A FEASIBILITY ANALYSIS ON UTILIZING AN EXISTING ENVIRONMENTAL CHAMBER LABORATORY FOR FREEZING STUDIES RELATING TO WATER MANAGEMENT IN PEM FUEL CELLS

By

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This report, "A Feasibility Analysis on Utilizing an Existing Environmental Chamber Laboratory for Freezing Studies Relating to Water Management in PEM Fuel Cells" is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN MECHANICAL ENGINEERING.

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ABSTRACT

Water management in PEM fuel cells is a problem, the solution of which makes PEM cells most useful in the transportation sectors. The water production, as well as the hydration needs of the membrane, creates special considerations when using PEM fuel cells for transportation in geographical regions which have freezing weather conditions. The resolution of these freezing problems as well as flooding problems are of special interest to auto companies due to the desirable power density capabilities of the PEM cells and the relatively low operating temperatures. The purpose of this report is to document the findings of a study to analyze the suitability of the environmental chamber located on the sixth floor in room 601D of the R.L. Smith MEEM building to conduct freeze/thaw studies on PEM fuel cells. It has been felt this chamber provides a suitable location for timely testing of fuel cells with relatively little required work to prepare it and the surrounding lab for cold temperature testing.

This report describes requirement for an environmental chamber and control room for cold temperature tests (0^oC to -20^oC) for PEM fuel cells; and verifies the feasibility of using room 601D and the existing environmental chamber at Michigan Technological University. The Test Chamber and the Control Room need to be set up with explosion proof electrical connections, lighting, a hydrogen detection system that activates a ventilation system to prevent an accumulation of hydrogen reaching the 25% LEL(1% by volume in air).[2,28]

Information obtained from Arbin Instruments indicated that a 75 kW fuel cell at 120V, 600 amps, would consume approximately 2,000 standard liters per minute (SLM) at approximately 2 bar (31 psig) inlet pressure. This pressure varies with cells and load

function. A pressure and volume control regulator must be contained in the test stand. The fuel cell test stand would be set up in the Test Chamber, while the load bank and instrumentation shall be set up in the Control Room outside the chamber.

At this time, based on the analysis of information available, the most feasible alternative is to remodel and use room 601D at an estimated probable construction cost of $112,911.

I. Background

There is a growing public pressure to develop and deploy fuel cell technology because of the potential to provide clean, portable electric power derived from hydrogen; which is available from a variety of sources including water, biomass, ethanol, methane, and petroleum. The environmental impact from mass deployment of fuel cells will be significant due the elimination of fossil fuel derived pollutants. The only products of the hydrogen-oxygen reaction in a polymer electrolyte membrane (PEM) fuel cell are water and heat. While greenhouse gases, such as carbon dioxide, result from the production of hydrogen from petroleum, such production can be centralized and the carbon dioxide recovered before being released into the atmosphere. Hydrogen derived from non-petroleum, renewable energy sources will provide a measure of economic security and stability from uncertainties associated with dependence upon foreign oil. Fuel cell technology also has the potential for providing American workers with manufacturing jobs; particularly important in those states where automotive engine manufacturing will be displaced. It is imperative that the United States establish and maintain leadership in fuel cell technology as part of a long-term, sustainable energy policy.

The potential of fuel cells is not yet realized for a number of unresolved technical problems. The most pressing issues being: (1) hydrogen infrastructure; that is, the distribution of hydrogen or fuel reformation technology for portable fuel cells, (2) platinum loading; the amount of platinum required per fuel cell is too expensive for mass deployment. There is an urgent need for improved electrolyte membranes and electrodes in order to reduce the amount of precious metals needed or to eliminate the use of precious metals altogether, and (3) thermal control and water management. The inability to properly control temperature and manage the product water is one of the primary impediments to reliable operation of fuel cells.

I.A. Freeze Issues in PEM Fuel Cells

The water production in a PEM fuel cell as well as the hydration needs of the membrane create special problems when using PEM fuel cells for portable power in a freezing environment. Current PEM fuel cell systems are not freeze tolerant because of the product water residing in the gas flow channels and the porous electrodes. The expansion of the water upon freezing within the confined spaces of the fuel cell would result in catastrophic failure. The issue of freeze tolerance is particularly acute for transportation applications in geographical regions which have freezing weather conditions.

One potential option for preventing freeze-induced damage is complete dehydration of the fuel cell following shutdown. Complete dehydration, however, would require a significant amount of energy and it would be very difficult to restart the fuel cell since the polymer electrolyte must be hydrated in order for the fuel cell to operate. For the automotive industry, where fuel economy and quick startup are important consumer issues, dehydration after shutdown is not a realistic option.

The solution to this problem is to conduct freezing research on PEM fuel cells to develop design criteria to be used for developing freeze tolerant fuel cell components and systems. For example, research could focus on the removal of liquid water from those areas of the fuel cell which would be damaged or destroyed should the ambient temperature be below freezing when the fuel cell is shut down. Such research would deliver design tools for transferring the water to "freeze safe" areas of the fuel cell. This type of research on freezing of fuel cells is critical to deployment of fuel cell powered vehicles. However, a literature review has found virtually no information on any available fuel cell freezing studies. Nonetheless, freezing of PEM fuel cells is recognized as a critical research area. [14]

Freeze-related fuel cell research requires a specialized facility; few of which exist. This, again, is particularly true for the automotive industry where scalability issues preclude using small (< 10 kW) fuel cell stacks to collect experimental data. The target fuel cell power size for automotive applications is 75 kW. The minimum fuel cell power range for freeze-related experimental research directed towards automotive applications is 10 kW to 30 kW. [15,16] The are only a handful of test facilities worldwide which have the capability to study the effect of freezing on 10 to 30 kW fuel cells suitable for the automotive industry and these facilities are all located within automotive companies, including suppliers. [14] There is no known independent (government or academia) facility capable of studying the freezing of 10-30 kW fuel cells.

I.B. Opportunity for Michigan Technological University

Michigan Technological University (MTU) has the capability to lead research and testing of PEM fuel cells in a freezing environment. The existing ME-EM Energy Thermofluid Research Cold Room Facility located in 601D of the R.L. Smith Building, which allows for extreme temperature and humidity control, could be outfitted with a state-of-the-art fuel cell test station which will include reactant feed controls (flow rate, species concentration, and humidification), stack pressure control, nitrogen purge for stack dehydration, electrical load control, thermal control of the stack, and data acquisition. Specialized measurements using AC Impedance and High Frequency Resistance will be integrated into the fuel cell test station to gather data on transport polarization losses associated with flooding. Since the problem of fuel cell freezing is most acute for the automotive industry, it is natural to target test capabilities to the automotive power train. This need leads to a size of 10 kW or greater, and up to 30 kW, which provides a scalable range. There sizes are based upon conversations with Ballard Power Systems and GM, and literature regarding the Bavarian fuel studies. [15, 16] The Bavarian bus utilized four 30 kW PEM cells to power electric drive motors. [7] The Cold Room is large enough to house fuel cell stacks as large as 75 kW. The combination of the fuel cell test stand with the ME-EM Cold Room would be a facility unique within the United States.

I.C. Project Description

This report documents the findings of a feasibility study on the suitability of utilizing the ME-EM Cold Room, located in room 601D of the R.L. Smith Building, to conduct freeze/thaw studies on PEM fuel cells in a power range of interest to the automotive industry. The ME-EM Cold Room provides a suitable location for timely testing of fuel cells with relatively little work required to convert it and the surrounding lab for freeze experiments on fuel cells.

The study is broken into three major divisions; requirements, current capabilities and recommended modifications. The requirements which must be met by the Cold Room Laboratory in order to test a 30 kW PEM fuel cell stack are detailed in Chapter II and the current capabilities of the Cold Room Laboratory are presented in Chapter III. The recommended modifications are presented in Chapter IV. A summary of the study is given in Appendix A. The bulk of the modifications are related to safe handling and storage of hydrogen.

I.C.1. Fuel Cell and Test Requirements

It is proposed to test PEM fuel cells in the 10 kW to 30 kW power range. Based upon data gathered, the physical size of the 75 kW unit is expected to be 200 cm X 50 cm X 32 cm [1,2,4,9,11]. The target power range of 10 kW to 30 kW is sufficient to provide scalable data for full-size fuel cell stacks directed towards automotive power. Test duration is based upon an estimated maximum cool down/warm up period of two hours bracketing a 4-8 hour maximum steady-state test period for a total single test period of no greater than 14 hours. Initially, only one test per week is required. Fuel consumption is estimated to be 8.3 kg/hr, at standard conditions.[5,26] Hydrogen consumption estimates are based upon information obtained from Arbin Instruments who have manufactured stack instrument and control systems for as large as 75 kW systems for companies and organizations such as NASA report [4] and Airgas Company, a supplier of bottled hydrogen [32]. The hydrogen could be stored in standard ”K” bottles (5,663 liters at a pressure of 2080 psig).[32] Alternative hydrogen storage and/or source options are discussed in Appendix F. Air or oxygen (oxidizer) consumption is estimated to be 16 to 18 kg/hr and could be obtained from ambient, compressed air (unoiled) provided by the building, or compressed air from cylinders. Purge requirement of an inert gas could be provided by bottled gas in the form of nitrogen or argon.

The test equipment should include reactant feed controls (flow rate, species concentration, and humidification), stack pressure control, nitrogen purge for stack dehydration, electrical load control, thermal control of the stack, and data acquisition. Specialized measurements using AC Impedance and High Frequency Resistance (HFR) will be integrated into the fuel cell test station to gather data on transport polarization losses associated with flooding. The specifications of the test equipment are based upon potential vendors' proposals. The types of test equipment available, including HFR, are given in Appendix E.

I.C.2. Facility Description

The ME-EM Cold Room Laboratory consists of a large environmental chamber, hereafter referred to as the Test Chamber, located within Room 601D of the R. L. Smith Building. Room 601D will be referred to as the Control Room for the purposes of this report.

Figure 1 shows the current configuration of the ME-EM Cold Room Laboratory, room 601D of the R.L. Smith Building. The room and chamber are oriented north and south. The main entrance door is on the south end of room 601D. The door between room 601D and room 602 is a 1 hour fire-rated door, as is the door to the hallway. The power panel (PP) provides 208 V/3ø/100 amp electrical power. A fire alarm pull station (F) connected to the campus safety system is located outside the 601D door. A folding partition separates 601 from 601D. The partition is sound rated; however it is only ¾ hour fire rated. The north wall is an exterior wall containing a 67.3 cm (26.5") wide by 373.4 cm (12.24 ft.) tall window. The wall between 601D and 602 is a 1 hour fire-rated drywall and stud wall.

The compressor and condenser sit atop the Test Chamber. The condenser is cooled by water which then flows down the floor drain (FD). A 19 mm (3/4" NPT) water line (H2O) provides water to this room. A 38 mm (11/2"NPT) steam line (STM) provides steam to the Dryair humidifier located in the chamber. The condensate is drained to the 76 mm (3"NPT) floor drain (FD) in the room. There are two Dryair R150 desiccant dehumidifiers connected with two 100mm (4"NPT) supply ducts to the top of the chamber and with two 100mm (4"NPT) exhaust ducts to the bottom of the north chamber wall. There are two 100mm (4"NPT) ducts from the dehumidifiers to the EF-52 exhaust duct.

Figure 2 shows the modified Test Chamber and Control Room. The folding partition has been removed, and an 8" c.m.u. (concrete block), 2 hour fire-rated wall has been constructed on the east side. The wall between room 601D and 602 has been upgraded to a two hour wall. A gas-proof partition wall has been added to contain hydrogen on the chamber side of the wall. A strobe horn alarm system has been added to control entry. The test stand is shown in the test chamber; the feed-throughs are shown installed between the test stand and the control/instrumentation stand. The instrument and control stand are shown outside the test chamber. The fuel, oxidizer, purge gas, waste piping, and other piping is not shown for clarity. The lights and outlets within room 601D have been converted to hazardous location mounting boxes, plates, switches and outlet boxes.

A ventilated hydrogen storage cabinet has been installed with an explosion-proof fan and damper, supply and exhaust system. Additionally, compressed gas cylinder racks with appropriate restraints are shown. Additional hydrogen, air, and nitrogen compressed gas cylinders are stored in similar racks outdoors or in the sub-basement. Symbols S1, S2, and S3 indicate gas sensors for hydrogen and oxygen. These sensors are part of the Argus (See Appendix C for details.) hydrogen detection and alarm system. This system is shown connected to a strobe and horn system, indicated by the "S" near the pull box, to warn of hydrogen accumulation. The condenser/compressor system is shown relocated on a shelf in room 602. The unit is re-piped through fire-safed sleeves in the wall to avoid passage of hydrogen. There is an additional window adjacent to the hydrogen gas cabinet. An access panel has been installed in this window for intake of outside air and exhaust from the cabinet. The balance of both of the windows has been further replaced with explosion relief vents/diaphragms to release pressure, should there be a deflagration. A limited area fire suppression system is recommended in the interest of extinguishing fire. Figure 3 shows the location of Control Room 601D and its relationship to the rest of the sixth floor.

