Spring 2023

ACT

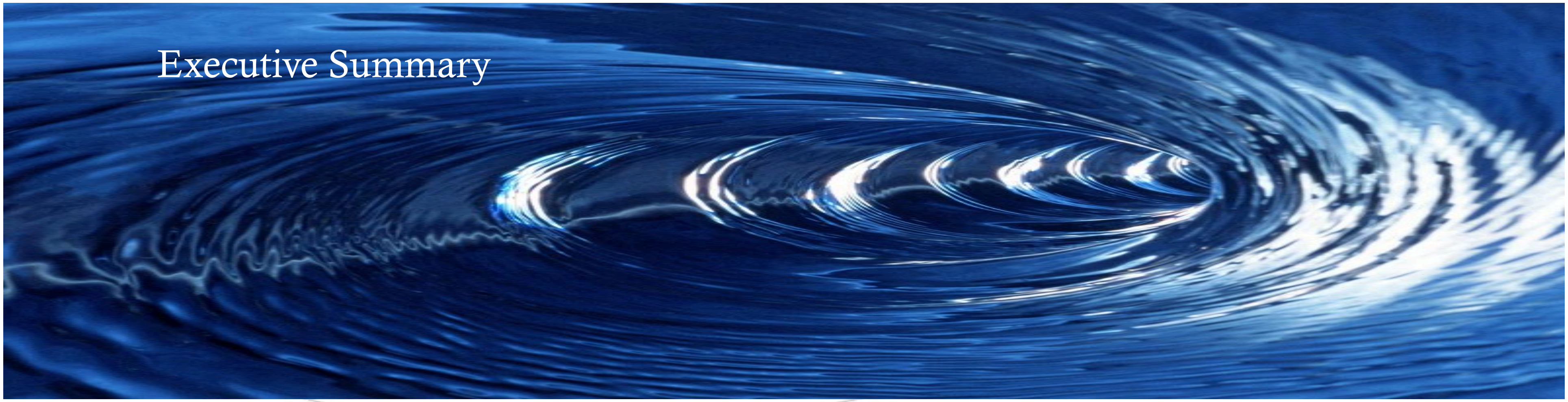
ADVANCED COMBUSTION TECHNOLOGIES, INC.

Independent 3rd Party Fuel Cell Run Test April 2023

by

SNAER INC

Executive Summary



Advanced Combustion Technologies, Inc. is a U.S.-based company that has developed and secured multiple U.S. patents relating to a novel method for water electrolysis, to efficiently produce hydrogen gas from an electrolyte solution consisting of de-mineralized water and potassium hydroxide (KOH).

One of the unique elements of the company's Hydrogen Production Unit ("HPU") is the use of dual plasma arcs in the electrolyte. ACT states that the HPU can produce a kilogram of hydrogen gas utilizing less than three kilowatt hours (kWh) of electrical energy.

To evaluate this claim, NAER Inc. developed and conducted an independent testing project which is described in this report.

SPRING 2023, ADVANCED COMBUSTION TECHNOLOGIES, INC.

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After familiarizing itself with the technical elements of the HPU, its components and its operation, NAER developed a Test Procedure described herein to verify ACT's power efficiency claims and to evaluate the potential commercial viability of the ACT technology. The test procedure was conducted by ACT staff at the ACT research and fabrication facility located in San Juan Capistrano, CA. The process involved the following tasks:

- Task 1: Write the Test Procedure, followed by ACT review, discussion and approval.
- Task 2: Observe and record data during the Test Procedure at the ACT facility, specifically the power and electrolyte consumption of the HPU, collect samples of gas production, and monitor HPU operating conditions such as temperature and electrolyte pH throughout the Test Procedure.
- Task 3: Following the Test Procedure, verify sample gas components and concentrations via certified lab analysis, compile and analyze the HPU data.

DESCRIPTION OF THE HYDROGEN PRODUCTION UNIT (HPU)

