AVRC™

Advanced Vehicle Research Center

Design & Build a Portable Hydrogen Refueling Station

January 30th, 2008

U.S. Department of Energy

http://www.hydrogen.energy.gov/

Foreword

DISCLAIMER: ***The information in this report is provided for educational purposes only***. Neither the Advanced Vehicle Research Center, North Carolina Solar Center, nor the North Carolina State University is a Professional Engineering firm. Information in this report should not be used as final design decisions. A licensed professional should be consulted before utilizing information provided in this report for engineering calculations, decisions to purchase equipment or fabrication of any systems.

The system in this report was designed in whole by AVRC and the North Carolina Solar Center. The complete team included Philip Crawford, Tim Lupo, PE, Keith McAllister, PE, Richard Dell Jr., Dick Dell, and Glenn Edmonds.

Systems of similar design and purpose may exist, but any similarity in design is unintentional. It is incumbent on the user of this report to not infringe on the intellectual property of those with existing systems.

Those readers who would like to get more information on the build issues outlined in this document, or ***discuss support for utilizing this document*** to build a complete Portable Hydrogen Refueling station should contact the AVRC "Portable Hydrogen Refueling Station" Program Manager at the following office number: 919.870.9494 or by email at H2@avrc.com.

http://www.avrc.com

http://www.ncsc.ncsu.edu/

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EXECUTIVE SUMMARY

Focused on next generation research and development, the **Advanced Vehicle Research Center** (AVRC) is a private for-profit corporation that collaborates with multi-national automotive companies and leading universities.

The mission of the Advanced Vehicle Research Center (AVRC) is to provide modern automotive testing facilities for use in the design, development, testing and certification of advanced vehicle technologies, sub-systems and components. The first facility is being planned for the Nash County area out of a planning office in Nashville, North Carolina. The second facility is being developed in the Southeast region of the USA.

Advanced Vehicle Research Center (AVRC) facilities will provide safe, secure, and private environments that will help companies reduce the time and cost of product development. The North Carolina Nashville facility will be easily accessible by Interstate 95 and Route NC-64, and serviced by Raleigh-Durham International Airport.

The AVRC is funded through several sources and contracts, each with their own set of deliverables. One such deliverable for the Department of Energy is this “Design and Build” document for a portable hydrogen refueling station (the Station). The Station is designed to be a self-contained, portable refueling facility for hybrid and hydrogen powered vehicles. The AVRC contracted with the North Carolina Solar Center (NCSC) of the North Carolina State University (NCSU) to provide technical support for this project. This document details the design of the Station and describes the steps necessary for its construction. Each component of the Station is described in terms of its technical specification, operation requirements, and how it contributes to the overall function of the Station. These specifications allow the user of this document to identify equipment necessary to construct the Station, and the method of construction describes how each component is incorporated into the Station.

Additionally, and very importantly, an overview of safety issues is also given related to construction *and* operation of the Station. Finally, an economics section discusses implementation costs of the Station’s components.

The Station is designed to be a completely self-contained, portable refueling unit with all its components integrated into its footprint, except for its high pressure storage and dispensing system, which will be held by a separate trailer. The Station could operate in connection with the utility grid and existing water supply, but the conceptual design is for the Station to be capable of performing all refueling operations in remote areas where utilities are inaccessible. Therefore, all necessary electricity is expected to be generated on-site and all necessary water is to be contained onboard.

Construction of the Station allows the user the flexibility of refueling hybrid and hydrogen powered vehicles in a wide variety of settings, ranging from urban, roadside applications to remote locations completely inaccessible to the grid. The current cost is estimated to be approximately $300,000. Specific costs are discussed in the Economics section, page 40. As the technologies mature and develop, component costs will decrease, making the Station a more feasible economic investment.

INTRODUCTION

The intent of the project was to utilize existing market-ready or near market-ready technologies to create a station capable of providing hydrogen for the fueling of hybrid and hydrogen fueled vehicles. It was also envisioned that the unit could be transported to various locations to support education, outreach, research and demonstration activities.

The NC Solar Center and AVRC met to establish the specific parameters of the Station and the team began to research existing technologies and operations to determine what components would be readily available. The team reviewed codes and standards to determine regulatory limitations on the Station. After design options were discussed with AVRC, the Preliminary Design Concept was completed.

After the Preliminary Design Concept phase of the project was completed, the Scope of Work (SOW) was revised to reflect AVRC's shifting emphasis toward other related projects in the work being done for Department of Energy. The revised SOW no longer required the construction of the Station. Instead, the new requirements were for a document detailing a conceptual design of the Station. Final Design Concept requirements for the project are as follows:

- Develop equipment specifications
- Specify "off the shelf equipment"
- Visit AVRC site, existing refueling operations, and/or vendors
- Develop conceptual design drawings
- Develop equipment interconnection documents
- Conduct engineering calculations to determine loads
- Investigate regulatory compliance
- Meet with AVRC personnel to review design options
- Develop detailed guide to constructing a H_2 refueling station
- Develop Economic Costing Model

This document includes equipment specifications, safety considerations, identification of vendors and manufacturers, system design drawings and diagrams, load calculations, economic modeling, and connection and construction details. The Appendices contain detailed information about these aspects of the design. The intention of this document was to provide information that would act as a guide for knowledgeable individuals to design and construct a Mobile Hydrogen Generation and storage station.

HYDROGEN ECONOMY

The hydrogen economy describes a new system in which our energy needs will be predominantly met by hydrogen, rather than carbon-based fossil fuels. The primary reasons for shifting to a hydrogen economy are to eliminate much of the pollution and greenhouse gas emissions produced by fossil fuels, provide a new source of energy to replace the limited petroleum supplies, and reduce dependence on foreign controlled resources.[1]

In order to shift to a hydrogen economy, major changes will be necessary to our energy infrastructure. According to the United States Department of Energy (DOE), their Hydrogen Program is dedicated to working with industry, academia, national laboratories, and federal and international agencies to:

- "Overcome technical barriers through research and development of hydrogen production, delivery, and storage technologies, as well as fuel cell technologies for transportation, distributed stationary power, and portable power applications,"
- "Address safety concerns and develop model codes and standards,"
- "Validate and demonstrate hydrogen and fuel cell technologies in real-world conditions, and"
- "Educate key stakeholders whose acceptance of these technologies will determine their success in the marketplace."[2]

Cooperation between national and international organizations will be vital to making the transition to this new economy. Each segment of this network will bring perspectives unique to their target applications. In this way, component technologies can be developed independently, and then integrated with other technologies to form the complete infrastructure of the hydrogen economy.

According to the DOE Hydrogen Program, there are four major challenges that must be addressed to pave the way for commercialization of fuel cell and hydrogen infrastructure technologies:

Fuel Cell Cost and Durability - Information and statistical data for concept and developmental fuel cell vehicles is often limited and proprietary. Validation is required for vehicle drivability, operation, and survivability in extreme climates, and emissions from hydrogen internal combustion engines (ICE). Although various components have been tested and validated independently, validation of integrated systems is necessary for system development.

Hydrogen Storage – Current technology does not meet the requirements for large scale transportation or stationary applications. Capital cost, long-term durability, fast-fill dispensing efficiency, and structural integrity of hydrogen storage systems must be addressed before the technology can be commercially available to a wide market. Research and development is needed to address performance, failure, and operating cycle life in real-world applications.

Hydrogen Production and Delivery – Currently the cost of hydrogen production is high, the availability of hydrogen production systems is low, and production and delivery technologies are still in their early stages of development. Data is limited for integrated coal-to-hydrogen/power plants with sequestration options, the high-temperature production of hydrogen from nuclear power, and renewable hydrogen production systems. Delivery options must be developed, tested, and validated for every potential production technology.

Public Acceptance – In order to foster acceptance of the hydrogen economy, the public will need to be educated, personnel will need to be trained to operate and maintain the infrastructure, and codes and standards will need to be developed and adopted.[3]

The design of the Station is a step toward making available a real world application of portable hydrogen production and refueling technologies. This project and projects like it help to demonstrate that the technical and safety barriers that currently stand in the way of widespread commercial acceptance of these technologies can be overcome.

A real opportunity for promoting the educational component of the Public Acceptance Challenge came about when AVRC was asked to develop a Distance Learning Laboratory program by the NC Solar Center for a Department of Labor Education Training Agency grant. The resulting curriculum that was developed as a companion to this document for the Distance Learning Lab program was created in three segments, of which the first, the Lecture and Review segment, is now published on the AVRC website at http://www.avrc.com/h2_e2_lecture_and_review.doc

HOW IT WORKS

Final Concept Design

This section gives an overview of some of the technologies incorporated in the design of the Station, and provides a basis for the understanding of the components' operation. Specific equipment used in the Station is also identified.

The Station operates as follows:

- Electricity is produced by the diesel generator and distributed to the Stations equipment through the Service Entrance Panel.
- Water is held in the onboard water supply tank, and is gravity-fed to the hydrogen generator.
- The hydrogen generator uses the electricity and water to produce hydrogen via electrolysis.
- The hydrogen is sent to the compressor where it is compressed to its working pressure of 6000 psi.
- The chiller pumps coolant to cool the compressor.
- High-pressure hydrogen is pumped from the compressor to storage tanks where it is ready to be dispensed when needed.

The Station's flow chart is shown in Figure 1 below.

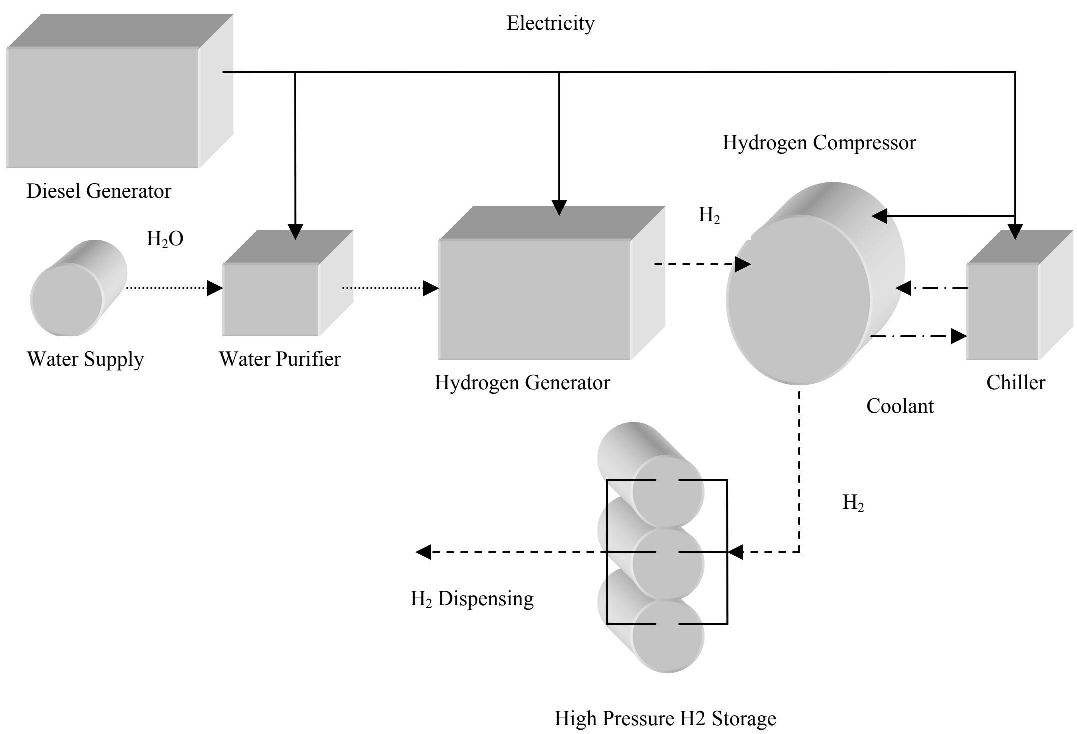

Figure 1: Component Flow Chart

The Station's concept design calls for it to fit in a portable container which can be transported on the bed of a truck to specific utilization sites. The Station can then be removed from the truck bed and set up as a temporary fueling station wherever needed.

The Station is designed to produce its own electricity and carry its own water supply. Electricity for all the Station's equipment will be provided by an onboard diesel generator and water is supplied by a built-in storage tank. However, the design could easily be modified to incorporate utility supplied electricity and water or electricity produced by alternative means, such as a Photovoltaic system.

If the Station is offloaded and used for extended periods, it must be ensured that a supply of fuel is available for the generator or that an electrical service is available to provide 3-Phase, 240V, 200A power. A supply of water may also be needed if the Station's built-in supply tanks do not hold a sufficient supply. The Station will require a mounting pad that is level, stable, and capable of supporting the Station's full weight.

A Hogen RE 40 hydrogen generator has been selected for this design. This generator is capable of producing approximately 40 SCFH, or 960 SCFD, of fuel grade hydrogen by electrolysis. For a vehicle such as the Honda FCX, which when full has a fuel volume of 1592 ft^3, this production rate will allow approximately 4.2 vehicles to be refueled per week.

After the hydrogen has been produced, it flows to the hydrogen compressor. Here the hydrogen is compressed to a pressure suitable for use in fueling vehicles or for storage. Current specifications indicate the fuel tanks of hydrogen vehicles, such as the Honda FCX, have maximum operating pressure of approximately 5000 psig. Therefore, the hydrogen is compressed to a pressure of 6000 psig in order to move the hydrogen from the storage device to the vehicle. This high-pressure hydrogen is stored in a storage system until it is used for fueling. The size of the storage system can be adjusted to meet specific application requirements.

In order to identify suitable equipment for use in the Station, manufacturers were interviewed and product specification documents were reviewed. Specific component manufacturers are identified in the report in order to create a basis for constructing the Station. A sample RFI can be found in Appendix G. However, other manufacturers may be found to better fit the individual needs of those using this document, so the manufacturers specified in this document should not be taken as an all-inclusive list.

Below is a description of the basic function of each of the main components of the Station. More specific information regarding component selection and construction is provided in the Installation and Specification section.

Electrical Power Source

When most people think of electrical power use they relate to their home electric utility bill. Energy consumption, measured in kilowatt-hours (kWh), is charged at a given rate to determine the total. In order to determine an average demand (kW), the total consumption can be divided by the number of hours in the billing period. For example, an average home may consume 720 kWh in a 30 day period.

$720\ kWh / (30\ days * 24\ hrs / day) = 1kW$

Further, knowing that Amps = Watts/Volts, the service requirements can be found by simply dividing by the supply voltage, typically 240 V for residential service.

$1000\ W / 240\ V = 4.2\ A$

Yet most homes have a 200 A service from their utility supplier. The discrepancy lies in the definition of average power consumption. The average power consumption is the integration of the instantaneous energy demand over a given time period. The instantaneous consumption may often be near zero, such as a mild spring day when no one is home and the only thing using electricity is the digital clock on the night stand. Contrast this to a cold winter night when the electric water heater has both of its 4000 W elements energized to heat the tank after the dishwasher has run, the electric clothes dryer is operating along with the 15 kW of strip heat in the heat pump, and nearly every light is on in the house. This condition may only occur for a few minutes each year but the electrical system must be robust enough to handle power demanded during this time.

The Station faces a similar situation with the added complexity of the ability to start motor loads without voltage sags which may cause components to cycle off and on. Motors can draw several times their rated name plate values for short durations which could potentially cause severe voltage sags if the system is not designed properly. Therefore, when selecting the power source for the Station, it was vital to select a diesel powered generator capable of providing sufficient electricity.

It was determined that the total run load of the components would be about 33 kVA. Adding the total startup loads if all equipment in the Station was started simultaneously would significantly increase the total load. However, it is assumed that not all equipment would be started up at the same time, as the water purifier would be started first, followed by the electrolyzer, the compressor, and then the chiller. It was calculated that a 50 kW diesel generator will provide sufficient power to operate all the components.

The 50 kW Generac Model SD050 diesel generator was selected for the Station. The generator is shown in Figure 2.[4] At maximum power for continuous use it supplies 40 kW. It generates 120/240 Volts at a frequency of 60 Hertz, and during continuous use supplies more than enough power to run all components simultaneously. The dimensions of the generator are 93 x 40 x 55 inches, and it weighs 2900 pounds.

Figure 2: Generac 50 kW Diesel Generator[5]

A key feature of the generator is its vibration isolators. Because the generator will be mounted on a platform that is attached to the Station's container, it is important that vibrations be reduced as not to negatively impact the operation of adjacent components. The generator's vibration isolators eliminate most of these vibrations.

Electrical Interface

When dealing with electricity, the most important issue is safety. To control electrical flow and prevent overloading, Load Panels are used. These panels are commonly known as breaker panels, switch boxes, or fuse boxes. They act as a type of traffic controller for an electrical application.

For residential uses, panels receive electricity through cables routed from utility lines. After entering the panel, electricity is first routed through a main breaker, then through smaller breakers for each individual circuit. Electricity is then distributed through the circuit to power lights and appliances that are fed by that circuit. Branching allows control of electrical flow to each circuit, as well as allowing smaller wiring to be used inside the residence, since the load has been greatly reduced for each branch. The main breaker can be used to shut off electricity to all circuits at once.

The Station will employ a panel similar to that used for commercial applications, rather than residential, in that the panel will be a 3-phase 240/120 panel. Rather than receiving electricity from utility lines, however, it will receive electricity from the Station's diesel generator. From the panel, electricity will be routed to each of the Station's components.

If the Station is used in locations where utility service is available, it will be possible to supply electricity from the grid. A service pole can be installed, and wired into the Stations panel, bringing electricity to the Station similar to the way it would be supplied to a residence.

Water Supply

The Station will require a constant supply of water for the operation of the hydrogen generator. The Station is designed to be used in remote locations, so an onboard water storage tank will be used. The tank will be fabricated onto an interior wall of the Station's container. Its dimensions and construction are discussed in the Installation and Specification section.

The electrolyzer, which receives water from the purifier, requires 5.6 gallons/day to operate. The 144 gallon water tank will provide sufficient water to operate the Station for approximately 25 days at full load without refilling the tank.

The water purifier has an internal pump. Additionally, the water supply tank will be mounted high on the wall so that water can be gravity-fed on demand. Therefore, no booster pumps will be required.

Water Purifier

The operation of the hydrogen electrolysis generator requires ASTM Type II de-ionized (DI) water. That is, water having greater than 1 megohm-cm resistivity. Water is de-ionized by removing ions, such as cations from sodium, calcium, iron, copper and anions such as chloride and bromide. The process removes all ions except H_3O+ and $OH-$, but it may still contain other non-ionic types of impurities such as organic compounds that will also need to be filtered. De-ionized water is useful for applications such as scientific experiments and hydrogen production where the presence of impurities may be undesirable.[6]

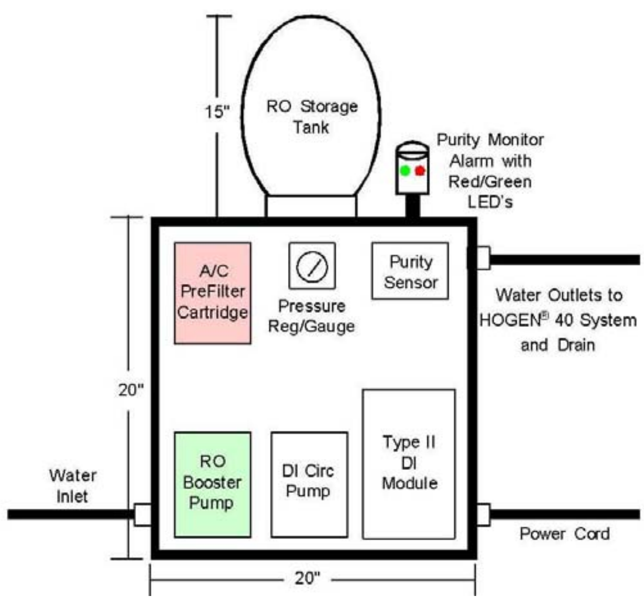

Figure 3: Diagram of Aqua Solutions Water Purification System

The water purifier passes tap water through filter cartridges containing beds of cationic and anionic resins which electro statically remove impurities. The water is further filtered to remove particulate impurities. The result is very pure, de-ionized water. The filters will eventually become exhausted and must be replaced. The water purification system is shown in Figure 3.[7]

The water purifier employed with the Station includes a reverse osmosis (RO) pretreatment system. This process uses pressure to force water through a semi-permeable membrane which filters impurities while allowing the pure water to pass through. The use of an RO system allows the water purifier to process virtually any quality potable tap water.

The purity of the treated water is tested by measuring the water's resistivity. This is a much quicker and less complicated procedure than chemical testing. The electrical resistance of water is very sensitive to the amount of dissolved solids it contains, and the resistivity can be tested quickly and continuously with a built-in monitor.

An Aqua Solutions Model H-40-C combination reverse osmosis plus type 2 DI (RO+DI) water purification system was selected for use in the AVRC demonstration. This unit was chosen because of the minimum operator attention and overall durability needed in expected remote environments. This system can operate with any tap water containing less than 1,000 parts per million of total dissolved solids. The system is powered by a 12 VDC power adapter which utilizes 120VAC input at 50 to 60 Hz. The system draws less than 1 amps at 110/220VAC. More detailed information is available in Appendix E, Specification Sheets.

The system is designed to produce up to 2 LPM (liters per minute) of deionized water. This converts to approximately 760 gallons per day which is more than required by the electrolyzer (5.6 gallons per day). Inlet water pressure can range from 10 to 100 psi.

In line with a zero point emission project, the Aqua Solutions system offers a discount for replacing the DI module. Due to the low level environmental hazard that occurs from the conventional disposal of ion exchange resins, Aqua Solutions accepts the return of used DI modules so that they may be recycled at the factory. A discount on future purchases of DI modules or replacement kits is then available to the consumer.[8]

Figure 4 shows an image of the Aqua Solutions unit.

Figure 4: Aqua Solutions Model H-40-C

Hydrogen Generator

The Hogen RE 40 hydrogen generator was selected for use in the Station. It produces hydrogen from water and electricity by means of Proton Exchange Membrane (PEM) electrolysis, which is just the reverse of a PEM fuel cell process. The Hogen generator produces 99.999+% pure hydrogen gas on demand.

Deionized water is introduced into the system where water is split into oxygen, protons, and electrons on one electrode (anode) by applying a DC voltage higher than a thermoneutral voltage (1.482 V). Protons pass through the polymer electrolyte membrane and on the cathode combine with electrons to form hydrogen. Passage of protons through the membrane is accompanied by water transport (electro-osmotic drag).