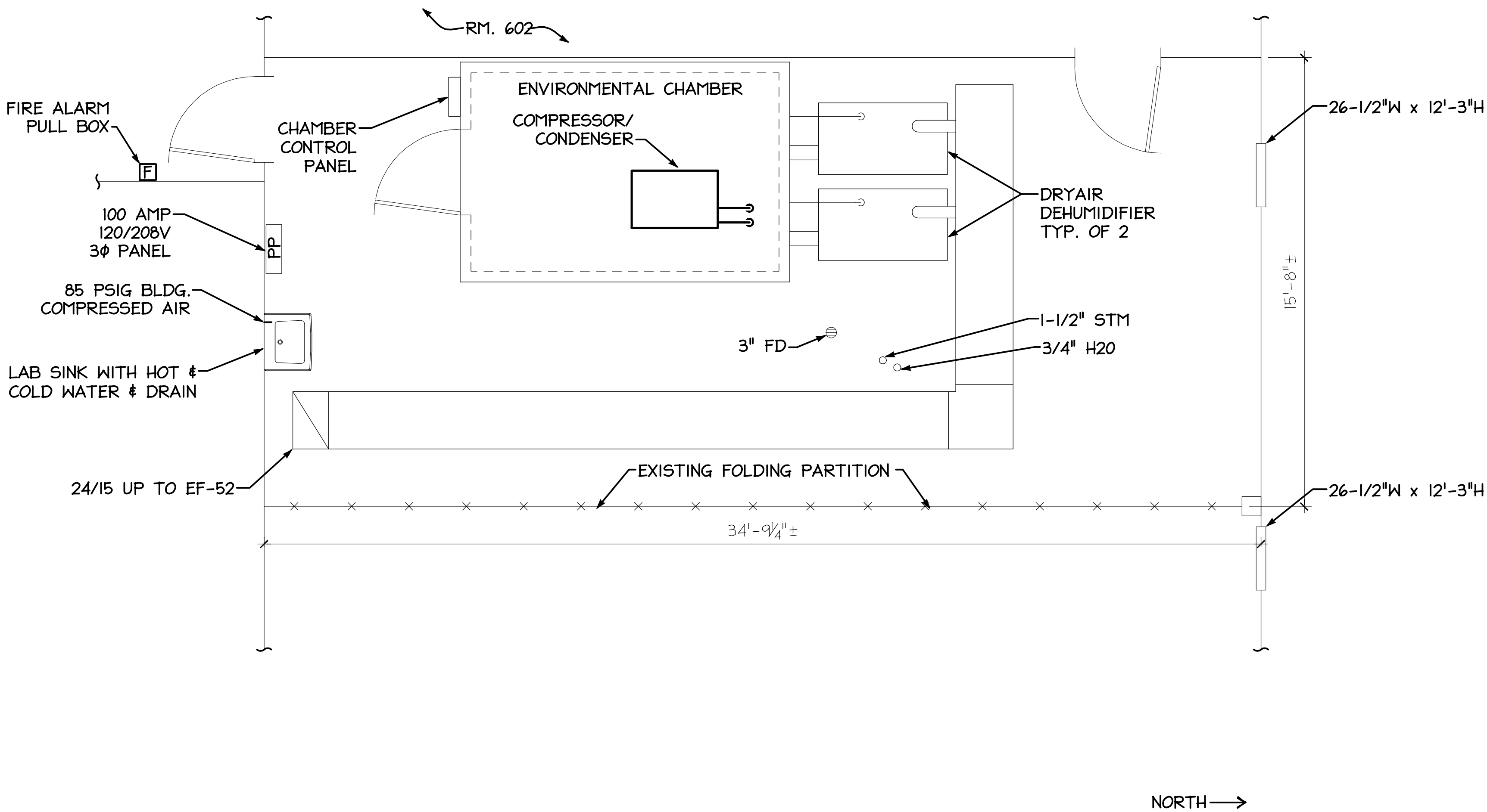


FIGURE 1		
RM. 601 D	R.L. SMITH BLDG.	AS-IS
SCALE 1/4" = 1'-0"±	DATE 3-30-05	SHEET 1 OF 2

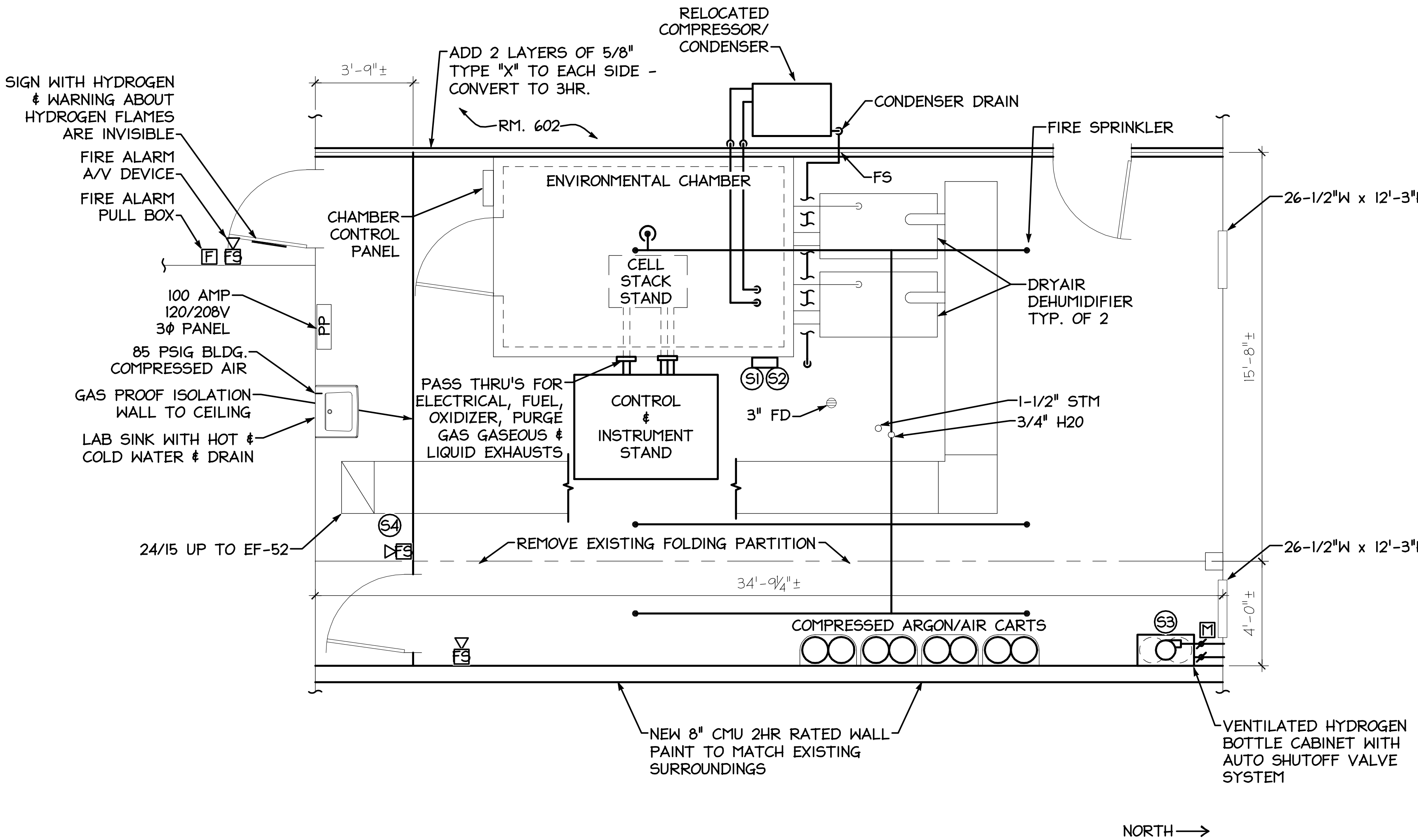
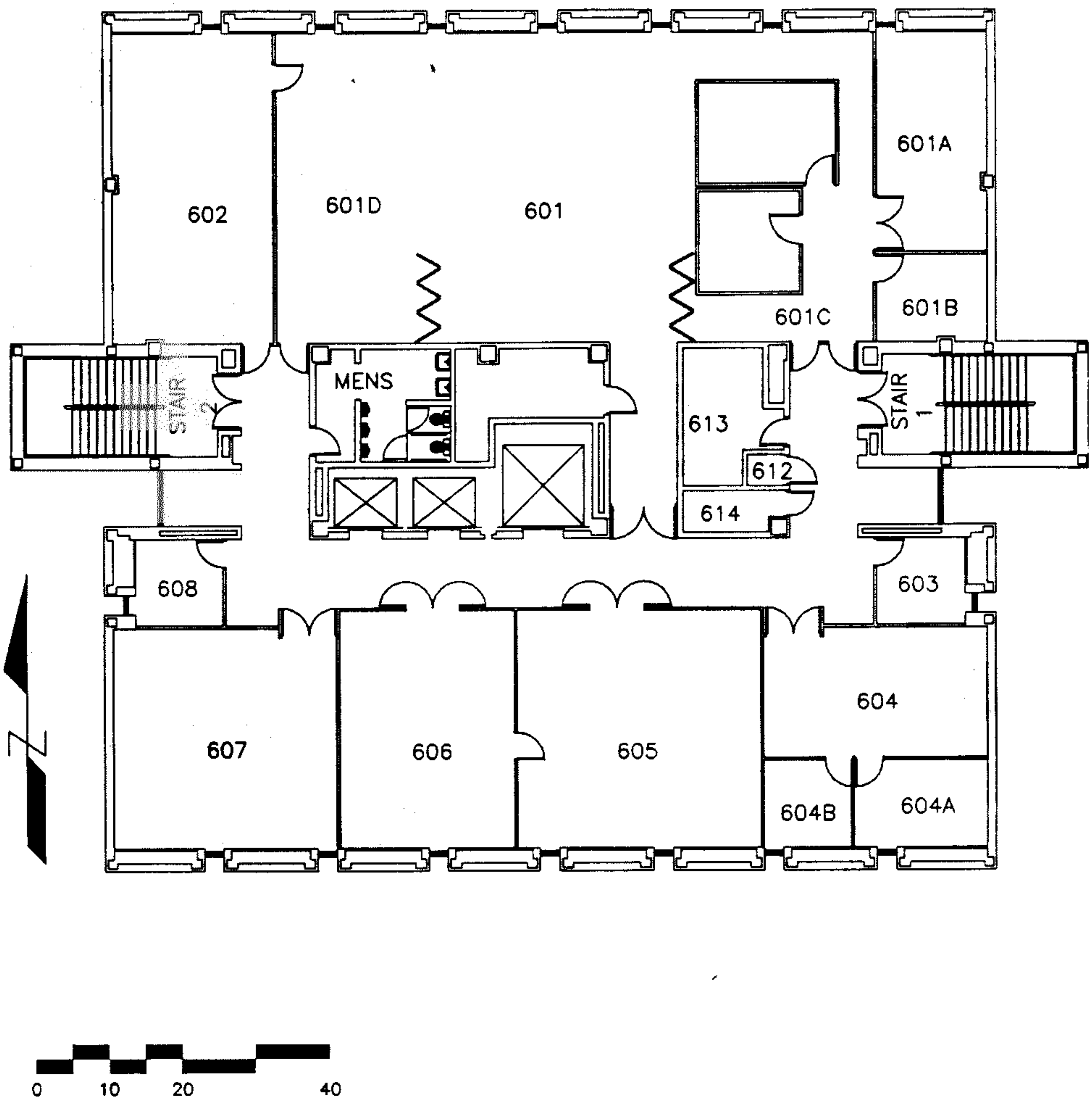


FIGURE 2		
RM. 601 D	R.L. SMITH BLDG.	MODIFIED
SCALE 1/4" = 1'-0"±	DATE 3-30-05	SHEET 2 OF 2



FACILITIES MANAGEMENT
MICHIGAN TECHNOLOGICAL UNIVERSITY

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SHEET 8 OF 14

II. Facility Requirements

II.A. Test Chamber

The Test Chamber is the cold room located in room 601D. The fuel cell systems to be tested would be placed inside the Test Chamber while the experiment diagnostics and fuel cell control equipment would reside outside the Test Chamber in the Control Room.

