U.S. DEPARTMENT OF ENERGY | Fossil Energy

23rd Annual SOFC Project Review Meeting
October 25, 2022

Aris Energy Solutions – DE-FE0031978

Dan Connors, COO

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

ARIS ENERGY SOLUTIONS

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

NASA

Gaia Energy Research Institute

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

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

Phase Two - One (1) BG-60 6.0kW Fuel Cell – 6 kW

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

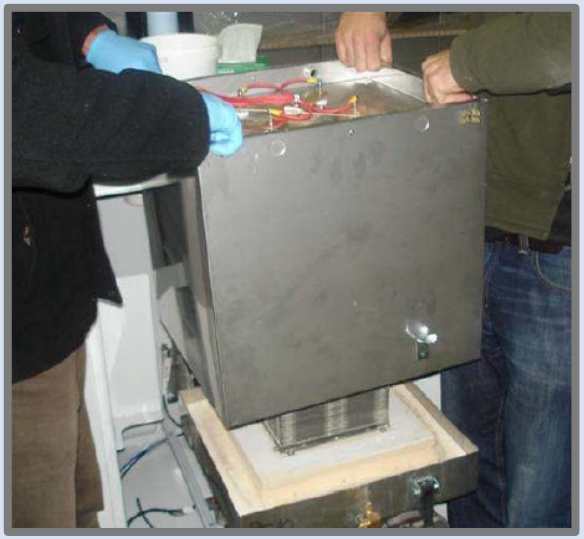
In Year 3 replicate that work on the 6kW BG-60 product

Tasks 2-3 at National Energy Technology Laboratory
RESULTS/CONCLUSIONS

1. 6 Kw “BG-0 Quad” installed and operated at/above rated 60% electrical efficiency at/above rated fuel cell power.
2. Electrical 1-line was developed and implement to enable the BlueGen fuel cell European electrical output to interact with the US building/grid.
3. 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
4. Subsequent Phase 2 work at NETL (Task 3) should utilize later BlueGen BG-15 design, with DC output, plus some assist from batteries, and Phase 1 lessons learned in a dynamic load following demonstration

Task 2 work at National Energy Technology Laboratory

Installing SOFC Stacks into the Balance of Plant



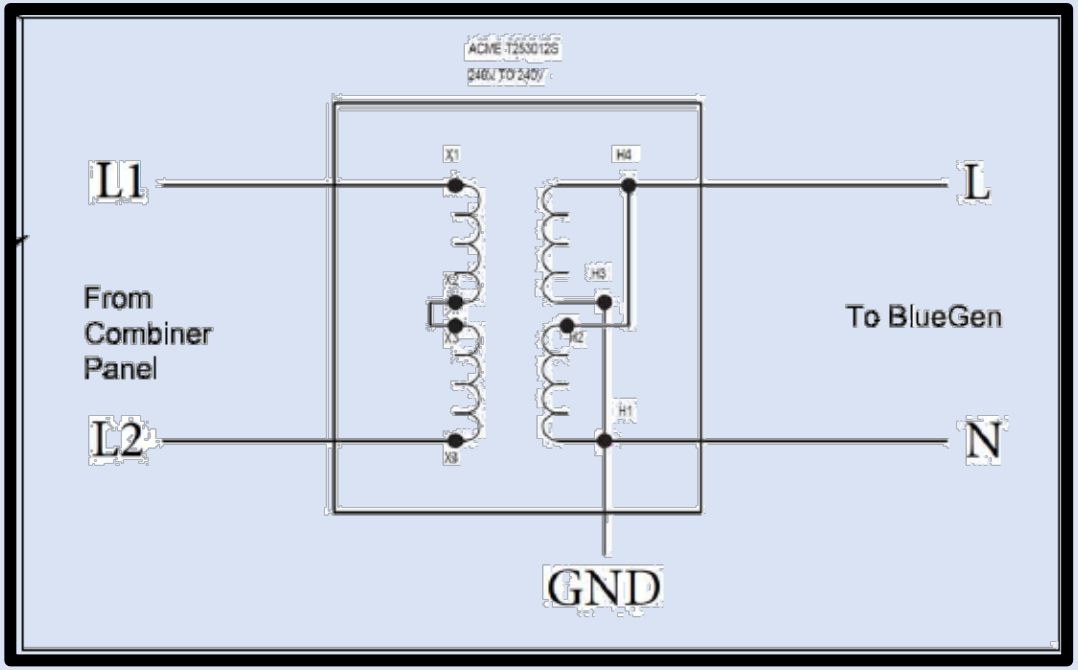
The solid oxide stacks for the BlueGen fuel cells are shipped separately from the Balance of Plant (BOP). A skilled factory trained technician carefully installed the SOFC stack onto manifold, the manifold was then placed into the hot box, and the hot box installed into the BOP.