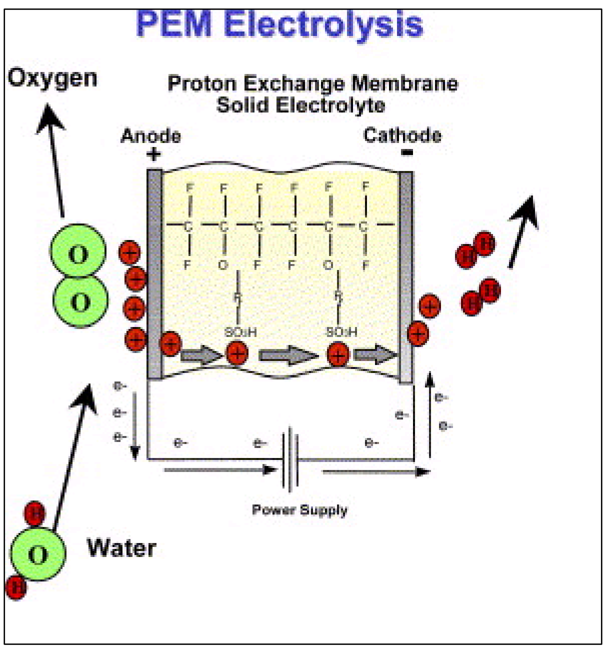

Figure 5: PEM Electrolysis Diagram

Hydrogen is dried, pressurized, and made available for storage. The generator itself produces no greenhouse gases. Hydrogen, water, and oxygen are the system's only emissions.

The principle of the PEM electrolyzer is just the reverse of the PEM fuel cell. (See Figure 5)[9] However, the materials used in the equipment are generally different. Carbon materials, such as catalyst support, porous electrode structures (carbon fiber paper or carbon cloth) and bi-polar plates, commonly used in fuel cells cannot be used on the oxygen side of a PEM electrolyzer due to corrosion. Therefore, metallic components are primarily used in PEM electrolyzers. The catalyst is typically platinum or platinum alloys. Just as in fuel cells, individual electrolyzer cells may be stacked in order to achieve the desired voltage output.[9]

The Hogen RE hydrogen generator has internal water circulation pump, oxygen/water phase separator, hydrogen/water phase separator, hydrogen dryer, hydrogen management manifold, and electronic controls. Auxiliary equipment that must be incorporated includes the power supply, purified water supply system, and hydrogen storage system.

The Hogen RE 40 was chosen because of its commercial availability, proven reliability, and relative ease of operation. There is a nominal amount of user inputs to the Hogen RE 40. Integration of other system components as related to the RE 40, such as the water purification system, is relatively straight forward.

The production rate and delivery pressure of hydrogen were also important factors when weighing electrolyzer options. The Hogen RE 40 delivers hydrogen at a product pressure of 200 psig at a rate of 44 SCFH.[10] However, due to support of auxiliary equipment within the electrolyzer, a fraction of the product gas is spent internally. This leads to a unit output of approximately 38-40 SCFH at full production. Additional specifications can be found in Distributed Energy's specification sheet on the Hogen RE hydrogen generator in Appendix E, Specification Sheets.

Figure 6: Hogen RE 40

The Hogen RE 40 was manufactured with renewable energy sources in mind. An optional package allows the generator to accept DC voltage in the range of 60-200 VDC. The generator may also be powered by AC current, single phase, 50/60 Hertz (Hz), at 200-240 VAC.

The RE 40 is a fully automated, pushbutton start and stop system. Another safety feature of the RE 40 is the on-board hydrogen detection system. Automatic fault detection and system depressurization also ensure safe operation of the electrolyzer unit.

Hydrogen Compressor

In order to move hydrogen from the electrolyzer into the vehicle being fueled, a pressure difference must exist. The electrolyzer produces hydrogen at approximately 200 psi, and hydrogen-fueled vehicles will require a pressure of around 5000 psi to fill their tanks. Therefore, the hydrogen must be compressed prior to the fueling process.

The Station uses a high pressure storage process to produce sufficient volume and pressure. After hydrogen is generated by the electrolyzer, it is stored at 200 psi in a low pressure accumulator tank. It is then fed to the compressor where it is compressed to a greater pressure than that required for fueling, and is discharged to the high pressure storage tanks. Figure 7 shows a diagram of the process. Note that this diagram also shows an optional accumulator tank. This tank may be used in applications where the compressor requires greater flow rate than the hydrogen generator can produce.

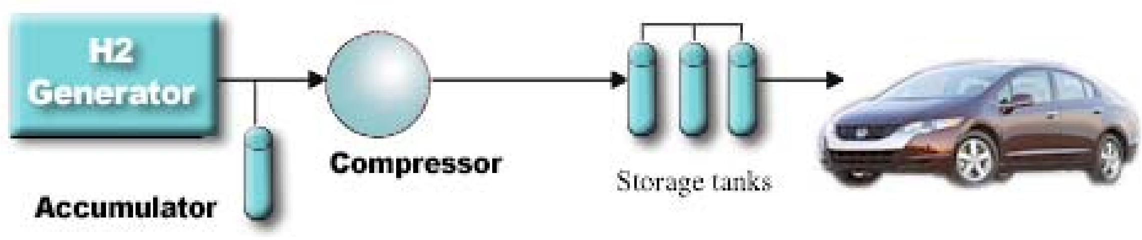

Figure 7: Diagram of hydrogen compression and storage with optional accumulator tank

Hydrogen is stored at the working pressure of the vehicle because it allows for direct filling. Pressure in the high pressure tanks can be equalized, either manually or automatically, using the manifold/regulator provided by the manufacturer. Once the storage tanks are filled, no further production is possible.

The hydrogen compressor selected for use with the Station is the Hydro-Pac C06-05-140/300LX-V. The compressor is a 5 horsepower, two-stage unit. It produces a discharge pressure of 6000 psi and displaces up to 6.4 SCFM. It requires an inlet pressure of 140 psi. Standard power for the compressor is 230 Volts and 16 Amps.

Figure 8: Hydro-Pac Two Stage Hydrogen Compressor

The compressor requires a cooling rate of 13,5000 BTU/hr to operate. For this application, a chiller will provide the cooling fluid. Chilled water will be circulated through the compressor's cooling loop that connects the gas barrel jackets, interstage cooler, aftercooler, and hydraulic oil cooler in series.

Chiller

Inefficiencies in the operation of the compressor require that the excess heat be removed from this device. For equipment in the size range considered for the Station, chilled water systems are often chosen over chilled air devices.

The chiller consists of a refrigeration unit and a closed coolant loop. The chiller's refrigeration unit is a closed-loop system that compresses its refrigerant gas, which is then passed through the condenser where it is cooled and condensed into liquid. The liquefied refrigerant is then passed through a throttling device that lowers the pressure. Finally, the refrigerant passes through the evaporator where the refrigerant draws heat from the coolant (hot water from the hydrogen compressor, in this case) and evaporates. The low pressure refrigerant vapor then repeats the cycle and the cooled water is then returned to the reservoir, and is ready to be recirculated to the compressor.[11]

A Lytron RC045 recirculating liquid chiller was selected as the cooling device for the hydrogen compressor. The chiller consists of a refrigeration system, coolant loop, and electronic controls. Coolant is pumped from the chiller's internal reservoir to the hydrogen compressor at a rate of 4.3 gallons/minute. After circulating through the hydrogen compressor, the coolant returns to the chiller where it flows through the internal heat exchanger to be cooled.

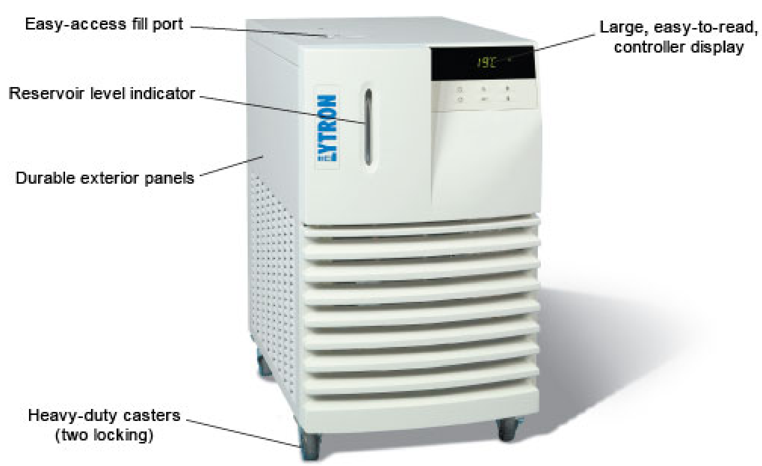

Figure 9: Lytron Kodiak Recirculating Chiller

At an ambient temperature range of 50 - 90°F, the chiller has a cooling capacity of 20,100 Btu/hr, which is sufficient for cooling the hydrogen compressor. Figure 9 shows the Lytron chiller.[12]

External Hydrogen Storage and Supply

One of the challenges faced when producing hydrogen is storage. Whether the application is hydrogen-fueled vehicles or large scale hydrogen production, it is vital to have safe, reliable storage capabilities that will not fail prematurely over time.

For applications where hydrogen is produced in larger quantities for storage, conventional steel and aluminum storage tanks are typically used. These tanks routinely handle pressures up to 5800 psig.[13] These storage tanks are safe and reliable as long as they are used properly and inspected regularly. They generally require flow controls, pressure relief systems, and detection components to operate properly. Ancillary equipment, such as piping, seals, and joints, must also be suitable for hydrogen use.

Hydrogen is produced for the Station by a Hogen RE 40 electrolyzer at 200 psig and a rate of 44 SCFH.[14] However, a vehicle being refueled would require pressure of approximately 5000 psig in order to approach its maximum capacity. Further, a flow rate of 40 SCFH would create a very slow refilling process. To address this, external hydrogen storage tanks are employed, and will receive hydrogen from the compressor at 6000 psig. Per DOT regulations, the storage system must have controls to ensure that tanks are not over-pressurized.

Being a relatively new technology, dispensing systems for the hydrogen refueling stations are not readily available on the commercial market. Companies such as Air Products, Linde Gas, and Powertech offer systems that include storage or a complete turn key system. It is reasonable to assume that this component has not reached levels of customer demand that have allowed companies to develop it as a stand-alone product. The option chosen for the Station is to acquire the necessary distribution equipment from the supplier of the storage systems, Air Products.

INSTALLATION AND SPECIFICATIONS

This section of the report provides details for the construction of the Station. The intent of this section is to provide equipment specifications and connection information for qualified builders to use when designing and building a similar hydrogen refueling system. The components were selected as representative of equipment matching required specifications for the Station. Other components may be commercially available, and could be used instead of those specified below. This document only serves as a guide to knowledgeable individuals, and should not be used as an engineering blueprint.

The general arrangement of the Station's components is shown in Figure 10. More detailed drawings are shown in Appendix C.

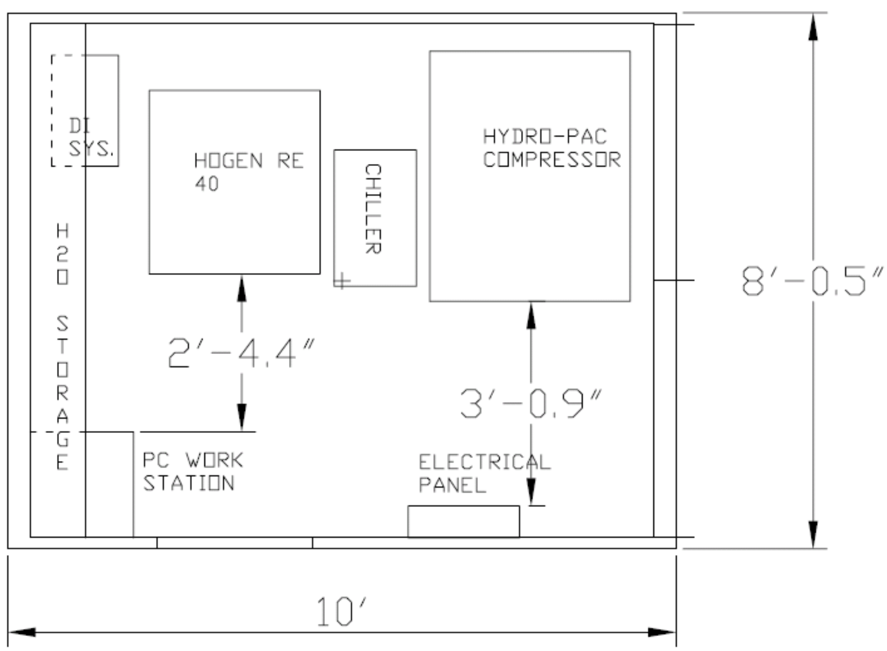

Figure 10: General cargo container equipment layout. Note: Dimensions are approximate, technical drawings can be found in Appendix C

System Container

Components of the Station will be mounted inside a steel dry cargo container. The container can be customized according to the requirements of individual applications. In this case, the container will be sized at 10 x 8 x 8.5 feet, with a weight of approximately 2500 lbs. The insulated walls and frame are constructed of steel. The flooring can be of steel or plywood.

Table 1
Dry Cargo Container Specifications

Physical Characteristics		
Exterior	120 x 96 x 102 inches	L x W x H
Interior	112 x 92.5 x 94 inches	L x W x H
Weight	2500 pounds	
Volume	566 ft^3	
Walls	Corrugated Steel	Walls are insulated
Flooring	1-1/16 inch	Marine grade plywood

Note: These dimensions are approximate and will vary depending on the individual container and any customization.[15]

The container will be carried on the bed of a flatbed truck, and can be unloaded at the refueling site when needed. A lift bar can be fabricated to assist in the lifting of the container, as by a crane.

This type container generally has a double door on one end, with the other end closed. However, for this application an extra door will be installed on the side wall near the closed end of the container. This will serve as an entrance and egress to comply with safety standards, as well as aiding in ventilation. The configuration of the doors is shown in Figure 11.

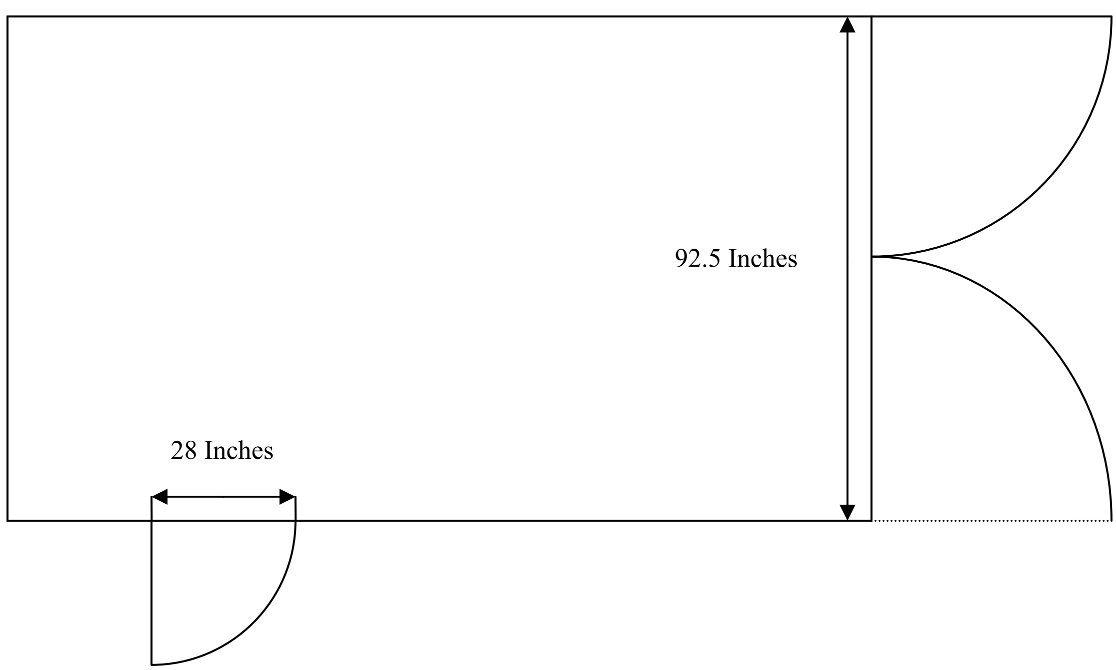

Figure 11: Configuration of Container Doors

Components are to be securely fastened to the walls or flooring of the container during installation. Applicable installation regulations should be followed during the construction of the Station, and work should only be performed by qualified contractors. See Appendix A for a listing of some of the applicable standards.

Electrical Power Source

The Station is designed to operate in remote locations, such as areas that are not accessible to the electric utility grid. Therefore, all electricity will be produced by an on-board diesel powered generator. Because of space, temperature, and ventilation issues, the generator will be mounted to the front end of the Station's container. The steel floor railings of the container will be extended approximately 7 feet in order to support the generator. With the generator attached to the container, the entire Station can be removed from its transport truck together, making hauling and set-up simpler.

The generator was sized according to the electrical load of the Station's components. The electrical load of the components is approximately 33 KVA. It was calculated that a 50 kW generator would be required to handle the startup loads and cumulative operating loads of the components. The Generac Power Systems 50 kW Diesel Engine Model SD050 generator was selected for use with the Station. Table 2 shows specifications for the unit.

There are many on-line software programs that may be employed to determine generator size. It is the responsibility of the engineer of record to determine the correct size generator for a given application.

Table 2
Generac Power Systems 50 kW Diesel Engine Generator – Model SD050

Operating Data		
Output Voltage	120/240 V	
Phase	3	
Frequency	60 Hz	
Rated Current	120 A	
Physical Characteristics		
Size	92.9 x 40 x 55.1 inches	L x W x H
Weight	2900 lbs	
Heat Rejection		
Coolant Capacity - System	4.5 gallons	
Coolant Capacity - Engine	2.75 gallons	
Heat Rejected	109,000 Btu/hr	
Coolant Flow	28 gpm	
Max. Air Temp. to Radiator	140°F	
Max. Ambient Temp.	122°F	
Engine Characteristics		
Rated RPM	1800	At 60 Hz
HP	52	At rated kW
Fuel Consumption	3.1 gal/hr	At 100% load
Duration Factors		

Temperature		
4% for every 10°F above	77°F	
Altitude		
2.6% for every 1000 ft above	3500 ft	

The Generac generator will draw its fuel from the transport truck's fuel tanks. This will allow the Station to operate while not requiring that a separate fuel tank be hauled to every work site. To connect the generator to truck fuel tank, the following will be needed:

- 12 V Electric Fuel Pump Harness
- 115V Receptacle
- Electric Fuel Pump, Filter & Water Separator
- 5/16 inch Fuel Hose
- Adapter & fittings to connect to truck fuel tank

If the Station is removed from the truck, it will require a fuel supply for operation. This may be a permanent on-site storage tank or a portable storage tank with associated pumping equipment.

A licensed electrician should be used to install and connect the generator, and the National Electrical Code (NEC) should be used as the basis of this installation. Power quality issues can be mitigated with a proper design based on the NEC.

Electrical Interface

Electricity will be routed from the generator to a load panel. Being an essential element of any significant electrical installation, panels are widely available on the commercial market. The panel selected to be installed as the Station's main electrical interface is a typical 120/240 Volt breaker panel used for small industrial applications. Table 3 shows the electrical load of the components.

Table 3 Component Electrical Ratings

Description	Rated Amps	Breaker Size	Conductor	Conduit
Compressor	16	20	12	1
Heater	18	30	10	1
Hogen Electrolyzer	45	50	8	1
Chiller	19.6	30	10	1
Water Purifier	2	15	12	1
Receptacle	15	15	12	1
Receptacle	15	15	12	1
Lights	15	15	12	1
Comp. Receptacle	15	15	12	1
Ventilation	3.6	15	12	1

Total kVA = 33.26

Note: Specifications taken from respective manufacturers' published information.

The panel will be mounted to the inside wall of the Station's container. It will be mounted close to the main door and will act as the main power control panel for all components. Additionally, its location will make it easily accessible in case of an emergency, when power may need to be turned off quickly. A wiring diagram of the load panel is provided in Appendix C.

As with any electrical application, a licensed electrician should be used to install and connect the generator to the SEP and the SEP to each of the Station's components. The National Electrical Code (NEC) and all applicable regulations should be followed for this installation.

Water Supply

The Station will require a water supply to operate the hydrogen generator. Since the Station is designed to operate in locations without water utilities, the water will be contained on-board in a built-in water supply tank. This tank will be fabricated from steel and attached to the container wall at the opposite end from the doors. It will run the entire 92.5-inch width of the back wall and will be 36 inches high and 10 inches deep. The tank will hold approximately 144 gallons of water. The hydrogen generator will use only about 5.6 gallons per day, so this tank will provide enough water for extended use without refilling.

Water will flow from the supply tank via an outlet adapted for a 1/4" "John Guest" push-to-connect fitting, which accepts 1/4" polyethylene tubing. A port will be located on top of the container to serve for filling and venting the water supply tank.

Water Purifier

All water supplied to the hydrogen generator must first be purified. This is performed by the Aqua Solutions Deionizer. Water is supplied to the deionizer via 1/4" Outer Diameter (OD) polyethylene tubing. The tubing is connected from the storage tank to the deionizer via "John Guest" push to connect fittings. Again, 1/4" polyethylene tubing is used in conjunction with "John Guest" push to connect fittings to supply water from the deionizer to the Hogen hydrogen generator. These connections are shown in Figure 5. Table 4 shows specifications for the deionizer.

Table 4
Aqua Solutions Model H-40-C

Water Purification		
Maximum Flow Rate	2 Liters/min	
Minimum Water Purity	>2 Megohm-cm	
Maximum Allowed Total Dissolved Solids (TDS)	1000 PPM	
Reservoir Storage Tank Capacity	10 Liters	7 Liters usable
Ambient Operating Temperature	50 – 104°F	
Physical Characteristics		
Size	20 x 12 x 20 inches	L x W x H
Weight	50 lbs	
Electrical Characteristics		
Input Voltage	100/240 VAC	
Phase	1 / 3	
Frequency	50/60 Hz	
Input Power	<2.0 A	
Operating Power	<2.5 A	
Interface Connections		
Electrical Conductor	#12	THHW
Electrical Conduit	1”	PVC
Recommended Breaker	15 A	
H_2O Inlet/Outlet	1/4” polyethylene tubing	John Guest push-to-connect fittings

Hydrogen Generator

Hydrogen is generated for the Station by a Hogen RE 40 Hydrogen Generator. See Table 5 for specifications. The hydrogen product supply from the Hogen RE 40 incorporates 1/4” Parker CPI S.S. compression fittings and 1/4” OD tubing to supply hydrogen product to downstream gas equipment. The 1/4” OD tubing is recommended to be electro polished stainless steel. Swagelok supplies this tubing as part number SS-T4-S-035-20. Wall thickness of the tubing is 0.035 inches and the tubing is supplied in a nominal length of 20 feet.

Before reaching the Hydro-Pac Compressor, a manual ball valve should be installed on the hydrogen product line for manual flow control. Swagelok manufactures an applicable valve, part number SS-43GS4. Before the manual ball valve, a check valve should be installed in the product line to prevent accidental hydrogen flow to the Hogen unit. Swagelok manufactures an applicable check valve, part number SS-CHS4-5. Following the manual ball valve, a pressure gauge should be installed on the process line. Swagelok provides an applicable pressure gauge (PGI-63C-PG300-LAQ) displaying pressures from 0-300psig. This pressure gauge should be integrated into the process line via a “T” fitting with an applicable tubing adapter on the middle port. An applicable Swagelok fitting part number is SS-400-3. Following the pressure gauge assembly, a Relief valve should be placed on the process line for control of overpressure in the system. An appropriate set up could be assembled using a Swagelok Tee Fitting (SS-400-3-4TFT) and a Swagelok Proportional Relief Valve (SS-RL3M4-S4) set to a cracking pressure of 225psi.