II.A.1. Space

The Test Chamber volume should be small enough to enable relatively quick changes of environmental conditions. Since the primary focus of this testing is water management in freezing conditions, the ability to quickly cool the cell and maintain temperatures at or below 0^o C/32^o F is important. It is estimated that the fuel cell stack and support stand [2,5,8,9,26] occupy 200 cm in length x 46 cm high x 60 cm in length plus suggested connection space of almost 25 cm all the way around the assembly. The total working space around the cell and stand should be 40 cm to 60 cm. The instrumentation and test stand diagnostics including gas control, humidity control, loads, measurement, etc. will occupy about 2.5 m x 2 m outside and adjacent to the environmental chamber. To control the environmental conditions inside the cell, an evaporator coil, located near the ceiling, for the refrigeration, will occupy 180 cm x 30.8 cm x 61 cm; a humidifier will occupy 21 cm x 21 cm x 15 cm, and a dehumidifier is connected to two supply ducts located low and two return ducts located high. Lights and miscellaneous connections will occupy another 40 cm x 21 cm x 15 cm. Total equipment volume is estimated to occupy approximate dimensions required of 2.2 m x 1.4m x 1.83 m. [2,5,8,9,27] See sketches available from suppliers in appendix E.

II.A.2. Heat Rejection

In order to enable the study of water migration, heat rejection and freezing, the environmental control unit will need to reject 10.54 kW (36,000 BTUH) at 75 kW fuel cell operation. This will require a refrigeration system capable of at least 3 tons of heat rejection to maintain freezing conditions during cell operation. [6]. The relative humidity for the surroundings should be maintained as close as possible to outdoor conditions of a particular geographical region where fuel cells are expected to operate in cold weather. This could be Houghton, Michigan or Marquette, Michigan where ASHRAE 97.5% conditions are -14.48ºC and 25% relative humidity. [3]

II.A.3. Humidity Control

The Test Chamber requires the ability to control relative humidity between 5% and 95%.

II.A.4. Feedthroughs

Feedthroughs require entrance to the chamber through a spark proof connector. This will require an umbilical cord to be run through a gas-tight access in the wall. The fuel cell test diagnostic systems offer multi-function cables which can be connected to the test stand prior to operation or fuel delivery. The only connection through the wall will be a fire-safed opening sealed with fire stop compound such as 3M Fire Barrier moldable putty. The feedthroughs are available, with the exception of fuel, purge, and oxidizer gas piping, in a wrapped umbilical-type cable. The piping for the gases and exhausts are expected to be 25mm or 32mm pipe (1" or 1.25") maximum 37mm (1.5") to accommodate the 1500 SLM of hydrogen and the 4,000 SLM of air, and the 4,000 SLM short-term consumption of nitrogen or argon purge gas, and the 4500 SLM of water and vapor exhaust products. Gas flow quantities are based on an upper limit for future capacity to 75 kW.

II.A.5. Safety

Safety requirements are planned primarily around the explosive characteristics of hydrogen. The commercially available test stands contain gas sensors to detect the presence of hydrogen accumulations around or near the fuel cell. A number of standards and codes define the requirements which should be met in a research setting. The rules and standards include, but are not limited to, the following categories:

II.A.5.a. Flammability

International Construction Code (ICC)[18,21,23,25] prevents confinement and pocketing of unignited flammable gases, including requirements for ventilation, service, maintenance, and inspection of utilization of equipment.

II.A.5.b. Flammable Storage

NFPA 55[17] is the standard for storage, use, and handling of compressed gases and flammable fluids in portable and stationary containers, cylinders, equipment, and tanks. The compressed gas requirements apply and generally require the following for a test facility: 1) one exterior wall; 2) no direct opening into another interior occupied space; 3) adjacent rooms have 2 hour fire separation or a full fire sprinkler system in accord with NFPA 13[17]; 4) meet the requirements of NFPA 50A [28]; 5) ventilation in accordance with the International Mechanical Code (IMC) section 502.16.[19]

II.A.5.c. Hydrogen Systems

NFPA 50A [28] is the "Standard for Gaseous Hydrogen Systems at Consumer Sites" and defines a number of conditions applying to our system: 1) a system whose total content will be slightly over 400 SCF(11,300sl); 2) containers shall be in accord with ASME Sec. VIII; 3) containers and the room entrance shall be marked with

HYDROGEN; 4) pipe and tubing shall be constructed in accordance with ASME standard B31.3 [33] code for plant process piping; 5) location and requirements for storage of cylinders; 6) electrical requirements shall meet the requirements of NFPA 70 [22], article 501 (National Electrical Code) for Class 1, Div. 2 locations for electrical within 15 feet; 7) ventilation shall be in accordance with International Mechanical Codes [19,28] with outlets at high points and inlets at low points; 8) explosion venting may be provided in accord with NFPA 68 [29]; 9) fire protection caution at room entry regarding the nearly invisible hydrogen flames; 10) NFPA defines the system as including stationary or portable containers, pressure regulators, pressure relief devices, manifolds, interconnecting piping, and controls as required; 11) NFPA 57 [7] shall apply only if gaseous oxygen is to be used as an oxidizer. However, this is not a current consideration because the plan is to use air.

II.A.5.d. Other Applicable Standards

In addition there may be in effect at the time this testing begins a number of other standards including, but not limited to, the following:

1. The IEC Work Group 3 “Stationary Fuel Cell Plant Safety”;[30]
2. Revisions to the UL/ANSI 20 75 standard for “Gas and Vapor Detectors and Sensors”;[24]
3. Revisions to NFPA Standard 583 “Standard for the Installation of Stationary Fuel Cell Power Plants”;[25]

4. Revisions to IEC Tech Committee 105, Working Group 5 "Stationary Fuel Cell Power Plant Installation";[30]
5. Revision of BE EN 50013 "Guide for Selection, Installation Use and Maintenance of Apparatuses for the Detection and Measurement of Combustible Gas and Oxygen";[23]
6. Revisions to the International Construction Code Series including the IFC table 2209.3.1, IBC, IMC, and other in the series.[20]

II.A.6. Ventilation

In the International Mechanical Code, Section 502.16 for hydrogen fuel vehicle refueling locations, and as defined in NFPA 50a [28], mechanical ventilation systems shall be arranged as follows.

Inlets shall be uniformly arranged on exterior walls near the floor. Outlets shall be arranged at a high point of the room in exterior walls or the roof (ceiling). Ventilation shall be continuous mechanical ventilation or by a mechanical system activated by a hydrogen detection system activating at a gas concentration of 25% of the Lower Explosion Limit (LEL). Table 1 on the next page gives comparisons of the percent of LEL of hydrogen, referred to herein, to the percentage of hydrogen by volume in air. The detection system, in all cases, shall shut down the fuel supply system in the event of failure of the ventilation system. The ventilation rate shall be at least 1 CFM per 12 cubic feet of room volume (0.00138 $m^3/s/m^3$). The mechanical ventilation system shall operate continuously unless it is interlocked with a gas detection system designed in accordance with the International Fire Code, section 2210.7.2, 2000 edition.[17] In addition to the precautions listed, further precautions shall be made to control hydrogen supply in the event of power loss in the building. Should the detector be activated and the power lost, the system valve shall close.

TABLE 1. Comparison of % LEL to % H_2 by Volume, in Air

%LEL	% H_2 by Volume
20	0.8
40	1.6
60	2.4
100	4.0

Due to the fact that this facility is located on the sixth floor, a ventilated cabinet will be required to allow 400 cubic feet (11,300 sl) of hydrogen to be utilized at one time. This is due to the IFC [20] limitation of 12.5% of volume allowed on the sixth floor. In addition to the list of precautions and activities above, there shall be a complete safety plan including, but not limited to, an evacuation plan, fire suppression plan, warning signs plan, fire prevention plan, and an acceptable alarm plan. There is a requirement in NFPA 50A [28] for a wall or membrane to have a 25 psf, or less, relief pressure. An explosion membrane can also handle this. In addition, the gas detection system must prevent an accumulation of hydrogen in the chamber or in the surrounding spaces to less than 25% of LEL. There is to be adequate outside air to replace the air in the room with adequate air to prevent the hydrogen from the system from replacing the 21% of oxygen in room air.

II.B. Control Room

II.B.1. Space

Since the instrumentation will be kept outside the environmental chamber, the space required for that will be a minimum of $8m^3$. However, for ventilation and dehumidification systems, the estimated space is another $8m^3$ for a total of $16m^3$, or a space about 2.5 m in length, height, and width. Considering volume dilution for ventilation, the optimal space size will be as small as possible to work in. The H_2 cylinder storage space separation of 4.5 m from the work site will require a room about 10 meters long or a remote storage location for hydrogen.

II.B.2. Utilities

The electrical power supply to the room should be at least 208 V, single phase, 100 amp supply. There will need to be a source of water and a drain capable of handling a 9.5 lpm to 32 lpm discharge.

II.B.3. Environmental Control

For humidification purposes and possible heating, a low pressure steam supply is advisable. In addition to heating, it's advisable for cooling the control room that a cooling system be available to reject at least 3 to 4 tons (36,000 to 48,000 BTUH).

II.B.4. Safety

The control room will require one exterior wall, no exits accessible directly to another occupied or common space; 2 hour fire separations between adjacent spaces, and if an explosion vent, in accord with NFPA 68 (Standard for Venting Deflagrations). The control room shall contain a redundant gas detection and shut down system, and a continuous ventilation system in full accordance with the codes and standards listed for the test chamber. Hydrogen gas and compressed air storage shall be separated by 1.52 m, while the hydrogen shall be stored in a ventilated gas cabinet. Hydrogen storage is limited to two 5,663 l (200 ft^{3} @ 2080 psig) bottles (standard ‘k’ bottles), piped to a manifold in the cabinet, with a manual and an automatic shut off valve located outside the continuously ventilated cabinet. [17,28] The fuel and oxidizer shall be piped to the test stand gas control and treatment system in accordance with ASME B31.3 “Code for Process Piping for Industrial Plants.[33]

II.B.4.a. Flammable Storage

The control room requires adequate space to contain the test chamber, the instrumentation, data acquisition, and controls for the test stand. The control room also requires adequate space to locate the gas cabinet at least 5 feet from the fuel cell. The electrical systems within 7.6 m (25 feet) of the test chamber shall be in accordance with NFPA 70 (National Electrical Code)[22] paragraph 510.0, class II, div. D explosion proof.

Section II C. Building and Campus

II.C.1. Safety

Both the Test Chamber and the Control Room shall be connected to central security via connection to the building fire alarm system notifying campus safety of 1) over concentration of H^2; 2) activation and shutdown of the emergency hydrogen shut off valve; 3) loss of power to the sixth floor lab; 4) activation of smoke and fire alarm. An alarm capability is expected to be purchased with the test stand. In addition to the above alarms, fire extinguishers and warning signs warning of the nearly invisible flames of hydrogen shall be posted outside the room, and just inside the control room entry. [28]

III. Current Capabilities

III.A. Test Chamber

III.A.1. Space

The existing test chamber has inside dimension of 2.41m(7’11”) high x 3.33m (10’11⅛”) long x 2.17m(7’1⅝”) wide. This inside dimension allows adequate clearance for up to a 75 kW fuel cell stand and test stand. [26]

III.A.2. Heat Rejection

The chamber has maintained steady state temperatures as low as -30^{o} C and has capabilities of heating to (104^{o}F) 40^{o}C. The R12 refrigeration system [31] is capable of rejecting up to 36,000 BTU per hour to the water cooled condensing unit. Temperature measurement capabilities are available.

III.A.3. Humidity Control

The environmental chamber has a direct steam injection humidification system capable of controlling relative humidity within +/- 2%. In addition, the chamber is attached to two Dryomatic Model R150 desiccant dehumidifiers capable of dehumidifying to within +/- 1% of the relative humidity set point.

III.A.4. Feedthroughs

Feedthroughs are currently available at a number of points. Many of these locations will be unnecessary once the test stand and control room instrument orientation is made.

III.A.5. Safety

There are no existing capabilities for combustible gas sensing, alarm, or control.

III.A.6. Ventilation

The current Test Chamber and Control Room (601D) will require the addition of the hydrogen safety and monitoring systems. The chamber has adequate ventilation with capabilities of exhausting and making up of $0.144 m^3/s$ (300 CFM). The code requirement of 1 CFM per 12 ft^3 ($0.0038 m^3/hr\ m^3$) of room volume requires 490 $ft^3 \div 12 ft^3/CFM = 41$ CFM. The existing system has the capacity of almost 8 times the required ventilation requirement. This also allows for the provision of room pressure air to the fuel cell for operation if such tests are desired.