Task 2 Work at National Energy Technology Laboratory

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

Terminals	BlueGen VAC
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

Load Testing 6kW BlueGen SOFC System

The objectives of the evaluation are:

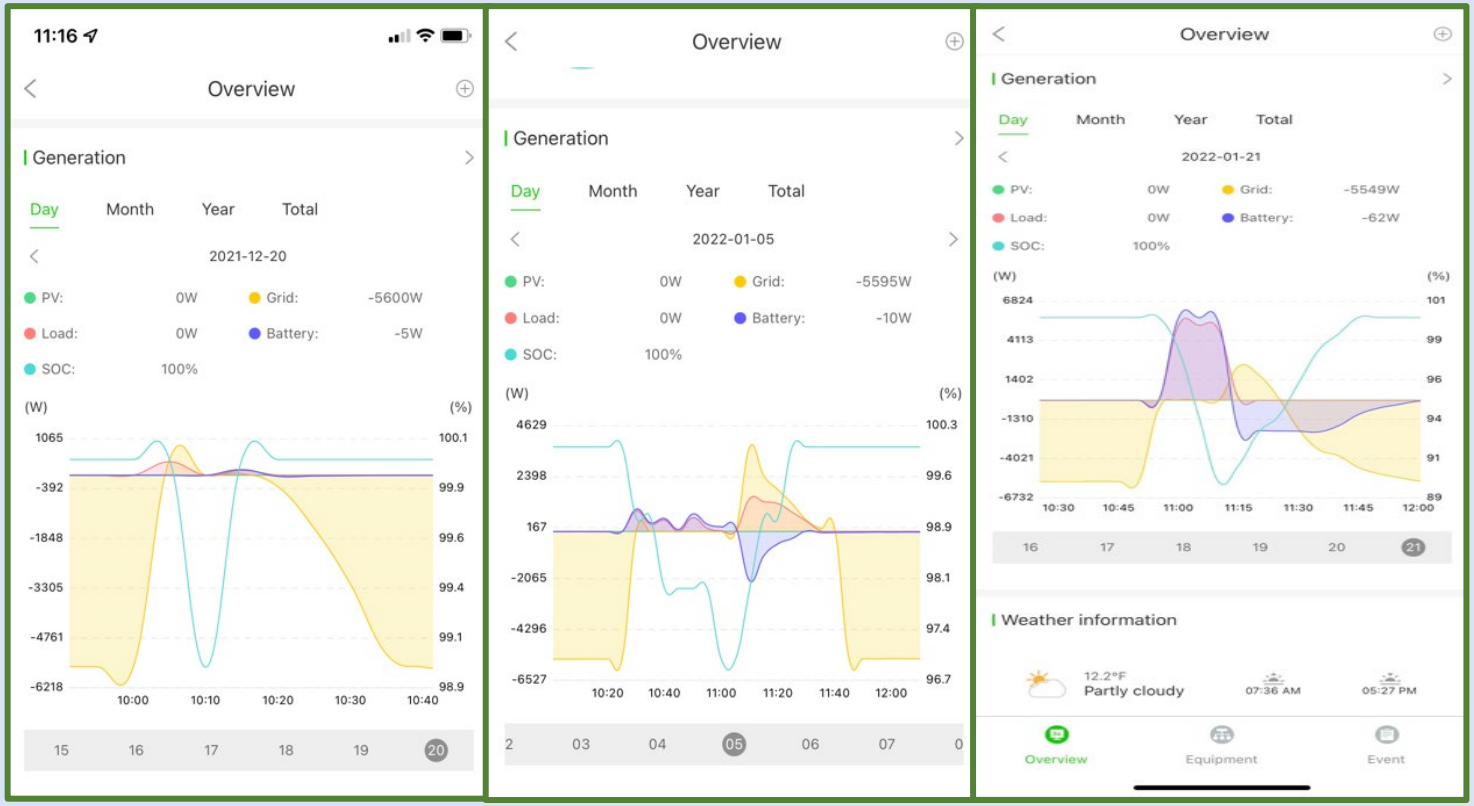
- Understand the BlueGEN/Sol-Ark system response during the transition to off-grid mode
- Test the capability of the standalone operation of BlueGEN Appliances
- Gather information to develop protocols for the load-following testing