For the product ventilation outlet, 3/8” OD tubing is required. This can either be stainless steel tubing (for rigidity and durability) or copper tubing that is purchased at any hardware store. Vent lines should be routed to the exterior of the containment following NFPA and other rules and guidelines. The Hogen Oxygen ventilation port should be connected via “John Guest” 1/4” push to connect fittings to polyethylene tubing which is routed to the exterior of the containment unit and vented following correct NFPA and other applicable guidelines. Water ventilation is connected in a similar manner as the oxygen ventilation. However, the vented water could be collected and recycled back into the water supply tank or into the Aqua Solutions H_2O storage container. If the water is collected and disposed of rather than being reused, all applicable local environmental regulations must be followed. Connections are shown in Figure 12.

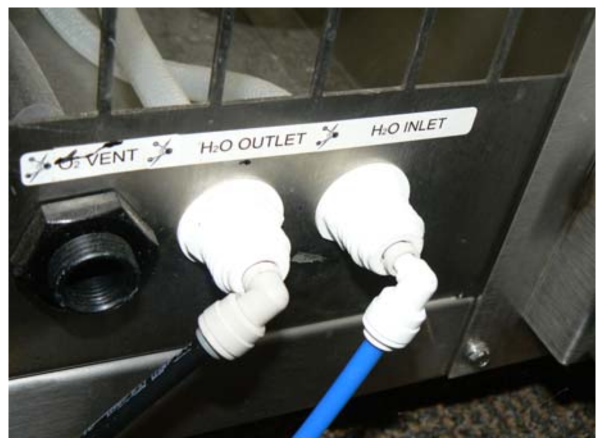

Figure 12: Terminal Connections for Relion Fuel Cell and I comms Interface screen

Table 5 Hogen RE 40 Hydrogen Generator

Hydrogen Production		
Production Rate	44 SCFH (1.16 Nm^3/h)	Doesn't consider internally spent hydrogen
Delivery Pressure	200 psig	
Purity	> 99.999%	Requires 10% purge rate
DI Water Requirements		
Max Use Rate	5.6 gpd	
Water Quality	ASTM Type II (required)	ASTM Type I (preferred)
Physical Characteristics		
Size	30.9 x 38.1 x 41.4 inches	L x W x H
Weight	600 lbs	
Enclosure rating	NEMA 3R, IP22	Outdoor and intrusion ratings
Storage/Transport Temperature	41°F - 140°F, 0 – 95% humidity	Non-condensing
Ambient Operating Temperature	41°F - 122°F, 0 – 95% humidity	Non-condensing
Ventilation Requirements	> 1000 CFM	
Electrical Characteristics		
Grid Service Rating	10 kVA	
Input Voltage	200-240 VAC (60-200 VDC)	
Phase	1	
Frequency	50-60 Hz	
Max Power Consumption	10 kW	
Power/Volume Gas	15-18 kWh/1000 ft^3 H_2	
On Board Breaker Rating	30 A	
Interface Connections		
Electrical Conductor	#8	THHW
Electrical Conduit	1"	PVC
Recommended Breaker	45 A	
H_2 Product	Parker 1/4" CPI	Stainless steel compression tube fittings
H_2 Vent	Parker 3/8" CPI	
O_2 Vent	3/8" FNPT	
H_2O Inlet/Vent	1/4" polypropylene	Push-to-lock tube fittings

Table 6 Electrolyzer Hydrogen Production[14]

H_2 Production	
Load Provided (Kilowatts)	**H_2 Output (SCFH)**
1 kW	5.7
1.5 kW	8.6
2 kW	11.4
2.5 kW	14.3
2.7 kW	15.4
3 kW	17.1
3.5 kW	20
4 kW	22.8
5 kW	28.5
6 kW	34.2
7 kW	40
Note: A minimum of 1 kW must be supplied to the electrolyzer	

The Hogen RE hydrogen generator is sensitive to movement and vibration during operation. It is possible that vibrations caused by the operation of adjacent components, particularly the hydrogen compressor, would cause disruption in the normal operation of the generator. Therefore, to ensure proper function is maintained, components such as the compressor may need to be isolated by use of vibration dampeners. At a minimum, dampeners should be applied to the generator.

Hydrogen Compressor

A Hydro-Pac Hydrogen Compressor Model C06-05-140/300LX is being used in the Station.[16] See Table 7 for compressor specifications.

As discussed above, hydrogen is routed from the Hogen to the compressor via 1/4" OD tubing. A tubing-to-thread adapter is needed. The compressor uses 1/2" FNPT threads, so a Swagelok fitting, part number SS-400-1-8 would be sufficient.

Coolant is fed to the compressor by the chiller unit. The chiller unit plumbing package includes Nylabraid™ tubing and Armorflex™ insulation. NPT thread-to-tubing barb fittings are supplied with the optional plumbing package. The compressor cooling inlet/outlet connections are 3/4" NPT female threads.

Due to the high pressure outlet of the compressor, extreme caution must be taken when specifying the connections. Outlet fittings should be rated to withstand at least 6600 psi. It is imperative to follow all manufacture recommendations on connections, fittings, piping, and any and all gas handling equipment. Failure to properly specify and install components may result in serious injury or possibly death. While part recommendations have been made through out this document, it is the responsibility of the final design and build team to ensure proper part selection and installation.

Using a thread-to-tubing adapter (such as Swagelok 2507-810-6 Union) high pressure tubing should be connected to the outlet of the compressor. A possible tubing option may be Swagelok SAF 2507 Super Duplex tubing. With an outer diameter of 1/2" and a nominal wall thickness of .065", this tubing can withstand working pressures of 10,100 psi.

Following the compressor outlet, a pressure relief valve should be installed to prevent over pressurization of the system. Bauer Compressors manufactures an acceptable pressure relief valve, VAL-0154, rated for 6500psi. This relief valve should be connected to the process line using a union tee fitting such as Swagelok 2507-810-3. Use of this union fitting also requires a male tubing adapter such as Swagelok 2507-8-TA-1-4 and a Female NPT Hex Coupling; Swagelok part number SS-4-HCG-10K.

For process flow control, a manual ball valve such as Swagelok SS-H83PS8 should be installed after the pressure relief assembly. Final connection to the Air Products high pressure storage system is unclear and pending design specifications from Air Products. However, a possible quick connection couple supplied by Snap Tite (part number SPHC8-8F and SPHN8-8F) would provide an acceptable means of quick connection.

Table 7
Hydro-Pac Hydrogen Compressor Model C06-05-140/300LX

Hydrogen Compression		
Outlet Capacity at Min. Inlet	3.1 SCFM	
Outlet Capacity at Max. Inlet	6.4 SCFM	
Minimum Inlet Pressure	140 psig	
Maximum Inlet Pressure	300 psig	
Discharge Pressure	6000 psig	
Physical Characteristics		
Size	45 x 36 x 36 inches	L x D x H
Weight	570 lbs	
Heat Rejection		
Cooling Type	Chilled Water	
Heat Rejected	13,500 Btu/hr	
Coolant Flow	2 gpm	
Electrical Characteristics		
Input Voltage	230 VAC	
Phase	3	
Frequency	60 Hz	
Current	16 A	
Motor Size	5 hp	
Max Power Consumption	3.8 kW	
Interface Connections		
Electrical Conductor	#12	THHW
Electrical Conduit	1”	PVC
Recommended Breaker	50 A	
Hydrogen Inlet	1/2" FNPT	Adapted to 1/4” stainless steel tubing
Hydrogen Outlet	1/2" FNPT	Rated for 6600 psig; Connected by thread-to-tubing adapter to outlet tubing
Coolant System	3/4" FNPT	Connected by thread-to-tube barb fittings to Nylabraid tubing with Armor Flex insulation

Chiller

The hydrogen compressor is cooled by a Lytrol Kodiak Model RC045 chiller. See Table 8 for chiller specifications.

The coolant fluid is water, and the inlet and outlet connections are 1/2" FNPT that connects to Nylabraid™ Hose covered with Armorflex™ insulation which, in turn, are connected to the compressor’s 3/4” FNPT, as discussed above.

The cooling system is closed-loop, so a constant supply of water is not needed. Water in the chiller’s reservoir is refilled only as needed. Therefore, it is not necessary to have a permanent connection for this refilling. Water is simply added through the easy access fill port located on top of the unit.

For safety, the Remote Start option is included with the chiller. This allows power to the chiller to be cycled through a relay so an external circuit can control the unit's on/off function.

Table 8
Lytrol Kodiak Model RC045 Chiller

Cooling		
Cooling Capacity	20,100 BTU/hr	
Temperature Stability	±0.1°C	
Coolant Temperature Range	40 - 95°F (5 - 35°C)	
Ambient Temperature Range	50 - 95°F (10 - 35°C)	
Reservoir Capacity	6 Gallons	
Pump Displacement	4.3 gpm	Positive Displacement, Brass
Physical Characteristics		
Size	21.4 x 27.8 x 31.9 inches	L x W x H
Weight	270 lbs	
Heat Rejection		
Cooling Type	Chilled Water	Closed Loop
Electrical Characteristics		
Input Voltage	208/230 VAC	
Phase	1	
Frequency	60 Hz	
Current	19.6 A	
Compressor Size	1.5 hp	
Interface Connections		
Electrical Conductor	#12	THHW
Electrical Conduit	1"	PVC
Coolant Inlet	1/2" FNPT	Connected by thread-to-tube barb fittings to Nylabraid tubing with Armor Flex insulation
Coolant Outlet	1/2" FNPT	Connected by thread-to-tubing adapter to outlet tubing

External Hydrogen Storage and Distribution

Hydrogen storage for the Station will be handled by a trailer-mounted storage system produced by Air Products. This storage system will be transported on a trailer separate from the Station's container and generator, and will consist of storage containers, connectors, piping, controlling devices, and dispensing hardware. This trailer may be pulled by the transport truck or another vehicle.

The high pressure tanks will be limited to 5000 psig, but can be arrayed to increase the amount of hydrogen stored, and provide a greater capacity for vehicle refueling. During installation and use of such a system, special attention should be given to the International Code Council (ICC) International Fire Code (IFC) and NFPA 55, Standard for Gaseous Hydrogen Systems at Consumer Sites. The hydrogen tanks must be certified for use with NGV-2, ISO 11439, FMVSS304, and CSA B51 Part 2.[17] In order to be transported carrying hydrogen, these cylinders must be certified to a DOT standard (HMR; 49 CFR Parts 171-180) which is administered by the RSPA branch of the U.S. DOT.[18] Information regarding DOT regulations for Hydrogen fuel transportation may be found at the DOT Hydrogen Portal website.[19]

The dispensing system will be an integrated part of Air Products high pressure storage system. The technology for dispensing hydrogen to refuel vehicles is relatively new, so commercial availability of these units is limited. The IFC and NFPA 52, Compressed Natural Gas (CNG) Vehicular Fuel Systems, have important requirements regarding dispensing systems, and must be followed.

Instructions for connecting the high pressure storage system to the Station's hydrogen compressor will be provided by Air Products.

Heating and Ventilation

Equipment in the Station has an operational temperature range of 40 - 120°F. Therefore, heating and ventilation systems may be necessary to keep the interior of the container within this range. Additionally, the ventilation system will be used as part of the safety system, evacuating any hydrogen that could have resulted from an accidental release. Calculations for sizing these systems are shown in Appendix D.

A 5.6 kW space heater was selected for use in the Station based on the expected ambient winter temperatures and interior air changes. This unit will be mounted on the wall and ceiling. A wide variety of suitable space heaters is available commercially, and should be selected to suit expected environments.

The ventilation system will be mounted in the roof of the container. It is expected to run only in the case of emergency, but can be started if additional ventilation is needed to control the interior temperature. The fan sized for the Station is a Broan Model 350 that will move air at a rate of 1050 SCFM. Depending on the configuration of the Station and its expected environment, it may be beneficial to use a positive pressure blower rather than a ventilation fan. Decisions on specific equipment would be made by the engineer of record.

Table 9
7.5 kW Space Heater

Electrical Characteristics		
Input Voltage	240 VAC	
Phase	3	
Frequency	60 Hz	
Current	18 A	
Output	7.5 kW	
Interface Connections		
Electrical Conductor	#10	THHW
Electrical Conduit	1"	PVC

Table 10
Roof Mounted Attic Ventilator

Electrical Characteristics		
Input Voltage	120 VAC	
Phase	1	
Current	3.6 A	
Circulation	1050 SCFM	
Interface Connections		
Electrical Conductor	#12	THHW
Electrical Conduit	1"	PVC

Uninterruptible Power Supply

The Station's safety system incorporates an uninterruptible power supply (UPS) to maintain operation of vital safety equipment during a generator power failure. The power failure may be a result of generator failure or emergency shutdown. When an emergency stop or hydrogen sensor is triggered, the circuit disables the Hogen, the chiller, and the compressor. The UPS will maintain power to the emergency lights, ventilation fan, and safety shutdown system, including hydrogen sensors and emergency power stops.

An APC backup UPS was selected for the Station. Specifications for the UPS are shown in Table 11.

Table 11
APC Model RS Uninterruptible Power Supply

Electrical Input Characteristics		
Input Voltage	120 VAC	
Current	12 A	
Input Breaker	15 A	
Frequency	60 Hz	
Electrical Output Characteristics		
Output Voltage	120 VAC	
Output Capacity	865 W / 1500 VA	
Frequency	60 Hz	
Interface Connections		
Electrical Conductor	#12	THHW
Electrical Conduit	1”	PVC

MAINTENANCE AND OPERATION

Proper maintenance is required on all major pieces of equipment for longevity and proper operation. Below is a general description of the maintenance requirements for the equipment involved in the Station.

Hogen RE 40

The Hogen RE 40 maintenance requirements are relatively straight forward. As suggest by Distributed Energy personnel and outlined in the Hogen RE 40 user's manual[20], the internal hydrogen gas sensor must be calibrated every three months. This procedure involves following the steps outlined within the Hogen user's manual. If the unit will not be in service for any extended period of time, the cell stack must be hydrated by following the steps outlined in the Hogen user's manual. Please contact Distributed Energy directly for any other specific maintenance inquires.

Hydro Pac Hydrogen Compressor

The Hydro Pac compressor unit will require maintenance as suggested by the manufacturer. Hydro Pac literature suggests the following maintenance schedule[21]:

- 4,000 operating hours – change high pressure packing, reverse check valve seats
- 8,000 operating hours – change high pressure packing, rebuild check valves
- 12,000 operating hours – change high pressure packing, reverse check valve seats
- 16,000 operating hours – complete unit rebuild; includes high pressure packing, check valve rebuild and hydraulic seals

Hydro Pac will demonstrate these operations during the final assembly of the unit at the Hydro Pac facility. The supplied maintenance schedule is dependent on the operation conditions of the unit. Yearly oil filter replacement and oil evaluation/ replacement are also suggested by Hydro Pac personnel.[22]

Lytron RC045 Chiller

Proper maintenance of the Lytron Chiller unit is also suggested to maintain proper cooling duties for the compressor unit. Daily noise level checks, coolant level checks, and condenser fin cleanliness checks are recommended. The water filter should be inspected after the first operation, and then weekly thereafter. If a deionization package is installed the water resistively should be monitored on a weekly basis, and the deionization cartridge should be replaced as needed. Since the low level pump switch is a passive, it should be inspected every six months for proper operation. Algae inhibitors should be monitored in the water reservoir to prevent the formation and growth of algae colonies.

As indicated in the user's manual, pump motor bearings should be oiled as indicated. The pump strainer should be periodically checked and cleaned. Pump replacement is required by the following schedule:

- Positive Displacement – every 7,000 operating hours
- Centrifugal – every 28,000 operating hours
- Turbine - every 28,000 operating hours

Lytron should be contacted for any further questions regarding specific maintenance practices[23].

Generac Diesel Generator

Maintenance requirements are specified by individual manufacturers depending on models and service contracts. Maintenance schedules generally include the following[24]:

- Daily
  - Overall inspection
  - Coolant heater inspection
  - Coolant Level inspection
  - Oil level check
  - Fuel level check
  - Air charge piping check
- Weekly
  - Check and service air filter
  - Check and service battery components
  - Drain fuel filter
  - Drain water trap from fuel tank
- Monthly
  - Check coolant concentration
  - Check drive belt
  - Drain exhaust concentrate
  - Check starting batteries
- Six Months
  - Change oil and filter
  - Change coolant filter
  - Change air cleaner element
  - Clean crankcase breather
  - Check radiator hoses
  - Change fuel filters
- Yearly
  - Clean cooling system

Maintenance and service for the generator may be contracted to the manufacturer, or a secondary maintenance provider. An evaluation of onsite personnel should be taken into account when considering maintenance options for a diesel generator set.

SAFETY

Using hydrogen as an on-site fuel carrier presents unique safety-related challenges. Technologies related to the widespread commercial use of hydrogen are relatively new, so the development of safety codes and standards is a dynamic, on-going process. Many organizations are working independently and cooperatively to develop safety codes and standards that will enable the deployment of hydrogen technologies and the development of the hydrogen economy. Until the development of safety codes and standards catches up with the growth of technology, best practices will have to be adopted from those codes and standards which have been published, as well as from effective engineering and design approaches that already been implemented and proven. By following established protocol, the hazards related to hydrogen use can be minimized. A list of published safety codes and standards can be found in Appendix A.

For the Station, safety is the most important priority. During the design process, consideration was given to factors such as combustion, pressure, and material embrittlement. By mitigating these potential hazards, the system can be implemented with very little risk. It is incumbent upon any individual or organization seeking to build a hydrogen refueling station to ensure that all applicable codes and standards are met.

The information in this report is provided for educational purposes only. Neither the North Carolina Solar Center nor North Carolina State University is a Professional Engineering firm. Information in this report should not be used as final design decisions. A licensed professional should be consulted before utilizing information provided in this report in engineering calculations, decisions to purchase equipment or fabrication of any systems.

Pressure Hazards

When systems use hydrogen in a gaseous form, and that gas is stored under pressure, special precautions must be taken to reduce the resulting risks. The Station will produce its own hydrogen and compress it before storing it in a high pressure (5000 psig) storage system.

It is important that no component of the Station exceed its Maximum Allowable Working Pressure (MAWP). Therefore, the storage tanks will be equipped with pressure relief valves, pressure regulators, and gauges by the supplier. It is also possible to purchase these valves and gauges separately, but it is recommended that this safety equipment come directly from the manufacturer of the storage system. These valves and gauges may be unique to the system and the manufacturer will have the best insight to its design. For the hydrogen production process two locations serve for high pressure release. A high pressure relief valve is place on the high pressure output of the compressor and is rated for 6500 psig (see component H107 in drawing “H1,” Appendix C).

Not only is it vital that the piping used to move hydrogen between the equipment and the storage tanks be rated for applicable pressures, but it is also important that the system be provided with isolation valves to stop the flow of hydrogen in case of an emergency. As noted in drawing "H1" in Appendix C, manual isolation valves have been placed inline between the Hogen electrolyzer and the hydrogen compressor and between the compressor and the final high pressure storage connection. These isolation valves are listed as components H101 (low pressure side) and H109 (high pressure side) in drawing "H1."

As an added measure of safety, the high pressure storage tank system will be isolated from the other components of the Station. This storage system will be transported on a separate trailer and only connected to the Station when in operation. This isolation prevents potential buildup of large amounts of hydrogen inside the Station, as well as removes the storage system from potential ignition sources such as the electrical system, hydrogen compressor, and diesel generator. Both the high pressure and the low pressure storage systems are to be provided with grounding straps for added safety.

Codes and standards exist for pressure vessels, and should be closely adhered to for any pressurized hydrogen application. ISO/TR 15916 states hydrogen storage containers should be:

- Designed, built and tested in accordance with appropriate standards and codes;
- Constructed with materials appropriate to the application;
- Have appropriate thermal insulation, if required;
- Equipped with shutoff valve, pressure control system, vent system, and pressure relief valves to prevent overpressure;
- Located according to appropriate codes and standards regarding quantity and distance;
- Legibly marked in accordance with applicable codes and standards.

Additionally, ISO/TR 15916 states the following considerations for piping, joints, and connections should be followed:

- Designed, built and tested in accordance with appropriate standards and codes;
- Constructed with materials appropriate to the application;
- Have appropriate flexibility;
- Located according to appropriate codes and standards;

- Should not be located beneath electrical power lines or buried below ground;
- Corrosive resistant materials should be used;
- Appropriate supports, guides, anchors, pressure-relief devices, and thermal insulation should be used;
- Should be marked to indicate contents and direction of flow.[25]

Combustion Hazards

Due to design limitations respective to mobility on public roads, containment of the system is met with an elongated storage container. Unfortunately, the elongated storage container provides an inherently hazardous environment when considering the effects of rapid combustion of a hydrogen cloud. If rapid combustion were to occur within the container, the channel shape encourages flame acceleration. "If the compartment has a vent opening only in one of the side-walls, it is even more important to avoid an elongated shape."[26] This is because the flame now has a longer distance which to accelerate over and turbulence of the expanding gas increases rapidly. To reduce turbulence, placement of the equipment within the container should take into account ventilation areas and the direction of both the burning velocity and gas velocity if an explosion were to occur.

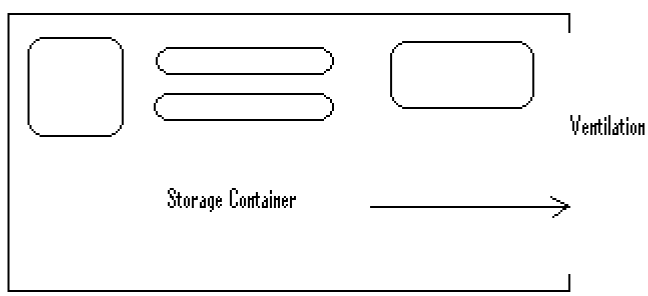

Figure 13: Example of equipment placed with minimal blockage of ventilation path

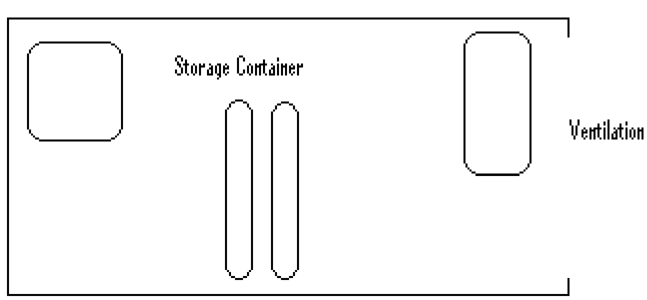

Figure 14: Example of equipment interfering with proper ventilation path.

