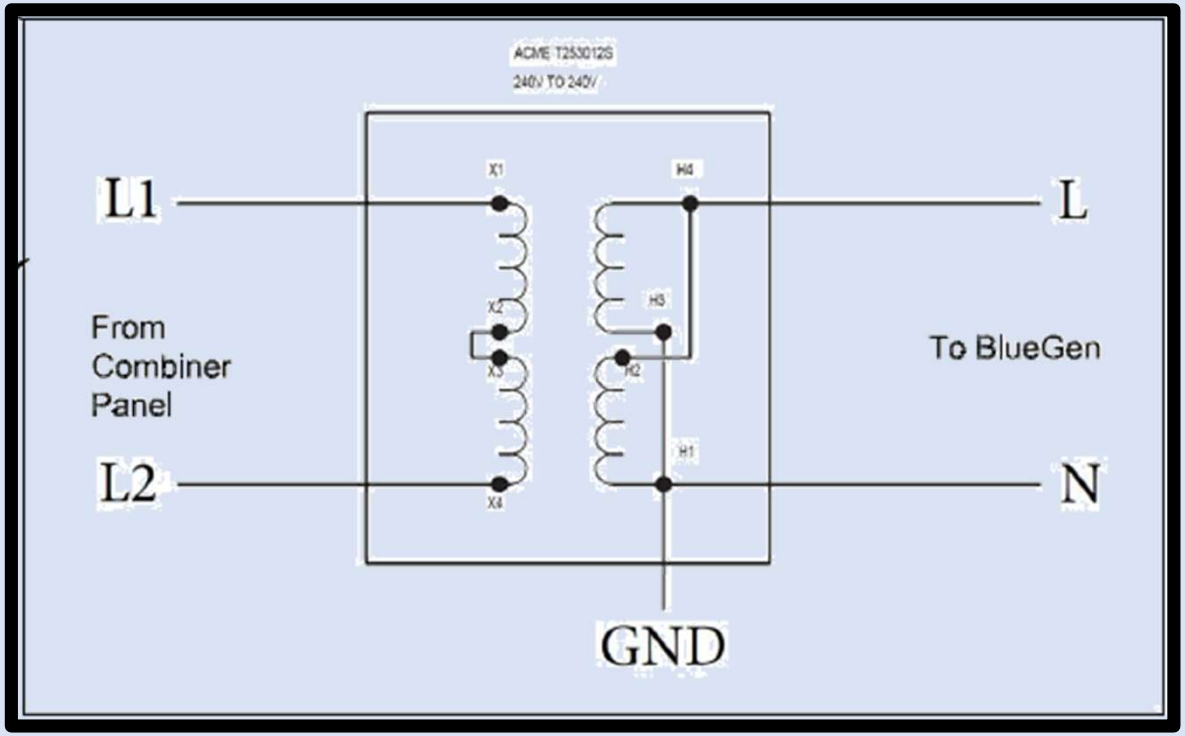
Task 2 Work at National Energy Technology Laboratory

A transformer was used to allow the BlueGen fuel cell European electrical voltage to interact with the Hybrid Inverter and Building Grid

This solution was repeated at all the systems installed by Aris.

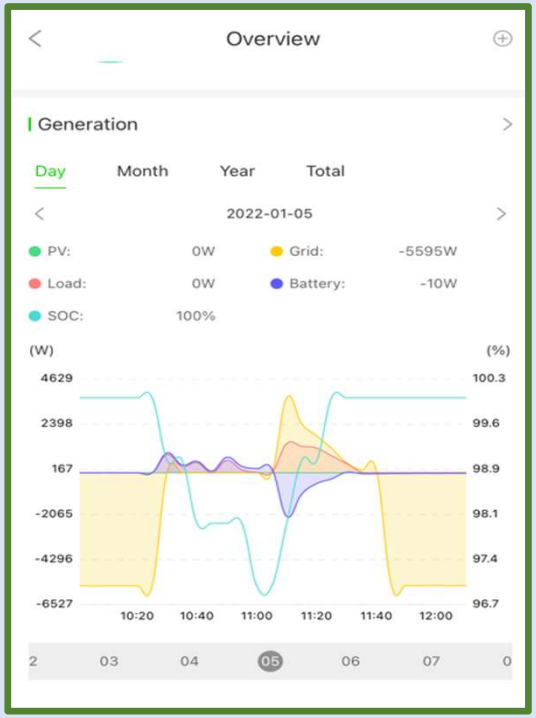
Terminals	European Voltage
L to N	220
L to G	220
N to G	0

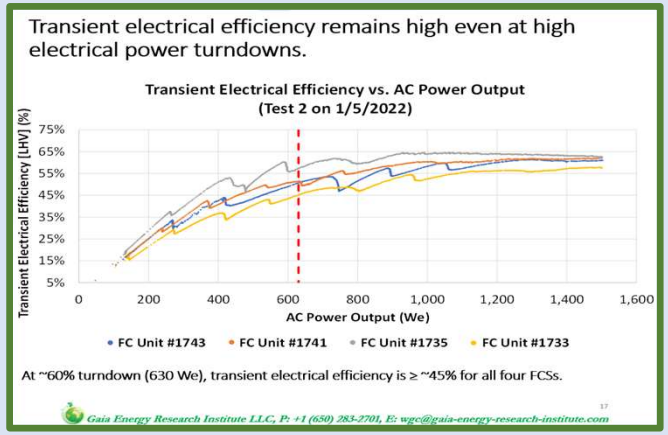
Terminals	US VAC
L1 to N	120
L2 to N	120
L1 to L2	240