#	Date	E-Load Set Point
Test #1	Monday, December 20, 2021	6000
Test #2	Wednesday, January 5, 2022	2500
Test #3	Friday, January 21, 2022	4950
Test #4	Wednesday, February 16, 2022	3000
Test #5	Wednesday, February 23, 2022	750
Test #6	Monday, February 28, 2022	750
Test #7	Tuesday, March 15, 2022	3000
Test #8	Monday, March 21, 2022	750
Test #9	Monday, April 4, 2022	NA

California Instruments 3091LD AC Electronic Load in foreground and Sol-Ark hybrid inverter as "AC Coupling" in background

Task 2 Work at National Energy Technology Laboratory

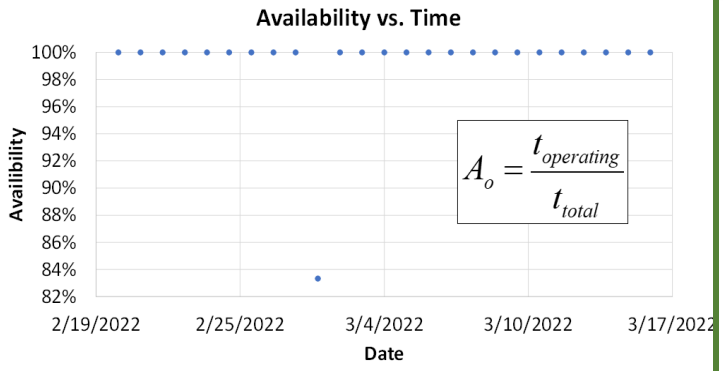
Although the BlueGEN units were able to operate at peak-rated capacity in off-grid operation, they were unable to load follow. The units repeatedly demonstrates the ability to ramp up output after shutting down from a grid disconnect event. The newer model BG-15 will be able to load follow to a much 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 planned for the 2nd phase of work at NETL



Task 2/Task 7 Work at NETL

Task 7 TEA by Gaia Energy Energy Research Institute

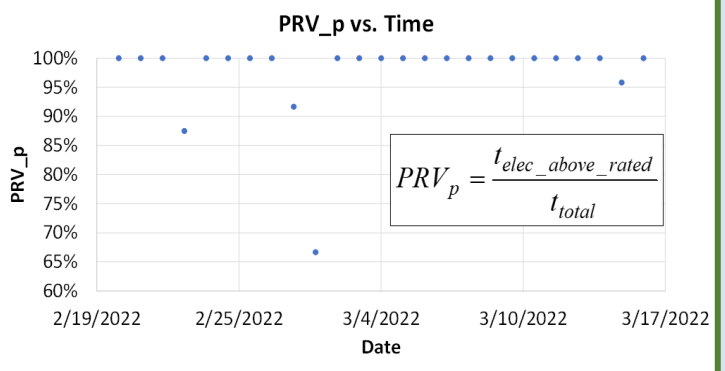
For one FCS, operating over a 1-month time period, the aggregate availability is 99.3%.