The equipment and storage capabilities of the components contained within the cargo container were evaluated to estimate the possible disaster situations. A 10 foot cargo container, as mentioned in this report, has an approximate internal volume of 566 cubic feet. Equipment within the container reduces the air volume to approximately 481 cubic feet. The flammability limits of hydrogen by volume range from the lower flammability limit (LEL) of 4% to the upper flammability limit of approximately 90%.[27] 4% of the cargo container volume equates to 19.2 cubic feet. At 70°F and 1 atmosphere, this is equal to 0.05 lb-moles of hydrogen within the container. At full production, the Hogen RE 40 would be required to run for 24 minutes with all product being leaked to the atmosphere to bring the atmosphere of the cargo container to the LEL of hydrogen, according to the production capacity information provided by Distributed Energy.[28] A leak time of just over 12 minutes at full production would be required to bring the atmosphere to 50% of the LEL.

Hydrogen has a high probability for detonation over deflagration.[29] Therefore, ventilation considerations should be taken into account with the design on the cargo container. The cargo container should be modified to include doors at both ends, as well as ventilation windows on the sides of the container. A forced ventilation system should be relatively easy to install on the roof of the container to circulate air out of the container and prevent the build up of an ignitable gas cloud. This ventilation system is discussed in more detail in following sections of the document.

It is also strongly recommended that any hot surface, such as compressors or electrical generators be removed or separated from environments where the formation of a hydrogen cloud is possible. For the Station, the diesel generator is being mounted outside of the container. An alternative would be to construct a solid blast wall inside the container between the hydrogen environment and the diesel generator. This option would allow all the components to be housed inside the container.

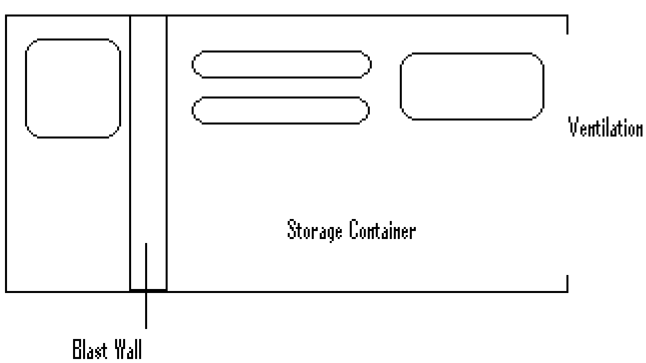

Figure 25: Example of a solid blast wall to separate diesel components from a possible hydrogen explosion.

The primary hazard presented by hydrogen systems is accidental combustion. The most common cause of combustion accidents is inadvertently released hydrogen. This can occur because of defective piping, valves, and other gas-carrying devices, as well as faulty installation and improper maintenance of equipment. When hydrogen is released and mixed with an oxidizer such as air, and an ignition source such as open flames, hot surfaces, or friction is present, combustion can occur. The principle forms of combustion are fire and explosion.

According to ISO/TR 15916, Technical Report: Basic Considerations for the Safety of Hydrogen Systems, the following techniques should be followed to prevent the formation of unwanted hydrogen/oxygen mixtures:

- Purging – Inert gas should be used to purge a system of air prior to charging the system with hydrogen. The system should also be purged of hydrogen before air is allowed to re-enter.

- Leak-free system – Systems should be leak tested prior to its initial operation and frequently during its operating life. Any detected leaks should be immediately repaired.

- Disposal/Ventilation – Properly designed ventilation systems should be used to vent hydrogen into the atmosphere and prevent its collection in confined spaces.

- Maintain positive pressure – Systems should maintain positive pressure to prevent external air from entering and mixing with the hydrogen.

In addition to ensuring that hydrogen and oxygen do not combine to form a combustible mixture, potential ignition sources should be eliminated. According to ISO/TR 15916, the following are sources of ignition which should be addressed when designing and operating a hydrogen system:

- Electrical – static discharge, electric arc, lightning discharge, electrical charge from equipment operation, short circuits, and static discharge.

- Mechanical – Impact, friction, metal fracture, tensile rupture, vibration, and flexing.

- Thermal – Open flames, hot surfaces, exhausts, explosive charges, reactive chemical materials, and shock waves.[30]

Ventilation

During the design of the container and its ventilation system, the goal of reducing the probability of a combustible from occurring is a key priority. Based on interior dimensions of a 10 ft container, a combustible atmosphere would require a volume of hydrogen at or in excess of the lower flammability level (LEL)[31]. The LEL for the chosen container is 19.2 cubic feet of hydrogen gas. This figure is 4% of the total interior air volume of the container, 481 cubic feet. Based on the expected average conditions of the container (1 atmosphere of pressure and 70°F) the following is breakdown of the estimated release of hydrogen into the environment for a worst case scenario.

- ~0.7 cubic feet of H_2 from a 1 minute Hogen leak
- ~2.5 cubic feet of H_2 from a 1 minute compressor leak

Total volume: 3.2 cubic feet, approximately 16% of LEL

With this situation in mind, a ventilation system designed for the container should change enough air so that the probability of reaching the LEL is all but zero. Note that the Hogen generator must exchange in excess of 1000 cubic feet per minute (CFM)[32]. This is a greater value than the total volume of the container, however, in the event of a hydrogen leak, internal sensors of the Hogen will cause the unit to cease further operation. Therefore, this should only be regarded as a secondary air exchanger. While it is shown that the possibility of reaching an explosive environment is low, a roof mounted exhaust fan which is capable of moving approximately 1050 CFM should be installed and supplemented by side wall mounted louvered vents for air intake to further reduce the probability of hydrogen build up during equipment malfunction.

Ventilation Requirements	
Total Air Intake	In excess of 2050 CFM
Total Air Exhaust	2050 CFM

The exhaust from the Hogen should be routed to the exterior of the container while the intake draws from the container environment.

Filtration of the intake should also be a design consideration based on expected operating environments. Replaceable/rechargeable filter units should be installed on any intake into the container unit.

The roof mounted exhaust fan should also be connected to an uninterruptible power supply in case of power failure to the cargo container.

Safety Control Equipment

Any system that employs hydrogen should be equipped with appropriate safety control equipment that complies with applicable safety standards and codes. The equipment should include warning and alarm systems that detect malfunctions and failures such as pressure changes, pump speed fluctuations, hydrogen leaks, hydrogen buildup in confined spaces, and fire. These systems should be independent of any other safety systems, and should have sufficient redundancy as to prevent any single system failure from disabling other safety components.

Safety Control Equipment incorporated into the design includes;

- External hydrogen sensors, detecting the presence of escaped hydrogen and initiating system shutdown at a volumetric concentration of 10% of LEL
- Internal hydrogen sensors on the Hogen electrolyzer which detect internal leaks from the Hogen and initiate system shutdown when a leak is present
- Uninterruptible power supply for ventilation and hydrogen sensing equipment
- Ventilation equipment to prevent a combustible atmosphere from occurring within the container
- Automatic shutdown system including the Hogen, chiller, and compressor, to be initiated by the detection of a hydrogen leak

The hydrogen system should also be equipped with flow regulation equipment and safety valves to control the flow of hydrogen during storage and use. These should be in addition to a manual or automatic process shutdown system. As with the warning and alarm systems, the flow control equipment should be designed and installed to ensure sufficient redundancy.

Active or passive hydrogen ventilation equipment should be installed to prevent the collection of hydrogen in confined spaces or remove it in the event of a leak. To allow the ventilation equipment to perform properly during accident mitigation, it should be independent of any system shutdown functions.

For an added level of safety, consideration should be given to installing fire protection equipment as part of the hydrogen system. This could include sprinkler, deluge, or dry-chemical systems. However, it should be noted that most hydrogen fires cannot be extinguished until the source of the hydrogen has been isolated. Therefore, it is important to install reliable means of flow control in conjunction with the fire protection equipment.

External remote stop sensors should be installed at each exit. In drawing "S2, Safety equipment placement" (Appendix C) example remote stop locations are shown. These locations are estimation and may be modified during final construction.

Hydrogen sensors should be placed in an elevated position near sources of potential leaks or in areas in which hydrogen accumulation is at a high probability. In drawing "S2, Safety equipment placement," example locations of hydrogen sensor placement are illustrated. These locations are estimations and may be modified during final construction. A possible hydrogen sensor to use in this design is the "PowerKnowz" Intelligent Gas Detector, manufactured by Neodym. This unit uses an audible alarm to alert personal to a 10% LEL condition. The sensor can be integrated into a control circuit by utilizing the relay contacts on the sensor.

For this design, a safety shutdown system has been illustrated by drawing "C1, H2 Safety loop connections" in Appendix C. This system incorporates an uninterruptible power supply (UPS) for operation during a generator power failure. If any remote stop or hydrogen sensor is triggered, the circuit disables the Hogen, the chiller, and the compressor. The UPS will maintain power to the emergency lights, ventilation fan, and safety shutdown system, including hydrogen sensors and emergency power stops. After being shut down by this system, each piece of equipment must be manually reset. A wiring schematic is given by drawing "C1," in Appendix C.

Hydrogen Embrittlement Hazards

Materials should be carefully evaluated for their suitability for use with hydrogen before they are incorporated into a hydrogen system. Hydrogen embrittlement is a major cause of component failure. These failures can often be unexpected and catastrophic. Metallic materials used in hydrogen applications should be tested in accordance with ISO 11114-4, Transportable gas cylinders -- Compatibility of cylinder and valve materials with gas contents -- Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement.

ISO/TR 15916 states that the risk of hydrogen embrittlement can be reduced in materials by taking the following precautions:

- Restricting the hardness of the material used to a safe value;
- Restricting applied stresses;
- Minimizing residual stresses;
- Minimizing cold plastic deformation;
- Minimizing frequent load cycles that lead to local fatigue;
- Using austenitic steels.[33]

ECONOMICS

Implementation Costs

The following table shows estimates for the various components along with the basis of that estimate. The numbers provided are based on conversations with vendors, estimates provided by the vendors, or the best available information. These numbers can change as design criteria changes and a more formal RFQ process develops.

Component	**Cost**	**Basis of estimate**
Electrolyzer[1]	$70,000	Estimate from Proton Energy Systems
Compressor[2]	$21,000	Estimate from Hydro-Pac
Chiller[3]	$6,000	Estimate from Lytrol
Water System[4]	$3,000	Estimate from Aqua Solutions
H_2 Storage & Dispensing System[5]	$10,000	Estimate
Electrical generation[6]	$15,000	Estimate from Generator suppliers
Station Container[7]	$1500	Estimate from Container Sales
Auxiliary Systems[8]	$25,000	Estimate, will vary depending on customization of Station.
Ventilation Fan	$100	Estimate from Broan
Heater	$500	Estimate from MOR Electric Heating
Fabrication	$150,000	Estimated to equal material cost
Total cost	**$302,100**	**Estimate of total installation cost**

Notes:

1. A Hogen RE40 Electrolyzer was purchased from Proton Energy Systems by the NC Solar Center for another project. The quote is based on cost of that generator.

2. Compressor cost based on an estimate provided by Tom Conelly with Hydro-Pac. Tom provided estimated pricing for both a CO 6-03-140/300 LX 3 hp and a CO 6-05-140/300 LX 5 hp compressor. The 3 hp compressor will likely be sufficient for the Station. However, if it becomes necessary to upgrade to a larger unit, the 5 hp compressor is estimated to cost $21,360. Additionally, this compressor requires a chiller.

3. Chiller estimate based on personal experience. Estimate should not be considered.

4. An Aqua Solutions water treatment system was purchased by the NC Solar Center for another project. The quote is based on cost of that system.

5. The hydrogen storage estimate is based on a typical high pressure gas cylinder. It is assumed that a cylinder will need a rack or some other means of securing it to

the vehicle. Little investigation has been done in the area of more exotic storage means thus this estimate should not be treated as firm. Dispensing units are not generally commercially available. Companies such as Air Products, Linde Gas and Powertech offer systems that include storage or a complete turn key system. It is reasonable to assume that this component has not reached levels of customer demand that have allowed companies to develop it as a stand alone product. However, it appears to be a relatively simple design problem. One solution would be for an engineer of record to design this system. Another would be to ask the supplier of the storage component to include a separate line item for this system in their response to future RFQs.

6. The estimate is provided by various generator suppliers for a 50 kW diesel-powered generator. The cost of electrical self generation is dependent on the other components chosen for the project. The design of this component is based on peak electrical loads and starting requirements for the various motor loads (i.e. compressor, chiller, generator, etc.). While the average electrical load may be much less than the rating of the electrical generator, the proper design must be able to meet highest demand seen by the generator while still being able to provide motor starting current. Estimates for the generator are based on the requirements of a 50 kW peak load.

7. A 20-foot steel shipping container is priced at approximately $1500. However, customization will be necessary to add doors, windows, ventilation openings, and an explosion wall. This customization will increase the price.

8. Auxiliary components include computers, data acquisition equipment, safety equipment, UPS, control systems, as well as piping and wiring to interconnect the various components. Additionally, because the hydrogen generator is sensitive to vibration and movement, vibration dampening devices will need to be employed to isolate each of the components. The estimate does not include ancillary devices required by individual components such as an oil reservoir for the compressor.

CONCLUSION

This design and build document provides details necessary for the construction of a portable hydrogen refueling station. Further, it demonstrates that market-ready or near market-ready technologies can be utilized to create another step in our nation's goal of developing a hydrogen economy. The Station's design shows it is economically feasible for entities to develop such technologies independently and then merge them with other technologies to create a much larger infrastructure.

Each component of the Station was found to be currently available on the market or available from a manufacturer under special conditions, such as customized construction. One example is the Air Products high-pressure storage and dispensing system. All elements of the system exist, but may be available only as a single turn-key system. As technologies such as the Station develop and become more common, it is anticipated that components will become more readily available.

Additionally, the capital costs associated with hydrogen production and use will decrease with market acceptance, mass production, and technological advancements. This can be correlated with the development of Photovoltaic technologies. As the public has embraced solar technology, systems have become more and more efficient while the costs have decreased. However, until the hydrogen economy has matured, it will be necessary for projects such as the AVRC Station to demonstrate the feasibility of incorporating hydrogen technologies in real world applications.

The Station is designed to be a completely self-contained, portable refueling unit capable of performing all refueling operations in remote areas where utilities are inaccessible. It is important to note, however, that the Station's design is compatible with integrating electricity from either an electric utility grid or from a renewable power source, such as Wind or Solar. The size of currently available photovoltaic systems made it impractical to incorporate it into the footprint of the Station, but as system efficiencies improve and sizes decrease, it may become more feasible to modify the Station's design to include PV panels on top of the container. Alternatively, if the Station is used in a location with access to existing PV systems or the utility grid, these power sources can be easily wired into the Station's main power panel. Being adaptable is a great asset to the Station, as its flexibility will directly correlate with its range of uses.

Real world application is the ultimate goal of this document. The current cost of building the Station is estimated to be approximately $300,000. However, as the technologies reach commercially feasible levels, the cost will decrease, making this type of application accessible to more and more users.

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[2] US DOE, Hydrogen Program: About the Hydrogen Program. http://www.hydrogen.energy.gov/about.html

[3] US DOE, Hydrogen Program: Technology Validation, http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation

[4] Figure 1 taken from Peak Power Tools specification literature. http://www.peakpowertools.com/Diesel-Generator-J-Deere-100-kW-Electric-Gen-Set-p/gtr552410.htm.

[5] Figure 2 taken from Generac website. http://www.generac.com/Default.aspx

[6] Wikipedia, De-ionized Water. http://en.wikipedia.org/wiki/Deionized_water

[7] Figures 3 and 4 taken from Aqua Solutions specification literature.

[8] Specification and DI module return information obtained from "Operating Manual, Aqua Solutions Model H-40-C: Revision: 3.04-02/05."

[9] Barbir, Franco. "PEM electrolysis for production of hydrogen from renewable energy sources**."** Connecticut Global Fuel Cell Center, University of Connecticut. Online article: ScienceDirect.com. October 19, 2004. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V50-4DKD442-4&_user=290868&_coverDate=05%2F31%2F2005&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000015398&_version=1&_urlVersion=0&_userid=290868&md5=a84870e30338742fb90d9f2d261bc49e

[10] Hogen RE Installation & Operation Instructions. Proton/Distributed Energy Systems Company document # PD-0100-0012 Revision 6.

[11] Information provided by Lytron from Kodiak Recirculating Chiller Technical Manual # 820-0043 Rev M, 1/21/2004.

[12] Image was taken from the Lytron website. http://www.lytron.com/standard/cs_kodiak.htm.

[13] International Organization for Standardization. ISO/TR15916, Basic Considerations for the Safety of Hydrogen Systems. 2004.

[14] Hogen RE Installation & Operation Instructions. Proton/Distributed Energy Systems Company document # PD-0100-0012 Revision 6.

[15] The Mobile Storage Group, Storage Container Specifications, http://mobilestorage-c.ndssearch.com/Container-Specifications.pdf; and ContainerSales.Com, Dry Cargo General Specifications, http://containersales.com/dry_cargo.html.

[16] Specifications for the hydrogen compressor were taken from literature provided by Hydro-Pac, as well as information from the Hydro-Pac Website http://www.hydropac.com/HTML/hydrogen-compressor.html.

[17] Dynetek Specification Sheet: 450 bar / 6527 psi Hydrogen DyneCell Cylinders @ 15°C / 59°F.

[18] Natural Gas Vehicle. http://www.ngv.org/nvg/nvgorg01.nsf/bytitle/Inspection.htm#A13

[19] DOT Hydrogen Portal, Safety and Technology Status for the Infrastructure Supporting Hydrogen Fuels Transportation. http://hydrogen.dot.gov/publications/report_to_congress_05_2004/html/report_to_congress_05_2004.html

[20] Hogen RE Installation & Operation Insturctions. Proton/Distributed Energy Systems Company document # PD-0100-0012 Revision 6. Also per conversation with Eric White, Distributed Energy Personnel.

[21] Maintenance schedule taken directly from literature supplied by Hydro Pac Personnel.

[22] Via telephone conversation per Jim Hartken on December 13th, 2007.

[23] Maintenance recommendations taken from "Kodiak Recirculation Chillers, Technical Manual RC006, RC011, RC022, RC030, RC045, G03, H03, J03 Series. Manual 820-0109 Rev. F 8/16/02 Lytron Inc. 2002.

[24] Maintenance recommendations taken from " Power Topic #302, Maintenance is one Key to Diesel Generator Set Reliability," by Tim A. Loehlein, Cummins Power Generators.

[25] International Organization for Standardization, ISO/TR 15916 Technical Report: Basic Considerations for the Safety of Hydrogen Systems. First edition. 2004-02-15.

[26] From "Gas Explosion Handbook," Bjerketvedt et. al. For more information of gas explosions please visit http://www.gexcon.com/index.php?src=handbook/GEXHBcontents.htm

[27] http://www.e-gases.com/products/hydrogen.htm

[28] http://www.distributed-energy.com/hydrogen_generation/onsite/hogen_s.html

[29] http://www.distributed-energy.com/hydrogen_generation/onsite/hogen_s.html

[30] International Organization for Standardization, ISO/TR 15916 Technical Report: Basic Considerations for the Safety of Hydrogen Systems. First edition. 2004-02-15.

[31] http://www.ccohs.ca/oshanswers/chemicals/compressed/compress.html

[32] Hogen RE Installation & Operation Instructions. Proton/Distributed Energy Systems Company document # PD-0100-0012 Revision 6.

[33] International Organization for Standardization, ISO/TR 15916 Technical Report: Basic Considerations for the Safety of Hydrogen Systems. First edition. 2004-02-15.

LIST OF APPENDICES

A. Codes and Standards
B. Parts List
C. Technical Drawings
D. Calculations
E. Specification Sheets
F. List of Vendors and Manufacturers
G. Sample RFI
H. Reports

APPENDIX A: CODES AND STANDARDS

The following list includes Codes and Standards with relevance to hydrogen refueling applications. This list is not all-inclusive, and additional Codes and Standards should be researched prior to any work involving hydrogen systems.

DOE, Guidance for Safety Aspects of Proposed Hydrogen Projects

DOTn 49 CFR, Parts 171-180, Regulations for Transportation Equipment and the Transport of Hazardous Materials

ICC, International Fuel Gas Code

ISO 11114-4, Transportable gas cylinders -- Compatibility of cylinder and valve materials with gas contents -- Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement.

ISO/DIS 15869, Compressed H_2 Storage

ISO/TR 15916, Technical Report: Basic Considerations for the Safety of Hydrogen Systems.

ISO 16110-1, Hydrogen Generators Using Fuel Processing Technologies – Part 1: Safety

ISO 17268, Compressed H2 Fueling Interface

ISO/CD 22734-1, Hydrogen Generators Using Water Electrolysis Process

NFPA 52, Compressed Natural Gas (CNG) Vehicular Fuel Systems

NFPA 55, Standard for Gaseous Hydrogen Systems at Consumer Sites

NFPA 70, National Electric Code

NGV-2, American National Standard for Natural Gas Vehicle Containers

OSHA 1910.103, Hydrogen

UL 2264, Gaseous Hydrogen Generating Appliances

APPENDIX B: PARTS LIST

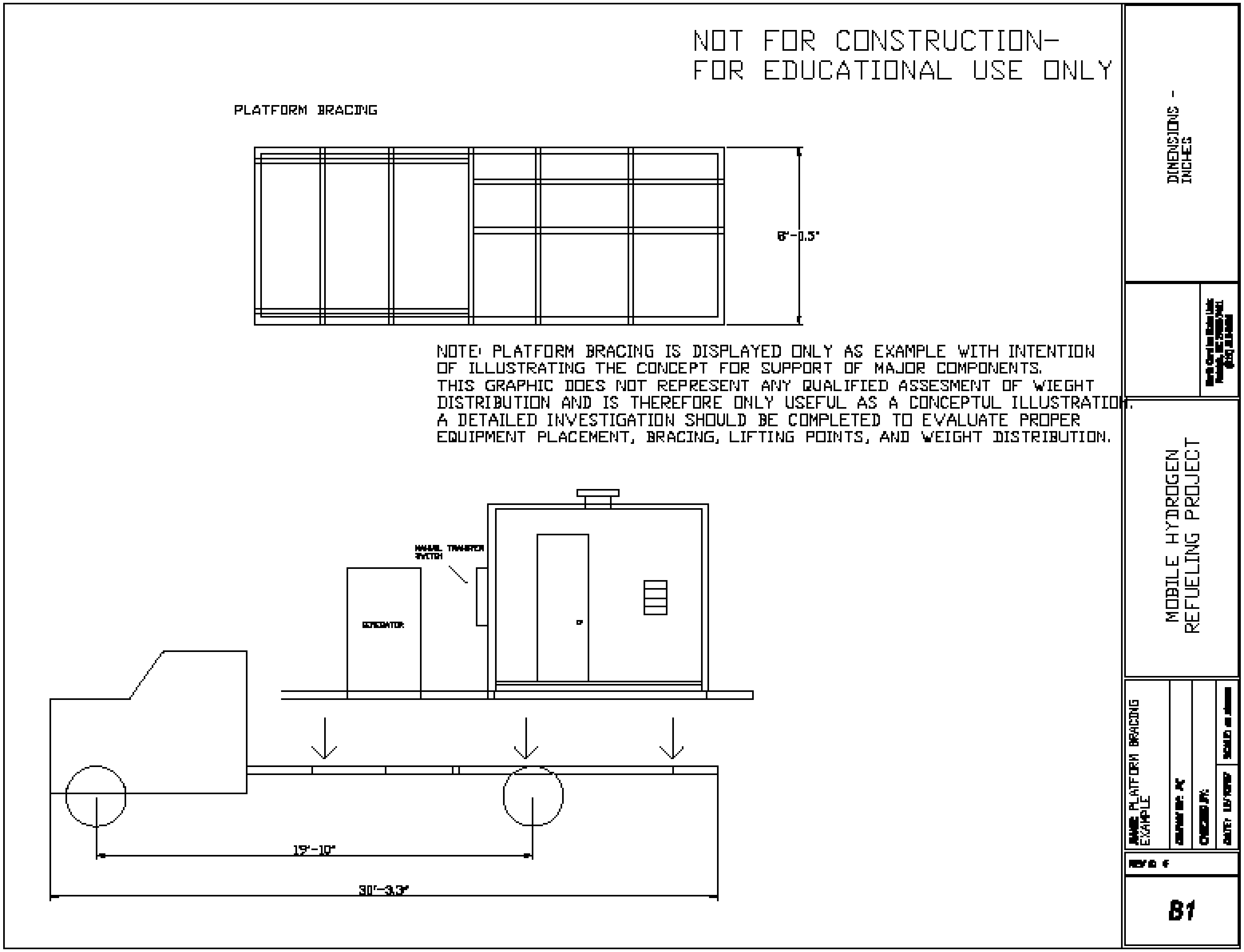
Hydrogen process line and safety equipment prices are approximate and listed from various suppliers. Please consult local supply companies for more accurate examples.