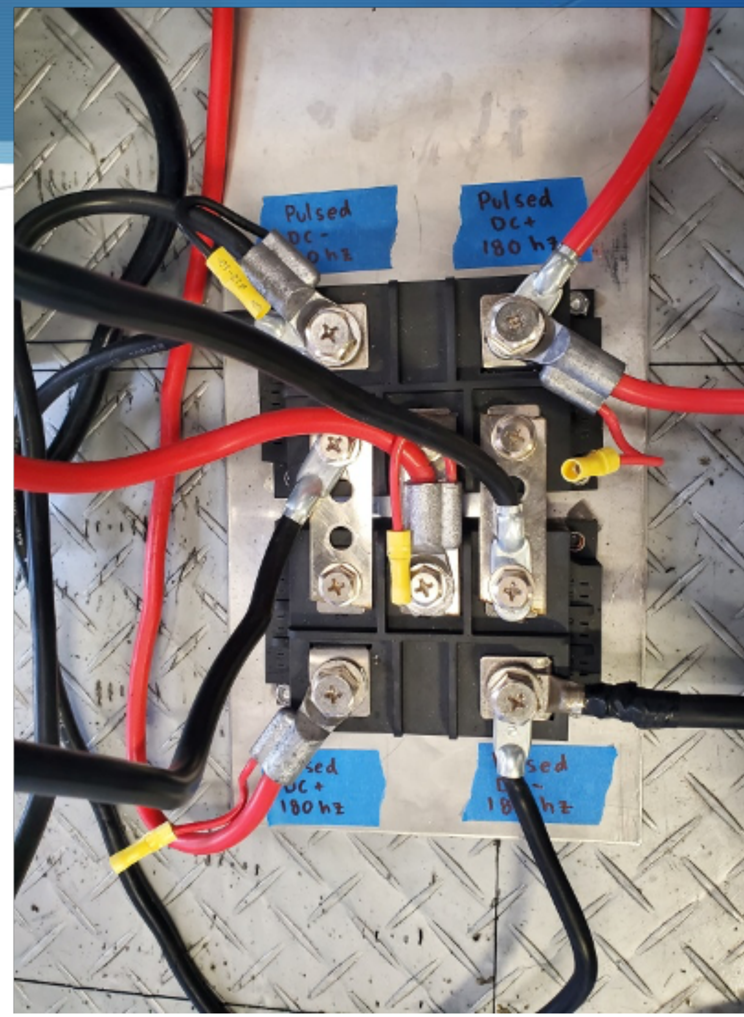
The HPU consists of a symmetrical pair of three electrolysis cell stacks arrange in series with a plasma torch positioned on the exterior end of the cell stacks and an "X-plate" positioned in the internal end as illustrated in Figure 1 below. Each cell stack consists of 4 nickel plates and 21 stainless steel plates and is exposed to a pulsed direct current ("PDC") of + & - 120 volts with a frequency of approximately 180 Hz. The individual plates are separated by nonconductive separators and submerged in the electrolyte solution of DI water and KOH. Separately, a 260 volt + & - PDC current, also pulsed at 180Hz, is across the plasma torch (as the Anode) to the X-plate (as the Cathode) which are also submerged in the electrolyte. The entire assembly is contained in a sealed reaction vessel that can hold up to 165 gallons of electrolyte fluid and operates at atmospheric pressure.

HPU Reaction Vessel with Cover

The HPU excludes certain components that would be considered “balance of plant” in an industrial application. These include the electrical control system, electrical power supply, hydrogen production buffer tank, cooling system, de-ionized water production, automatic fill and drain pumps, gas separation equipment, compressor/ storage tanks, system controls, and miscellaneous valves and instrumentation. This ancillary equipment necessary is now being developed and integrated into a fully operational system.

This “balance of plant’ would bring additional power consumption to the HPU which must be considered when evaluating the performance relative to other hydrogen production technologies.

75kV AC/DC Transformer and Rectifier



Electrolyte Details and Specifications

Prior to commencing the electrolysis process, the reaction vessel is filled with DI-T2 water and potassium hydroxide (KOH) to achieve an electrolyte solution of up to .001-.071% mass/volume, Because the volume of electrolyte is kept constant and no KOH is consumed, no additional chemicals are added to the system during operation. KOH serves the purpose of boosting the electrical conductivity of the electrolyte and preventing corrosion of the HPU components. As the water component of this electrolyte solution is consumed in the hydrogen generation process, a supply of de-mineralized water enters the vessel, thus maintaining the electrolyte concentration.

Table 1 – Electrolyte Specifications

Water Supply Parameters

Metric	Units	Specification
Flow	Liters/hour	Nom. 150
Pressure	PSIG	Max. 15
Temperature	C	Min. 65.5

Water Quality Parameters

Metric	Units	Specifications
PH		7.0-8.0
Resistance	Ohm cm	$\geq 1 \times 10^{-5}$
Chlorine Ion	Ppm	Max. 2
Turbidity	Ppm	Max. 1

Electrolyte Solution Analysis

Metric	Units	Specifications
PH		7.0-8.0
Resistance	MΩ cm	Min.$\geq 1 \times 10^{-5}$
Conductivity	µS/cm	<1 µS/cm
Chlorine Ion	Ppm	non-detectible
Turbidity	Ppm	<50 ppm

PPASE SYSTEM TESTING

NAER developed a Test Procedure to measure the power consumption and the amount of hydrogen being produced..