Availability is defined as the amount of time the unit is producing electric power divided by the total time of data collection.
Availability is plotted above daily and collected at 1 hour time intervals.

Gaia Energy Research Institute LLC, P: +1 (650) 283-2701, E: wgc@gaia-energy-research-institute.com

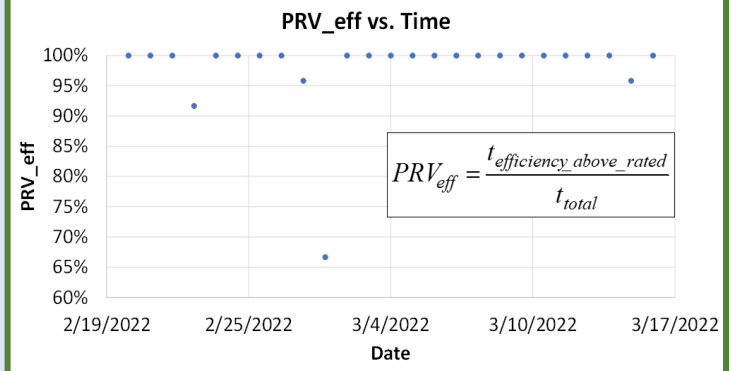
For one FCS, operating over a 1-month time period, the aggregate PRV_p is 97.6%.



PRV_p is defined as the amount of time the unit's power output ≥ the manufacturer stated power output (1.5kWe).
PRV_p is plotted above daily and collected at 1 hour time intervals.

Gaia Energy Research Institute LLC, P: +1 (650) 283-2701, E: wgc@gaia-energy-research-institute.com

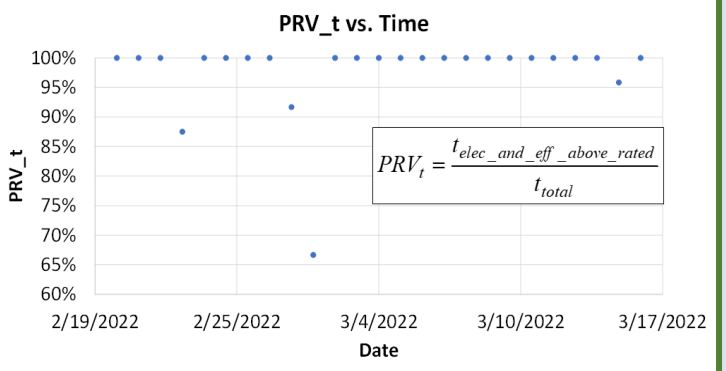
For one FCS, operating over a 1-month time period, the aggregate PRV_eff is 98%.



PRV_eff is defined as the amount of time the unit's electrical efficiency ≥ the manufacturer stated efficiency (60%).
PRV_eff is plotted above daily and collected at 1 hour time intervals.

Gaia Energy Research Institute LLC, P: +1 (650) 283-2701, E: wgc@gaia-energy-research-institute.com

For one FCS, operating over a 1-month time period, the aggregate PRV_t is 97.6%.



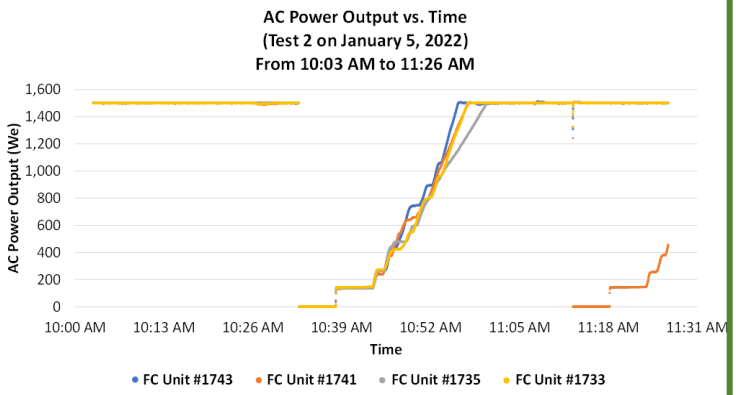
PRV_t is defined as the amount of time the unit's efficiency is ≥ the manufacturer stated electrical efficiency (60%) and power output (1.5kWe).
PRV_t is plotted above daily and collected at 1 hour time intervals.