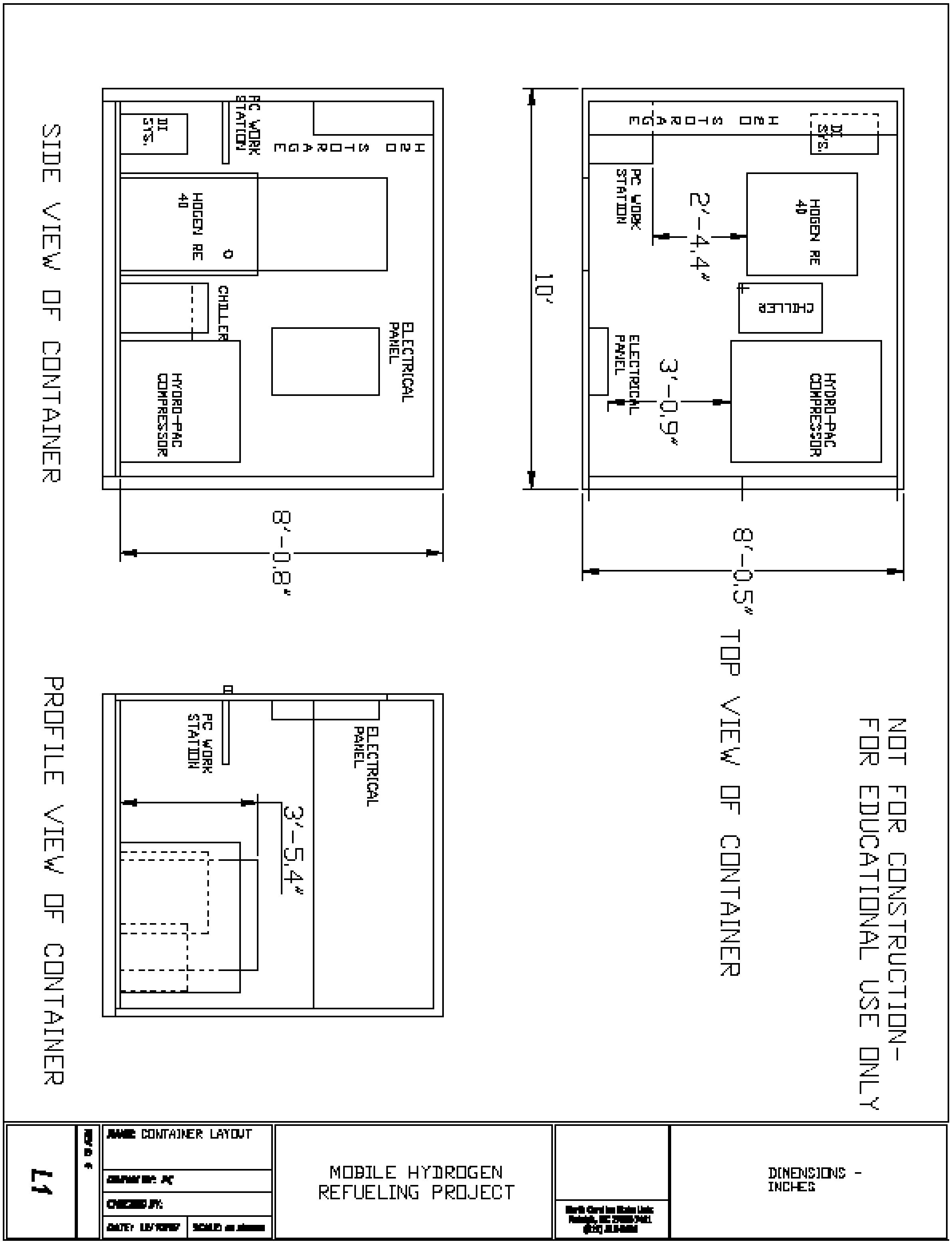
Hydrogen Process Line				
Part Description	**Part Number, Specification**	**Number Required**	**Estimated Cost (US $) per unit**	**Total Cost**
Manual Ball Valve	Swagelok – SS-43GS4	2	76.98	153.96
Check Valve	Swagelok – SS-CHS4-5	1	48.18	48.18
Tee Fitting	Swagelok – SS-400-3-4TFT	1	29.08	29.08
Tee Fitting	Swagelok – SS-400-3	1	19.48	19.48
Pressure Gauge	Swagelok – PGI-63C-PG300-LAQ	1	34.00	34.00
Tube to Thread Adapter	Swagelok – SS-400-1-8	1	10.66	10.66
Union (SAF)	Swagelok – 2507-810-6	1	119.72	119.72
Union Tee	Swagelok – 2507-810-3	1	196.29	196.29
Manual Ball Valve (HP)	Swagelok – SS- H83PS8	1	275.73	275.73
Proportional Relief Valve	Swagelok – SS-RL3M4-S4	1	148.94	148.94
Male Tubing Adapter	Swagelok - 2507-8-TA-1-4	1	88.36	88.36
Hex Coupling (FNPT)	Swagelok – SS-4-HCG-10K	1	8.41	8.41
ASME Relief Valve	Bauer – VAL-0154 (6500PSI)	1	477.00	477.00
Coupler	Snap-Tite – SPHC8-8F	1	60.00	60.00
Nipple	Snap-Tite – SPHN8-8F	1	60.00	60.00
½” SS Tubing	Swagelok – 2507-T8-S-065-20	Nominal 1000’	Quote	
¼” SS Tubing	Swagelok – SS-T4-S-035-20	Nominal 20’	Quote	
Emergency System Electrical Equipment				
UPS System	APC - BR1500LCD	1	249.99	249.99
Voltage Transformer	Square-D – 9070TF50D23	1	65.45	65.45
Fuse	Bussmann – LP-CC-10	5 (spares)	11.40	57.00
Fuse	Bussmann – LP-CC-4	3 (spares)	10.01	30.03
Fuse	Bussmann – LP-CC-1-1/2	3 (spares)	10.01	30.03
Terminal Bar	Ideal – 89-512 (12 pole)	2	16.69	33.38
Terminal Bar Jumpers	Ideal – 89-525	4	6.24	24.96
Emergency Stop Push Button	Telemecanique – XB4BT8465 (2 Contact NC/NO)	3	50.15	115.45

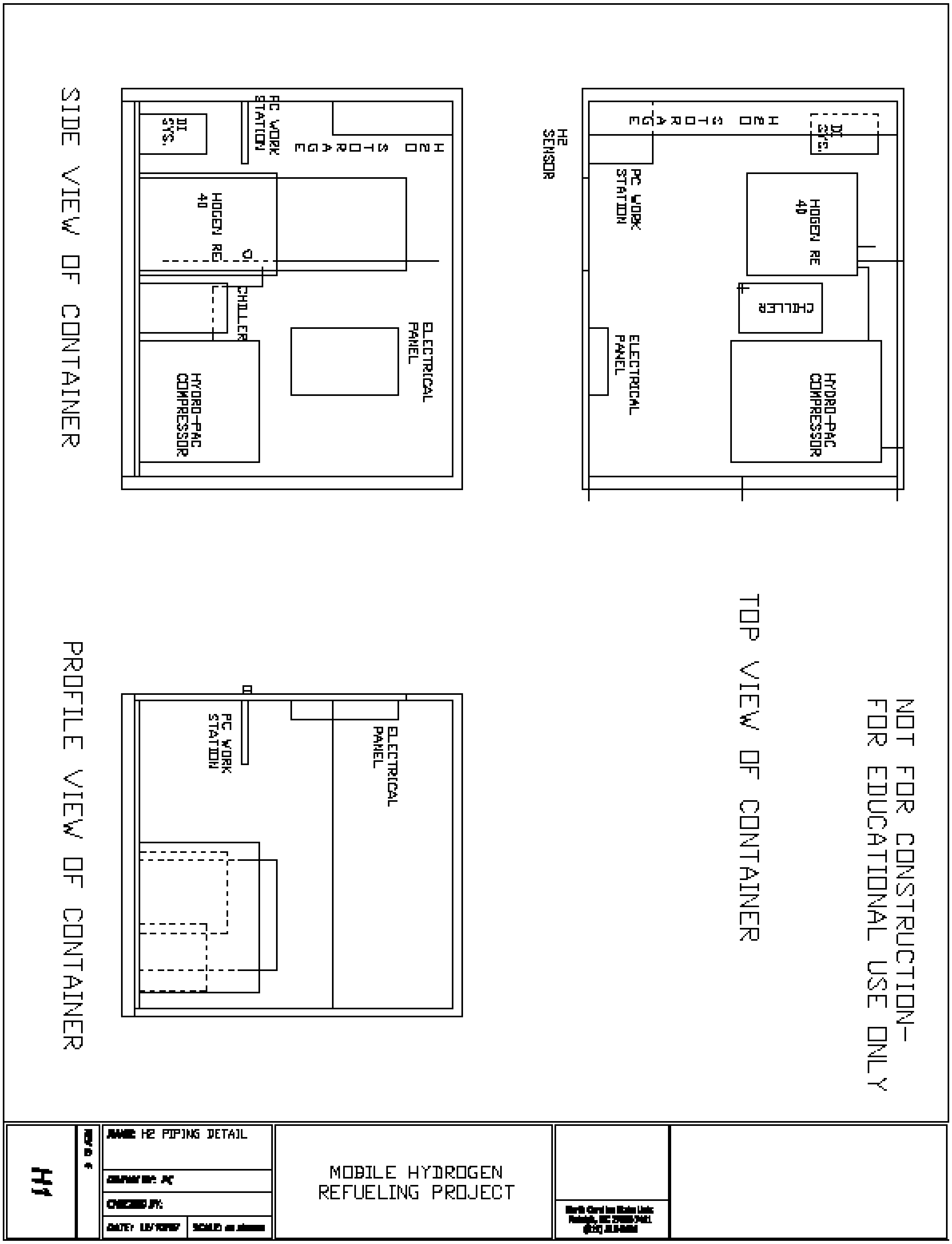
22mm Push Button (Momentary)	Telemecanique – XB4BA31	1	18.94	18.94
Latching Relay	Omron – 11 DPDT (Grainger Stock – 2W924)	1	41.60	41.60
Relay Socket	Dayton – 11 pin Octal (Granger Stock – 6X156)	1	7.94	7.94
NEMA Magnetic Motor Starter	Square D – 8536SCG3	1	306.25	306.25
Preassembled Dual Push Button Control	Square –D – 9001BG201	1	51.20	51.20
Insulated Wire	AWG 12	Nominal 50’	0.50 (per ft) est	25.00
Insulated Wire	AWG 18	Nominal 50’	0.50 (per ft) est	25.00
Insulated Wire	AWG 22	Nominal 50’	0.50 (per ft) est	25.00
Emergency System Equipment				
Fiberglass Enclosure Panel Box	Weigmann – HW-201610CHQR	1	299.25	299.25
Interior Plan for Fiberglass enclosure	Weigmann – HW-MP2016CS	1	50.05	50.05
Intake/Exhaust Fan	Broan – 350 (1050CFM)	1	57.90	57.90
Emergency Lighting system	Lithonia Model IND12100	1	196.25	196.25

APPENDIX C: TECHNICAL DRAWINGS

List of Drawings:


NOT FOR CONSTRUCTION-
FOR EDUCATIONAL USE ONLY
PLATFORM BRACING
8'-0.5"
NOTE: PLATFORM BRACING IS DISPLAYED ONLY AS EXAMPLE WITH INTENTION OF ILLUSTRATING THE CONCEPT FOR SUPPORT OF MAJOR COMPONENTS. THIS GRAPHIC DOES NOT REPRESENT ANY QUALIFIED ASSESMENT OF WIEGHT DISTRIBUTION AND IS THEREFORE ONLY USEFUL AS A CONCEPTUL ILLUSTRATION. A DETAILED INVESTIGATION SHOULD BE COMPLETED TO EVALUATE PROPER EQUIPMENT PLACEMENT, BRACING, LIFTING POINTS, AND WEIGHT DISTRIBUTION.
19'-10"
30'-3.3"
DIMENSIONS - INCHES
MOBILE HYDROGEN REFUELING PROJECT
PLATFORM BRACING EXAMPLE
B1


SIDE VIEW OF CONTAINER
PROFILE VIEW OF CONTAINER
TOP VIEW OF CONTAINER
NOT FOR CONSTRUCTION-
FOR EDUCATIONAL USE ONLY
DI SYS.
PC WORK STATION
H2O STORAGE
HOGEN RE 40
CHILLER
ELECTRICAL PANEL
HYDRO-PAC COMPRESSOR
8'-0.8"
8'-0.5"
10'
2'-4.4"
3'-0.9"
3'-5.4"
NAME: CONTAINER LAYOUT
MOBILE HYDROGEN
REFUELING PROJECT
DIMENSIONS -
INCHES
L1


SIDE VIEW OF CONTAINER
DI SYS.
PC WORK STATION
H2O STORAGE
HOGEN RE 40
CHILLER
ELECTRICAL PANEL
HYDRO-PAC COMPRESSOR
TOP VIEW OF CONTAINER
H2 SENSOR
PROFILE VIEW OF CONTAINER
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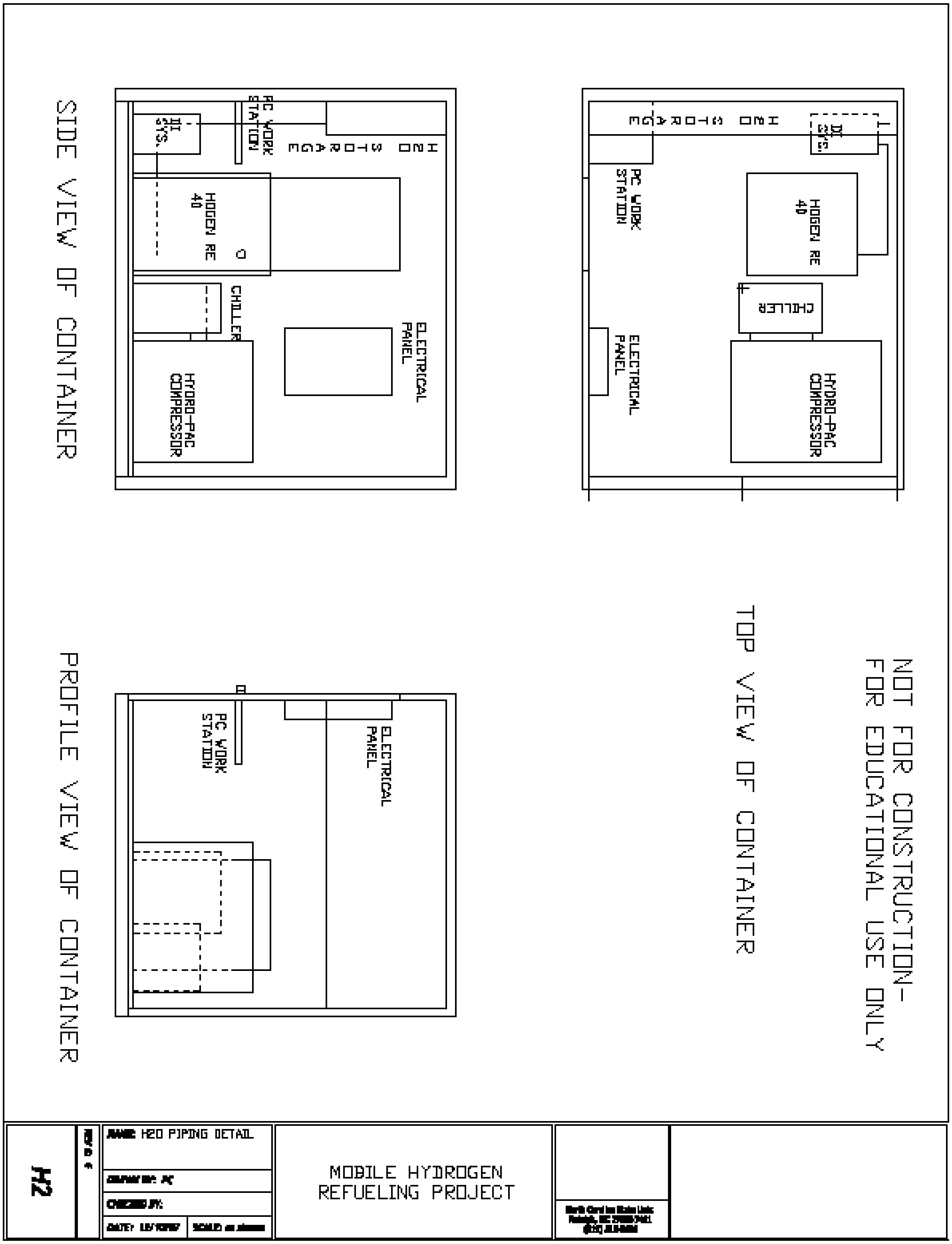
FOR EDUCATIONAL USE ONLY
NAME: H2 PIPING DETAIL
CHECKED BY:
MOBILE HYDROGEN
REFUELING PROJECT
H1