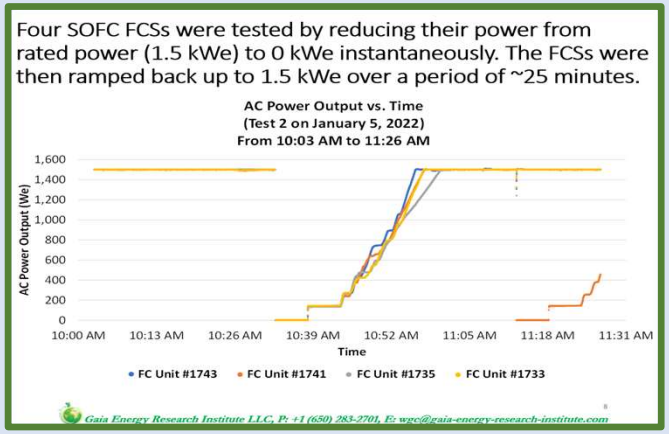


Task 2 Work at National Energy Technology Laboratory

Although the BlueGEN units were able to operate at peak-rated capacity in off-grid operation, they were unable to load follow. The units repeatedly demonstrated the ability to ramp up output after shutting down from a grid disconnect event. The newer model BG-15 2.0 will be able to load follow to a greater degree, should be accompanied by some battery support to dynamically load follow, and will be easier in a DC output fuel cell. This configuration is currently in design, some installation work has begun for the 2nd phase of work at NETL.







Task 2 at National Energy Technology Laboratory

RESULTS/CONCLUSIONS

- 6 Kw “BG-0 Quad” installed and operated at/above rated 60% electrical efficiency at/above-rated fuel cell power.
- Electrical 1-line was developed and implemented to enable the BlueGen fuel cell European electrical output to interact with the US building/grid.
- Used an “AC coupling” approach to successfully toggle from grid-tied to off-grid mode many times and operate at full power, always able to re-connect when grid restored, but was not able to reliably demonstrate “dynamic load following” on the BG-0 BlueGen.
- Although the BlueGEN units were able to operate at peak-rated capacity in off-grid operation, they were unable to load follow. The units repeatedly demonstrated the ability to ramp up output after shutting down from a grid disconnect event. The newer model BG-15 2.0 (DC output) will be able to load follow to a greater degree, will be accompanied by some battery support to dynamically load follow, and should be easier to accomplish in a DC output fuel cell. This configuration is Task 3, the next phase of work at NETL.

Task 3 at the National Energy Technology Laboratory

Task 3 Project Goals:

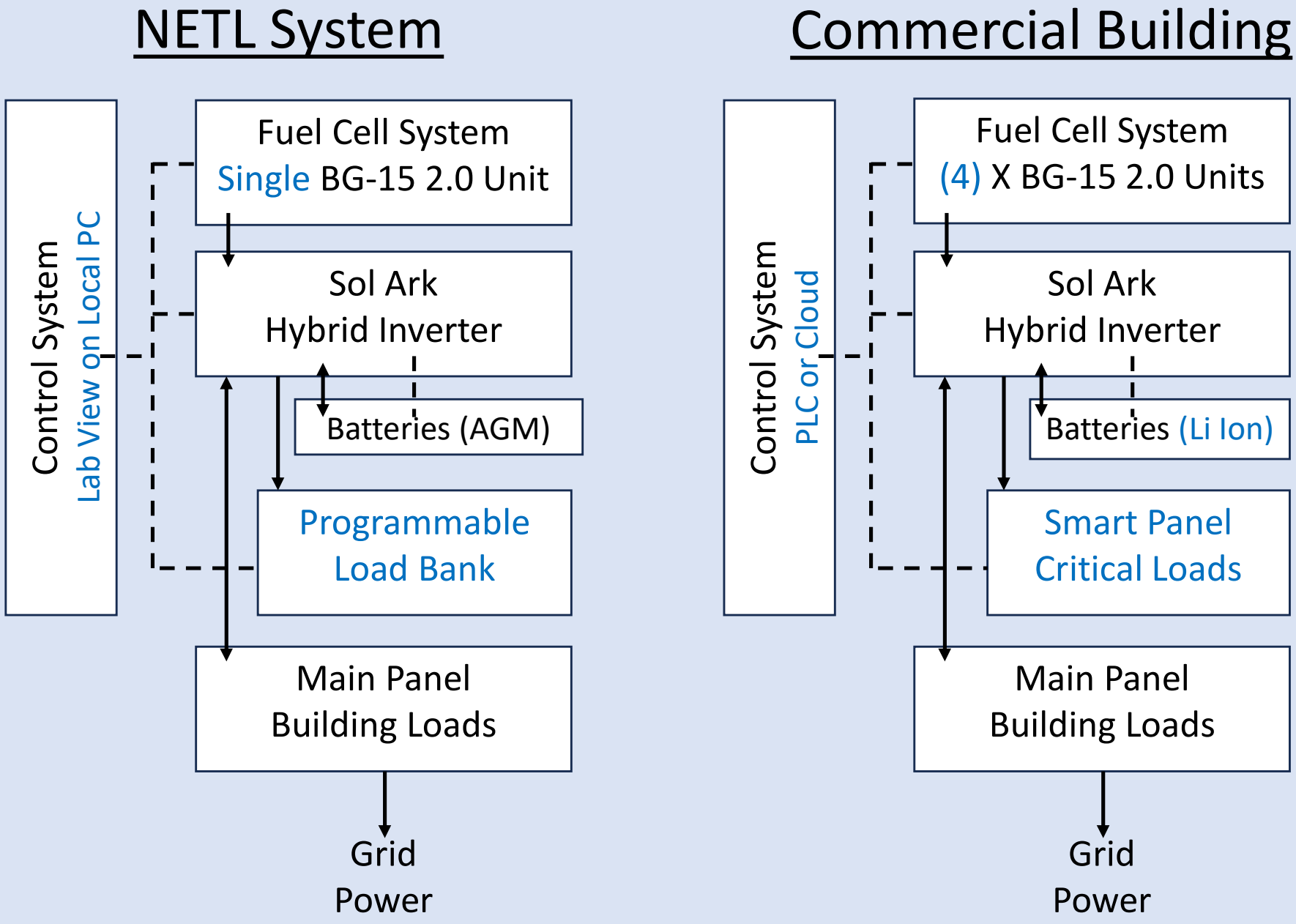
1) Obtain first US prototype operation of the new SolydEra BG-15 2.0 product by operation at NETL to test load-following capability

The current Task 3 (NETL Phase 2) work being done will utilize the newest BlueGen BG-15 2.0 design, with DC output, plus some assistance from batteries, with a new external power output control system, and Phase 1 lessons learned in a dynamic load following demonstration

Completed Activities:

- One of the existing BlueGen BG-0 SOFCs from Task 2 was removed, and the BlueGen BG-15 2.0 was installed in its place.
- This allowed the reuse of the piping and electrical wiring already in place. This included the natural gas line, city water supply, drain lines, exhaust vent, existing Sol-Ark hybrid inverter, batteries, the E-Load, and other panels and wiring as appropriate.

