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NASA Glenn Research Center's Fuel Cell Stack, Ancillary and System Test and Development Laboratory

Patricia L. Loyselle
Glenn Research Center, Cleveland, Ohio

Kevin P. Prokopius
Analex Corporation, Cleveland, Ohio

Larry A. Becks
QSS Group, Cleveland, Ohio

Thomas H. Burger, Joseph F. Dick, George Rodriguez, Frank Bremenour, and Zedock Long
Akima Corporation, Fairview Park, Ohio

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

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Akima Corporation
Fairview Park, Ohio 44126

Introduction

A flexible (modular) fuel cell test facility was designed and constructed at the NASA Glenn Research Center for the evaluation of fuel cells, ancillary components and powerplant subsystem designs in support of NASA's exploration and aeronautics missions. The facility allows for testing of fuel cell powerplants and components under a variety of conditions with minimal reconfiguration. Fuel cells and subsystems of various types can be easily evaluated utilizing various fuels and oxidants under both static as well as dynamic power load conditions.

Test Facility's Purpose and Capabilities

NASA's future missions require the operation of fuel cell powerplants under a variety of conditions and utilizing various reactants. This fuel cell facility was designed with the flexibility to evaluate both components and subsystems under many of the conditions expected for a particular mission. The central facility test area (Figs. 1 and 2) was originally configured to allow for testing of large Proton Exchange Membrane (PEM) fuel cells and powerplants or multiple smaller fuel cells and powerplants in excess of 10 kW using either humidified or non-humidified gaseous reactants. This capability was important to adequately evaluate not only the fuel cell and powerplant behavior by themselves but also under various reactant feed architectures and power management configurations. The original infrastructure has since been modified to also accommodate a bank of five high temperature furnaces in order to evaluate individual Solid Oxide Fuel Cells (SOFCs) and stacks. Figures 3 and 4 show the test facility including the SOFC infrastructure.

Depending on fuel cell type, fuel cell powerplants can operate on a variety of fuels that include hydrogen containing various impurities, reformate or direct from hydrocarbon fuels. The facility was designed with this fuel variability in mind, as well as the potential need to prehumidify the fuel prior to entry into the fuel cell. The typical oxidant used for fuel cells for NASA missions is oxygen; however, this can also be delivered as oxygen with various impurities or as air. The facility currently is configured to accommodate air, humidified or not humidified, however the facility can be reconfigured to handle oxygen. Fuel reformers can also be accommodated in the facility allowing the evaluation of future reformer designs, fuel cell stack designs operating under reformate, and power systems' designs relying upon reformate fuel.

Figure 1.—Fuel Cell Test Facility (front side) including data monitoring, collection and control system.

Figure 2.—PEM Fuel Cell Test Facility (back side).

Figure 3.—SOFC test stands (front side).

Figure 4.—SOFC test stands (back side).

Various different fuel cell types can be tested with a minimum level of design, fabrication, and installation effort. Specifically, there has been much attention drawn to the utilization of solid oxide fuel cells for aerospace applications. Ample area, up to 100 ft^2, is available to accommodate high temperature furnaces and any necessary reactant pretreatment for the operation and testing of solid oxide fuel cell stacks and power systems. The large tubular furnace shown in Figures 5 and 6 can be used to test 4 in. diameter solid oxide fuel cells as well as small solid oxide fuel cell stacks. The large furnace is part of a complete test stand that provides for semi-automated control of flow, pressure and temperature to the cells under test. It contains safety interlocks that prevent the flow of hydrogen to the cell/stack in the event of furnace shutdown. It also contains a data acquisition system that allows for complete monitoring of the cell's performance during the entire test duration. The four small tubular furnaces shown in Figures 7 and 8 have been sized to allow for testing of cells up to 2 in. in diameter. Each of the four stations has been outfitted with mass flow controllers for the hydrogen fuel and mass flow meters for the air reactant and nitrogen purge gases. Individual temperature controllers monitor the cell's temperature at each station. The data acquisition system for monitoring the performance of each test stand is contained in a portable equipment rack. The test facility is designed to run unattended allowing for life cycle studies to be performed on a number of different solid oxide fuel cells and solid oxide fuel cell stacks.