Gaia Energy Research Institute LLC, P: +1 (650) 283-2701, E: wgc@gaia-energy-research-institute.com

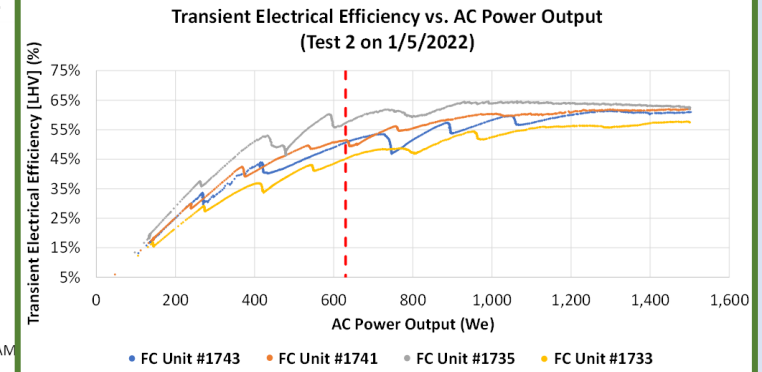
Task 2/Task 7 Work at NETL

Task 7 TEA by Gaia Energy Energy Research Institute

Four SOFC FCSs were tested by reducing their power from rated power (1.5 kWe) to 0 kWe instantaneously. The FCSs were then ramped back up to 1.5 kWe over a period of ~25 minutes.

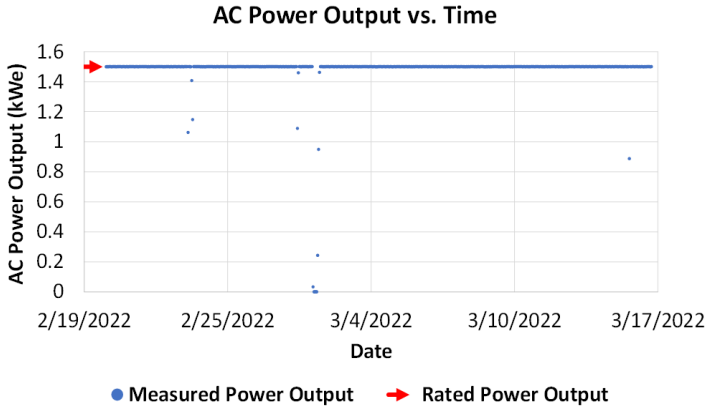


Transient electrical efficiency remains high even at high electrical power turndowns.

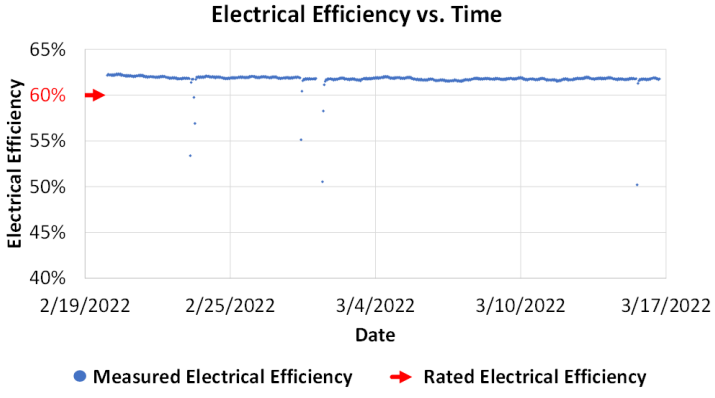


At ~60% turndown (630 We), transient electrical efficiency is ≥ ~45% for all four FCSs.