SIDE VIEW OF CONTAINER
H2O STORAGE
PC WORK STATION
DI SYS.
HOGEN RE 40
CHILLER
ELECTRICAL PANEL
HYDRO-PAC COMPRESSOR
TOP VIEW OF CONTAINER
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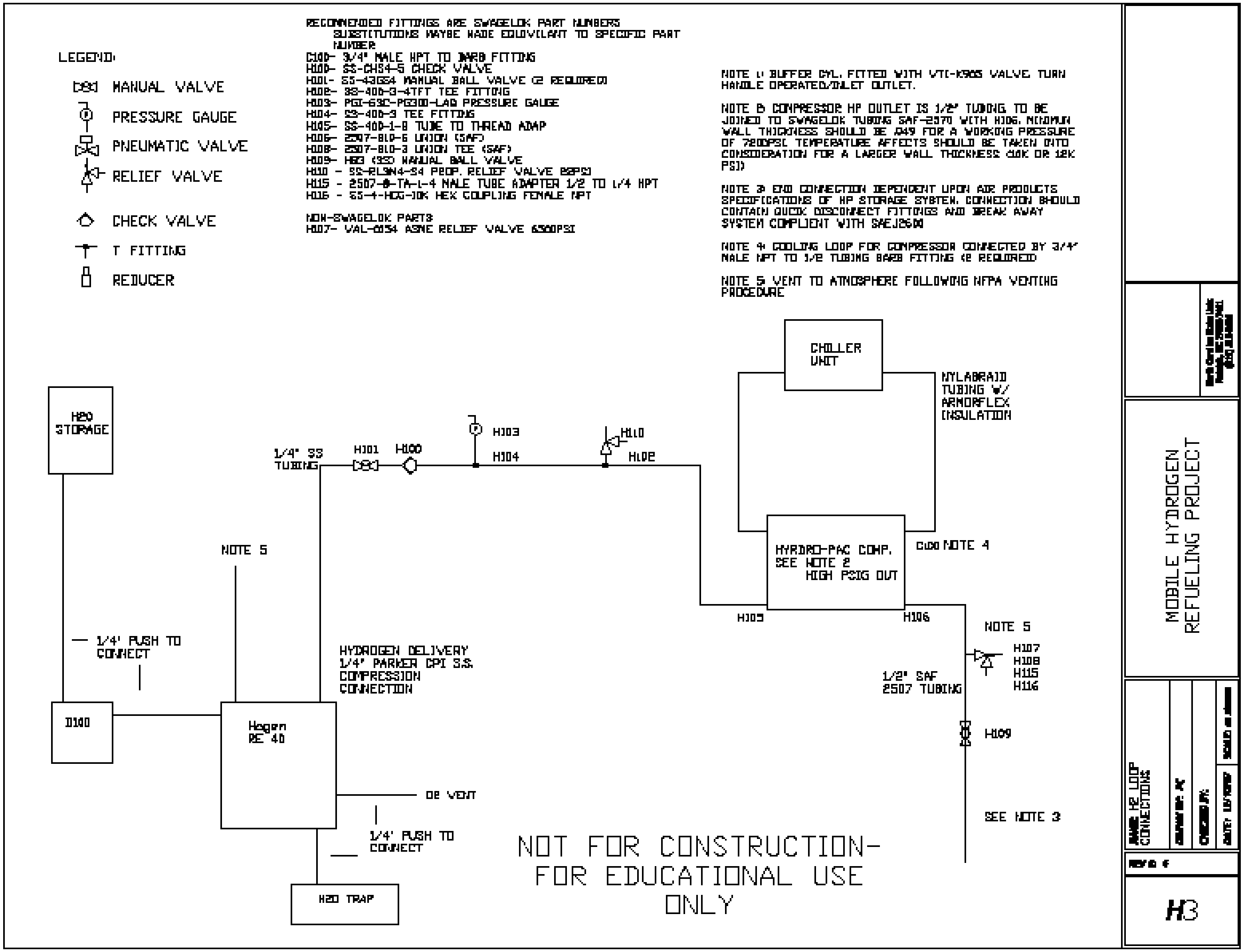
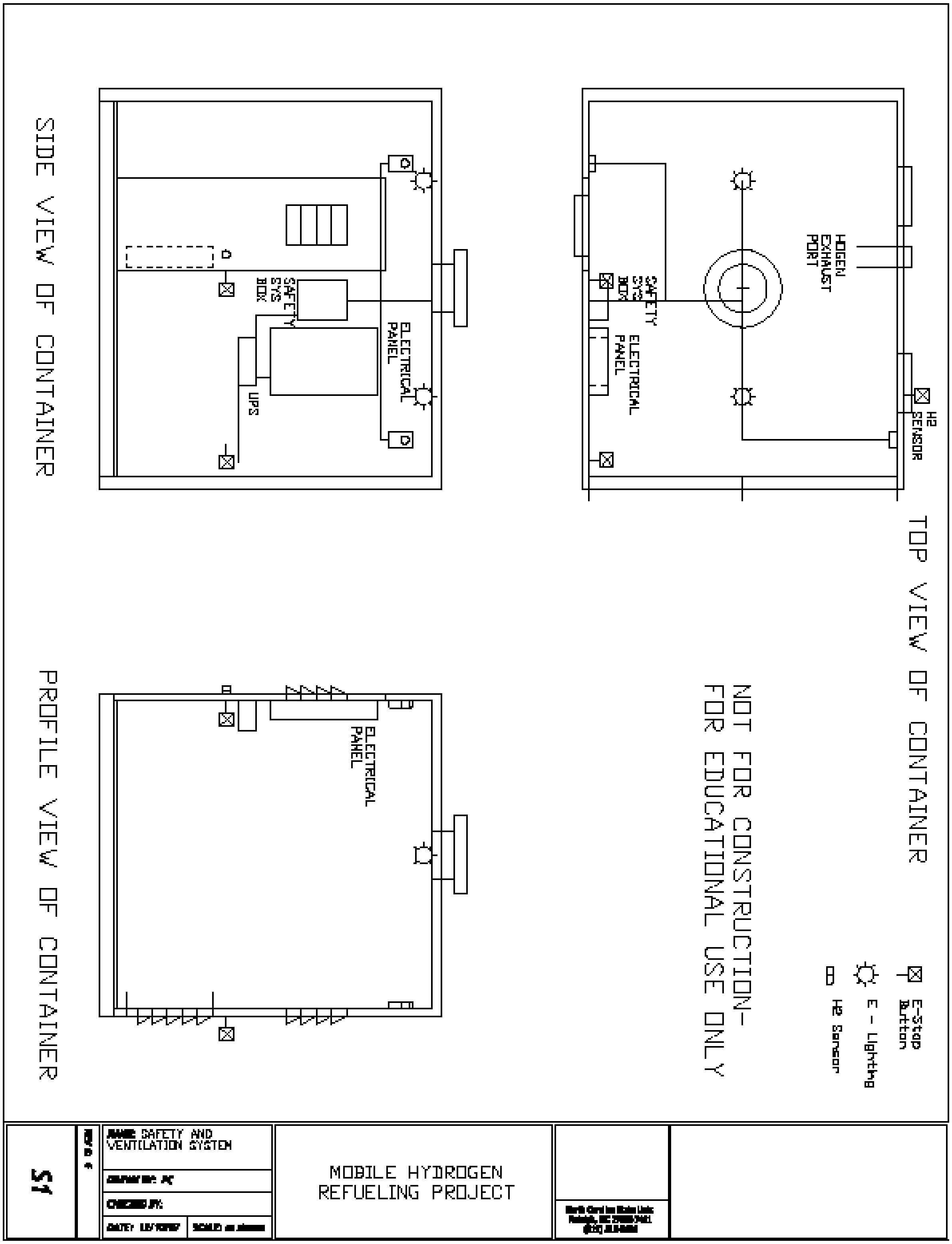
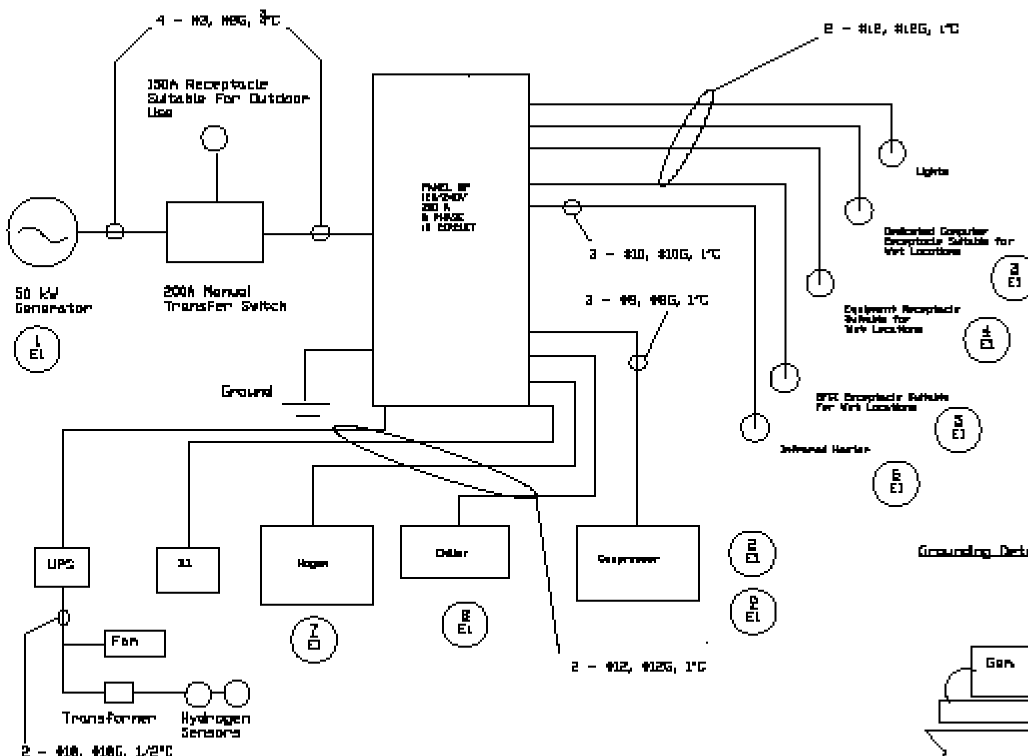
ELECTRICAL PANEL
HYDRO-PAC COMPRESSOR
PROFILE VIEW OF CONTAINER
PC WORK STATION
ELECTRICAL PANEL
NOT FOR CONSTRUCTION-
FOR EDUCATIONAL USE ONLY
H2
NAME: H2O PIPING DETAIL
DRAWN BY: PC
CHECKED BY:
MOBILE HYDROGEN
REFUELING PROJECT


LEGEND:
MANUAL VALVE
PRESSURE GAUGE
PNEUMATIC VALVE
RELIEF VALVE
CHECK VALVE
T FITTING
REDUCER
RECOMMENDED FITTINGS ARE SWAGELOK PART NUMBERS
SUBSTITUTIONS MAYBE MADE EQUIVILANT TO SPECIFIC PART NUMBER
C100- 3/4" MALE NPT TO BARB FITTING
H100- SS-CHS4-5 CHECK VALVE
H101- SS-43GS4 MANUAL BALL VALVE (2 REQUIRED)
H102- SS-400-3-4TFT TEE FITTING
H103- PGI-63C-PG300-LAQ PRESSURE GAUGE
H104- SS-400-3 TEE FITTING
H105- SS-400-1-8 TUBE TO THREAD ADAP
H106- 2507-810-6 UNION (SAF)
H108- 2507-810-3 UNION TEE (SAF)
H109- H83 (SS) MANUAL BALL VALVE
H110 - SS-RL3N4-S4 PROP. RELIEF VALVE 82PSI
H115 - 2507-8-TA-1-4 MALE TUBE ADAPTER 1/2 TO 1/4 NPT
H116 - SS-4-HCG-10K HEX COUPLING FEMALE NPT
NON-SWAGELOK PARTS
H107- VAL-0154 ASME RELIEF VALVE 6300PSI
NOTE 1: BUFFER CYL. FITTED WITH VTI-K965 VALVE. TURN HANDLE OPERATED/INLET OUTLET.
NOTE 2: COMPRESSOR HP OUTLET IS 1/2" TUBING TO BE JOINED TO SWAGELOK TUBING SAF-2570 WITH H106. MINIMUM WALL THICKNESS SHOULD BE .049 FOR A WORKING PRESSURE OF 7200PSI. TEMPERATURE AFFECTS SHOULD BE TAKEN INTO CONSIDERATION FOR A LARGER WALL THICKNESS (10K OR 12K PSI)
NOTE 3: END CONNECTION DEPENDENT UPON AIR PRODUCTS SPECIFICATIONS OF HP STORAGE SYSTEM. CONNECTION SHOULD CONTAIN QUICK DISCONNECT FITTINGS AND BREAK AWAY SYSTEM COMPLIENT WITH SAEJ2600
NOTE 4: COOLING LOOP FOR COMPRESSOR CONNECTED BY 3/4" MALE NPT TO 1/2 TUBING BARB FITTING (2 REQUIRED)
NOTE 5: VENT TO ATMOSPHERE FOLLOWING NFPA VENTING PROCEDURE
CHILLER UNIT
NYLABRAID TUBING W/ ARMORFLEX INSULATION
H2O STORAGE
1/4" SS TUBING
H101
H100
H103
H104
H110
H102
NOTE 5
HYRDRO-PAC COMP. SEE NOTE 2 HIGH PSIG OUT
C100 NOTE 4
H105
H106
NOTE 5
1/4" PUSH TO CONNECT
HYDROGEN DELIVERY 1/4" PARKER CPI S.S. COMPRESSION CONNECTION
H107
H108
H115
H116
1/2" SAF 2507 TUBING
D100
Hogen RE 40
H109
O2 VENT
1/4" PUSH TO CONNECT
SEE NOTE 3
H2O TRAP
NOT FOR CONSTRUCTION- FOR EDUCATIONAL USE ONLY
MOBILE HYDROGEN REFUELING PROJECT
NAME: H2 LOOP CONNECTIONS
H3


SIDE VIEW OF CONTAINER
SAFETY SYS BOX
ELECTRICAL PANEL
UPS
TOP VIEW OF CONTAINER
HOGEN EXHAUST PORT
SAFETY SYS BOX
ELECTRICAL PANEL
H2 SENSOR
PROFILE VIEW OF CONTAINER
ELECTRICAL PANEL
NOT FOR CONSTRUCTION-
FOR EDUCATIONAL USE ONLY
E-Stop Button
E - Lighting
H2 Sensor
S1
NAME: SAFETY AND VENTILATION SYSTEM
MOBILE HYDROGEN
REFUELING PROJECT



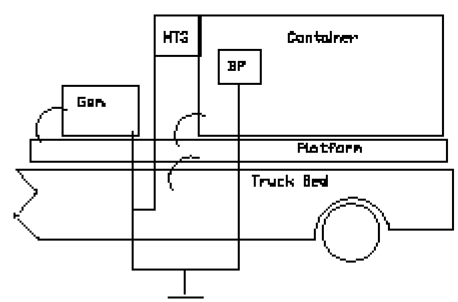
NOT FOR CONSTRUCTION – FOR EDUCATIONAL PURPOSES ONLY

Description	CB#	Ph	Rated Amps	Amps A	Amps B	Amps C	Breaker Size	THHW Conductor	PVC Conduit
Compressor	1	A,B,C	16	16	16	16	20	12	1
Compressor	3	A,B,C							
Compressor	5	A,B,C							
Heater	2	A,B,C	18	18	18	18	30	10	1
Heater	4	A,B,C							
Heater	6	A,B,C							
Hogen Electrolyzer	7	A,B	45	45	45	0	50	8	1
Chiller	8	C	19.6	0	0	19.6	30	10	1
Water Purifier	9	C	2	0	0	2	15	12	1
Receplacle	10	B	15	0	15	0	15	12	1
Receplacle	11	A	15	15	0	0	15	12	1
Lights	12	C	15	0	0	15	15	12	1
Comp. Receptacle	13	C	15	0	0	15	15	12	1
Ventilation	14	C	3.6	0	0	3.6	15	12	1
Total Amps				94	94	89.2			
Total kVA =	33.26			11.28	11.28	10.70			

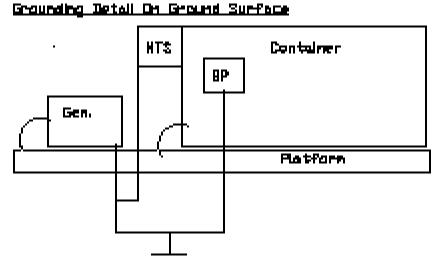
Notes

1. As Prime Power Supply, 120/240V, 3-phase generator rated 32 kW, 96 amps.
2. Circuit breaker in panel shall serve as primary disconnecting means.
3. Isolated ground receptacle for computer. Receptacle shall be marked with an orange triangle located on the face of the receptacle.
4. GFCI protection is not required. Label receptacle 'Not GFCI Protected, For Motor Use Only'.
5. Circuit may contain up to 4 receptacles. Label receptacles 'GFCI Protected'.
6. Heater rated 7.5 kW @ 208V.
7. Hogen rated 10kW @ 240V.
8. Chiller rated 3/4 hp @ 230V.
9. Compressor rated 23kW @ 230V.

Grounding Detail On Truck Bed



Grounding Detail On Ground Surface

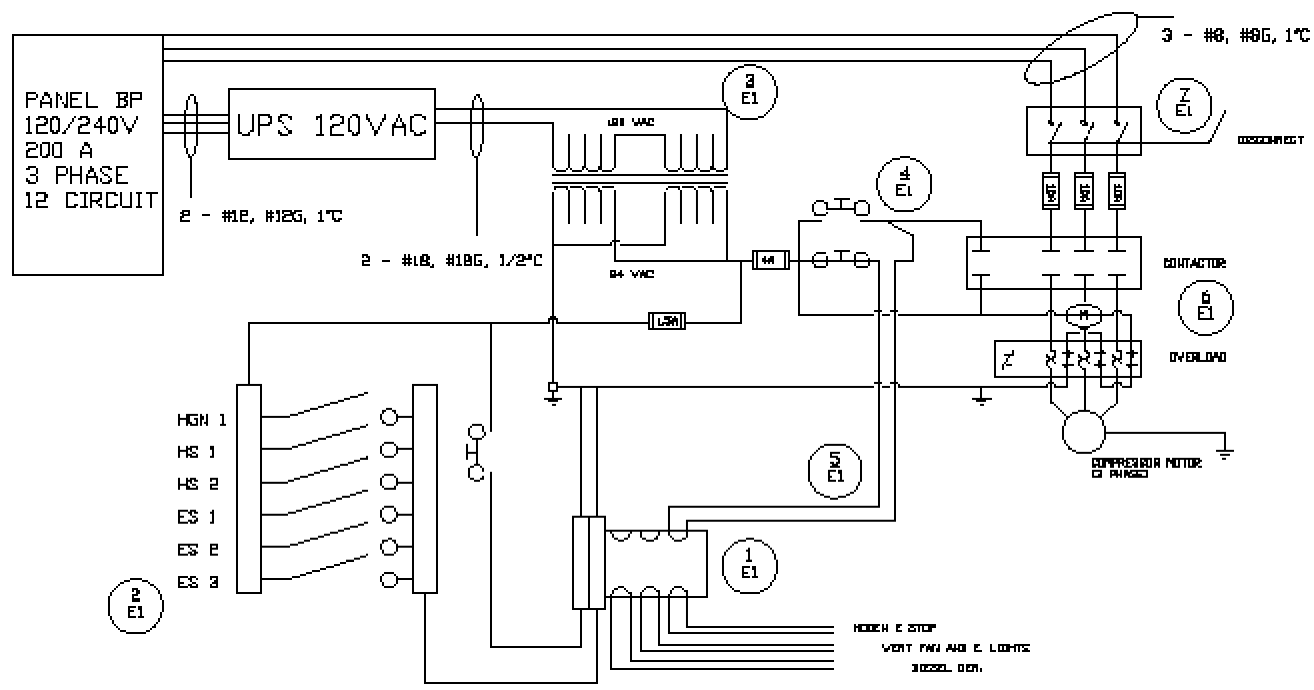


DRAFT

MOBILE HYDROGEN REFUELING PROJECT

NAME: Electrical Riser Diagram

E1



Notes

1. Dual Coil Latching Relay: 24VAC control voltage. 15VA coil rating
2. Terminal bar connections to Hogen, hydrogen sensors, and Estop NO relay contacts.
3. 120VAC to 24VAC Transformer.
4. Stop/Start 2 button, momentary switch.
5. Normally closed relay connection in series with Stop button. Note 4.
6. Contactor and thermal overload utilize 24VAC control voltage.
7. Manual disconnect either at panel or optional auxiliary.

Abbreviations:

HGN 1: Hogen NO Estop output
HS 1: Hydrogen Sensor NO Alarm output
HS 2: Hydrogen Sensor NO Alarm output
ES 1: Emergency stop NO momentary switch
ES 2: Emergency stop NO momentary switch

NOT FOR CONSTRUCTION-
FOR EDUCATIONAL USE
ONLY

MOBILE HYDROGEN
REFUELING PROJECT

NAME: H2 SAFETY LOOP
MOTOR CONTROL
INTERCONNECTION

M1

APPENDIX D: CALCULATIONS

List of Calculations:

- Atmosphere Explosion Potential
- Heating Requirements

Atmosphere Explosion Potential:

Equipment

	L	W	H	Volume
	ft	ft	ft	ft^3
H2O Storage	0.8	3	7.7	18.5
DI H2O Sys	1.7	1	1.7	2.9
Hogen RE 40	2.6	2.3	3.5	20.9
Chiller	1.8	2.3	2.7	11.2
Compressor	3.8	3	3	34.2

Total Equipment Volume 87.7 ft^3

Internal Volume of Container

L	W	H	Volume
ft	ft	ft	ft^3
9.4	7.7	7.9	568.8

Volume of Container 568.8 ft^3

Approximate Air Volume of Container

	Container Volume	568.8	ft^3
-	Equipment Volume	87.7	ft^3
	Air Volume	481.1	ft^3

LEL
Volumes

50% of LEL (2% Of Air Volume)

9.6 ft^3

LEL (4% of Air Volume)

19.2 ft^3

Molar Amounts of H2 to reach 50% of LEL and LEL

$$\boxed{PV = nRT}$$

P=	Pressure	atm
V=	Volume	ft^3
n=	moles	
R=	Gas Constant	$ft^3*atm*R^{-1}*lb\text{-}mol^{-1}$
T=	Temperature	R°

50% LEL

Assumptions

P=	1	atm
V=	9.6	$ft^3*atm*R^{-1}*lb\text{-}mol^{-1}$
n=	unknown	moles
R=	0.7302	$ft^3*atm*R^{-1}*lb\text{-}mol^{-1}$
T=	530	R°

Moles of H2= 0.025 lb-moles

LEL

Assumptions

P=	1	atm
V=	19.6	$ft^3*atm*R^{-1}*lb\text{-}mol^{-1}$
n=	unknown	moles
R=	0.7302	$ft^3*atm*R^{-1}*lb\text{-}mol^{-1}$
T=	530	R°

Moles of H2= 0.050 lb-moles

Hazardous Condition Evaluation

Hogen H2 Production Rate				
44	SCFH	=	0.122546	lb-moles/hour
359.05	ft^3(STP)	=	1	lb-mole
STP =	Standard Temperature and Pressure			

A leak from the Hogen at full production would require 12.6 minutes to reach 50% of LEL

$$\frac{0.025 \text{ lb-moles}}{0.122546 \text{ lb-moles/hour}} = 0.20 \text{ hours or } 12.17 \text{ minutes}$$

$$\frac{0.050 \text{ lb-moles}}{0.122546 \text{ lb-moles/hour}} = 0.41 \text{ hours or } 24.35 \text{ minutes}$$

Notes

1. The Hogen RE 40 is the only hydrogen producing equipment in the cargo container, and therefore the only equipment taken into account for a hydrogen leak evaluation.

2. The amount of hydrogen which could possibly accumulate with in the process line has been considered negligible. If design changes created a condition for notable storage of hydrogen within the process lines, a hazard evaluation containing this criterion would need to be completed.

3. The amount of hydrogen which could possibly accumulate within the compressor has been neglected due to the source of hydrogen being the Hogen RE 40. If a large compressor or compressor modification is adapted, calculations concerning the amount of hydrogen stored within the compressor would need to be completed.

4. These calculations are approximations based on the best available data during this stage of the design phase. During final evaluation and preliminary construction, calculations based on specific equipment and configurations should be completed to avoid the potential of reaching an explosive atmosphere condition.

Heating Requirements

Air Volume of Container

481 ft^3

Air Movement

1000 ft^3/min via Hogen air exchange rate

High Temperature Environment

32 °F Air
20 % Relative Humidity

Data from Pyschrometric chart

Density	12.3	ft^3/lb-Dry Air
Btu/lb-Dry Air	8.2	Btu/lb-Dry Air

Heat Added to Volume

Chiller	1.5	hp x	9.49E-04 Btu/sec = / 1.34E-03 hp		63.66	Btu/min
DI Sys					11	Btu/min
Lights	500	watts x	9.49E-04 Btu/sec = / 1.00 w		28.46	Btu/min
Computer and Safety Sys.	500	watts x	9.49E-04 Btu/sec = / 1.00 w		28.46	Btu/min
			Total Btu/min =		131.58	Btu/min

lbs of dry air in volume

$$481\ ft^3 \times \frac{1\ \text{lb Dry Air}}{12.3\ ft^3} = 39.11\ \text{lb dry air}$$

Heat content of air

$$39.11 \text{ lb Dry Air} \times 8.2 \text{ Btu/lb-Dry Air} = 320.67 \text{ Btu}$$

Addition of heat by equipment per air exchange

$$481 \text{ ft}^3 \times \frac{1 \text{ min} \times 131.58 \text{ Btu}}{1000 \text{ ft}^3 \quad \text{min}} = 63.29 \text{ Btu}$$

Total heat content of air = 383.96 Btu

Heat content of Air per lb dry air

$$383.96 \text{ Btu} \times \frac{1}{39.11 \text{ lb dry air}} = 9.82 \text{ Btu/ lb dry air}$$

Temperature Change per Psychrometric Chart = ~ 7 °F

Heating requirements to meet 50 °F operating temperature

From Psychrometric Chart, air at 50 °F and 20% R. Humidity

13.6 Btu/lb dry air

12.8 ft^3/lb dry air

Lbs of dry air in volume

$$481 \text{ ft}^3 \times \frac{1 \text{ lb dry air}}{12.8 \text{ ft}^3} = 37.58 \text{ lb dry air}$$

Heat content of air

$$37.58 \text{ lb dry air} \times \frac{13.6 \text{ Btu}}{1 \text{ lb dry air}} \quad 511.06 \text{ Btu}$$

Subtraction of heat content of air at 32 °F and heat added by equipment

(From low temperature env. Calc) 383.96 Btu

Total = 127.11 Btu

An additional 127.11 Btu are needed for every air exchange

$$127.11 \text{ Btu} \quad \frac{1000 \text{ ft}^3\text{/min}}{481 \text{ ft}^3} \quad 264.26 \text{ Btu/min}$$

An additional 264.26 Btu/min are required to maintain 50 °F

$$264.26 \text{ Btu/min} \quad \frac{1 \text{ watt}}{0.056916 \text{ Btu/min}} \quad 4643 \text{ watts}$$

Approximately 4700 watts are required to maintain 50 °F in the container

Notes

1. Calculations are based on approximations of anticipated operating environments. Calculations considering actual operating environments should be completed before final design and construction.

2. Similar calculations were performed for a 90 °F environment. Heat radiated from equipment produced an approximate temperature increase of 6 °F.