III.B. Control Room

III.B.1. Space

The control room currently has dimensions of approximately 10.6 meters (34.8 feet) x 4.8 meters wide x 3.58 meters high (11.75 feet) and a volume of approximately 182 cubic meters.

III.B.2. Utilities

There is a 208 V, three phase/100 amp breaker panel within the control room.

III.B.3. Environmental Control

The control room is conditioned by the building air conditioning system and has the capability of rejecting approximately 1.5 to 3 tons (18,000-36,000 BTUH) of energy through the air system, when the heat is not rejected to the drain. In addition to the A/C system the room has an exhaust fan capable of exhausting 1,225 CFM, which when the gas detector indicates ventilation is required for the room (1CFM/12ft^3) (0.0038m^3/m^3hr) can exhaust nearly twice the required 529 CFM.

III.B.4. Safety

The control room has one exterior wall and one two hour wall to the adjacent space. The door is one hour rated. However, a moveable partition and a sheetrock partition are not two hour fire rated. The exterior wall contains a window which can satisfy the explosion vent requirement when converted to explosion vent material (safety plastic vent fabric).

III.C. Building and Campus

III.C.1. Safety

The building fire alarm system has an alarm wall switch in the 601D lab. This will allow connection of the alarm from the control room gas, electrical, and ventilation control system to be forwarded to campus safety.

IV. Recommendations

IV.A. Test Chamber

IV.A.1. Space

The Warren -Sherer Model "CER" environmental Test Chamber[31] has adequate space for containment of the test cell stack and test stand with internal dimensions or 3.327 m long x 2.175 m wide x 2.413 m high. The internal volume is 17.461 cubic meters.

IV.A.2. Heat Rejection

A BTU meter shall be added to accurately measure the heat rejection. The heat rejection capacity of the existing KRACK ELD 1000 refrigeration equipment is adequate for a 75 kW stack, down to -20^{o}C. However, the evaporator fan motors and controls will need to be converted to explosion proof motors and controls. The water shall be measured via an added flow meter and dumped down the drain. The estimated probable construction cost is approximately $2,371.

IV.A.3. Humidity Control

Humidity control is excellent because of the Bryair steam humidification system and the Dryair dehumidifiers.

IV.A.4. Feedthroughs

The chamber feedthroughs will require removal of existing electrical conductors and sealing of the openings with gas tight insulation foam to fill openings. Thereafter, an opening will be made that accommodates the test stand electrical load control and instrument umbilical; the fuel pipe, the oxidizer pipe, the purge gas pipe, and the by-product drain piping. It's estimated these pipes will all be 28 or 32 mm (1" or 1.25" NPT) stainless steel schedule 40 with Swagelok fittings to connect to the test stand and to the cell stack, except that the water drain pipe will be 37mm (1.5" NPT) stainless steel. Install two 15cm (6"NPS) Ø gas tight sleeves The estimated probable construction cost of this sealing, patching and connecting piping is $3,630. Electrical feedthroughs for other than instrumentation are for conversion of the lighting to explosion proof fixture; one explosion proof outlet; one explosion proof light switch connected with 3 way switch outside; an explosion proof sensor for hydrogen gas accumulation. The estimated probable construction cost of these improvements is $2,870.

IV.A.5. Safety

The gas detector connection to the ventilation/dehumidification system will require an explosion proof solenoid valve outside the chamber with an interlock to the campus security if the accumulation reaches 25% of LEL in the chamber. It is recommended a sensor be installed to a local alarm to alarm at the 20% of LEL to allow the opportunity to correct the accumulation by manual activation of the exhaust system. The estimated probable construction cost of this is $2,800.

IV.A.6. Ventilation

Emergency venting of the chamber is activated upon detection by the gas detector of hydrogen accumulation of 20% of hydrogen LEL. This will activate a relay which will turn on the second Dryair dehumidifier fan and the room EF-52 to exhaust the chamber to the EF-52 exhaust duct. The relay will also open outside air dampers to the room and to the Dryair units to evacuate the chamber and the control room. The estimated probable construction cost of this is $2,060.

Make-up air to the chamber will be provided from the control room via the same set of automatic dampers, controlled by an oxygen sensor, to prevent and to warn of low O^2 levels, located in the chamber, and depending upon the test stand requirement for oxidizer concentration measurement location (chamber or control room)

The supply and exhaust duct work will need to be reversed so that the exhaust is at the top and supply is at the bottom of the chamber, estimated probable construction cost is $480.

IV.B. Control Room

IV.B.1. Space

There are no recommendations for this.

IV.B.2.Utilities

There are no recommendations for this.

IV.B.3. Environmental Control

There are no recommendations for this.

IV.B.4. Safety

Control room modifications include the construction of a two hour fire-rated masonry wall 20 cm (8”) thick, fitted with insulation between 601 and 601D (See Figure 2). The estimated probable construction cost of the walls is $24,090. This wall should be located +/- 4' to the east of the current folding partition wall, along the next easterly beam and column line. This location will provide; 1) adequate spacing for location of the hydrogen gas storage cabinet; 2) Additional windows for the location of explosion venting. In addition, a masonry air lock portion will need to be constructed at the entrance to the control room. This room will be an accessible room with necessary 18" side approach at entry, 2 hour fire-rated, gas sealed door. This will enable the existing electrical panel to remain and be used within that air lock. A hydrogen gas detector at 20% LEL in the air lock will be connected to the alarm system to give a preliminary alarm. A new light fixture will be required to assist at the electrical disconnect panel.

In addition to these walls, the wall between 601D and 602 will need to have a layer of 5/8 "Type X" fire-rated sheetrock added to each side to convert this wall to a 2 hour fire rated wall assembly. At the same time the door and frame between rooms 601D and 602 will need to be replaced with a 2-hour fire rated door with an emergency lock, operable only from the control room. The door will require gas tight hydrogen resistant seals. The estimated probable cost of this construction is included in the $24,090 above.

The control room will need to have two openings cut into the lower portion of the outside wall and fitted with louvers and automatic motor operated dampers. These openings will be approximately 40.6cm x40.6cm (16"x16"), and will require installation of a 20.3cm x 40.6 (8"x16") long lintel above the opening to ensure strength in the masonry above the opening. These louvers will be interlocked with the gas detection system to open upon sensing in the chamber or the control room of hydrogen accumulation equal to 25% LEL. The damper operators will have end switches to activate a relay to turn on EF 52 to exhaust the control room. The dampers will remain open for a period of 10 minutes after the hydrogen concentration drops below 25% LEL. Estimated probable construction cost of these improvements is $3,320.

In addition to the fire rated wall construction, the existing windows will be removed and replaced with explosion venting materials to relieve a deflagration in accord with NFPA 68 [29]. In addition, a safety barrier or screen shall be placed over the vent from the inside to prevent access by room occupants. The venting material shall be contracted in a fashion to provide light to the room and a minimum R-7 thermal resistance. The estimated probable construction cost of these improvements is $3,890.

Further improvements include, but are not necessarily limited to, the following:

1) disconnect existing light and outlets and rewire two fixtures plus emergency and exit lights, and two outlets with explosion proof fixtures. Estimated probable construction cost is $3,680;

2) Provide a ventilated gas cabinet for two hydrogen cylinders 5,663 liters ($200ft^3$) each installed in the farther corner of the control room, at least 20 feet from the control stand. Estimated probable construction cost of this is $4,200;

3) Install a rack for two argon bottles along the new east wall at least five feet from the hydrogen tanks. Estimate probable construction cost is $480;

4) Install a rack along the new east wall for four air bottles to utilize in lieu of compressed building air. Estimated probable construction cost is $560;

5) Core drill two 101.6mm (4”) diameter holes above the cabinet and two 101.6 (4”) diameter holes above the floor for hydrogen cabinet inlets and exhaust vents to the outdoors. The cabinets shall have exhaust fans which continually relieve the space around the tanks. The hydrogen valve manifold shall be contained

within the cabinet. Estimated probable cost of these improvements for the cabinet is $780 (fan is included in 4 above).

Piping for all gases shall be supported along the masonry walls. Estimated probable construction cost of the piping systems is $13,060. All piping within all systems shall be designed and constructed in full accordance with ASME B31.3 code[32] for process piping in industrial plants.

The control room shall have a gas detector to detect hydrogen accumulation and activate the ventilation system at 20% of LEL. This detector will shut off the gas supply, open the outside air dampers, open the room exhaust dampers, and energize exhaust fan EF-52. The estimated probable construction cost of these improvements is $42,100.

In the interest of research safety it may be desirable to install a dynamic gas sensing system which samples every 30 seconds and allows the gas supply to remain connected to the fuel cell for up to 2 minutes after concentration exceed 25% LFL to allow the exhaust system to reduce the concentration. If the gas accumulation does not drop after 4 minutes, the automatic gas valve shuts off the hydrogen supply until the concentration reduces. At this point manual reset is required; however, this and could be connected remotely. Estimated probable construction cost of these improvements is $1,440.

IV.C. Building and Campus

IV.C.1. Safety

The alarms shall be connected to a relay panel which is further connected to the building fire alarm system and further to campus safety. Estimated probable construction costs is approximately $1,100 for panel and connections.

IV.D. Summary of Integrated Hydrogen Safety System

IV.D.1. Gas Storage and Alarm System

The protection of equipment, instrumentation and personnel is critical. The most imminent danger in this facility is the presence of hydrogen or other flammable fuels, such as natural gas. As mentioned when describing the fuel supply system, an explosion proof solenoid valve or non-electric operated valve rated for use with hydrogen gas or other gaseous fuels is installed at the tank valves in the compressed gas storage locker. This valve will shut off the supply of gas if: 1) the emergency stop switch is activated; 2) the main measurement and control program in the test stand is not operational; 3) the gas detection system (see Figure 2, and appendix C) records a high concentration of combustible gas (hydrogen); 4) or any of the gas detection sensors has failed due to power loss or other malfunctions.

The gas detection system (See Appendix C) consists of four different sensors. A combustible gas sensor will be configured to close one of its three relays of the concentration of hydrogen or other combustible gas reaches 20%, 40%, 60% if the LEL (lower explosive limit) of hydrogen, which is 4% by volume in air.

There is a sensor sampling tube connected on a high point in the environmental chamber which samples the chamber contents at least every 30 seconds; There is an additional hydrogen sensor located above the hydrogen gas cylinder storage cabinet which is connected in parallel to the gas control system.

Secondly, an O_2 sensor in the chamber shall close its relay if the O_2 concentration reaches a dangerously low level.

The hydrogen tank supply valves will shut if the first level of alarm(20 %LEL) on any of these three sensors is reached. The lack of hydrogen supply should alleviate any high concentrations of combustible gas. However, if the concentration of gas continues to rise, dampers will open and EF 52 will be energized at the 2^{nd} level of alarm to reduce harmful concentrations and replenish the control room and the chamber with fresh air. If the third level of alarm is reached, which is highly unlikely, considering the source of H_2 has been shut off, a visual "DO NOT ENTER" and audible alarm shall be triggered outside the facility, and at the public safety office.

The O_2 sensor is connected to the sensing tube in the environmental chamber to measure the O_2 concentration to determine if the consumption of oxygen by the fuel cell has adversely reduced the oxygen concentration in the chamber. This sensor only records O_2 levels and alarms if the level is reduced to unsafe levels; it does not connect to the hydrogen valve.

All four levels of gases shall be recorded by the data acquisition system and monitored by the main test stand control program.

IV.D.2. Safety Guidelines

The safety guidelines will be written around the explosive nature of hydrogen and should describe the systems and this operation. The procedures shall include:

1. Signage descriptions of alarms and warning signs.
2. Complete training in the use, movement, installation, changing, and systems for compressed hydrogen gas.
3. Complete training manual written for the fuel cell, the test stand, the instrumentation and the safety alarm systems.
4. Controlled access to the control room and test chamber.
5. Emergency procedures manual.
6. Explosion prevention techniques and understanding.
7. Fire extinguishing training and proper fire extinguishers.

IV.D.3.Operational Procedures

There are several items which need to be handled by operating procedures. The safety procedures and warning systems will alert people to not enter if there is a level of H_2 built up greater than 20% LEL. There will be a lock placed upon the doors from inside the room, and from outside when there is a test going on.

There will be a fire sign outside the door warning people of the invisible flames from a hydrogen fire.