The Protocol:

i) Include a list of preconditions and inspections to be assessed and confirmed prior to commencing the test.

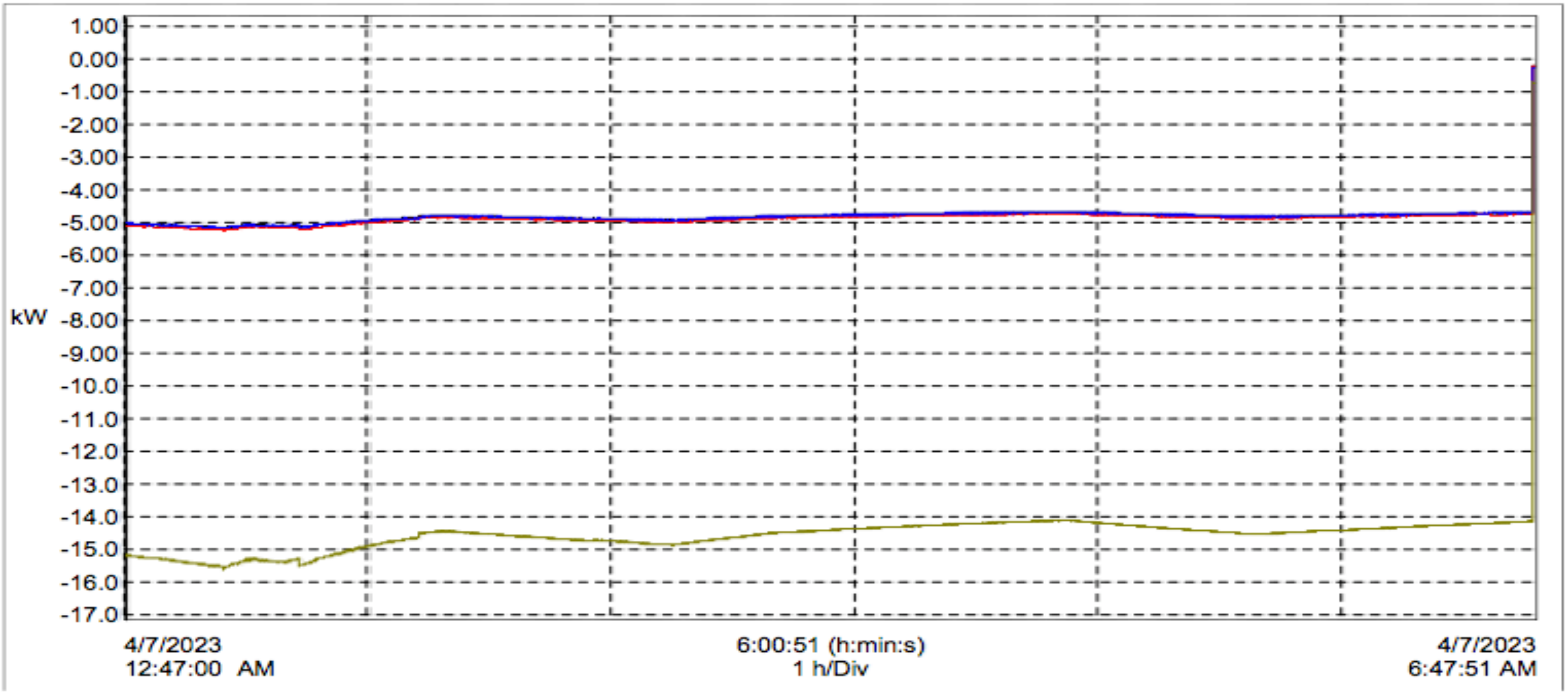
ii) Set specific data log sheets that identified all data to be collected during the test and established verification and signoff procedures to ensure the validity of collected data.

iii) This Test Procedure and associated data sign off sheets are included (in the full report) as Appendix A. Included in the data collection protocol was the collection of gas samples from the HPU for the purpose of confirming the presence of a stable rate of electrolysis during the one-hour data collection period.

Power Consumption Calculations

The power consumption of the HPU during the final hour of the test procedure was determined by collecting power load data using a calibrated Data Logger at two second intervals.
The chart in Table 3 below shows the power delivered to the HPU over the six-hour duration of the Test Procedure.
The chart illustrates that the power consumptions was stable and the average of the total (PT) power consumption was 14.6kW.