Off-Grid Load Following Controls System



Task 3 at the National Energy Technology Laboratory

Next Steps

- Prepare a new electrical one-line drawing.
- Update the electrical wiring of the existing fuel cell test stand to accommodate the new BlueGen BG-15 2.0 SOFC fuel cell with DC output.
- Develop and implement the new external power output control system
- Test system for load following capability
- Report writing

Task 4 with West Virginia University Research Corporation at the NASA Katherine Johnson IV&V Facility

Fifteen (15) SolydEra BlueGen BG-15 SOFC's – 22.5 kW

Task 3 Project Goals:

- Demonstrate a modular approach to scaling to a higher kW range via a Resilient 22.5kW prototype system of BG-15 units in service to help power the data center loads at the NASA/Fairmont WV facility for 12 months and integrate multiple AC coupling systems
- Obtain valuable installation and operating experience with the first US BG-15 fuel cell units

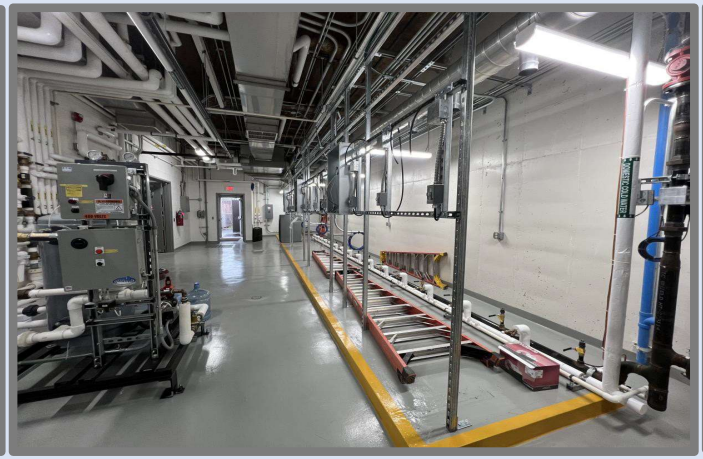
Task 4 at the NASA Katherine Johnson IV&V Facility

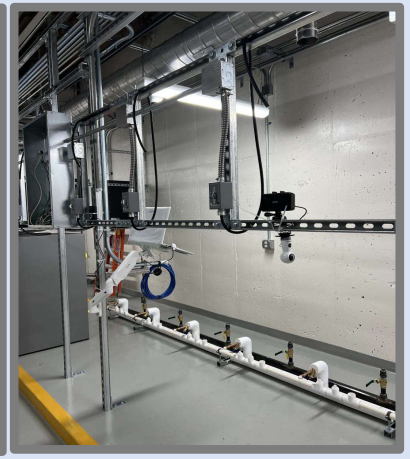
Construction Phase:

NASA Fuel Cell Schedule

Activity	Complete
Fuel Cell Delivery	6/15/2022
CJL Prepare Proposal	1/3/2022
Process CJL Contract	1/21/2022
Issue CJL PO	1/21/2022
CJL Design	4/8/2022
Design Review	4/15/2022
Design Finalize	4/22/2022
Contractor Pricing	5/6/2022
Award Contract for Construction	5/20/2022
Design Review with Contractors	12/5/2022
Contractor Mobilize	5/23/2023
Demo/Construction Phase	7/15/2023
Start up and Commissioning	8/18/2023

- Dr. Marcello Napolitano Ph. D, West Virginia University
  - Administrative, planning, and preliminary engineering work, guidance to the NASA team/site
- Dr. Xueyan Song Ph. D., West Virginia University
  - Administrative, planning, and preliminary engineering work, guidance to the NASA team/site
- Adam James, Project Manager, West Virginia University Planning
  - Design, Construction, and Scheduling