The current facility configuration is adequate for the evaluation of individual or multiple fuel cells or subsystems at a total gross power output of up to 12 kW. With minimal component and facility alterations, the facility could accommodate stacks and power systems with outputs exceeding 25 kW.

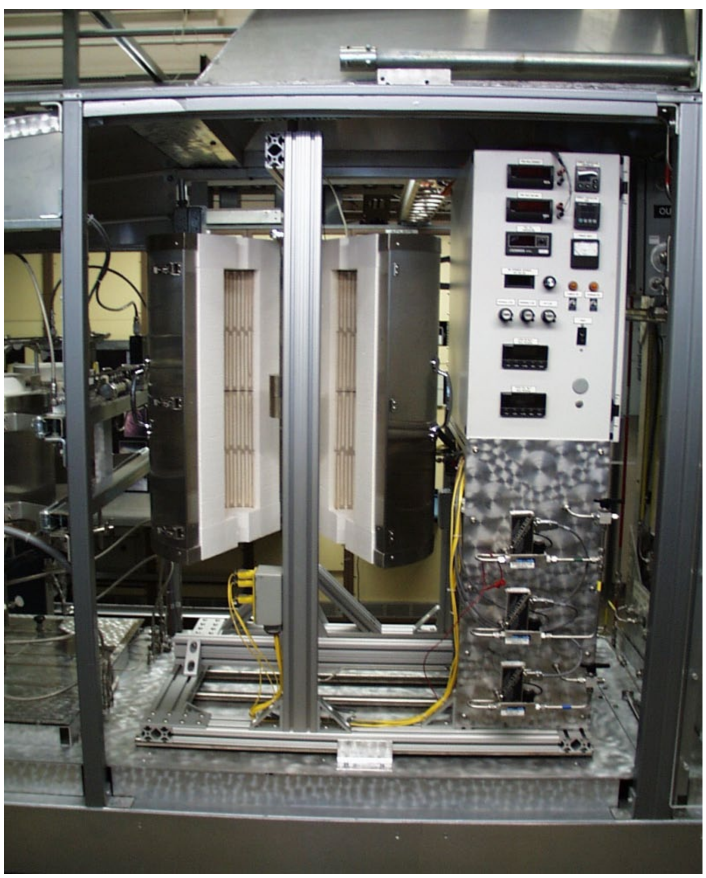

Figure 5.—Large tubular furnace SOFC stand (front view).

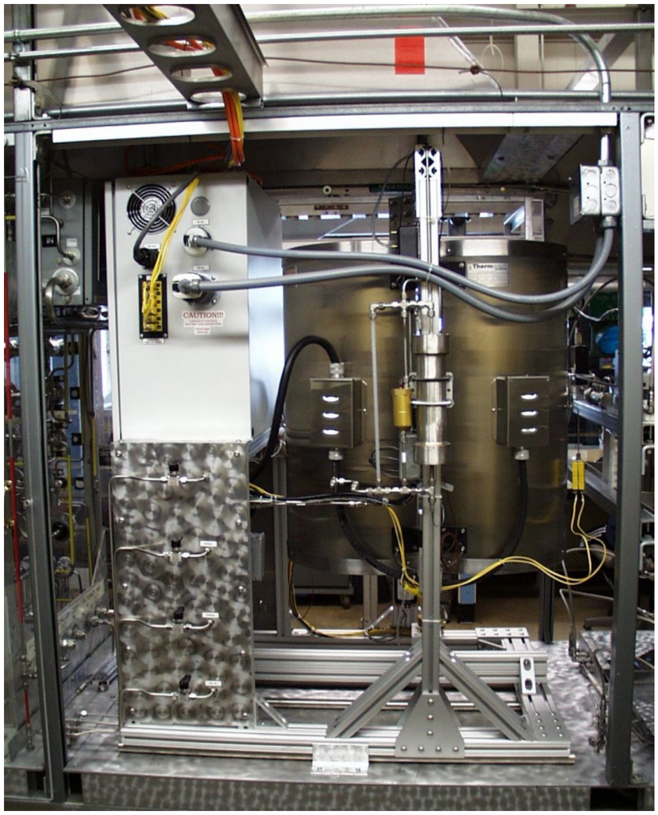

Figure 6.—Large tubular furnace SOFC stand (back view).