For one FCS, operating over a 1-month time period, measured electric power output meets or exceeds manufacturer-stated electric power output (1.5 kWe) 97.6% of the time.



For one FCS, operating over a 1-month time period, measured electrical efficiency meets or exceeds manufacturer-stated electrical efficiency (~60%) 98% of the time.



Tasks 4-5 with West Virginia University Research Corporation at NASA Katherine Johnson IVVF Facility, Fairmont, WV

Phase One - Sixteen (16) BG-15 1.5kW Fuel Cells – 24 kW
Phase Two - Eleven (11) BG-15 1.5kW Fuel Cells – 16.5 kW
Total Site Installed kilowatts – 40.5 kW

Demonstrate a modular approach to scaling to higher kW range via a Resilient 24kW prototype system of BG-15 units, in service to power critical data center loads at the NASA/Fairmont WV facility for 12 months, and integrate multiple AC coupling systems

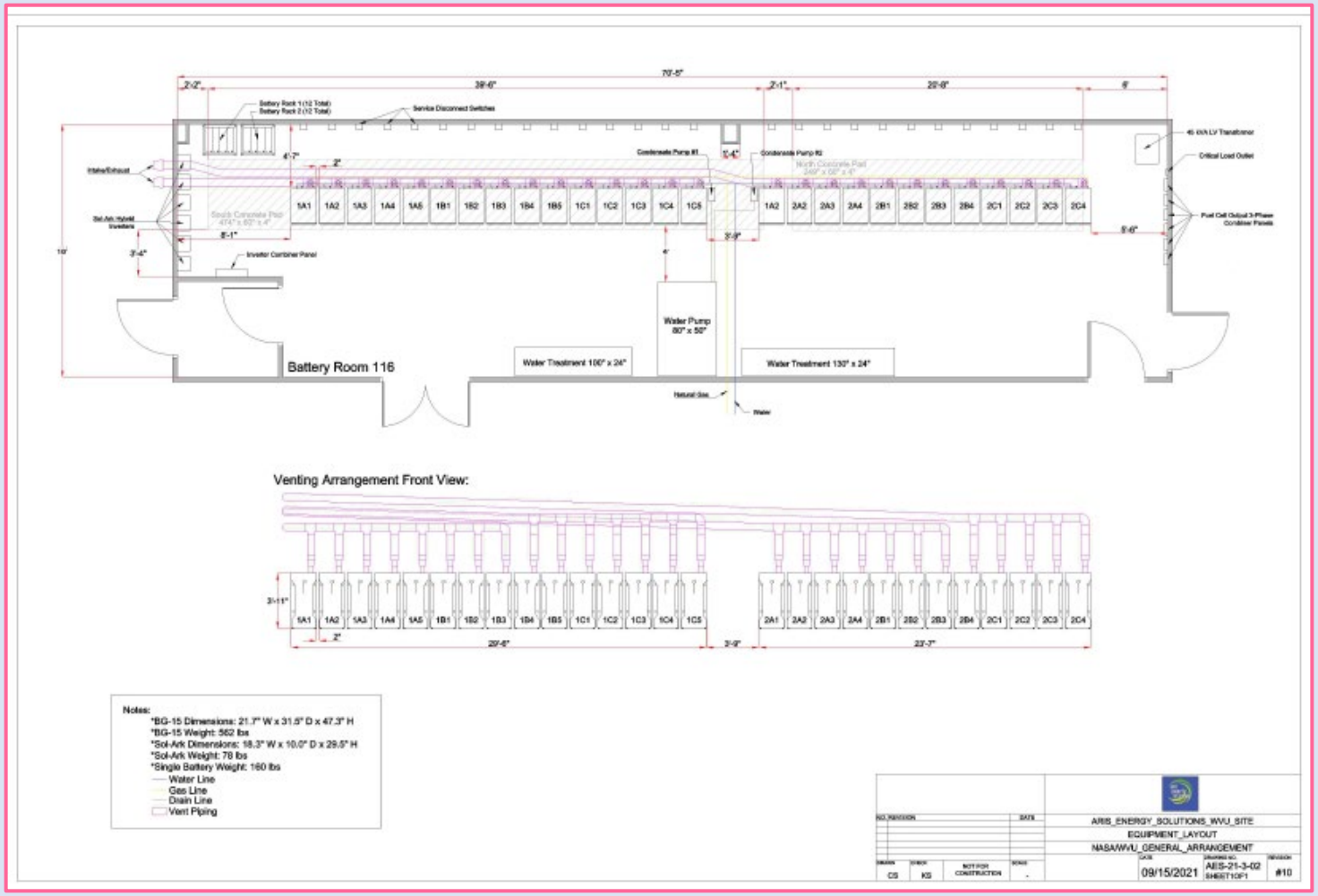
In Phase 2 at NASA, incorporate lessons learned to complete second part of the NASA data center installation, with an additional 16.5kW BG-15 capacity to operate for 12 months