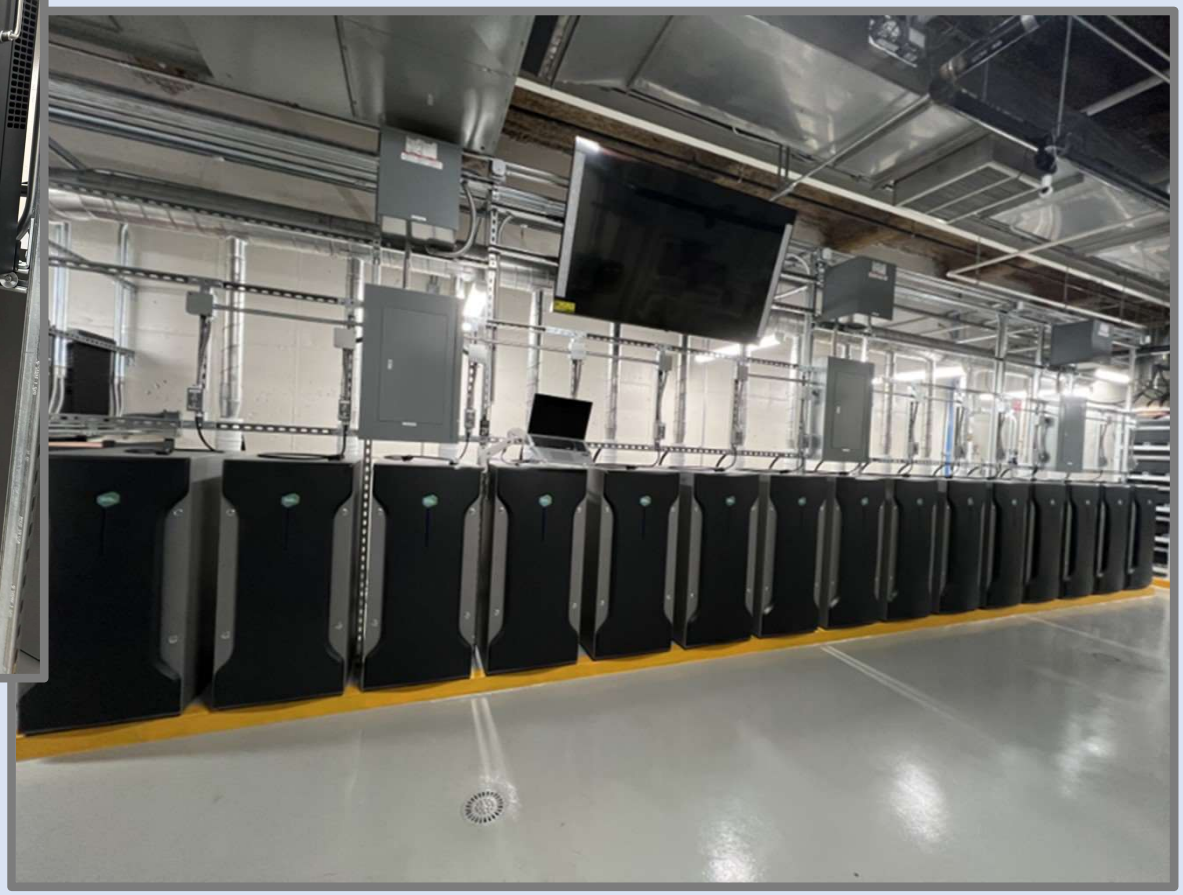




Task 4 at the NASA Katherine Johnson IV&V Facility

Fuel Cell Room with 15 BlueGen BG15 SOFC's

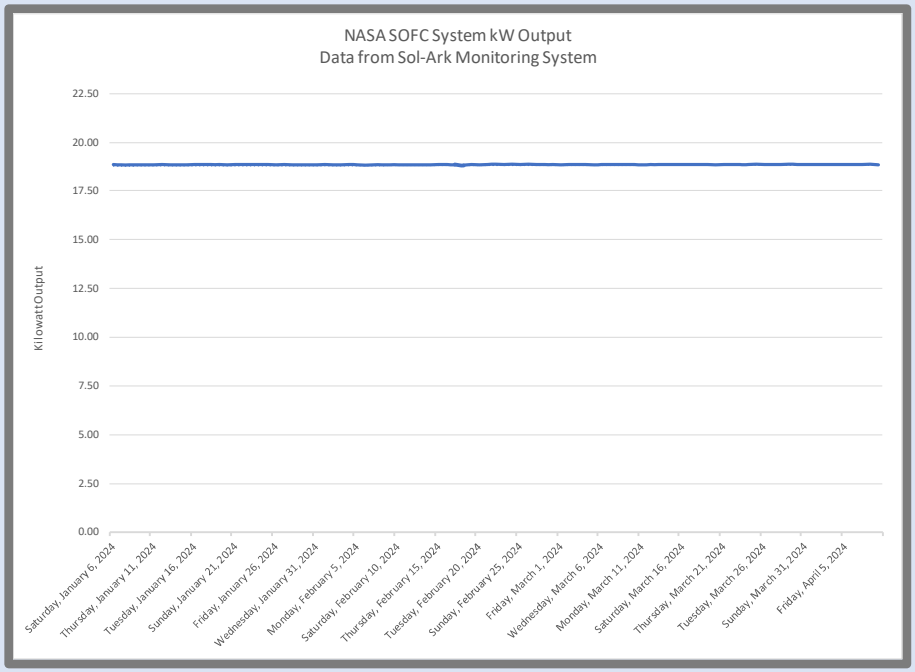
- Using three hybrid inverters electronically synced to obtain three-phase power.



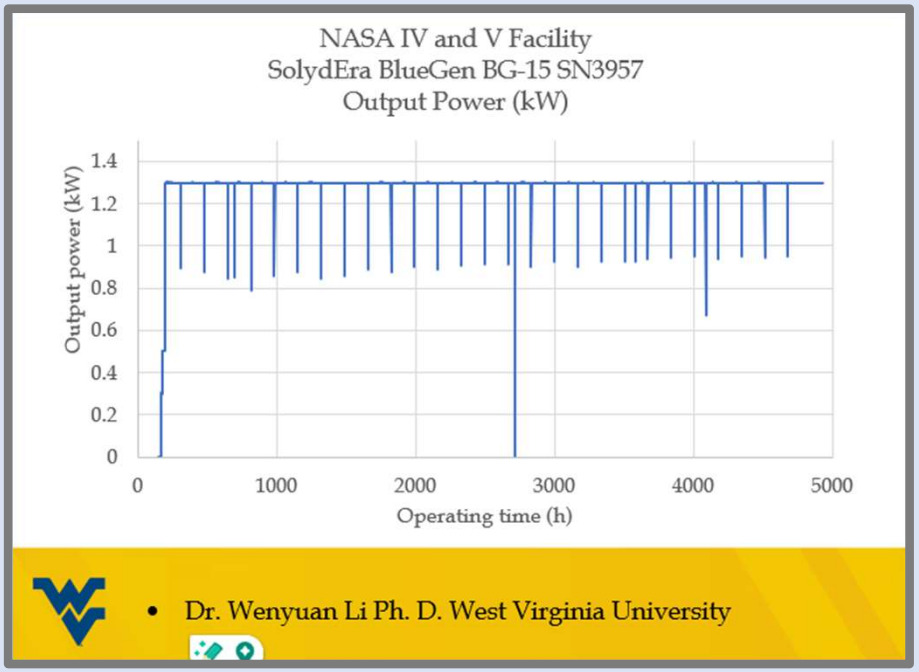
Task 4 at the NASA Katherine Johnson IV&V Facility Operation Phase:

- Dr. Wenyuan Li Ph.D., West Virginia University
  - Administrative, system monitoring and analysis
- Dr. Edward M. Sabolsky Ph.D., West Virginia University
  - Administrative, system monitoring and analysis

Data from Sol-Ark Hybrid Inverter Monitoring System showing 18.8kW Aggregate System Output



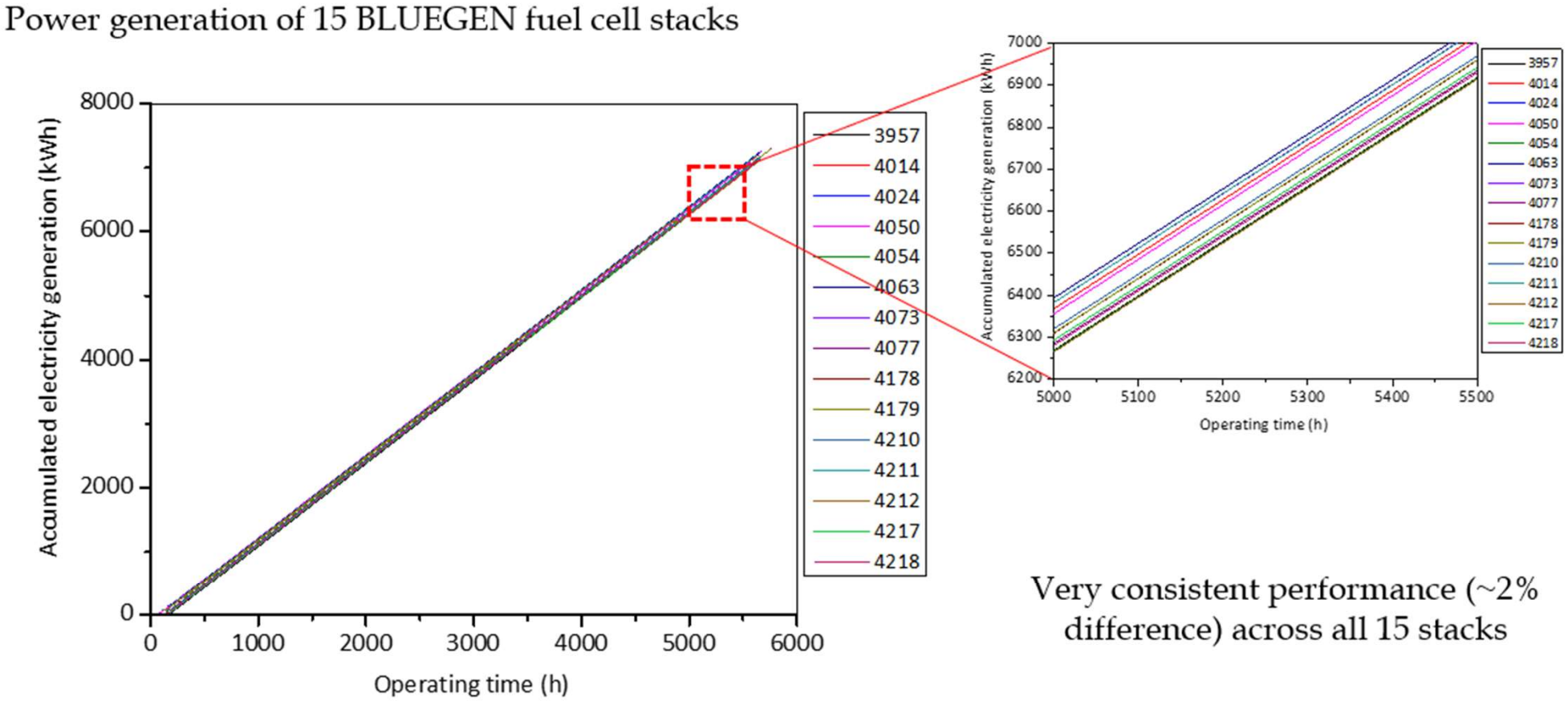
Data from the SolydEra Monitoring System showing the output from one BlueGen SOFC showing 1.3kW Unit Output