There will need to be a complete operating procedure written regarding the system from fuel supply to beginning a test to fire extinguishers.

For instance, if the test chamber H_2 limit goes off, the exhaust system turns on, no one should be able to enter the test chamber; however, exiting will be allowed. This will be one operational procedure. The H_2 valve closes and will need to be reopened manually once the alarm is cleared.

V. Conclusions

The Test Chamber and room 601D promise to serve as a suitable test site for freezing studies of PEM fuel cells in the 10 kW to 30 kW size range. The Test Chamber and lab with appropriate modifications will allow adequate testing to develop enough appropriate data to serve as reliable data for design criteria to use for development of appropriate technology to produce freeze resistant fuel cells of appropriate performance characteristics.

The appropriate modifications for the Test Chamber include, but are not limited, to the following:

1. Retrofit the evaporator fans with explosion proof motors;
2. Convert the lights, sensors, and outlet in the Test Chamber to meet NFPA 70, Chapter 510.0, explosion proof [22];
3. Install gas and spark resistant feed throughs for the connection of the test stand umbilical cords;
4. Install a fuel cell test stand to allow 10 kW to 30 kW cell stacks.
5. Install an H^2 sampling tube and an O^2 sampling tube and connect to the gas sensing alarm system.

The appropriate modifications to the Control Room include, but are not limited to, the following:

1. Revise the electrical in the control room to explosion proof construction, including lights, outlet switches, evaporator fan motors, relays, and instrument openings;

2. Convert the wall between 601D and 602 to a 2 hour fire rated wall, and change the door to a 2 hour fire rated door;
3. Remove the hanging folding partition wall and construct a 2 hour fire rated masonry wall 4 feet to the east of the folding partition wall;
4. Relocate the compressor to a shelf in room 602 and run the control, power, and refrigerant lines through the wall;
5. Revise the motors on the Dryair desicant dehumidifier to explosion proof motors;
6. Revise the Dryair ductwork to make the exhaust on top and supply air on bottom; install dampers to allow EF 52 to evacuate the chamber and control room when the hydrogen concentration exceeds 25% LEL;
7. Install a 2-bottle, ventilated, hydrogen storage cabinet with bottom inlet and top outlet to outdoors, with an automatic valve closure system. A hydrogen generation system was investigated, however, the physical size and storage capacity required made that alternative impractical at this time;
8. Install a limited area fire sprinkler system from the domestic water system into control room 601D;
9. Connect the hydrogen detection and alarm system to the university fire alarm system to public safety department.

At this time, based on the analysis of information available, the recommendation is to remodel the test chamber and room 601D and use it as a facility to perform freezing studies on PEM fuel cells.

The estimated probable construction cost is $112,911, not including the test stand and instrumentation (See Appendix E for details), which is estimated at $375,000. Table 2 on the next page provides a summary of the estimated recommendations costs.

Item	Paragraph	Table 2 Estimates of Probable Construction Costs Description	EPCC
1	IV.A.2	Evaporator Fan Motors/Controls	$2,371.00
2	IV.A.4	Feed throughs & Piping Chamber	$3,630.00
3	IV.A.4	NFPA 70 Explosion Proof- lights, etc. chamber	$2,870.00
4	IV.A.5	Add to Hydrogen Integrated System	$2,800.00
5	IV.A.6	Ventilation Control of Chamber	$2,060.00
6	IV.A.6	Reverse Ducts at Dryair	$480.00
7	IV.B.4	Walls	$24,090.00
8	IV.B.4	Ventilation Dampers	$3,320.00
9	IV.B.4	Deflagration Venting	$3,890.00
10	IV.B.4	NFPA 70 Explosion Proof- lights, outlets	$3,680.00
11	IV.B.4	Gas Cabinet, ducts, fan	$4,200.00
12	IV.B.4	Gas Cylinder racks in Control Room	$480.00
13	IV.B.4	Gas Cylinder racks in Control Room	$560.00
14	IV.B.4	Ventilation Air to Cabinet	$780.00
15	IV.B.4	Piping for Gases	$13,060.00
16	IV.B.4	Integrated Hydrogen Protection System	$42,100.00
17	IV.B.4	Additional Gas Alarms	$1,440.00
18	IV.C.1	Point Connection to Public Safety	$1,100.00
	TOTAL ESTIMATED PROBABLE CONSTRUCTION COSTS =		**$112,911.00**

VI. References

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Appendices

A. Summary Matrix

B. List of Abbreviations

C. Proposed Gas Detection and Safety System
   - C.1. Argus Group Correspondence - March 9, 2005
   - C.2. Safety Equipment Corp. Correspondence - April 4, 2005

D. Applicable codes and standards

E. Test Equipment Specifications
   - E.1. Greenlight Power Correspondence - December 4, 2004
   - E.2. Greenlight Power Correspondence - April 4, 2005
   - E.3. Arbin Industries Correspondence - April 11, 2005

F. Hydrogen Source Alternatives

G. Alternative Test Chamber Locations

H. Calculation of Maximum Hydrogen Consumption

Appendix A. Summary Table of Requirements, Capabilities, & Recommendations

I.C.1 Fuel Cell Stack Requirements and Test Conditions	
A. Power Range	5 kW – 75 kW; Target power range of 10 kW to 30 kW
B. Test Duration	< 14 hours
C. Thermal Control	> - 20 degrees C
D. Humidity Control	+/- 2 % relative humidity
E. Test Frequency	1 to 2 times per week
F. Fuel Consumption (derived)	500 slm max
G. Air Consumption (derived)	1500 slm max
H. Purge Gas	Argon or Nitrogen
I. Diagnostic Requirements	See Appendix E

II, III, IV. Facility Requirements, Capabilities & Recommendations			
A. Test Chamber	**II. Requirement**	**III. Capability**	**IV. Recommendation**
1. Space	II.A.1. 280cm x 96cm x 140cm	III.A.1. meets requirement	IV.A.1. none
2. Heat rejection	II.A.2. 10.54 kW (36,000 BTUH)	III.A.2. meets requirement	IV.A.2. none
3. Humidity Control	II.A.3. Control RH between 2% & 95%	III.A.3. meets requirement	IV.A.3. none
4. Feedthroughs	II.A.4 Provide gas tight feedthroughs	III.A.4. feedthroughs are accessible	IV.A.3. install. two 15cm dia gas tight cyl feedthroughs
5. Safety - Flammability	II.A.5.a. prevent pockets of gas accumulation	III.A.5.a. Potential flammable pockets exist	IV.A.5.a. install gas sensing and alarm system
- Flammable Storage	II.A.5.b. NFPA55	III.A.5.b. no capability	IV.A.5.b. no gas storage in Test Chamber
- Hydrogen Systems	II.A.5.c. NFPA50a	III.A.5.c. no capability	IV.A.5.c. incorporate with test equipment
- Other	II.A.5.d. Other applicable Standards	III.A.5.d. no capability	IV.A.4.d. see IV.A.5.a
6. Ventilation	II.A.6. Inlets low, Outlets high; gas detection to shutoff H2 Ventilation = 0.00138 $m^3/s/m^3$ Make up air is required	III.A.6.a. Existing capacity is 8 times that required.	IV.A.6.a. reverse supply and exhaust

II, III, IV. Facility Requirements, Capabilities & Recommendations (cont.)			
B. Control Room	**II. REQUIREMENT**	**III. CAPABILITY**	**IV. RECOMMENDATION**
1. Space	II.B.1. 10m x 5m x 3m high	III.B.1. meets requirement	IV.B.1. none
2. Utilities	II.B.2. Electric 208V/1ph/100amp Water and Steam	III.B.2. meets requirement	IV.B.2. none
3. Environmental Control	II.B.3. 20 ^{o}C, 50% rh	III.B.3. meets requirement	IV.B.3. none
4. Safety	II.B.4. meet NFPA 50A, NFPA 55, NFPA 70, ASME B31.3 Ventilated gas cabinet; sprinkler system	III.B.4. some fire-rated walls & doors and window for explosion diaphragm	IV.B.4. modify to meet NFPA 50A, NFPA 55, NFPA 70, ASME B31.3 by adding firewall and gas storage, detection and alarm systems; relocate Test Chamber compressor, add sprinkler system

C. Building & Campus	II. REQUIREMENT	III. CAPABILITY	IV. RECOMMENDATION
1. Safety	II.C.1. Notify campus safety of alarms, Provide alarms, fire extinguishers, signs	III.C.1. Fire alarm pull located outside of 601D	IV.C.1. Connect gas alarm system into central fire alarm system. Provide fire extinguishers, signs and strobe and horn.

Appendix B. Abbreviations

LEL = lower explosion limit (4% by volume in air for hydrogen)

BAR = approximately 14.5 psig (1 bar = 1 atmosphere) pressure

psig = pressure in pound per square inch gage

^oC = temperature in degrees centigrade

^oF = temperature in degrees Fahrenheit

SLM = standard liters per minute (70oF and 14.7 psig)

sl = standard liters

KW = kilowatt

KWH = kilowatt hours

BTU = British thermal units

BTUH = British thermal units per hour

Kp = pressure in kilopascals

Pa = pressure in pascals

PEM = Polymer Electrolyte Membrane or Proton Exchange Membrane

CFM = Cubic Feet per Minute

ASHRAE = American Society of Heating, Refrigerating, and Air-Conditioning Engineers

psf = Pounds per Square Foot

lpm = liters per minute

Appendix C. Proposed Gas Detection and Safety System

C.1. Argus Group Correspondence – March 9, 2005

15075 EAST ELEVEN MILE ROAD • P.O. BOX 689 • ROSEVILLE, MICHIGAN 48066-0689 • 810/774-8900 • FAX 810/774-2780

Mr. Gary Gorsalitz, PE March 29, 2005
Byce and Associates, Inc.
1108 Champion Street
Marquette, Michigan 49855

Ref: **Combustible Gas (Hydrogen) Monitoring System for a Test Laboratory**

Dear Mr. Gorsalitz:

Per our telephone conversation, I am pleased to submit the attached proposal that should provide you with the information necessary to complete your project.

I am proposing the RKI "Pioneer" with three Combustible Gas sensors (calibrated on Hydrogen) – one Sample-Draw type for the Test Chamber and two Diffusion types for the Control Room and Gas Cabinet. Sample will diffuse or be drawn to the sensors, be analyzed for combustible gas (Hydrogen) content with alarm thresholds set at 10%, 25%, and 40% LEL. Relay contacts (rated at 8A) can be used to control actions such as external alarms, fans, and equipment shutdown; 4-20 mA signals can report to the building management system.

Since Hydrogen is lighter than air the proper place to mount the detectors is at the ceiling and since the ceiling is high (in the case of the Control Room) I have included remote calibration adapter.

I have proposed several options including a selective type of detector (one that will only sense Hydrogen), Audible/Visual Alarms, Calibration Kit, Start-Up Service, etc. Of these, the Calibration Kit and Alarms are the most important.

The equipment will come calibrated and programmed, however it is liable to get out of adjustment during transportation and installation so we offer a Start-Up Service (we coordinate with your contractor or in-house electrician, verify the wiring after installation, calibrate and set alarm thresholds, and provide training for your employees covering operation, use, and routine maintenance). I have included this as an option since distance makes it expensive (our closest office is Chicago).

Thank you for your interest and for this opportunity to submit our proposal. If you have any questions or if I may be of additional service, please call on me anytime.

Yours truly,

James A. Fitzgerald AIA
President

A COMBUSTIBLE GAS MONITORING SYSTEM

In a Cold Test Laboratory

Prepared for
Byce and Associates, Inc.
1108 Champion Street
Marquette, Michigan 49855

Prepared By:
The ARGUS GROUP
46400 Continental Drive
Post Office Box 698
Chesterfield, Michigan 48047

Contact:
James A. Fitzgerald AIA
Phone: 800-873-0456
FAX: 586-840-3201
E-Mail: jfitzgerald@argus-group.com

MULTI-POINT GAS MONITORING SYSTEM

Provide a continuous Gas Detection System to monitor Combustible Gases (Hydrogen) in Cold Test Facility in order to warn personnel and protect property. The system will consist of a Main Control Panel (located at the entrance to the Control Room), Two (2) Diffusion Sensors (one in the Gas Cabinet and one in the Control Room), and One (1) Sample-Draw Sensor (for the Test Chamber). Relays and signal outputs are provided for connection to ventilation, building control, security, and other equipment.

1. Main Control Panel:

The gas monitor is housed in a NEMA 4X wall-mounting enclosure with the power supply, display, relays, logic, and electronic circuitry. Each control panel will operate its' own remote detector. Electrical connections are made to marked terminals within the cabinet.