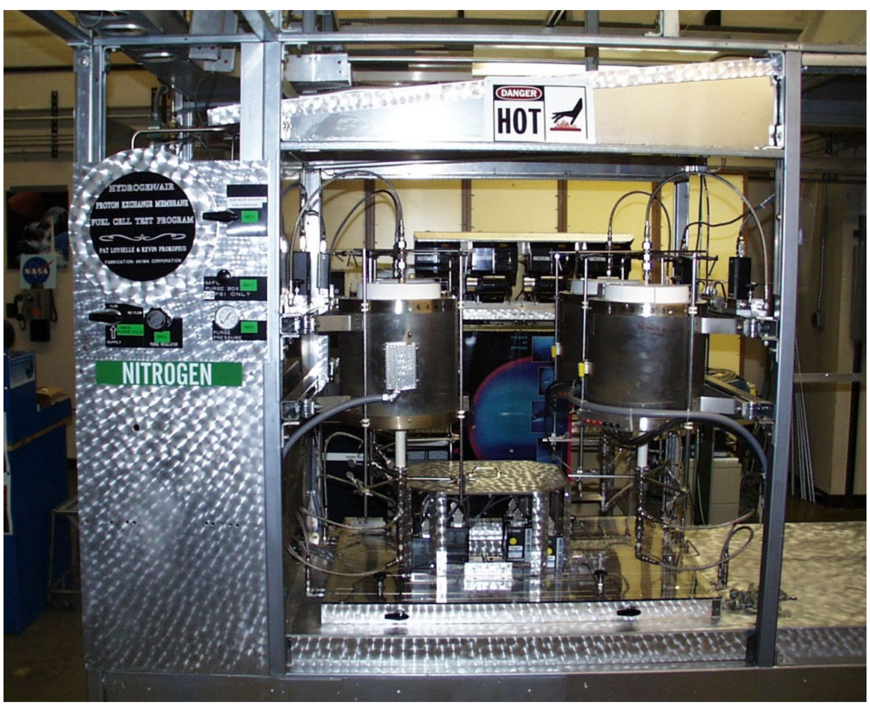

Figure 7.—Small tubular furnace SOFC stand (four—front view).

Figure 8.—Small tubular furnace SOFC stand (four—back view).

Facility Configuration and Subsystems

The fuel cell test facility can be used for the evaluation and characterization of individual cells and stack designs, ancillary components and power subsystems. Ancillary components can be evaluated individually or as part of a fuel cell power subsystem. Subsystem designs and performance characteristics can also be evaluated and optimized under various operating conditions within the facility. The fuel cell facility is composed of several subsystems; *hydrogen/fuel*, *air/oxidant*, *gaseous purge, coolant, deionized water supply, power load control, data acquisition and system safety controls, and ventilation*. The *hydrogen/fuel subsystem* allows for the control and monitoring of several key parameters including pressure, flow rate, temperature and humidity. The *air/oxidant subsystem* also allows for the control and monitoring of the same parameters as the hydrogen system but also includes a “clean-up” system for the inlet gas to remove particulates and other contaminants such as oil prior to entry into the fuel cell. The *gaseous purge subsystem* provides for the quick removal of reactants from the system as well as an inert environment for select hardware. The *coolant loop* removes the waste heat produced by the fuel cell stack or subsystem as well as the waste heat generated by the electronic load bank. The *deionized water supply subsystem* feeds on demand treated water to the reactant humidification tanks and to the 32 kW air-cooled chiller. The *power* drawn from the fuel cell stack or subsystem can be controlled in two ways, via an electronic load bank or by the utilization of an electric motor/dynamometer system. The electronic load allows for the testing and evaluation of fuel cells as well as fuel cell power subsystems under “ideal” power load conditions. A 21 kWe DC electric motor/dynamometer assembly allows for the testing and evaluation of fuel cells as well as fuel cell power subsystems under “real” power load conditions. Power draws from the stack can be easily tracked and performance curves established at various motor speeds. The *data acquisition and control system* manages the collection of data, monitors the entire process and facilitates safe system shutdowns. Lastly, the *ventilation subsystem* maintains a safe working environment during test operations, keeping the concentration of hydrogen gas below 1 percent by volume in air (Hydrogen’s lower explosive limit of 4 percent by volume in air). Provided in the following sections is a detailed description of these subsystems.