Electrical efficiencies observed at 55.5% average over 5,700 hour duration

Task 4 at the NASA Katherine Johnson IV&V Facility

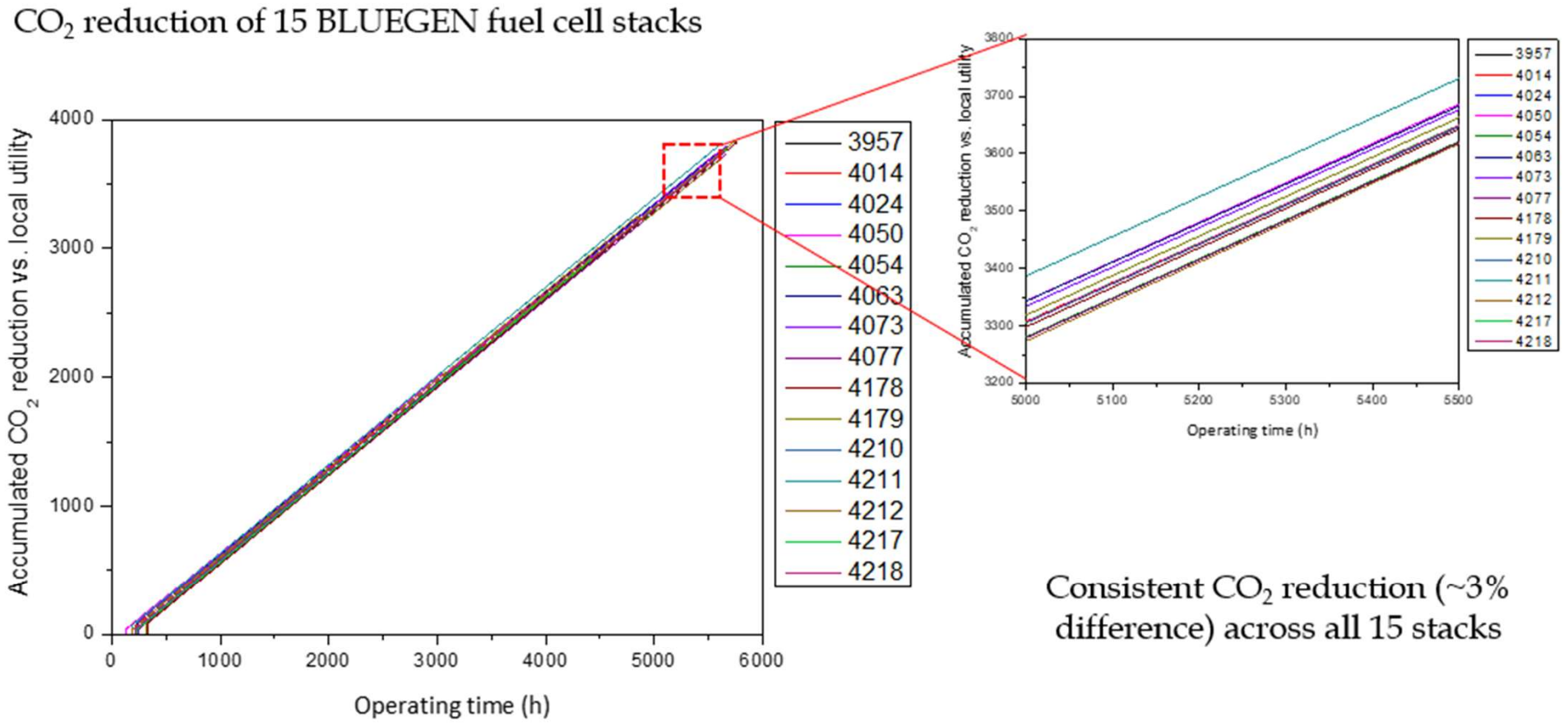
Operation Phase:



Xingbo Liu, Edward Sabolsky, Wenyuan Li

Task 4 at the NASA Katherine Johnson IV&V Facility

Operation Phase:



Xingbo Liu, Edward Sabolsky, Wenyuan Li

Task 4 at the NASA Katherine Johnson IV&V Facility

Operation Phase: Over 100 MW-hrs produced to date

SOFC Fuel Cell Room with 15 BlueGen BG15 SOFC's

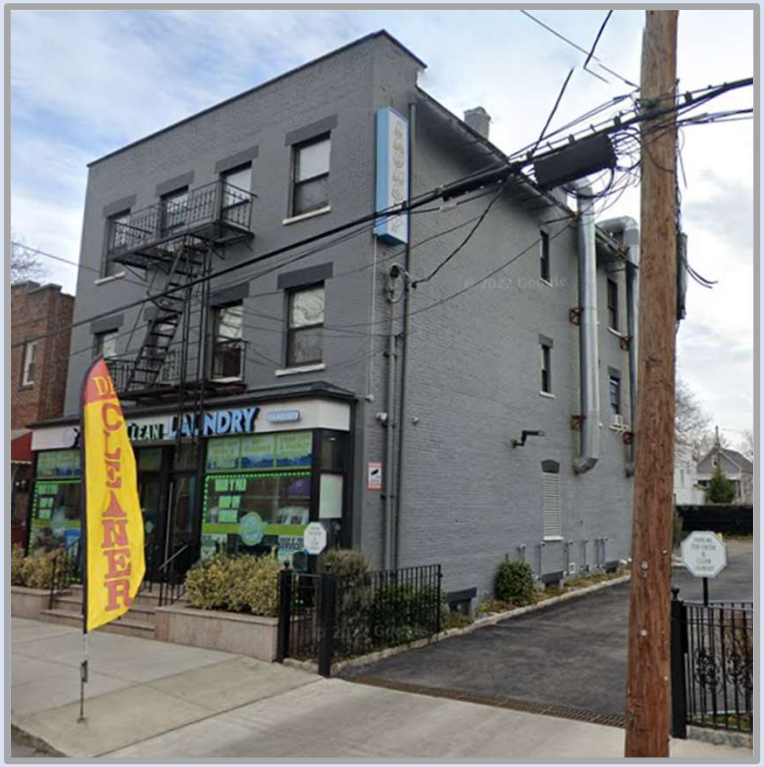
Task 4 at the NASA Katherine Johnson IV&V Facility Operation Phase:

RESULTS/CONCLUSIONS

1. Overcame electrical integration of European equipment into a US 480v facility
2. Successfully completed first of it’s kind electrical and mechanical design
3. Delivered latest model BlueGen BG-15 SOFC fuel cells
4. Installed the entire system
5. Installed Hot Box Module with SOFC stacks in 15 BlueGen's
6. Successfully Started-Up and Commissioned System
7. In operation for 5,700 hours, data collection and analysis ongoing

Task 6 Field Demonstration at Commercial Site

- 6-Family Residential Building with a Commercial Tenant on the first floor
- Building has 12kW existing solar PV on the roof
- Large bank of commercial washing machines and dryers with random startup load cycles
- The fuel cells will increase the energy generated onsite 4x, and provide a surplus kW-hr/year to the Con Ed grid
- ConEd will apply the dollar value of the building's total energy output as a credit to offset any other ConEd customer account