A. Housing: NEMA 4X Fiberglass cabinet, RFI Shielded
Size: 13.0" W x 16.5" H x 4.5" D

B. Channel Relays: Alarm 1, 2, and 3 or Fail for each channel, Plug-in, SPDT isolated 8 amp terminals. Relays may be configured in the field as latching or self-resetting, normally energized or de-energized, and increasing or decreasing alarm. Relays may be programmed with a time delay to reduce nuisance alarms due to calibration, RFI, EMI, or temporary gas conditions.

C. Common Relays: One "master" set (Alarm 1, 2, 3, and Fail Relay) for the system, Plug-in, SPDT isolated 10 amp terminals. Fail Relays (except master) may be configured in the field as latching or self-resetting, normally energized or de-energized, increasing or decreasing alarm, and with a time delay on alarm.

D. Power supply: Terminals for 100-125/220-250 VAC, 50/60 Hz input power (this circuit should be dedicated to this gas detection system). Terminals are included for optional 18-30 volt DC stand-by power. Power supply includes step-down transformer, rectifier and switching-type regulator to provide regulated DC voltage for operation of electronics.

E. Terminals:

Remote Sensing Head:	(3), Power & Signal
Alarm 1:	(3), NO, NC, C
Alarm 2:	(3), NO, NC, C
Alarm 3:	(3), NO, NC, C
Fail Alarm:	(3), NC, NC, C
Recorder Output:	(3), 4-20 mA/0-1 V & Gnd

F. Circuit Board: (These controls are accessible when the case is opened)

1) Alarm adjust: Alarm 1, 2, and 3 - A single turn potentiometer used to set level at which warning alarm is actuated.

2) Alarm Logic: A bank of rocker switches to select latching/self-resetting, normally energized/de-energized operation

3) Zero Adjust: A small multi-turn potentiometer on the amplifier circuit board. This is used for periodic adjustment of zero in a gas free environment.

4) Span Adjust: A small multi-turn potentiometer on the amplifier circuit board. This is used for periodic adjustment to set the detector output to correspond to the concentration of span gas being admitted to the detector.

G. Display: (visible through front of instrument without opening door)

1) Meter: Digital LCD of each channel simultaneously including concentration and units of measure. Display is lighted for reading in low light areas.

2) Status Lights: Pilot: LED, to show that unit is active (light flashes during initial warm-up period).
Alarm 1: LED, to show that one or more active channels have reached first level of alarm.
Alarm 2: LED, to show that one or more active channels have advanced to second level of alarm.
Alarm 3: LED, to show that one or more active channels have reached the highest level of alarm.
Fail: LED, to show that one or more active channels are in fail condition - detector, wiring, or amplifier malfunction, or down scale reading on any channel.

3) Function: Initiates certain program tasks and access to data

2. Remote Sensing Head:

Remote sensing heads are supplied mounted in a wall housing which contains the sensor and the amplifier/transmitter board.

A. Sensors: Type specific to each gas. Designed to operate in temperatures from -20° to +45° C and RH of 10 to 100%.

B. Range:

Arsine	0	to	0.20	ppm
Carbon Monoxide	0	to	200	ppm
Chlorine	0	to	5.00	ppm
Sulfur Dioxide	0	to	5.00	ppm
Combustibles	**0**	**to**	**100.0%**	**LEL**
Fluorine	0	to	5.00	ppm
Hydrogen Chloride	0	to	20.0	ppm
Hydrogen Cyanide	0	to	50.0	ppm
Hydrogen Fluoride	0	to	20.0	ppm
Hydrogen Sulfide	0	to	100	ppm

Nitrogen Dioxide	0	to	15.0	ppm
Nitric Oxide	0	to	100	ppm
Oxygen	0	to	30.0 %	Vol.
Phosphine	0	to	2.00	ppm
Silane	0	to	15.0	ppm
Sulfur Dioxide	0	to	15.0	ppm

(**bold print** indicates sensor included in this system)

1) Catalytic Sensor (Combustible Gases):

Detection is by catalytic oxidation on a heated platinum element. The element, installed at the point where gas is to be detected, is connected as one leg of a balanced Wheatstone bridge. A second, non-catalytic element is installed in the same environment for thermal compensation and the two elements are surrounded by a sintered stainless steel flame arrestor to form a complete detector assembly with mounting bracket. Calibrated on Hydrogen

2) Sample-Draw Sensor (Cold Test Chamber):

Detectors are supplied with Sample-Draw Adapters for applications where the sample location is remote, inaccessible, or in a hostile atmosphere (hot, cold, dirty, etc.).

An Electric Pump transports sample through ¼" tubing from each area to the Sensor for analysis. A flow meter to indicates positive sample flow, flow-sensing circuit indicates loss of sample, filters remove liquids and particulates, and an amplifier communicates with the Control Panel.

3) Remote Calibration Adapter (ceiling of Control Room):

Detectors can be supplied with Remote Calibration Adapters for applications where the sensor location is remote, inaccessible, or in a hostile atmosphere. . The Adapter consists of a cup-style extension to the sensor and length of tubing to the main floor area. The calibration gas is injected into the tubing to the ceiling mounted detector. When reaction takes place the reading is compared to the reference and adjustments (if necessary) are made without need for ladders, etc.

3. **Calibration:**

Calibration is accomplished by one man using the kit of materials supplied. During calibration alarms are disabled (for a 5-minute period) by pushing the Alarm Disable button.

4. **Wiring Requirements:**

All electrical service wiring must meet the safety standards of the applicable local and national electrical codes. Sensor signal and power wiring may be run in common conduit where jobsite conditions allow. The Gas Monitoring System power circuits should be a dedicated to this system and not shared with other equipment!

A. Main Panel Wiring: Three conductor, grounded, 120 VAC, 15 A

B. Combustible Gas Sensor Wiring, sample-draw:
Two 3- conductor Twisted, Stranded, Shielded, #16 cable

C. Combustible Gas Sensor Wiring, diffusion (up to 1000'):
One (1) Twisted, Stranded, Shielded, 3-#16 Conductor cable

D. Audible/Visual Alarm:
Three conductor, grounded, 120 VAC, 15 A
(may be jumpered from instrument power)

5. **Operational Sequence:**

Note: Alarm thresholds used in this scenario are for purposes of illustration and may be adjusted in the field to any level within the range of the detector.

A. Normal Situations:

During normal operation each sensor will continuously sample its' area and a signal will be sent to and analyzed by the Main Control Panel. The Green "Pilot" LED will be "ON" on the Control Panel and the Meter will display the gas concentration for each detector (readings will be in the range of 0 to 10 %LEL Hydrogen).

B. Warn Alarm Situations:

If any sensor detects a gas concentration above the "Alarm 1" threshold (readings will be in the range of 10 to 25 %LEL for Hydrogen) the Red "Alarm 1" LED will be "ON", the Buzzer Alarm will sound on the Panel (slow beep), the associated Relay(s) will energize to operate any external devices such as fans, and the Meter will display the gas concentration for all detectors.

A person responding to the alarm can determine the problem location, the gas concentration, and observe trends. Pressing the "Reset" button will silence the Buzzer Alarm (however, the display for the detector in alarm will alternate between the gas concentration reading and an alarm message). Appropriate procedures should then be followed to eliminate the hazard.

When the gas concentration returns to a level below the "Alarm 1" threshold, the "Alarm 1" LED will automatically extinguish and the associated Relay will de-energize.

C. Alarm Situations:
If any sensor detects a gas concentration above the "Alarm 2" threshold (readings will be in the range of 25 to 40 %LEL for Hydrogen) the Red "Alarm 2" LED will be "ON", the Buzzer Alarm will sound on the Panel (faster beep), the associated Relay(s) will energize to operate any external devices (such as a strobe light or higher fan speed), and the Meter will display the gas concentration for the detector. (Note: the alarms and relays will reactivate even if they had been "reset" at the Alarm 1 level).

A person responding to the alarm can determine the problem location, the gas concentration, and observe trends. Pressing the "Reset" button will silence the Buzzer Alarm (however, the display for the detector in alarm will alternate between the gas concentration reading and an alarm message). Appropriate procedures should then be followed to eliminate the hazard.

When the gas concentration returns to a level below the "Alarm 2" threshold, the "Alarm 2" LED will automatically extinguish and the associated Relay will de-energize (NOTE: the Alarm 1 LED and relays may still be engaged unless the Reset button is pressed).

D. High Alarm Situations:
If the gas concentration continues to increase above the "Alarm 3" threshold (readings will be in the range of 40 to 100 %LEL for Hydrogen) the Red "Alarm 3" LED will be "ON", the Audible alarm will sound on the Panel (very fast beep), the Meter will display the gas concentration for the detector, any associated remote Audible alarm(s) will operate, and the associated Relay(s) will energize to operate any external devices or to control actions such as equipment shutdown.

A person responding to an "Alarm 3" should carefully investigate the detector in alarm, determine the location of the problem, the gas concentration being detected, and observe trends. Appropriate personnel should be notified and procedures should be followed to eliminate the hazard, shutdown the equipment, and alert other personnel.

Pressing the "Reset" button will silence the Buzzer Alarm (however, the display for the detector in alarm will alternate between the gas concentration reading and an alarm message). Appropriate procedures should then be followed to eliminate the hazard.

When the gas concentration returns to a level below the "Alarm 2" threshold, the "Alarm 2" LED will automatically extinguish and the associated Relay will de-energize (NOTE: the Alarm 2 and 1 LEDs and relays may still be engaged unless the Reset button is pressed).

D. Fault Alarm Situations:
A "Fault" alarm can occur if a sensor fails or is disconnected, if power failure occurs within the Control Panel or Amplifier Board, or due to either failure to calibrate, an incorrect adjustment of the circuit causing a below-zero reading, or low flow (sample-draw sensors only).

If the sensor detects a gas concentration below the Fault Alarm level threshold (reading will be approximately 10% below Zero on the Meter) the Yellow "Fail" LED will be "ON" on the Panel and the Buzzer Alarm will sound (continuous beep).

A person responding to the alarm should investigate the detector, and then he can initiate appropriate procedures to correct the problem.

When the meter reading returns to a normal level above the Fail Alarm threshold, the "Fail" alarm LED, Relay, and audible alarm will be automatically reset.

Byce and Associates, Inc. for a Cold Test Chamber

6. **Cost Proposal** **March 29, 2005**

1 each **Hydrogen Monitoring System complete with** **$4,835.00 each**

- One (1) Pioneer Control Panel with Power Supply, Digital Display, Relays, Alarm LEDs, Buzzer Alarm, Modules for four Detectors, and 4-20 mA output; NEMA 4X Wall Mount Housing
- Two (2) Combustible Gas Transmitters, diffusion, Hydrogen
- One (1) Remote Calibration Adapter
- One (1) Combustible Gas Transmitters, sample-draw, Hydrogen

Recommended Accessories:

Calibration Kit **$455.00 each**

complete with Certified Calibration and Zero Air Gases, Regulator, Fittings, Adjustment Tool; All in a Carrying Case

Audible/Visual Alarms:

Explosion proof - Audible	$1,050.00 each
Explosion proof - Visual (strobe)	$870.00 each
Not explosion proof Audible/Visual	**$355.00 each**

Optional Accessories:

Start-Up Service consisting of consisting of verification of the installation done by others, initial calibration and programming, and a training session for owners personnel — $800.00/day plus travel expense reimbursement