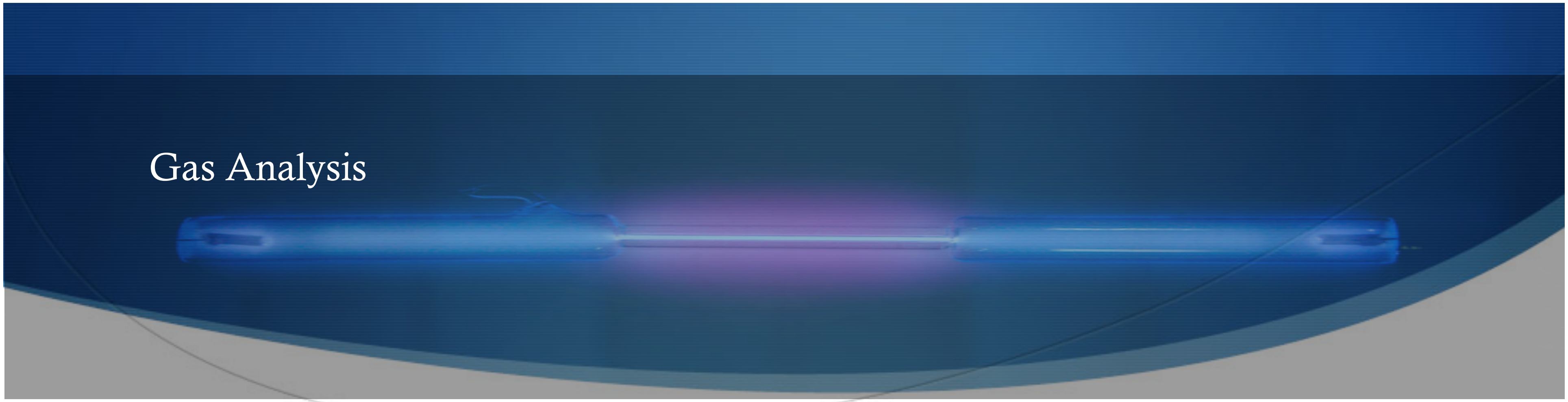
Name	AVG	MIN	MAX	Units
P1 (1 s)	-4.849k	-5.199k	-228.0	W
P2 (1 s)	-4.899k	-5.268k	-238.0	W
P3 (1 s)	-4.847k	-5.187k	-247.0	W
PT (1 s)	-14.59k	-15.64k	-714.0	W



Gas Analysis

The HPU was not equipped with a system to collect and separate the oxygen and hydrogen produced by electrolysis and measure the hydrogen production directly. Instead, the purpose of the gas analysis was to confirm electrolysis had occurred by the presence of oxygen and hydrogen in the collected samples.

Upon the conclusion of testing, NAER produced this report summarizing the results showing the raw data and the calculations used to convert the recorded variables into flow rates and specific values. NAER believes that this test protocol is in conformance with industry prototype testing best practices.



Gas Analysis

The four gas samples collected during the final hour of test operation were analyzed by

AtmAA Lab

https://atmaa.com/

Given the collection procedure it was expected that atmospheric gas (air) would be found in the gas sample and this was confirmed by the results showing the presence of significant nitrogen which is not a product of electrolysis. As shown in the tables and discussion in Appendix B, the samples confirmed an over-abundance of oxygen compared to typical air gas ratios (25% vs 21%) and the presence of significant hydrogen (18%), thereby confirming that the production of hydrogen gas through electrolysis had occurred during the test.

WITNESS TESTING AT THE FACILITY

On April 7, 2023, NAER tested a single HPU at the ACT Facility in San Juan Capistrano with the objective of obtaining evidence of the behavior of the HPU for hydrogen production versus power consumption as per the Test Procedure.

During the visit, NAER Field Engineers visually observed the arrangement of equipment in the facility, installed temporary monitoring and measurement equipment, observed the operation of the HPU over a six-hour period, and collected data and gas samples during the final hour of this test period. The gas samples were subsequently delivered to the AtmAA laboratory in Calabasas, California.

The HPU test took place over a period of approximately twelve hours. This section is a collection of independent remarks regarding NAER Field engineers' observations during this visit to the facility.

TEST RESULTS AND DISCUSSION

NAER was able to observe the successful operation of the HPU (subject to sub-optimal factors discussed below) for the planned six-hour test run and gathered specific power and electrolyte consumption data during the final hour of the six-hour period, per the Testing Procedure.