3. Calculations are based on approximations of the Psychrometric Chart by the Carrier Corporation.

4. Calculations neglect conductive heat losses. Insulation for the system will be necessary to avoid conductive losses.

APPENDIX E: SPECIFICATION SHEETS

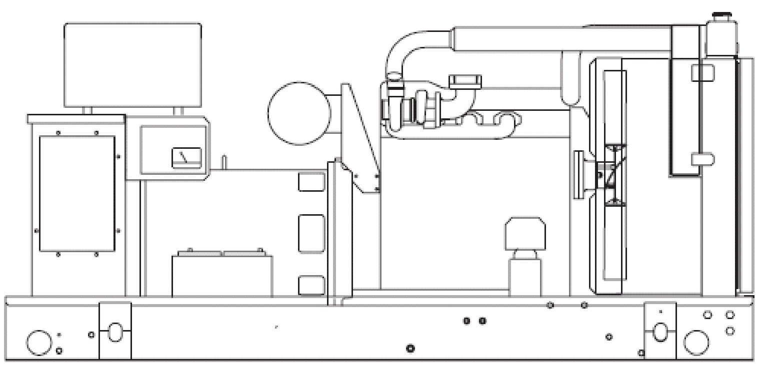
List of Specification Sheets:

Generac Diesel Generator
AquaSolutions Water Purifier
Hogen RE40 Hydrogen Generator
HyrdoPac Hydrogen Compressor
Lytrol Chiller

SD050 Liquid Cooled Diesel Engine Generator Sets

Standby Power Rating
50KW 60 Hz / 50KVA 50 Hz

Prime Power Rating
40KW 60 Hz / 40KVA 50 Hz



Power Matched
GENERAC 3.0DT ENGINE
Turbocharged

FEATURES

- **INNOVATIVE DESIGN & PROTOTYPE TESTING** are key components of GENERAC'S success in "IMPROVING POWER BY DESIGN." But it doesn't stop there. Total commitment to component testing, reliability testing, environmental testing, destruction and life testing, plus testing to applicable CSA, NEMA, EGSA, and other standards, allows you to choose GENERAC POWER SYSTEMS with the confidence that these systems will provide superior performance.
- **TEST CRITERIA:**
  - ✓ PROTOTYPE TESTED
  - ✓ SYSTEM TORSIONAL TESTED
  - ✓ ELECTRO-MAGNETIC INTERFERENCE
  - ✓ NEMA MG1 EVALUATION
  - ✓ MOTOR STARTING ABILITY
  - ✓ SHORT CIRCUIT TESTING
  - ✓ UL COMPLIANCE AVAILABLE
- **SOLID-STATE, FREQUENCY COMPENSATED DIGITAL VOLTAGE REGULATION.** This state-of-the-art power maximizing regulation system is standard on all Generac models. It provides optimized FAST RESPONSE to changing load conditions and MAXIMUM MOTOR STARTING CAPABILITY by electronically torque-matching the surge loads to the engine.
- **SINGLE SOURCE SERVICE RESPONSE** from Generac's dealer network provides parts and service know-how for the entire unit, from the engine to the smallest electronic component. You are never on your own when you own a GENERAC POWER SYSTEM.
- **ECONOMICAL DIESEL POWER.** Low cost operation due to modern diesel engine technology. Better fuel utilization plus lower cost per gallon provide real savings.
- **LONGER ENGINE LIFE.** Generac heavy-duty diesels provide long and reliable operating life.
- **GENERAC TRANSFER SWITCHES, SWITCHGEAR AND ACCESSORIES.** Long life and reliability is synonymous with GENERAC POWER SYSTEMS. One reason for this confidence is that the GENERAC product line includes its own transfer systems, accessories, switchgear and controls for total system compatibility.

GENERAC®
POWER SYSTEMS, INC.

APPLICATION
& ENGINEERING DATA

SD050

GENERATOR SPECIFICATIONS

TYPE .... Four-pole, revolving field
ROTOR INSULATION .... Class H
STATOR INSULATION .... Class H
TOTAL HARMONIC DISTORTION .... <3%
TELEPHONE INTERFERENCE FACTOR (TIF) .... <50
ALTERNATOR .... Self-ventilated and drip-proof
BEARINGS (PRE-LUBED & SEALED) 1
COUPLING .... Direct, Flexible Disc
LOAD CAPACITY (STANDBY) 100%
LOAD CAPACITY (PRIME) 110%

NOTE: Emergency loading in compliance with NFPA 99, NFPA 110. Generator rating and performance in accordance with ISO8528-5, BS5514, SAE J1349, ISO3046 and DIN6271 standards.

VOLTAGE REGULATOR

TYPE .... Full Digital
SENSING .... 3 Phase
REGULATION .... ± 1/4%
FEATURES .... Built into H-100 Control Panel, V/F Adjustable
Adjustable Voltage and Gain

GENERATOR FEATURES

- Revolving field heavy duty generator
- Quiet drive coupling
- Operating temperature rise 120°C above a 40°C ambient
- Insulation is Class H rated at 150°C rise
- All prototype models have passed three phase short circuit testing

CONTROL PANEL FEATURES

- TWO FOUR LINE LCD DISPLAYS READ:
  - Voltage (all phases)
  - Current (all phases)
  - Power factor
  - kW
  - kVAR
  - Transfer switch status
  - Engine speed
  - Low fuel pressure
  - Run hours
  - Service reminders
  - Fault history
  - Oil pressure
  - Coolant temperature
  - Time and date
  - Low oil pressure shutdown
  - High coolant temp shutdown
  - Overvoltage
  - Overspeed
  - Low coolant level
  - Low coolant level
  - Exercise speed
  - ATS selection
  - Not in auto position (flashing light)
- INTERNAL FUNCTIONS:
  - I^2T function for alternator protection from line to neutral and line to line short circuits
  - Emergency stop
  - Programmable auto crank function
  - 2 wire start for any transfer switch
  - Communicates with the Generac HTS transfer switch
  - Built-in 7 day exerciser
  - Adjustable engine speed at exerciser
  - RS232 port for GenLink® control
  - RS485 port remote communication
  - Canbus addressable
  - Governor controller and voltage regulator are built into the master control board
  - Temperature range -40°C to 70°C

ENGINE SPECIFICATIONS

MAKE .... GENERAC/DEERE
MODEL 5030TF270
ENGINE FAMILY 7JDXL03.0063
CYLINDERS 5
DISPLACEMENT .... 3.0 Liter (186 cu.in.)
BORE .... 86 mm (3.4 in.)
STROKE .... 105 mm (4.1 in.)
COMPRESSION RATIO 18:1
INTAKE AIR .... Turbocharged
NUMBER OF MAIN BEARINGS 5
CONNECTING RODS .... 5-Drop Forged Steel
CYLINDER HEAD .... Cast Iron
PISTONS .... 5-Aluminum Alloy
CRANKSHAFT .... Die Forged, Induction Hardened Steel

VALVE TRAIN

LIFTER TYPE .... Solid
INTAKE VALVE MATERIAL .... Heat Resistant Steel
EXHAUST VALVE MATERIAL .... Heat Resistant Steel
HARDENED VALVE SEATS .... Replaceable

ENGINE GOVERNOR

❒ ELECTRONIC .... Standard
FREQUENCY REGULATION, NO-LOAD TO FULL LOAD .... Isochronous
STEADY STATE REGULATION .... ±0.25%

LUBRICATION SYSTEM

TYPE OF OIL PUMP .... Gear
OIL FILTER .... Full flow, Cartridge
CRANKCASE CAPACITY .... 11 Liters (11.7 qts.)

COOLING SYSTEM

TYPE OF SYSTEM .... Pressurized, Closed Recovery
WATER PUMP .... Pre-Lubed, Self-Sealing
TYPE OF FAN .... Pusher
NUMBER OF FAN BLADES 6
DIAMETER OF FAN .... 560 mm (22 in.)
COOLANT HEATER .... 120V, 1800 W

FUEL SYSTEM

FUEL .... #2D Fuel (Min Cetane #40)
(Fuel should conform to ASTM Spec.)
FUEL FILTER .... 5 Micron
FUEL INJECTION PUMP .... Unit Type Cam Driven
FUEL PUMP .... Mechanical
INJECTORS .... Unit Type Multi-Hole, Nozzle
ENGINE TYPE .... Direct Injection
FUEL LINE (Supply) .... 6.35 mm (0.25 in.)
FUEL RETURN LINE .... 6.35 mm (0.25 in.)

ELECTRICAL SYSTEM

BATTERY CHARGE ALTERNATOR .... 20 Amps at 12 V
STARTER MOTOR .... 12 V
RECOMMENDED BATTERY .... 12 Volt, 90 A.H., 27F
GROUND POLARITY .... Negative

Rating definitions - Standby: Applicable for supplying emergency power for the duration of the utility power outage. No overload capability is available for this rating. (All ratings in accordance with BS5514, ISO3046 and DIN6271). Prime (Unlimited Running Time): Applicable for supplying electric power in lieu of commercially purchased power. Prime power is the maximum power available at variable load. A 10% overload capacity is available for 1 hour in 12 hours. (All ratings in accordance with BS5514, ISO3046, ISO8528 and DIN6271).

GENERAC
POWER SYSTEMS, INC.

SD050

OPERATING DATA

	STANDBY				PRIME			
	SD050				SD050			
GENERATOR OUTPUT VOLTAGE/KW-60Hz			Rated AMP				Rated AMP	
120/240V, 1-phase, 1.0 pf	50		208		40		167	
120/208V, 3-phase, 0.8 pf (NOTE: Consult your Generac dealer for additional voltages.)	50		173		40		139	
120/240V, 3-phase, 0.8 pf	50		150		40		120	
277/480V, 3-phase, 0.8 pf	50		75		40		60	
600V, 3-phase, 0.8 pf	50		60		40		48	
GENERATOR OUTPUT VOLTAGE/KVA-50Hz			Rated AMP				Rated AMP	
110/220V, 1-phase, 1.0 pf	40		182		32		145	
115/200V, 3-phase, 0.8 pf (NOTE: Consult your Generac dealer for additional voltage)	50		144		40		115	
100/200V, 3-phase, 0.8 pf	50		144		40		115	
231/400V, 3-phase, 0.8 pf	50		72		40		58	
480V, 3-phase, 0.8 pf	50		60		40		48	
MOTOR STARTING KVA								
Maximum at 35% instantaneous voltage dip with standard alternator; 50/60 Hz	208/240/416V		480V		208/240/416V		480V	
	82/100		93/113		82/100		93/113	
FUEL								
Fuel consumption—60 Hz — Load	25%	50%	75%	100%	25%	50%	75%	100%
gal./hr.	1.2	2.4	3.3	4.4	1.0	1.8	2.6	3.5
liters/hr.	4.5	8.6	12.5	1.2	3.6	6.8	10.0	13.3
gal./hr.	1.0	1.8	2.6	3.5	0.8	1.5	2.1	2.8
Fuel consumption—50 Hz — liters/hr.	3.6	6.8	10.0	13.3	2.9	5.5	8.0	10.6
Fuel pump lift	40'				40'			
COOLING								
Coolant capacity — System - US gal. (lit.)	4.5 (17.0)				4.5 (17.0)			
Engine - US gal. (lit.)	2.75 (10.4)				2.75 (10.4)			
Coolant flow/min. — 60 Hz - US gal. (lit.)	28 (106)				28 (106)			
50 Hz - US gal. (lit.)	23 (87)				23 (87)			
Heat rejection to coolant 60 Hz full load BTU/hr.	135,900				109,000			
Heat rejection to coolant 50 Hz full load BTU/hr.	115,500				92,600			
Inlet air — 60 Hz - cfm (m^3/min.)	7500 (212.4)				7500 (212.4)			
50 Hz - cfm (m^3/min.)	6225 (176.3)				6225 (176.3)			
Max. air temperature to radiator °C (°F)	60 (140)				60 (140)			
Max. ambient temperature °C (°F)	50 (122)				50 (122)			
COMBUSTION AIR REQUIREMENTS								
Flow at rated power — 60 Hz - cfm (m^3/min.)	166 (4.7)				140 (4.0)			
50 Hz - cfm (m^3/min.)	140 (4.0)				120 (3.4)			
EXHAUST								
Exhaust flow at rated output 60 Hz - cfm (m^3/min.)	448 (12.7)				380 (10.8)			
50 Hz - cfm (m^3/min.)	380 (10.8)				320 (9.1)			
Max recommended back pressure Inches Hg	2.2				2.2			
Exhaust temperature 60 Hz (full load) °F (°C)	1044 (562)				925 (496)			
Exhaust outlet size	2.5" O.D. Turbo				2.5" O.D. Muffler			
ENGINE								
Rated RPM — 60 Hz / 50 Hz	1800 / 1500				1800			
HP at rated KW — 60 Hz / 50 Hz	79 / 64				64 / 52			
Piston speed — 60 Hz - ft./min. (m/min.)	1536 (1230)				1536 (1230)			
50 Hz - ft./min. (m/min.)	1279 (1025)				1279 (1025)			
BMEP — 60 Hz / 50 Hz - psi	189 / 181				151 / 147			
DERATION FACTORS								
Temperature								
6.7% for every 10°C above - °C	25				25			
4.0% for every 10°F above - °F	77				77			
Altitude								
0.8% for every 100 m above - m	1067				1067			
2.6% for every 1000 ft. above - ft.	3500				3500			

STANDARD ENGINE & SAFETY FEATURES

SD050

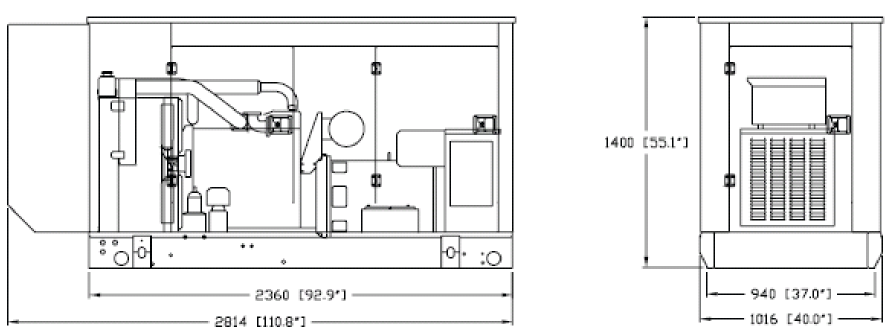
- High Coolant Temperature Automatic Shutdown
- Low Coolant Level Automatic Shutdown
- Low Oil Pressure Automatic Shutdown
- Overspeed Automatic Shutdown (Solid-state)
- Crank Limiter (Solid-state)
- Oil Drain Extension
- Radiator Drain Extension
- Factory-Installed Cool Flow Radiator
- Closed Coolant Recovery System
- UV/Ozone Resistant Hoses
- Rubber-Booted Engine Electrical Connections
- Coolant Heater
- Secondary Fuel Filter
- Fuel Lockoff Solenoid
- Stainless Steel Flexible Exhaust Connection
- Battery Charge Alternator
- Battery Cables
- Battery Tray
- Vibration Isolation of Unit to Mounting Base
- 12 Volt, Solenoid-activated Starter Motor
- Air Cleaner
- Fan Guard
- Control Console
- Radiator Duct Adaptor
- Ischronous Governor

OPTIONS

- **OPTIONAL COOLING SYSTEM ACCESSORIES**
  - 208/240V Coolant Heater
- **OPTIONAL FUEL ACCESSORIES**
  - Flexible Fuel Lines
  - UL Listed Fuel Tanks
  - Base Tank Low Fuel Alarm
  - Primary Fuel Filters
- **OPTIONAL EXHAUST ACCESSORIES**
  - Critical Exhaust Silencer
- **OPTIONAL ELECTRICAL ACCESSORIES**
  - 2A Battery Charger
  - 10A Dual Rate Battery Charger
  - Battery, 12 Volt, 135 A.H.
- **OPTIONAL ALTERNATOR ACCESSORIES**
  - Alternator Upsizing
  - Alternator Strip Heater
  - Alternator Tropicalization
  - Voltage Changeover Switch
  - Main Line Circuit Breaker
- **CONTROL CONSOLE OPTIONS**
  - Digital Controller H100 (Bulletin 0172110SBY)
- **ADDITIONAL OPTIONAL EQUIPMENT**
  - Automatic Transfer Switch
  - Remote Relay Panels
  - Unit Vibration Isolators
  - Oil Make-Up System
  - Oil Heater
  - 5 Year Warranties
  - Export Boxing
  - GenLink® Communications Software
- **OPTIONAL ENCLOSURE**
  - Weather Protective
  - Sound Attenuated
  - Aluminum and Stainless Steel
  - Enclosed Muffler

Distributed by:

Design and specifications subject to change without notice. Dimensions shown are approximate. Contact your Generac dealer for certified drawings. DO NOT USE THESE DIMENSIONS FOR INSTALLATION PURPOSES.



mm [in]

WEIGHT: 2900 lbs.

GENERAC® POWER SYSTEMS, INC. • P.O. BOX 8 • WAUKESHA, WI 53187
262/544-4811 • FAX 262/544-4851

Bulletin 0169810SBY / Printed in USA 02.04, rev: 05.07

Model H-40-C and H-40-C-H Type II RO+DI Systems

AQUA SOLUTIONS®
Water purification, pure and simple™

Designed for Hydrogen Generators and Laboratory Analyzers

Features & Benefits

- *Meets UL, CSA, and CE Mark Specs.*
- *Produces >2 Megohm-cm DI water from ordinary tap water.*
- *Includes purity monitor with flashing red LED alarm.*
- *Price includes a spare activated carbon prefilter cartridge and DI module(s).*
- *System recirculates water continuously, ensuring maximum quality at all times.*
- *Price includes built-in activated carbon & sediment prefilter cartridge.*
- *Optional 0.2 micron final filter capsules and UV sterilizers are available.*
- *Prefilter and DI cartridge/module can be replaced in less than 5-minutes.*
- *Accepts 100-240 VAC, 50/60 Hz input power at <2 Amps.*
- *Safe, quiet, low voltage (12 VDC) internal operation.*
- *User installable & serviceable.*
- *Made in the USA.*

AQUA SOLUTIONS, INC.
8 Old Burnt Mountain Road
Jasper, GA 30143 USA
Phones: 706-692-9200
800-458-2021
Fax: 706-692-9203
E-mail: mail@aqua-sol.com
Internet: www.aqua-sol.com

Product Availability

AQUA SOLUTIONS *Model H-40-C Reverse Osmosis plus Type 2 DI (RO+DI) System* is designed to support Hydrogen Generators and Laboratory Analyzers. The H-40-C RO+DI system is a self-contained unit, measuring just 20" wide by 20" high by 12" deep.

Model H-40-C-H is a high capacity version of the H-40-C. It includes an external DI module, giving it 2.5 times the total ion exchange capacity of the H-40-C, plus a larger (42-Liter vs 10-Liter) RO storage tank.

Either system requires potable tap water, a drain, and a 100-240 VAC, 50-60 Hz grounded electrical outlet in order to operate. It can be bench, shelf or wall-mounted up to 10-feet away from the hydrogen generator and/or laboratory analyzer.

The systems include built-in reverse osmosis (RO) pretreatment to reduce operating costs by as much as 90%, while allowing them to run on virtually any quality potable tap water. The RO purified water is stored in a 10-Liter or 42-Liter pressurized storage tank. The 42-Liter RO tank is optional on model H-40-C.

A purity monitor provides a continuous readout of the purified water quality on its LCD display. The display can be located anywhere within 6' of the system for user convenience. When the water quality falls below the setpoint, a red LED flashes to signal that it is time to replace the activated carbon prefilter and DI module with the included spares.

During operation, a quiet, 12 VDC pump continuously circulates purified water through the DI module(s) and purity monitor on its way out to the hydrogen generator and/or analyzer and back into the system. The quality of the purified water is maximized by this recirculation process, *which does not diminish the capacity of the DI module.*

The system price includes one installed plus one spare Purification Kit. The kit includes one prefilter cartridge plus one or two DI modules. The cartridge and module(s) can be replaced in less than 5-minutes, without disrupting the operation of the hydrogen generator or analyzer.

After installing the spare prefilter cartridge and DI module(s), a replacement purification kit should immediately be ordered and kept in stock to eliminate down-time.

Model H-40-C and H-40-C-H Type II RO+DI Systems

Designed for Hydrogen Generators and Laboratory Analyzers

Water purification, pure and simple™

Model Number	General Description
H-40-C	**AQUA** SOLUTIONS model *H-40-C Reverse Osmosis plus Type 2 DI (RO+DI) System* for operation on *ordinary tap water* containing up to 1,000 ppm of TDS (total dissolved solids).

The system provides Type II (or better) deionized (DI) water to one or more hydrogen generators and/or laboratory analyzers at up to 2 Liters/min, with a maximum daily output of ~50 Liters/day with the standard 10-Liter RO storage tank. Purchase of an optional 42-Liter RO storage tank upgrade increases the daily output to ~200 Liters/day. The system runs on 12VDC, supplied by an external 100-240 VAC, 50-60 Hz power supply.

The price of the **AQUA** SOLUTIONS model H-40-C *includes two (2) Purification Kits, Part Number 2613H40.* One kit is installed at startup, the other is a spare. The spare kit is installed when a red LED on the purity monitor flashes on and off, indicating that the purification kit is exhausted. The purification kit includes an activated carbon prefilter artridge and a high purity DI module. The system includes a reverse osmosis (RO) cartridge, that is replaced as required. It has an estimated life of 2-3 years under normal usage, provided the activated carbon prefilter cartridge is replaced whenever the DI module is replaced. Optional 0.2 micron final filter capsules and UV sterilizers are available for both systems.

H-40-C-H	**AQUA** SOLUTIONS model *H-40-C-H RO+DI System* is identical to model H-40-C except that it includes a larger (42-Liter) RO storage tank and an additional 2618DI external DI module, which increases its DI capacity by a factor of about 2.5 and its daily output to ~200 Liters/day.