Hydrogen/Fuel Subsystem

A six-station high purity hydrogen k-bottle gas manifold is located directly outside of the test facility as seen in Figures 9 and 10. Figure 9 gives an overall view of the subsystem with the cylinder storage cages while Figure 10 focuses on the gas manifold alone. Prior to entering the facility, the hydrogen pressure is regulated from bottle pressure down to 100 psig. If the manifold pressure should exceed 100 psig, a relief valve opens venting the excess pressure through a vent stack located 15 ft above the building roofline. In addition to the pressure relief there is a flow-limiting orifice located in the supply line just before it enters the room to further minimize the quantity of hydrogen permitted into the facility. The size of this orifice can be changed to meet demand. The currently installed orifice limits the amount of hydrogen into the room to a level that could operate up to a 12 kW fuel cell stack or fuel cell stack power system dead-ended.

Figure 9.—Hydrogen gas supply manifold and cylinder storage.

Figure 10.—Close-up view of the hydrogen gas supply manifold.

Inside the facility, the dry hydrogen gas can be fed directly to the test article or be humidified prior to entering the stack. The hydrogen gas can be humidified up to a level of 100 percent relative humidity. Flow rates, pressures, relative humidities, and temperatures of the hydrogen stream into and out of the fuel cell process are monitored via a LabView data acquisition system. Excess hydrogen is vented via a manifold header which directs the gas out of the facility and through the vent stack preventing the hydrogen concentration in the room from exceeding 1 percent by volume in air, thereby maintaining a safe operating environment at all times.

Air/Oxidant Subsystem

The current fuel cell test facility uses air as its oxidant supply. Pure oxygen could be used with minimal modification to the facility. The current air subsystem is configured to deliver air at pressures between 5 psig and 60 psig and at temperatures between 25 and 80 °C. The air flow capacity is 25 scfm and is currently limited by the air filter/driver system. The air supply line pressure is 120 psig and the oxidant is first pretreated through a series of filters and a dryer to remove particulates, oil and water before entering the fuel cell process. Specifically, the building air first enters a coalescing filter, followed by a heatless regenerative desiccant dryer, particulate filter and lastly a vapor adsorbing filter. In a similar manner to the hydrogen fuel, the dry air can be humidified as required based on the fuel cell manufacturer’s specifications. Figure 11 shows the tank used for humidifying the particulate-free dry air and the series of filters and the heatless air dryer. The filter/dryer subsystem has been labeled “FILTERED-AIR SYSTEM” as seen in the figure. Flow, pressure, relative humidity, and temperature are monitored throughout a given test. Exit air lines from the test article are routed underneath the installed facility ventilation system and are exhausted outside of the building during operation.

Figure 11.—Hardware used for filtering/humidifying the supply air and deionizing tap water as the supplied cooling media.

Gaseous Purge Subsystem

This facility is equipped with a gaseous nitrogen purge system. There are two k-bottles of nitrogen located inside the test facility to handle the removal of hydrogen and air from the fuel cell inlet and outlet process lines downstream of the humidification tanks. This tie-in line allows for the quick removal of the supplied fuel and oxidant from the system to safely allow changes in test articles, for performing modifications to the existing system and in the event of an emergency shutdown. There is also a tie-in to an installed purge box that contains mass flow controllers for both gases and to a collection pan used to contain water that is drained from the hydrogen humidification tank and the hydrogen gas/liquid water phase separator on the exhaust side of the stack. This will vent any soluble hydrogen gas out of the pan and up to the roof vent stack. This is in place in order to maintain a concentration of hydrogen below 1 percent by volume in the contained space, well below hydrogen’s lower flammability limit of 4 percent by volume in air. Once sufficiently vented, the collection pans on both the hydrogen side and the air side can be drained. For a complete purge of the entire process, a k-bottle of nitrogen can be installed inside the six-station gas manifold outside of the facility. This is required after completing a major facility modification or when the system has been idle for a significant period of time.

Coolant Subsystem

Inside the fuel cell test facility is an air-cooled, closed loop 32 kW chiller that will handle the heat dissipation requirements from the 12 kW resistive electronic load bank and from any water-cooled fuel cell stack or subsystem under test. Deionized water coolant flows to both pieces of hardware and can be individually regulated and monitored for pressure, flow rate and temperature into and out of the equipment. A separate fill line allows for the addition of deionized water to the system at the chiller reservoir in the event of evaporation or other loss.