Task 4 Work With WVURC at NASA Fairmont, VW
RESULTS/CONCLUSIONS

1. Engineering to integrate the fuel cells in the facility is approximately 80% complete.
   a) There was considerable work required to design and review suitable 1-line electrical plan to integrate in client's facility.
   b) Mechanical layout drawing with gas/water/venting runs prepared
2. WVURC/NASA authorized shipment. Delivery of (16) Fuel cells from Germany delayed due to logistics challenges but now arrived at NASA/Fairmont
3. Installation work is approximately 15% complete

Task 4 Work with WVURC at the NASA Fairmont WV Site

Fuel Cell Room with 27 BlueGen BG15 SOFC's
Gas, Water, Venting Manifolds



Task 6 Field Demonstration at Commercial Critical Power User Site

- Four (4) BG-15 1.5kW Fuel Cells – 6 kW
- Install/operate a 6kW BG-15 Quad at a commercial user site for 12 months

Original host site, a modular data center, had changing priorities with DoD work so it is being replaced with another suitable site.

Example 7.5kW system shown above

<u>Discussions with candidate sites:</u>

- Major Electric Utility Public School System (resilient EV charging)
- Small Municipal Microgrid
- Major Urban Hospital
- National Retail Banking Firm
- Food Distribution Center

<u>The Confirmation of the new site requires:</u>

- Commercial agreement with new end user
- Submittal of DOE Environmental Survey
- DOE approval of new plan

Task 7 – TEA by Gaia Energy Research Institute

Over the 3 year program, Gaia Energy Research Institute, who has an intimate understanding of fuel cell technologies and economics, will chart a path towards the cost and market goals.

Results and Conclusions

Gaia has also analyzed the operating performance of the BlueGen SOFC system deployed at NETL.

Conclusions:

- (1) **Availability** is defined as the time that the system is operating compared with the total time since commissioning. An analysis of the measured data indicates average availabilities are **~99.3%.**
- (2) **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 **~98%.**
- (3) 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 average PRVs for Power are **~97.6%**.
- (4) **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 average **PRV for Efficiency and Power** are **~97.6%**.

Looking Forward

1. Task 4 - WVURC/NASA Phase 1 Completion
   a) Installation, Start-up, and Commissioning

2. Task 3 - NETL Phase 2
   a) Dynamic load following. Aris recommending BG-15 fuel cell with DC output, batteries, SolArk hybrid inverter, and controls

3. Task 5 - WVURC/NASA Phase 2
   a) Installation/Start-up and Commissioning

4. Task 6 - Commercial Critical Power User Field Demonstration

5. Task 7 – Techno Economic Assessment

U.S. DEPARTMENT OF ENERGY | Fossil Energy

Thank you

Aris Energy Solutions

Dan Connors

dconnors@aris-re.com