H-40-C and H-40-C-H System Specifications

System cabinet dimensions:	20″ wide by 12″ deep by 20″ high
System operating/shipping weight:	~50-75 lbs
Input power to AC Adaptor at 100/240 VAC, 50/60 Hz:	< 2.0 Amps
System operating power from AC Adaptor at 12 VDC:	< 2.5 A
Minimum/maximum acceptable water inlet pressure:	20 to 70 PSI
Maximum allowed total dissolved solids (TDS) in tap water feed:	1,000 PPM
Maximum purified water flow rate:	up to 2 Liters/min
Minimum water purity:	>2 Megohm-cm (0.5 μS/cm)
Purity monitor:	LCD readout in μS/cm with adjustable setpoint and flashing red LED alarm
Ion exchange capacity: H-40-C	~2,000 grains as $CaCO_3$
Ion exchange capacity: H-40-C-H	~5,000 grains as $CaCO_3$
System warranty:	One (1) year
RO storage tank: H-40-C	10-Liters (~7 Liters useable) upgradable to 42-Liters (~30-Liters usable)
RO storage tank: H-40-C-H	42 Liters (~30 Liters useable)
Replacement RO cartridge part number	CR1812H1
Replacement pump part number:	2000CP-12VDC
Purity monitor part number:	M-PRONTO-CON
AC power adaptor part number:	TR-12VDC-2.5AMP
Purification kit part number for H-40-C:	2613H40
Kit includes CC1050 10″ AC prefilter cartridge, plus one 2613DI mixed bed DI module.	
Purification kit part number for H-40-C-H:	2613H40-H
Kit includes CC1050 10″ AC prefilter cartridge, plus one each 2613DI and 2618DI mixed bed DI modules.	
Optional 0.2 micron (absolute) final filter capsule part number	DC2022
Optional 100-240VAC, 50-60 Hz UV sterilizer part number	UV2006S
Placement	Indoors or sheltered where the temperature ranges between 10 and 40 degrees Centigrade

1.2 Product Specification

HOGEN® RE 40	
Description	On-site Hydrogen Generator with Renewable Input capability, Automated, Site Ready Package
Electrolyte	Proton Exchange Membrane
Hydrogen Gas	
Production rate	To 44 SCFH / 1.16 NM^3/h
Delivery Pressure	To 200 psig / 13.8 barg
Purity	Better than 99.999% , <5 ppm H2O, <1ppm other gases Requires 10% purge rate Consult factory for higher purity
Feed Water Specification	
Use rate	~5.6 gallons per 24h day (450 ml/h)
Quality	Requires deionized water feed per: ASTM: Type II (required) Type I (preferred)
Power Specification	
Grid Service Rating	10 kVA
Electrical Specification	AC: 200-240 VAC, 1 phase, 50/60 Hz, Isolated DC: 60 – 200 VDC Maximum Current: 150A Maximum Power: 10kW Maximum Power Point Tracking (MPPT) Non-Isolated Consult factory for other
Power/volume gas	15-18 kWh/100ft^3 H_2, average (6.08 – 7.6 kWh/NM^3 H2) estimated
Environmental	
Location	Indoor, non-freezing, level ±3°C
Ventilation	Proper ventilation must be provided from a non-hazardous area at a rate greater than 1000 CFM
Ambient Temperature	5°C to 50°C, 0-95% humidity non-condensing(at sea level to 5000ft/1520m)
Storage and Transport	5°C to 60°C, 0-95% humidity non-condensing
Controls, Safety Features	
Standard Features	Fully automated, pushbutton start/stop. Tank filling or load following generation rate available.
Communications	Remote Monitoring of Several System Parameters via Ethernet, modem or RS-232
On-board ventilation	On-board blower draws 1000 SCFM fresh air. (Air filter supplied) NFPA 496 Type Z pressurization, purge, and EN 1127-1, Clause 6.2.
Other safety features	On-board H2 detection. Automatic fault detection and system depressurization.
Enclosure	
IP/NEMA Rating	IP22 / NEMA 3R
Dimensions L x W x H	30.9" x 38.1" x 41.4" / 78.5 cm x 96.8 cm x 105.2 cm
Weight	600 lbs / 272.16 kg
Connections	
Gas and Water ports	*H_2 product:* Parker ¼" CPI™ , *H_2 vent* Parker 3/8" CPI™ Compression, tube fittings, 316 SS O_2 vent: 3/8" FNPT *Water in, Water drain* 1/4" diameter polypropylene plastic- push to lock- tube fittings

Electrical Power	Connections: On-board AC circuit breaker, 30A On-board DC contactor
Remote Alarm and Shutdown	Form C external alarm terminal strip connection (20VA), Circuit Breaker shunt trip
Design Standards	NFPA 496; NFPA 50A; NEC 500 article 501; EN 60204-1; EN 1127-1; EN 60079-10
Certifications	Electrolyzer CE Registered; EX II 3 G per ATEX Directive (EN 1127-1) DC Converter CE certification pending

SCFH - Standard Cubic Feet per Hour @ 70 °F, 1 ATM; NM3 - Normal cubic meter @ 0 °C and 1 ATM

LX SERIES™

Low-Pressure Gas Compressors

Compressor Capacity in (scfm) - Two-Stage Units
140 to 300 psi Inlet Pressure
Hydrogen Gas

Maximum Discharge Pressure		Model Number	Motor hp	Inlet Pressures (psig)								
				140	160	180	200	220	240	260	280	300
	1500 PSI	C1.5-03-140/300LX	3	5.5	6.2	7.0	7.7	8.4	9.1	9.8	10.5	11.2
		C1.5-05-140/300LX	5	8.9	10.0	11.2	12.4	13.5	14.7	15.8	17.0	18.0
		C1.5-10-140/300LX	10	16.7	18.8	21	23	25	28	30	32	34
		C1.5-15-140/300LX	15	26	29	33	36	39	43	46	49	52
		C1.5-20-140/300LX	20	35	39	44	48	52	57	61	66	70
		C1.5-40-140/300LX	40	69	77	87	96	105	114	123	131	140
		C1.5-60-140/300LX	60	104	116	131	144	157	171	184	197	209
	3000 PSI	C03-03-140/300LX	3	3.3	3.7	4.2	4.6	5.1	5.5	5.9	6.4	6.7
		C03-05-140/300LX	5	5.4	6.0	6.8	7.5	8.2	8.9	9.6	10.3	10.9
		C03-10-140/300LX	10	10.2	11.5	12.9	14.2	15.6	16.9	18.2	19.5	21
		C03-15-140/300LX	15	15.4	17.3	19	21	23	25	27	29	31
		C03-20-140/300LX	20	20	23	25	28	31	33	36	38	41
		C03-40-140/300LX	40	42	47	53	59	64	69	75	80	85
		C03-60-140/300LX	60	62	70	79	87	95	103	111	119	126
	6000 PSI	C06-03-140/300LX	3	1.7	1.9	2.2	2.4	2.6	2.9	3.1	3.3	3.5
		C06-05-140/300LX	5	2.8	3.2	3.6	4.0	4.3	4.7	5.1	5.5	5.8
		C06-10-140/300LX	10	5.4	6.1	6.8	7.6	8.3	9.0	9.7	10.4	11.1
		C06-15-140/300LX	15	9.4	10.6	11.9	13.1	14.4	15.6	16.8	18.0	19.2
		C06-20-140/300LX	20	12.3	13.8	15.6	17.2	18.8	20	22	24	25
		C06-40-140/300LX	40	29	32	36	40	44	47	51	55	58
		C06-60-140/300LX	60	42	47	53	59	64	70	75	81	86

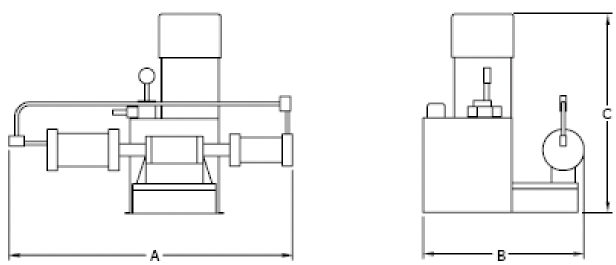
HYDRO-PAC INC
HIGH PRESSURE PUMPS, COMPRESSORS AND EQUIPMENT
P.O. Box 921, 7470 Market Road
Fairview PA 16415
U.S.A.

www.hydropac.com
info@hydropac.com
Phone: 800-394-1511
Phone: 814-474-1511
Fax: 814-474-3421

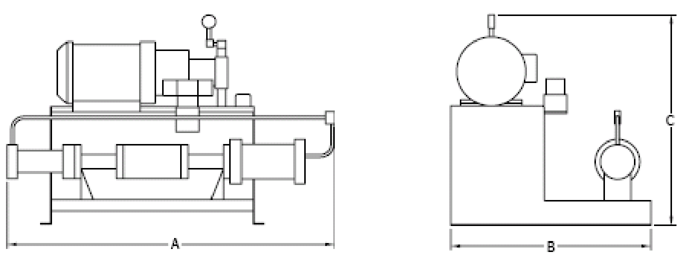
Common Specifications - 1500, 3000 and 6000 psi Units

Motor Power		Cooling Fluid		Weight with oil		Reservoir Volume		Length "A"		Width "B"		Height "C"		Connection Sizes	
HP	KW	gpm	lpm	lb	kg	gal	l	in	mm	in	mm	in	mm	Inlet	Discharge
3	2.3	1	4	570	260	10	37	45	1143	28	711	31	788	½ FNPT	½ tube
5	3.8	2	8	570	260	10	37	45	1143	36	915	36	915	½ FNPT	½ tube
10	7.5	3	12	900	410	30	111	47	1194	30	762	31	788	½ FNPT	½ tube
15	11	4	16	1200	545	40	148	68	1727	37	940	42	1067	½ FNPT	½ tube
20	15	5	19	1200	545	40	148	68	1727	37	940	42	1067	½ FNPT	½ tube
40	30	10	38	3500	1590	70	260	95	2413	53	1347	47	1194	1 FNPT	¾ tube
60	45	15	57	3700	1680	70	260	95	2413	53	1347	49	1245	1 FNPT	¾ tube

Inlet connection sizes refer to US standard taper pipe sizes. Discharge connection sizes refer to ferrule-type tube connections.



3 and 5 hp Units



10, 15, 20, 40 and 60 hp Units

tel (781)-933-7300
fax: (781)-935-4529

STANDARD PRODUCTS : Kodiak Recirculating Chillers

▸ DESCRIPTION ▸ PICTURES ▸ PERFORMANCE ▸ SPECIFICATIONS & ORDERING ▸ SELECTING A CHILLER

Interactive Product Selector
PDF of Catalog Section
Application Notes
Product Pricing
Pump Selection

Kodiak® Recirculating Chillers Specifications[1]

First select your model number

		RC006	RC009	RC011	RC022	RC030	RC045
Cooling capacity[1]	W kBTU/Hr	825 2.8	1050 3.6	1650 5.6	2400 8.2	3450 11.8	5900 20.1
Compressor capacity	HP	1/4	1/3	1/2	3/4	1	1 1/2
Temperature stability[2]		± 0.1°C					
Fluid connections		1/2" FNPT					
Reservoir capacity		1 gal / 4 liters		2 gal / 8 liters		6 gal / 23 liters	
Coolant temperature range		40°F to 95°F / 5°C to 35°C					
Ambient temperature range		50°F to 95°F / 10°C to 35°C					
Dimensions (W x D x H)	inches mm	12.5 x 19.0 x 22.0 318 x 483 x 559		14.8 x 24.5 x 26.5 376 x 623 x 673		21.4 x 27.8 x 31.9 543 x 705 x 810	
Weight	dry lbs (kg)	97 (44)	100 (45)	122 (55)	166 (75)	260 (118)	270 (122)

Next, pick an electrical configuration

Electrical configurations and full load amperage[3]

		RC006	RC009	RC011	RC022	RC030	RC045
G03: 115V, 60 Hz, 1ph	Amps	9.9	12.2	14.3	n/a	n/a	n/a
H03: 230V, 50 Hz, 1ph	Amps	4.5	5.3	6.3	9.5	13.7	17.2
J03: 208/230V, 60 Hz, 1ph	Amps	n/a	5.8	7.4	10.0	14.5	19.6

Now, select a pump

Pump options (refer to selecting a pump and system pump graphs)

	RC006	RC009	RC011	RC022	RC030	RC045
BB: PDP[4], Brass, 1.3 gpm / 4.9 lpm	●	●	●	●		
BC: PDP[4], Brass, 1.8 gpm / 6.8 lpm	○	○	○	○		
BE: PDP[4], Brass, 2.3 gpm / 8.7 lpm	○	○	○	○		

BG: PDP[4], Brass, 4.3 gpm / 16.3 lpm			○	○	●	●
CB: PDP[4,5], Stainless Steel, 1.3 gpm / 4.9 lpm	○	○	○	○		
CC: PDP[4,5], Stainless Steel, 1.8 gpm / 6.8 lpm	○	○	○	○		
CE: PDP[4,5], Stainless Steel, 2.3 gpm / 8.7 lpm	○	○	○	○		
CG: PDP[4,5], Stainless Steel, 4.3 gpm / 16.3 lpm			○	○	○	○
AA: Centrifugal, 1/20 HP[6]	○	○				
DA: Centrifugal, 1/4 HP[6]			○	○	○	○
DD: Centrifugal, 1/2 HP[6]			○	○	○	○
EC: Turbine, 1/6 HP[6]	○	○	○	○		
EB: Turbine, 1/2 HP[6]			○	○	○	○
FB: Stainless Turbine, 1/2 HP[6]			○	○	○	○

Select your controller

Controller options

Package 1[7]: Digital temperature display, calibration offset, low flow shut-off, auto-restart, °C/ °F toggle, audible alarm and alarm mute.	○	○	○	○	○	○
Package 2: Package 1 plus digital pressure sensing, low level, low/high temperature, pressure display, fault shut-off (toggle on/off), relay contacts.	●	●	●	●	●	●
Package 3: Package 2 plus RS232.	○	○	○	○	○	○

Add any additional options

Available options (full description of these options can be found below)

External flow valve	○	○	○	○	○	○
External pressure relief valve	○	○	○	○	○	○
Anti-siphon system	○	○	○	○	○	○
Air filter	○	○	○	○	○	○
5 micron water filter[8]	○	○	○	○	○	○
Heater[9]			○	○	○	○
Internal insulation package	○	○	○	○	○	○
Low temperature operation		○	○	○	○	○

Water-cooled condenser			Ö	Ö	Ö	Ö
0.1°C set point	Ö	Ö	Ö	Ö	Ö	Ö
DI water cartridge[8]	Ö	Ö	Ö	Ö	Ö	Ö
High purity plumbing	Ö	Ö	Ö	Ö	Ö	Ö
PAO compatibility			Ö [9]	Ö	Ö	Ö
Remote start	Ö	Ö	Ö	Ö	Ö	Ö

To arrive at a part number

RC011 G03 BB 2 M___

RC011 chiller with G03 (115V, 60 Hz, 1ph) electrical configuration, a BB pump, and controller package 2

Customization options (A 4 digit option code will be assigned at time of order, based on selected options. Leave blank if no additional options selected)

● = standard Ö = available option
[1]At 20°C setpoint, 20°C ambient, 60Hz input supply [2]Assumes stable load [3]With standard pump [4]PDP = Positive Displacement Pump [5]Only available with high purity plumbing [6]Actual flow rate depends on system pressure drop. [7]5 piece min order [8]Not available with AA and DA pump [9]Not available in G03 electrical configuration

Cooling System Kodiak Options

Option	Benefit
Protection Options	
External flow valve: HIGHLY RECOMMENDED. A manually adjustable globe valve installed on the back of the chiller in parallel with the chiller coolant supply/return.	Allows the operator to control the flow rate to the application. As the external flow valve is opened, more of the flow bypasses the application.
External pressure relief valve: A manually adjustable pressure relief valve (50 to 100 psi or 0 to 50 psi) installed on the back of the chiller in parallel with the chiller coolant supply/return.	Allows the chiller to continue to run and maintain temperature if the flow to the application is interrupted. When flow to the application is stopped, the pressure relief valve opens and bypasses flow to the chiller's return. It can also be used to prevent the chiller supply from exceeding a predetermined pressure setting.
Anti-siphon system: Check and solenoid valves installed internal to the chiller on the supply and return lines, respectively.	Allows the chiller to be installed at an elevation below the application. Prevents backflow and subsequent overflowing of the chiller's vented tank (if not installed, fitting leaks in the application can allow air to displace the coolant, resulting in backflow to the tank).
Air filter: Internally mounted on the air inlet to the condenser coil.	Filters incoming air to the chiller's condensing coil, preventing dust build up which can lead to decreased performance. The easy-access filter is simple to replace, reducing the need to clean the condensing coil and refrigeration components.
5 micron water filter: Externally mounted on the supply from the chiller.	Filters process coolant being supplied to the application, protecting equipment from blockage or damage due to particulate buildup.
Special Applications Options	
Heater: Submerged 2,000 Watt electric resistance heater with built-in over temperature shut-off (non-adjustable).	Allows chiller to reach elevated set points faster (useful for applications in cold start-up situations or where the coolant set point is frequently cycled). This feature does not extend the coolant temperature range of the chiller.
Internal insulation package: Insulated tank, pump head, and coolant lines.	Eliminates condensation forming on the components in contact with the fluid when operating chiller at set points below the ambient dew point.
Low temperature operation: Chiller coolant temperature range is –5°C to +25°C. (Note: internal insulation package must also be selected).	Optimizes performance for low temperature operation and provides additional low temperature cooling capacity compared to standard chillers. Contact Lytron's applications engineering department for

	performance graphs.
Water-cooled condenser: Refrigerant is condensed using water (rather than ambient air) via a liquid-to-liquid heat exchanger.	Heat that would normally be rejected to the ambient environment is transferred to an external liquid coolant source, avoiding room warming and possible air conditioning overload. Also, water-cooled chillers are quieter because there is no condenser fan. Contact Lytron for required facility liquid coolant flow rate and temperature requirements.
0.1°C set point: Allows 0.1°C increments of the set point and display temperatures.	Allows more precise control of the coolant delivery temperature. Available in °C only.
Fluid Compatibility Options	
Deionization (DI) water cartridge: Externally mounted DI cartridge (no indicator light) on the return to the chiller.	Filters ions from coolant to maintain a fluid resistivity level between 1 and 3 megohm/cm by partial flow through the resin bed. This feature does not include a resistivity indicator light. High purity plumbing is recommended with the DI water cartridge.
High purity plumbing: Includes nickel-brazed evaporator and nickel-plated or nylon fittings compatible with DI water. Not compatible with brass pumps.	All wetted materials are fully compatible with DI water to prevent component corrosion.
PAO compatibility: Includes pump, fittings, hose, and oil filter compatible with polyalphaolefin (PAO). Anti-siphon system and internal insulation packages are included in this option.	All wetted materials are fully compatible with PAO. Contact Lytron for PAO performance curves.
Convenience Options	
Remote start: Chiller power can be cycled through a computer or relay.	Allows an external circuit to control the chiller on/off function via dry contacts on the rear of the chiller.

Please refer to the chiller technical manual for further discussion of these features.

Cooling System Kodiak Controllers

Controller Option	Functionality	Controller Package 1	2	3
Digital temperature display	Easy-to-read display in either °C or °F.	•	•	•
Calibration offset	Allows temperature display to be offset to represent the temperature at a different point within the cooling circuit.	•	•	•
Low flow shut-off fault	Alerts user to a lack of coolant flow and shuts down the chiller to prevent the refrigeration system from freezing.	•	•	•
Auto-restart	Automatically returns chiller to its operating status prior to interruption of power, e.g., if the chiller was on, it will turn back on when power is restored.	•	•	•
°C/°F toggle	Enables temperature display to be viewed in °C or °F.	•	•	•
Audible alarm	Audible warning of all fault conditions.	•	•	•
Alarm mute	Silences audible alarm until the alarm is cleared or the chiller turned off.	•	•	•
Digital pressure sensing	Displays pump output pressure (psig or bar) and allows it to be transmitted through RS232.		•	•
Low level fault	Alerts user that the coolant level in the reservoir is at a critically low level (approaching the level of the pump's suction line). Switches chiller off if 'fault shut-off' is on.		•	•

Low/high temperature fault	Alerts user that the coolant temperature is outside of the user's defined set-point limits. Switches chiller off if 'fault shut-off' is on.		•	•
Fault shut-off (toggle on/off)	Allows chiller to be programmed to shut down on fault (on) or continue to run during fault conditions (off). The chiller will always shut down on the low flow shut-off alarm.		•	•
Relay contacts (normally open or normally closed)	Fault conditions of the chiller can be monitored by applying a low voltage power signal across dry contacts at the rear of the chiller. (Power loss to the chiller is not a fault condition.)2 Mating connector—AMP part number 350715-1 and 350547-1		•	•
RS232 communications	Allows complete control of all the chiller's controller features (changing/monitoring coolant set point, monitoring pressure, and fault alarms, etc.) from a remote computer for monitoring, control, and data logging.			•

Package 2 is the standard package.

Cooling System Kodiak Accessories

Item	Description	Part Number
Water Filter Kit:	1/2" fluid connections. Contains 5 micron filter, filter housing, mounting bracket ,1' hosing, base clamps, and assembly instructions.	**200-0441**
Plumbing package:	1/2" fluid connections. Contains 50' Nylabraid™ hose, 50' Armorflex™ insulation, male NPT to barb fittings, hose clamps.	**200-0193**
External pressure relief valve kit: (50 - 100 psi)	1/2" fluid connections. For applications requiring reduced pressure. This kit contains a pressure relief valve, 2 tees, hose clamps, and plumbing instructions. Assembly required.	**200-0196**
External pressure relief valve kit: (0 - 50 psi)	1/2" fluid connections. For applications requiring reduced pressure. This kit contains a pressure relief valve, 2 tees, hose clamps, and plumbing instructions. Assembly required.	**205-0080**
External manually adjustable flow valve:	1/2" fluid connections. For applications requiring flow control. Kit contains flow valve, 2 tees, hose clamps and plumbing instructions. Assembly required.	**200-0298**
115V power cord:	25'	**250-0092**
230V power cord:	25'	**250-0093**
RS232 cable:	10'	**250-0091**
Dry contact cable:	10'	**250-0159**
5 micron replacement water filters*		**330-0022**
Air filters*		**RC006/RC009: 330-1541** **RC011/RC022: 330-0977** **RC030/RC045: 330-0683**
Deionization cartridge		**430-0330**

*10 piece minimum

Standard Products | Product Selector | Custom Products | Drawings | Technical Support | Service | About LYTRON

APPENDIX F: LIST OF VENDORS AND MANUFACTURERS

Component	Name	Address	Website	Contact Name
Hydrogen Codes & Standards				
	Fuel Cell Standards		www.fuelcellstandards.com	Matt Romanow
	DOT		www.dot.gov	
	DOE		www.hydrogen.energy.gov	
Hydrogen Compressors				
	PDC	1875 Stout Dr. Warminster, PA 18974	www.pdcmachines.com	info@pdcmachines.com
	Hydro-Pac	P.O. Box 921 7470 Market Road Fairview PA 16415	www.hydropac.com	Tom Connelly
Hydrogen Generator				
	Teledyne	10707 Gilroy Road Hunt Valley, Maryland	www.teledyneengineeringsystems.com	
	Plug Power		www.plugpower.com	
	Distributed Energy Systems	10 Technology Dr. Wallingford, CT 06492	www.distributed-energy.com	Steve Szymanski
	Avalence	1240 Oronoque Rd P.O. Box 2246 Milford, CT 06460-1146	www.avalence.com	Tom Jackson
	ELT Elektrolyse Technik	Badborngasse 135510 Butzbach D -GERMANY	www.elektrolyse.de	
	Hydrogen Solar	350 Sunpac Court Henderson, NV 89015-4440	www.hydrogensolar.com	
	Treadwell	341Railroad Street Thomaston,CT 06787	www.treadwellcorp.com	
Hydrogen Storage and Distribution				
	Air Products	7201 Hamilton Blvd Allentown, PA 18195	www.airproducts.com	
	Linde AG	Linde Gas Division Seitnerstraße 70 D-82049 Höllriegelskreuth	www.linde.com	