Deionized Water Supply Subsystem

The facility contains a deionized water system capable of delivering deionized water at flow rates up to 0.75 gpm. The system consists of a 5 μm prefilter followed by an activated carbon tank, a mixed bed (worker) tank, and lastly a second mixed bed (polisher) tank. This particular subsystem pretreats the supply of tap water from the building prior to entering the process. The pretreated water is fed to both the hydrogen and air humidification tanks and is also available to replenish the coolant water supply that is circulated through the 32 kW chiller.

Power Load Control Subsystem

Power loads can be applied to a test article by two methods. The first is through a resistive electronic load bank which is used for testing and evaluation of stacks and subsystems under “ideal” power load conditions. This load can be operated in three different modes; controlled current, controlled voltage or controlled resistance. Each of these modes can be operated under steady state conditions, ramped conditions, or by providing a user defined power profile. The electronic load is capable of providing loads up to 12 kW and accommodating stack voltages between 0 and 100 V.

Along with the load bank, a 21 kW DC electric motor is also available for dissipating the generated power from the fuel cell stack under test. It can be utilized to perform systems level testing under “real” power load conditions. Performance characteristics under various motor speeds can be evaluated using the motor combined with a motor controller and a water brake absorber or dynamometer which will provide resistance to the rotating motor shaft allowing the user to obtain profiles of torque, rpm, and horsepower from the unit. All of the described hardware, including the data acquisition system for the dynamometer, can be seen in Figure 12.

The water is fed to the dynamometer directly from the building supply which is regulated to a given pressure. The water's inlet pressure, flow, and temperature are all monitored and recorded. The outlet temperature is also recorded in order to prevent the water from reaching and exceeding its boiling point. The discharged water is collected into a holding tank equipped with level switches and an audible alarm to prevent it from accidentally overflowing. The collected water, in turn, is pumped out of the facility and into the building drain. Figure 13 shows all of the controls used for providing resistance to the DC motor under test.

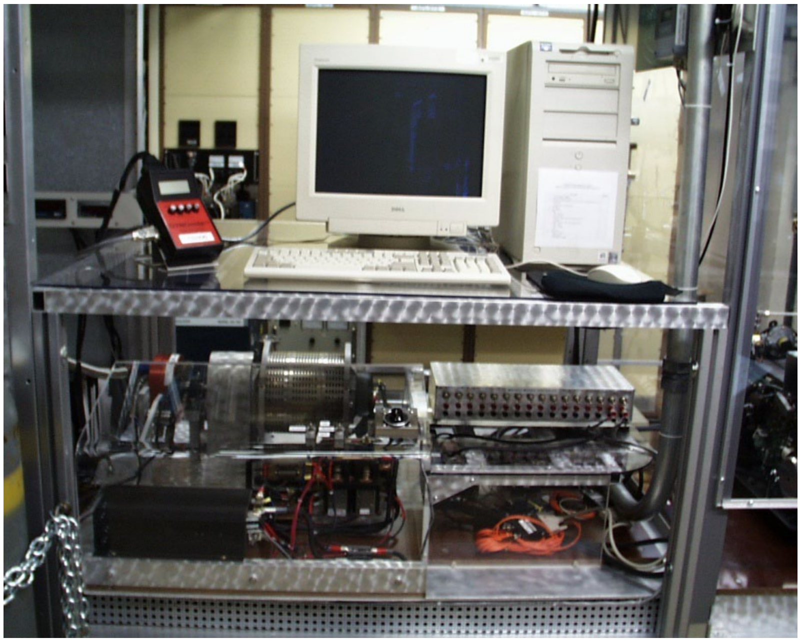

Figure 12.—The 21.2 kW DC motor with dynamometer and motor controller.