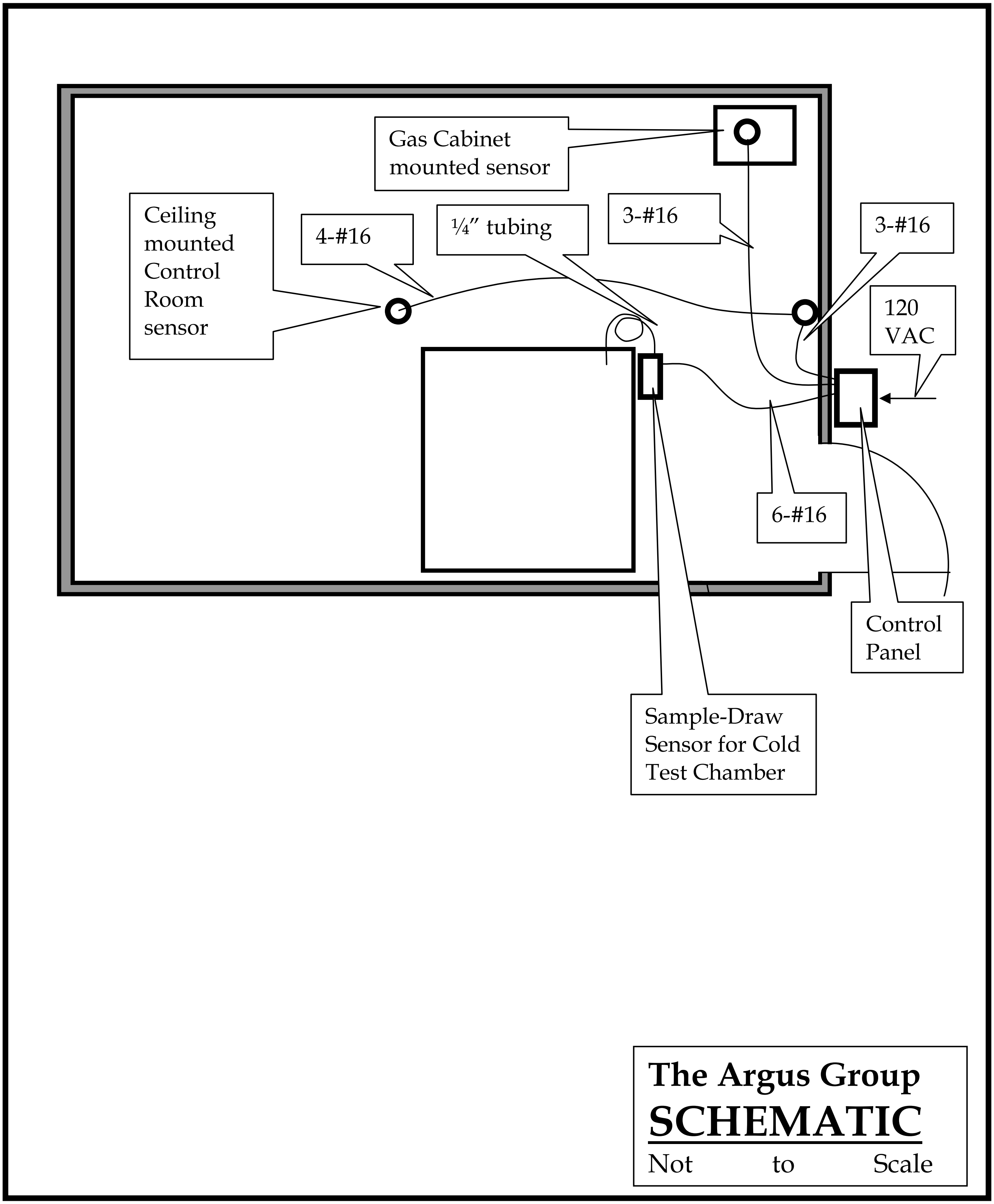
Back-Up Power Supply — $450.00 each
(to operate the instrument for 24 hours in the event main power is interrupted - one required for each system)

Cylinder Valve Shutoff System (for two cylinders) — $7,350.00 each

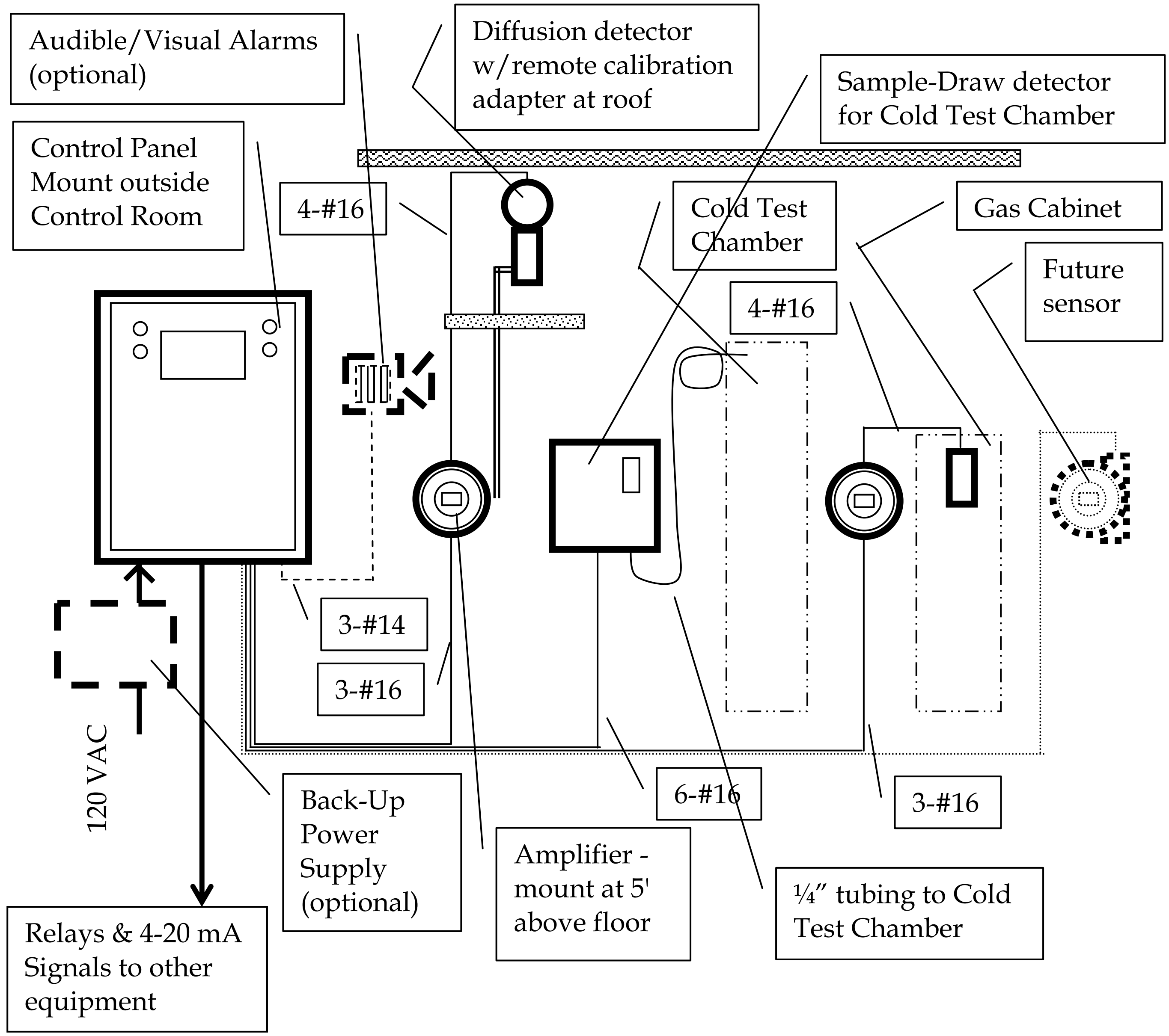
7. **Terms and Conditions:**

Prices will be firm for 30 Days. Proposal is for components of the gas detection system only and does not include installation labor and materials, demolition or reconstruction of surfaces, permits, sales taxes, freight, etc.

TERMS:	Net 30 Days to qualified accounts
F.O.B.:	Chesterfield, Michigan
SHIPMENT:	1 Week after Order



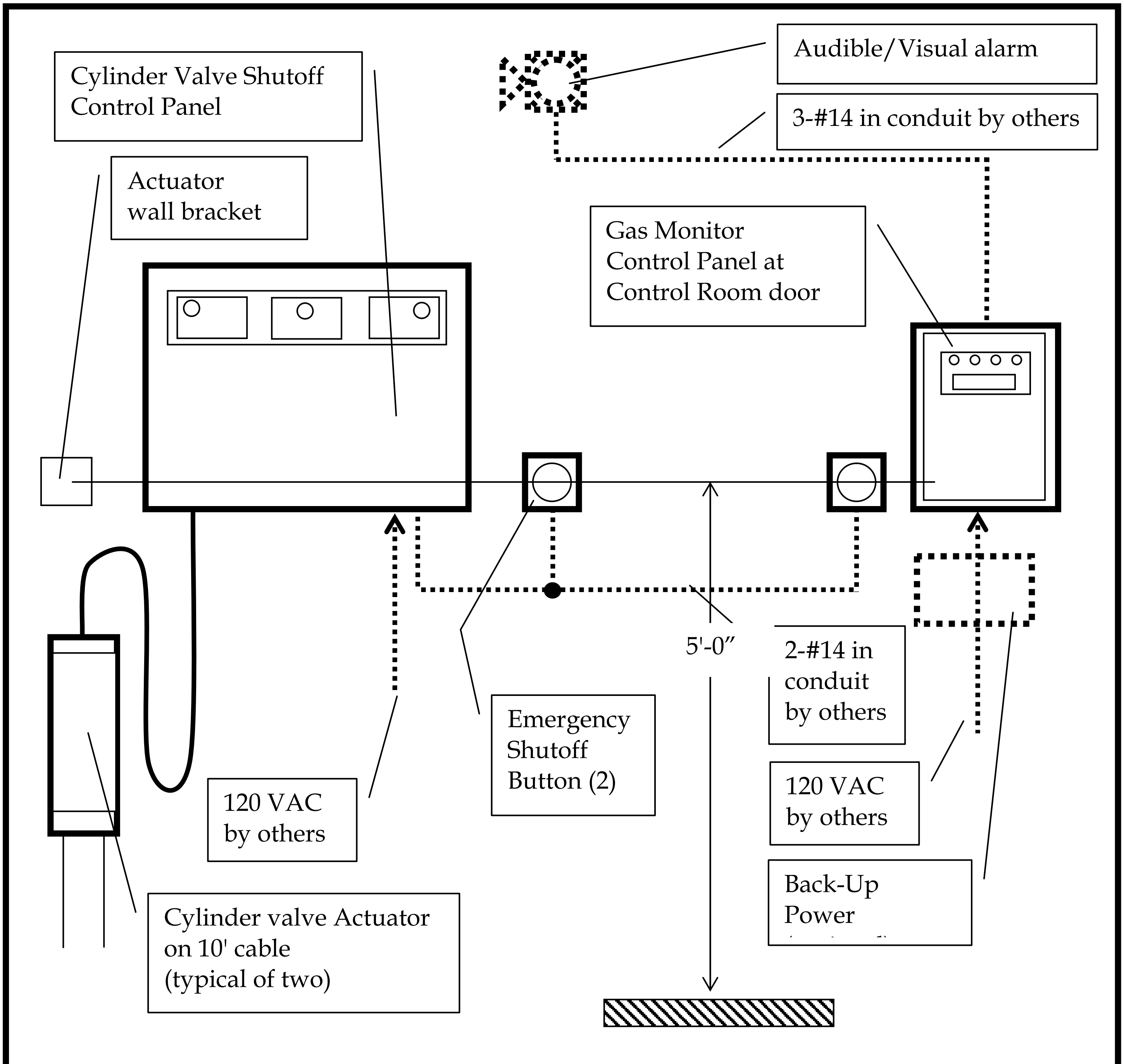
Hydrogen Monitoring System in a Cold Test Chamber Lab
for
Byce & Associates, Marquette, MI



NOTES:
1. **Installation labor & materials by others**
2. **Power & signal wiring in separate conduit**
3. **Fan controls, motor starters, etc. by others**
4. **See proposal for included items & options**

The Argus Group
SCHEMATIC
Not to Scale

Hydrogen Monitoring System in a Cold Test Chamber Lab
for
Byce & Associates, Marquette, MI



Notes:

1. Installation labor & materials by others
2. Power & signal wiring in separate conduit
3. Fan controls, motor starters, etc. by others
4. See proposal for included items & options

The ARGUS GROUP
SCHEMATIC
Not to Scale

Cylinder Valve Shutoff System in a Cold Test Chamber Lab
for
Byce & Associates, Marquette, MI

C.2. Safety Equipment Corp. Correspondence – April 4, 2005

Fyi

Gary J. Gorsalitz, P.E.
Professional Engineer
Byce and Associates, Inc.
1108 Champion St.
Marquette, Mi 49855
Ph: 906-226-3580
Fax 906-226-3590

-----Original Message-----
From: Ken Hettman [mailto:info@safetyequipmentcorp.com]
Sent: Monday, April 04, 2005 9:43 AM
To: Gary J. Gorsalitz P.E.
Subject: Re: ventilated cabinet for Compressed hydrogen gas tank storage

HELLO, OUR MODEL 7200, TWO CYLINDER GAS CABINET SHOULD WORK FOR YOUR REQUIREMENT.

COST: $1100.00
TERMS: NET 30 DAYS
DELIVERY: SHIP THE SAME WEEK YOU ORDER.
COLOR: BLUE
SHIPPING: FOB BELMONT, CA 94002
I WILL CALL YOU TO DISCUSS.