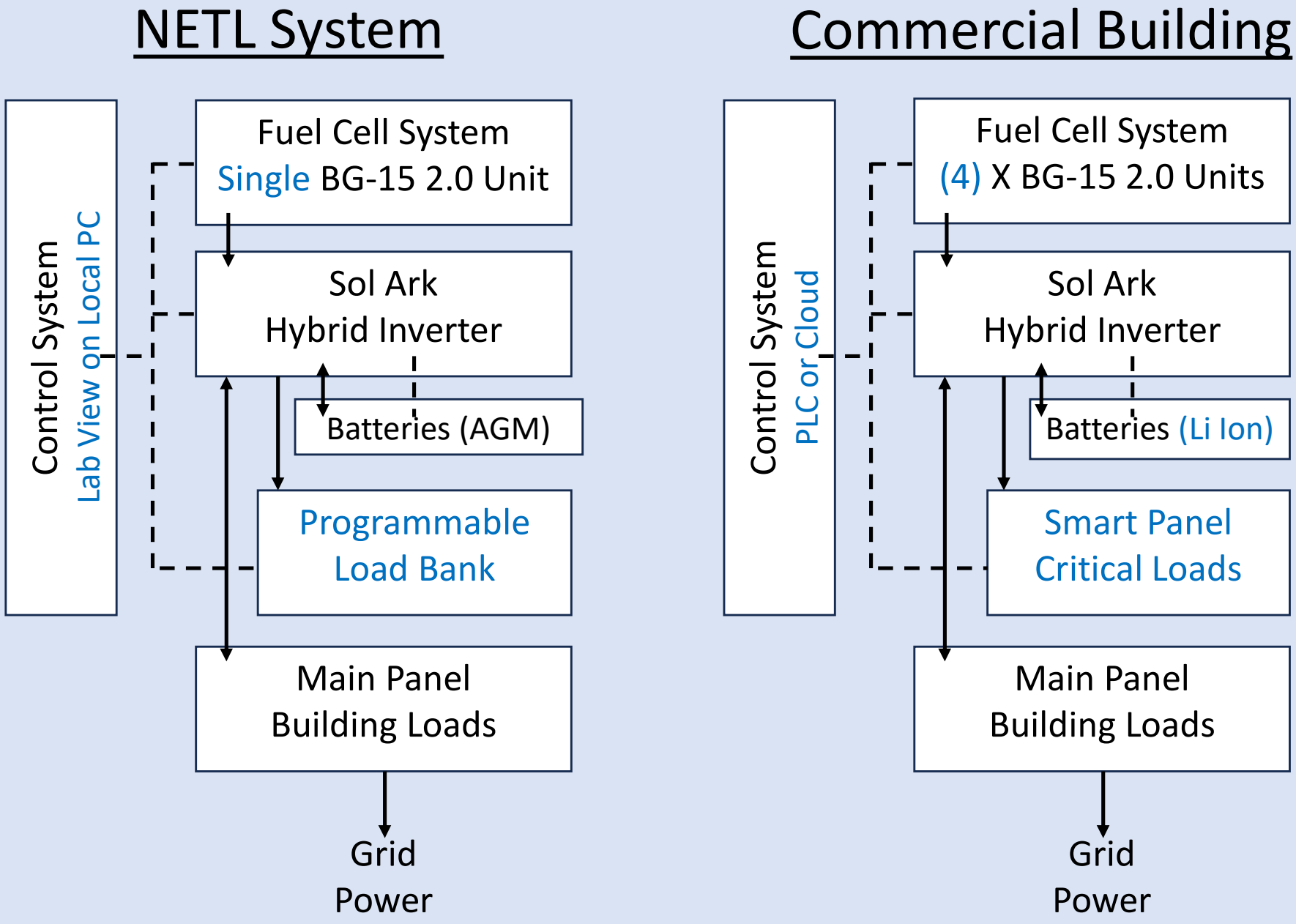
Task 6 Field Demonstration at a Commercial Site

System Description

The system will include Combined Heat and Power (CHP) for total efficiency in the 85-90% range

- Install and operate a 6kW BG-15 2.0 Quad system at a commercial site.
- Incorporate dynamic off-grid load following system design and controls from NETL Phase 2 work
- Obtain operational experience with the new BlueGen BG-15 2.0 product

Off-Grid Load Following Controls System



Task 6 Field Demonstration at Commercial Site

RESULTS/CONCLUSIONS

- A new electrical one-line drawing was prepared.
- Interconnect Permission from Consolidated Edison was authorized.
- The four SolydEra BlueGen BG-15 2.0 SOFCs were delivered to the site and set in place.
- The mechanical contractor completed all plumbing work, including the natural gas line, city water supply, drains, and CHP system, after obtaining a building permit from the City of Mount Vernon.
- The electrical contractor obtained the permit, and the electrical work is approximately 50% complete.
- The 12K hybrid inverter and two 5.12kWH Lithium Iron Phosphate Batteries (10.24kWh total) are installed.
- A new power output control system will be implemented, building on the NETL Task 3 work.

Task 7 – Engineering & Techno-Economic Analysis (TEA)

Dr. Whitney G. Colella, PhD, MBA, Gaia Energy Research Institute

Poster: *Objective Evaluation of the Engineering Performance of Stationary Solid Oxide Fuel Cell (SOFC) Systems Based on Measured, Time-Dependent Data*

Results and Conclusions

Gaia analyzed the operating performance of 4 BlueGen SOFC systems deployed at NETL over a period of 18 months, and 2 of these systems over a period of 24 months.