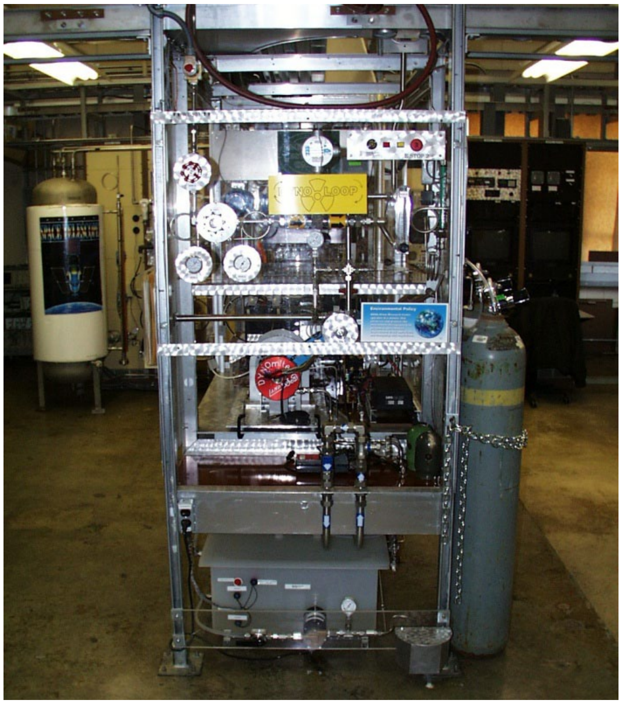

Figure 13.—The 21.2 kW DC motor/dynamometer controls.

Systems level testing under “real” power load conditions will be useful for evaluating both the ancillary components and the design of a scaled-up fuel cell power plant for various power and propulsion applications. Optimization of the size and weight for each component is critical for aerospace applications and can be investigated with relative ease here.

Data Acquisition and System Safety Controls

A LabView data acquisition system from National Instruments allows for monitoring and acquisition of data on individual cell and overall stack voltages, fuel cell stack temperatures, and instruments with four 20 mA outputs. Collected data can in turn be easily compiled and downloaded for evaluating fuel cell stacks or subsystems under various power duty cycles and operational conditions. Currently, over 100 channels are available to accommodate fuel cell stack, ancillary component and subsystem performance information. The modular nature of the equipment allows for easy expansion as it becomes necessary. The data acquisition system works hand-in-hand with a programmable logic controller (PLC) that monitors the entire process and facilitates mandatory shutdowns when upsets during normal operation occur. A visual touch screen allows for the operational control of normally closed and normally open process solenoid valves during system startups and shutdowns. Along with the visual display screen, there are a total of four Emergency-Stop (E-Stop) buttons in the facility to suspend test operations when necessary. These operate in conjunction with two hydrogen combustible alarm detectors. When the hydrogen concentration in the room reaches 1 percent by volume of hydrogen’s lower flammability limit in air or if an E-Stop button is activated, the PLC commands the system to close the hydrogen inlet supply valve, open the hydrogen vent line and institute a nitrogen purge of the system. Strobe lights, warning signs, a horn, and test in progress lights have been installed at both facility doors as additional measures for safe operation of various fuel cell stack test articles. Figure 14 shows a picture of the test facility’s monitoring and control system. The only device missing from the picture is one of the data acquisition chassis which was in for calibration.

Figure 14.—PLC, data acquisition, ventilation and ancillary system controls.

Ventilation Subsystem

Two ventilation hoods contain all process tubing and instrumentation used for testing the fuel cell stacks, components and subsystems. Any hydrogen lines not contained within the ventilated area are welded to prevent potential leak paths from fittings. Both hoods operate with installed two-speed explosion proof fans. The first is rated at 3000 cfm with a 3 hp motor and the second is set at 1500 cfm with a 1.5 hp motor. The larger of the two hoods vents the majority of process tubing on both the hydrogen and air sides along with the open space where the fuel cell test article is placed while the smaller hood handles the hydrogen humidification tank and the rest of the tubing. The hoods have been configured to operate at high speed when the E-Stop condition is not satisfied, when activated or when hydrogen in excess of 1 percent is detected. If a major leak of hydrogen into the facility were to occur, the higher ventilation fan speed would be sufficient to safely remove the hydrogen from the facility and maintain the hydrogen concentration well below the 4 percent lower explosive limit.

Summary

At the NASA Glenn Research Center, a fully operational fuel cell test and evaluation laboratory is available which is capable of evaluating fuel cell components and systems for future NASA missions. Components and subsystems of various types can be operated and monitored under a variety of conditions utilizing different reactants. This fuel cell facility can test the effectiveness of various component and system designs to meet NASA’s needs.

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