Table 3 –Test Results and Calculations

Measurement Device	Location	Function	Observation
Level Line Marker on Tank Wall	Internal wall of reaction vessel.	Measure electrolyte level of the HPU tank	Water level decreased during HPU operation; Amount of water used was 201 liters during the test period
Power data logger AEMC Instruments Model PEL 103 Calibrated 1-23	208 VAC into power supply transformer	Continually measure the Power Consumption for the HPU's transformer	Power usage increased as the temperature increased and was stable once the HPU was at operating temperature at 14.85 kW
Power consumption per unit of Hydrogen Production	(calculation)	Determine electric power consumption per unit of hydrogen production	kWh/Kg Hydrogen: 0.74

As calculated in Table 3 above, the HPU was able to generate a kilogram of hydrogen using less than one kWh of electric power. In preparing to conduct the test, ACT informed NAER that the system would be operating only on the + 120 VPDC power to the cell stack do to the configuration of the transformer. Consequently the stack was only receiving + 120 VPDC during the test when typically the stack would receive – 120 VPDC if the Full Phase Rectifier could be powered from the transformer. The significance of this is that the cell stacks only received power during the positive phase of the 120 VAC input to the rectifier, which results in less hydrogen production than designed. ACT stated that if the full system could be powered with as designed utilizing both + & - pulsed 120V DC then the hydrogen production efficiency would be greater than observed.

In addition to the electrical supply issue, ACT noted that the electrolyte solution (DI water and KOH) was set to 0.1% mass/volume KOH rather than the concentration ACT described as optimal which is 1.0% mass/volume KOH solution.
The KOH concentration was lowered due to the electrical configuration of the system, ACT stated that lower concentration also had the effect of reducing the hydrogen production efficiency.

While NAER agrees in principal that the above deviations likely had a negative impact on the HPU performance and power efficiency, it cannot validate the mathematical calculations by ACT of the potential performance of the HPU had these factors not been present. NAER recommends making the necessary changes to the power supply system that will allow the HPU to be operated as designed without risk of system damage or safety concerns. It is NAER's professional opinion that if the system is operated as designed the hydrogen production efficiency should increase.

Power consumption of a fully Integrated System:

As described above, the prototype HPU is comprised of the electrolysis unit. In order to function as a self-contained system, comparable to those technologies referenced in Section 2, the incorporation of "balance of plant" components that each would consume electrical power not included in the power consumption measured and reflected in the above calculations.

These components include:

Electrical control system
Electrical power supply
Negative pressure gas separation system
Hydrogen production buffer tank
Gas cooling system
Automatic fill and drain pump systems
Compressor/storage tanks
System controls / miscellaneous valves and instrumentation

NAER estimates that these components, once engineering and incorporated into an integrated HPU, would increase the power consumption of the system by 6-8kW. The impact on these adjustments to the efficiency of the HPU would be to increase the power consumed per Kg of hydrogen produced to 0.9-1.2 kWh/Kg.

PRELIMINARY ASSESSMENT OF COMMERCIAL POTENTIAL

The power consumption of the HPU per Kg of produced hydrogen of less than 1kWh is significantly below those levels in the 40-55kWh range disclosed by leading manufacturers of commercial electrolyzer and fuel cell products. Moreover, the adjusted power consumption reflecting the estimated "balance of plant" load that would be incorporated into an industrial project of 0.9-1.2 kWh/Kg is significantly below those of current market participants. It is also noted that the power consumed in the HPU is less than the power that could be produced by combusting this hydrogen in a utility scale gas turbine or other electricity generation system, raising the prospect of a "self-sustaining" power generation operation.

While publicly verifiable information is not currently available, NAER is aware of more recently commercialized technologies that, similar to the ACT technology, rely upon the electrolysis process but apply novel ancillary technologies to boost efficiency.

As market growth and government tax incentives drive investment in hydrogen production technologies, (both electrolysis-based and otherwise) it is reasonable to predict that rapid cost improvements will continue. However, at the present time it appears that the ACT technology has the potential to become a disruptive, low cost hydrogen production system in a very fast growing market. This supports the argument for further investigation of the ACT technology, beginning with investment in the design and development of a fully-integrated demonstration system that would produce an "apples to apples" comparison with the production economics of industrial projects using established electrolysis methods.

"Although the system seems to violate the law of conservation of energy, the ACT system does produce the hydrogen gas at the efficiencies stated in this report as the physical data determined the efficiency. NAER states that we do not understand how this ACT process accomplishes this; the physical empirical data cannot be denied.."

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