THANK YOU, KEN HETTMAN

SAFETY EQUIPMENT CORPORATION
PHONE# (650) 595-5422
FAX#   (650) 595-0143

----- Original Message -----

From: Gary J. Gorsalitz P.E.
To: info@safetyequipmentcorp.com
Sent: Sunday, April 03, 2005 7:28 AM
Subject: ventilated cabinet for Compressed hydrogen gas tank storage

Hi,

Please send information and pricing for a two tank(200cf) ventilated storage cabinet, with space for automated shutoff mechanism, bottom connections for inlet of ventilation air, and top outlet for exhaust to outdoors, with and without explosion proof , self contained fans(if available) ASAP. Thanks,

Gary G

Gary J. Gorsalitz, P.E.
Professional Engineer
Byce and Associates, Inc.
1108 Champion St.
Marquette, Mi 49855
Ph: 906-226-3580
Fax 906-226-3590

Appendix D. Applicable Codes and Standards

1. 2001 ASHRAE Fundamentals Handbook CD. *American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.*

2. NFPA 55, 2003, *Standard for the Storage, Use, and Handling of compressed and Liquefied Gases in Portable Cylinders.*

3. International Fuel Gas Code, 2004 , Section 703.1.2 and 703.1.3.

4. International Mechanical Code 2003. Section 304.4.2 and Section 502.16.

5. International Fire Code, 2003. Table 2209.1 *Minimum Separation for Gaseous Hydrogen Dispensers, Compressors, Generators, and Storage Vessels.*

6. International code Council, 2004. *Ad Hoc Committee for hydrogen gas (AHC-H2G).* www.1ccsafe.org/cs/cc/h2g/h2g2.html last visited 1-2-2005.

7. NFPA 70 – National Electrical Code, 2003, Proposed articl 692 *"Fuel Cell Systems"*, Paragraph 510.1 www.fuelcellstandards.com/2.1.6.3.htm last visited 1-21-2005.

8. BS-EN 50073 British Standard, 1998, Guide for selection, installation, use and maintenance of apparatus for the detection and measurement of combustible gas and oxygen.

9. ANSI/UL 2075, 2004. *Gas and Vapor Detectors and Sensors*.

10. CSA America. ANSI/CSA America FCI, 2004, formerly ANSI z21.83. *American National Standard for Fuel Cell Power Systems.*

11. NFPA 50A, 2003*. Standard for Gaseous Hydrogen Systems at Consumer Sites.*

12. NFPA 68, 2003*. Guide for Ventilating of Deflagrations*.

13. U.S. Fuel Cell Council.*www.usfcc.com/about/standards.html.* Last visited site on 1/21/05.

14. ASME B31.3 Code for Process Piping, 2003. *American Society of Mechanical Engineers.* New York, New York.

15. NFPA 853 Standard for the Installation of Stationary Fuel Cell Power Plants.2006

Appendix E. Test Equipment Specifications

E.1. Greenlight Power Correspondence – December, 4, 2003

X-Info: ODIN / NASA Glenn Research Center
X-Sender: allenjs@popserve.grc.nasa.gov
X-Mailer: QUALCOMM Windows Eudora Version 5.1.1
Date: Thu, 04 Dec 2003 17:56:21 -0500
To: jeffpam@bright.net
From: Jeff Allen <Jeff.Allen@grc.nasa.gov>
Subject: Fwd: Fuel Cell Test Station Specs
X-pstn-levels: (S:16.8198 R:95.9108 P:95.9108 M:98.0659 C:79.5348)
X-pstn-settings: 3 (1.0000:2.0000) r p m C
X-pstn-addresses: from <Jeff.Allen@grc.nasa.gov> [db-null]

Subject: Fuel Cell Test Station Specs
Date: Thu, 4 Dec 2003 14:28:31 -0800
X-MS-Has-Attach: yes
X-MS-TNEF-Correlator:
Thread-Topic: Fuel Cell Test Station Specs
Thread-Index: AcO6swnGxhvRphe5SJWAsAxXnpGBJAAAi8Jg
From: "Robert George" <RGeorge@greenlightpower.com>
To: <jeff.allen@grc.nasa.gov>
Cc: "Greig Walsh" <gwalsh@greenlightpower.com>

Mr Jeffrey Allen
National Center for Microgravity Research
c/0 NASA Glenn Research Center at Lewis Field

Dear Jeff

In response to our telephone conversation today, please find the Technical Specifications for a G100 Greenlight fuel cell test station suitable for single cell PEM testing attached.

For planning purposes, one could anticipate paying approximately US$115K for the basic test station which would include three days set up and training at customer site. (Note, when we spoke I thought this was extra but it is included in the price.)

Some optional extras: (prices approximate in US dollars)
Additional mass flow controllers $4000 each
AC Impedance measurement $ 15,000 for single cell
Additional Cell Voltage Monitoring$ 500 per channel
High frequency resistance testing $25,000 including CVM for 32 channels
Additional training at site $ 1000 per day
Thermal Management Module $16,000 (Includes heater and heat exchanger for automated heating and cooling of stacks).

We look forward to discussing this with you further as you progress your planning. Our Sales Engineer, Greig Walsh is available to assist you with any further technical questions that you may have. He may be contacted by telephone at 604 676 4038.

I can always be reached at one of the numbers below.

Sincerely, r.george

tel 250 598 7863 cell 250 514 2875

****
National Center for Microgravity Research
c/o NASA Glenn Research Center at Lewis Field
office: 216-433-3087
lab: 216-433-8742
jeff.allen@grc.nasa.gov

E.2. Greenlight Power Correspondence – April 4, 2005

Jeff

In response to our telephone conversation today please find the attached specifications for a test station we have used on applications up to 32kw. The set would handle gas flow volumes about twice what is listed in the specs. The standard humidification is contact but at higher powers you may need steam. We could provide a steam generator if necessary, or you could probably obtain your own for around US$17K.

A reasonable budget price for the G300 would be US$270,000 fob Vancouver. Additional Cell voltage monitoring runs about $780 per pair, an uninterrupted power supply system about $7000,

I look forward to discussing options with you as you develop your plan.

Sincerely Bob

Sales and Marketing

GREENLIGHT POWER TECHNOLOGIES

Unit C 4242 Phillips Ave, Burnaby

British Columbia Canada V5A 2X2

tel 250 598 7863 cell 250 514 2875

fax 604 676 4111

Brochures:

<<G500_2004_01.pdf>>

Spec sheets:

<<G500 Specification Table.pdf>>

[] G500_2004_01.pdf

[] G500 Specification Table.pdf

E.3. Arbin Industries Correspondence – April 11, 2005

-----Original Message-----
From: Antony Parulian [mailto:antony.p@arbin.com]
Sent: Monday, April 11, 2005 9:59 AM
To: 'Gary J. Gorsalitz'
Subject: RE: MTU Test Chamber/Lab

I worked on it last week but forget to send to you. Please find the attached file.

Antony Parulian

Arbin Corporation
762 Peach Creek Cut Off Road

College Station, TX77845

979-690-2751 x 142 (Phone)

979-574-3758 (Cellular)

979-690-2761 (Fax)

From: Gary J. Gorsalitz [mailto:ggorsalitz@chartermi.net]
Sent: Monday, April 11, 2005 8:48 AM
To: antony.p@arbin.com
Subject: MTU Test Chamber/Lab

Hi Antony,

Please send ASAP.

Thanks

Gary Gorsalitz, PE

[] 60kWFCTSestimation.doc

High Power FCTS	FCTS-60kW-400A-250V-1000/3000slpm COMPONENT SPECS	PEM Typ	PEM Adv
System Total Price (US $)		450,000	535,000
Anode gas flow unit 1	Gas flow-1000slpm	1	1
Anode gas flow unit 2	Gas flow-100slpm	Opt.	1
Cathode gas flow unit 1	Gas flow-3000slpm	1	1
Cathode gas flow unit 2	Gas flow-1000slpm	Opt.	1
Anode gas humidifier-H2O level-heater	DPH-GH-AWL-1000slpm-10kW/3kW	1	1
Cathode gas humidifier-H2O level-heater	DPH-GH-AWL-3000slpm-30kW/9kW	1	1
Stack cooling/heating	SC-60/2kW-auto	1	1
Anode PBPR	GEC-PBPR-1000slpm	1	1
Cathode PBPR	GEC-PBPR-1500slpm	1	1
Gas/H2O separation/drainage	GWS-AD-H	2	2
H2O fill meter	WFM-H	Opt.	2
H2O drain meter	WDM-H	Opt.	2
Programmable load bank	eload-PWM-2CR-1VR-100A-300V	4	4
Min.V at max. I (V)	DB not recommended	10	10
Inverter	inverter-400A-300V-120kW	1	1
Stack impedance	IO ACIM4	Opt.	1
Cell voltage & ACIM	IO ACIM4-cell-V-16	Opt.	8
Cell V monitor	IO V-HCMV-16ch	Opt.	128
Humidity sensor	IO HS-TT	Opt.	Opt.
Basic charge	SW-HW-LapPC FCTS	1	1
Chassis & Structure	Chs-54"x58"x77"	1	1
Chassis for e-load	Chs-27"x30"x77"	1	1

Appendix F. Hydrogen Source Alternatives

Since the compressor/condenser unit sits on the roof of the environmental chamber, the existing refrigeration, compressor, and condenser will be relocated to a shelf in the adjacent room (602) to avoid conflict with the explosion proof requirement. This will require construction of two angle brackets, a shelf, disconnection of the unit from its current controls and electrical, relocation of the unit, reconnection of the refrigerant lines, control wiring, power wiring, condenser water, liquid and hot gas, and drain. The estimated probable construction cost of this change is $4,100. This change will be required in whichever venue the unit is located, because the hydrogen accumulation is at the ceiling of the chamber just below the compressor unit, and the relays to start the compressor and controls would be more costly to change.

Two alternatives were initially considered for the hydrogen fuel source: 1) a hydrogen generation and storage system; 2) compressed hydrogen gas in standard compressed gas cylinders, such containing 200 cubic feet at approximately 2000 psig. After researching the hydrogen generation systems, this alternative was dropped because:

1. The size was considered too large for this facility 8 cubic meters weighing over 5000 pounds for a 1 kW system. It is estimated a 75 kW system would consume a major part of 601D.
2. The system would require an outdoor location some larger storage on the ground on the north side of the building, then a substantial piping system into the building.
3. The cost of compressed gas [32] is relatively inexpensive for the quantities needed for research at this facility.

Appendix G. Alternative Test Chamber Locations

In the initial stages of this study other spaces available in the building became apparent. The ME-EM department also has potential space available in the basement and sub-basement. All spaces would require similar modifications to be appropriate for testing. However, there would be considerable additional costs to disassemble and reassemble the chamber to move it from the 6th to another location. The estimated probable construction costs to relocate the chamber from 601D to the basement area are $4,100. Comparisons were made of the other available locations, and the following became apparent:

1. The requirement for one exterior wall limits the number of spaces which can be used. Basement and sub-basement rooms could be used by stretching the outside wall definition to include the space open to the chases which go up the outside of the building for outside air and to exhaust gas up to the roof.
2. In those cases where space is available the additional expense of relocating the environmental chamber is presented at a considerable cost. The existing chamber would need to be disassembled, relocated, and reassembled, with the risk of damage and difficulty in reassembling the systems to they perform as originally specified.
3. Any other available space would require the same modifications as room 601D for safety hydrogen detection and ventilation.

Seemingly, one clear advantage of using a basement or sub-basement room is the proximity to the multiple tank storage location outside the basement level. Although the 6^{th} floor location limits hydrogen storage to 400 cubic feet (2 K bottles) on the floor, this would require only four trips with a two bottle cart to complete a 14 hour test.

Appendix H. Calculation of Maximum Hydrogen Consumption

For a 75 kW fuel cell stack, convert 75 kW to btus per hour

75 kW x 3413 BTU/kWH = 255,975 BTUH

Assume 50% conversion= 255,975 / 0.5 = 511,950 BTUH

Using the conversion for Natural Gas for BTU/FT^3 as approximate for hydrogen gives

511,950 BTUH ÷ 1050 BTU/ft^3 = 487.57 ft3/hr x 28.305 SLM/ft^3 x 1hr/60min

= 230 SLM @ 50% eff

= 460 SLM @ 25% eff

Based on research, the average efficiency is, without reformation, 38% to 55%, depending on a number of factors. To be conservative in calculating hydrogen needs, 500 SLM will be used for the 30 kW cell. Based on the Arbin data sheet, this is maximum expected fuel flow; oxidizer is 1500 SLM.