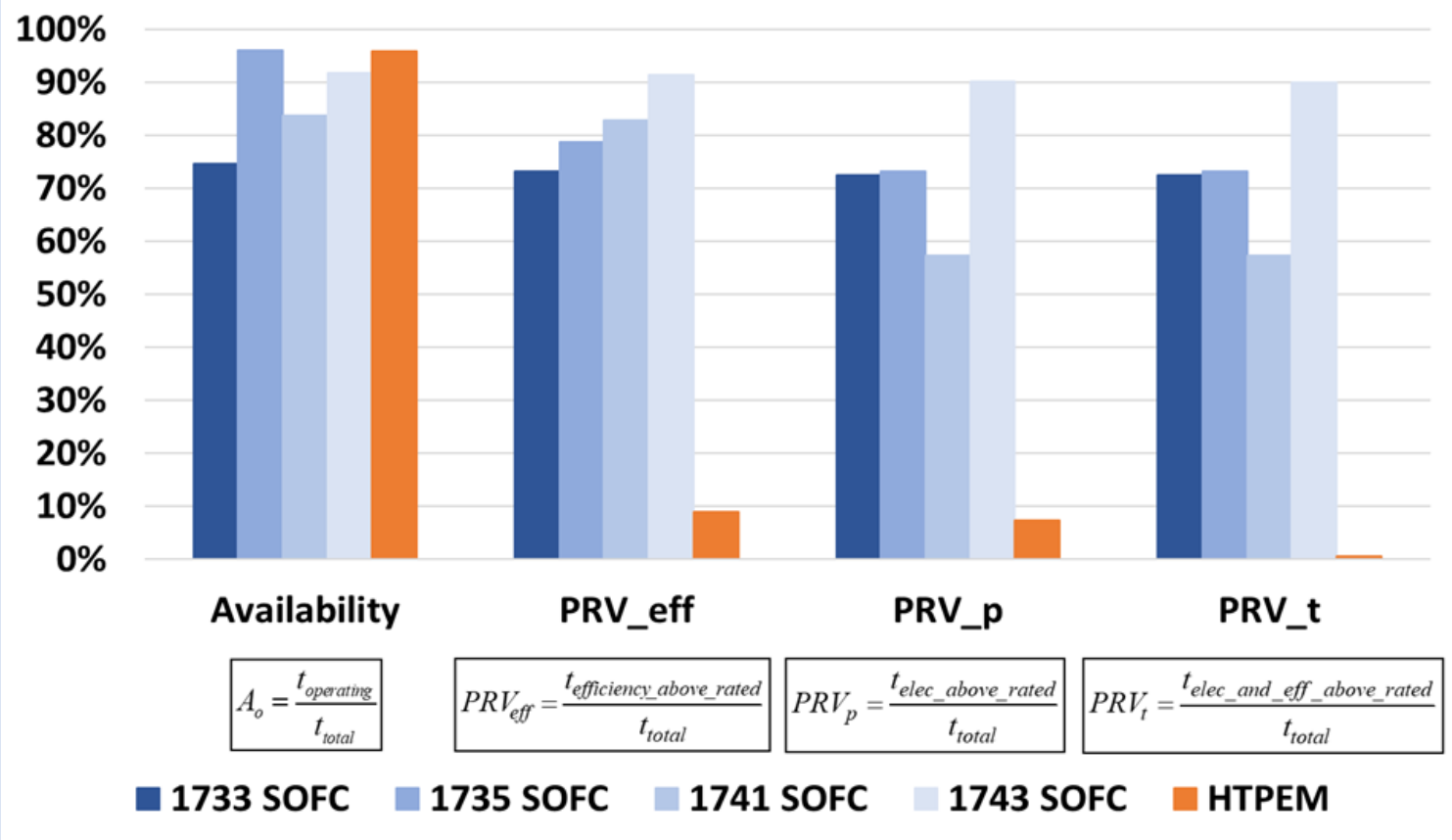
Availability is defined as the time the system has been operating compared with the total time since commissioning. An analysis of the measured data indicates that average availabilities are **~86.9%** in the 18 month group, and **83.7%** in the 24 month group.

Performance at Rated Value (PRV) for Efficiency is defined as the time that the system is operating at or above the rated electric efficiency, which is **60%** for these systems. An analysis of the measured data indicates average PRVs for Efficiency are **~82%** in the 18 month group, and **83.1%**in the 24 month group.

Performance at Rated Value (PRV) for Power is defined as the time that the system is operating at or above the rated electric power, which is **1.5 kW** for these systems. An analysis of the measured data indicates that average PRVs for Power are **~73.7%** in the 18 month group, and **82.2%** in the 24 month group.

Performance at Rated Value (PRV) for Efficiency and Power is defined as the time that the system is operating at or above both the rated electrical efficiency, **60%**, and at or above the rated electric power, **1.5 kW**. An analysis of the measured data indicates that the average PRV for Efficiency and Power is **~73.7%** in the 18 month group, and **82.2%** in the 24 month group.

Task 7 – Engineering & Techno-Economic Analysis (TEA)



Remaining TEA Activities

- Gaia will contribute to a techno-economic analysis (TEA) of how modular fuel cells can enhance resiliency for data centers and other critical power users.
- Gaia will review Aris' existing TEA model, including its functionality in analyzing simple payback results for various stationary fuel cell systems, such as the SolydEra BlueGen SOFC technology.
- Gaia will evaluate this TEA model for different product/market scenarios and suggest enhancements to provide additional user functionalities.

Remaining Work to Program Completion

1. Task 4 - WVURC/NASA
   a) Continue monitoring performance, analysis, and report writing.

2. Task 3 - NETL Phase 2
   a) Complete installation
   b) Install Hot Box Module in BOP Cabinet
   c) Test the ability of the system to load follow dynamically.
   d) Analysis and report writing

3. Task 6 – Commercial Site Field Demonstration.
   a) Complete Installation
   b) Start-Up and Commissioning
   c) Test the ability of the system to load follow dynamically.
   d) Analysis and report writing

4. Task 7 – Techno-Economic Analysis
   a) Continue monitoring performance, analysis, and report writing
   b) Complete TEA

Modular Fuel Cells Providing Resiliency to Data Centers and Other Critical Power Users.

Project DE-FE0031978 Budget

- Original DoE Award $ 2,659,199
  - To NETL Directly $ 800,000
- Remainder to Aris $ 1,859,199
- Funds Spent to Date $ 1,255,636
- Remaining Budget $ 603,563*

* Includes ~ $250,000 work done but not yet invoiced

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Thank you

Aris Energy Solutions

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