INEEL/EXT-03-00976

U.S. Department of Energy FreedomCAR & Vehicle Technologies Program Advanced Vehicle Testing Activity Arizona Public Service – Alterative Fuel (Hydrogen) Pilot Plant Design Report

Don Karner
James Francfort

December 2003

Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

INEEL/EXT–03–00976

U.S. Department of Energy
FreedomCAR & Vehicle Technologies Program

Advanced Vehicle Testing Activity

Arizona Public Service - Alternative Fuel (Hydrogen) Pilot Plant Design Report

Don Karner
James Francfort

December 2003

Idaho National Engineering and Environmental Laboratory
Transportation Technology and Infrastructure Department
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-99ID13727

Disclaimer

CONTENTS

1. INTRODCUTION 1
   1.1 Objectives 1
   1.2 Background 1
   1.3 Siting the Fueling Station 2
      1.3.1 Site Description 2
      1.3.2 Siting Process 3
      1.3.3 Permits 4
   1.4 Fueling Station Design 4
2. HYDROGEN SYSTEM 6
   2.1 Design Criteria 6
   2.2 Water Purification 8
   2.3 Hydrogen Production 8
   2.4 Dryer and Filters 9
   2.5 Low-Pressure Storage 11
   2.6 Hydrogen Compressor 12
   2.7 Hydrogen High-Pressure Storage 13
   2.8 Fuel Dispensing 14
   2.9 Emergency Shutdown System – EMS 15
   2.10 Auxiliary Systems 16
      2.10.1 Control Air 16
      2.10.2 Chiller 16
      2.10.3 Nitrogen 17
      2.10.4 Vacuum 17
   2.11 Drains, Vents, Tubing, Vent Stack, and Blowdown Tank 17
   2.12 Hydrogen System Valves 18
   2.13 Control and Instrumentation 20
   2.14 Electrical 21
   2.15 Color Coding of Fluid Lines 21
   2.16 Helium and Fire Sprinkler System 22
   2.17 Flame and Flammable Gas Detection 22
3. COMPRESSED NATURAL GAS SYSTEM 23
   3.1 Fueling Station Overview 23
   3.2 CNG System Design Criteria 23
   3.3 Low-Pressure Storage 25
   3.4 Medium-Pressure Storage 26

3.5 High-Pressure Storage 26
3.6 Storage Filling 26
3.6.1 Hand Control 27
3.6.2 Automatic Control 27
3.7 Fuel Dispensing 27
3.8 Emergency Shutdown System 28
3.8.1 Emergency Shutdown System Initiation 28
3.8.2 Emergency Shutdown System Automatic Actuations 28
3.9 CNG System Valves 29
3.10 Compressed Natural Gas System Filters 33
3.11 Control and Instrumentation 33
4. FUEL DISPENSING 38
4.1 Refueling Equipment at the 501 Facility 38
4.1.1 Existing Liquid Refueling Systems 38
4.1.2 Existing Electric Refueling Systems 38
4.1.3 New Gaseous Refueling 39
4.2 Fuel Dispensing System Description 40
4.2.1 Hydrogen Dispenser Operation 41
4.2.2 CNG Dispenser Operation 41
5. LESSIONS LEARNED 42
5.1 Codes And Standards 42
5.2 Facility Layout 42
5.3 Piping 42
5.4 Electrical Grounding 42
5.5 Construction 43
5.6 Fuel Dispensing 43
6. LIST OF APPENDICES 44

ACRONYMS

AOV	air-operated valve
APS	Arizona Public Service
BIT	built-in test
CNG	compressed natural gas
DCS	dispenser control system
DI	deionized (water)
EMS	emergency shutdown system
ESD	emergency shutdown
GGE	gasoline gallon equivalent
HCNG	hydrogen enriched compressed natural gas
HPS	high-pressure storage
ID	inside diameter
INEEL	Idaho National Engineering and Environmental Laboratory
IR	infrared
LFL	lower flammability limit
LPS	low-pressure storage
MAWP	maximum allowable working pressure
NFPA	National Fire Protection Association
OD	outside diameter
Pdc	Pdc Machines, Inc.
PLC	programmable logic controller
psi	pounds per square inch
psid	Pounds per square inch, differential
RO	reverse osmosis
scf	standard cubic feet
scfh	standard cubic feet per hour
UV	ultraviolet

1. INTRODCUTION

Hydrogen has promise to be the fuel of the future. Its use as a chemical reagent and as a rocket propellant has grown to over eight million metric tons per year in the United States. Although use of hydrogen is abundant, it has not been used extensively as a transportation fuel. To assess the viability of hydrogen as a transportation fuel and the viability of producing hydrogen using off-peak electric energy, Pinnacle West Capital Corporation (PNW) and its electric utility subsidiary, Arizona Public Service (APS) designed, constructed, and operates a hydrogen and compressed natural gas fueling station—the APS Alternative Fuel Pilot Plant. This report summarizes the design of the APS Alternative Fuel Pilot Plant and presents lessons learned from its design and construction. Electric Transportation Applications prepared this report under contract to the U.S. Department of Energy's Advanced Vehicle Testing Activity. The Idaho National Engineering and Environmental Laboratory manages these activities for the Advanced Vehicle Testing Activity.

1.1 Objectives

The objectives of constructing and operating the Alternative Fuel Pilot Plant have been to:

1. Ascertain the safety issues for a hydrogen production operation in a commercial setting
2. Evaluate the adequacy of existing codes, standards, regulations, and recommended practices within a commercial setting
3. Establish models for future codes and standards for distributed hydrogen generation systems within a commercial setting
4. Determine performance limitations of existing technologies and components
5. Evaluate the practicality of the systems in a commercial facility
6. Evaluate hydrogen and blended CNG/hydrogen as a potential fuel for internal combustion engines
7. Develop a working model of a refueling system for fuel-cell electric vehicles and internal combustion engine vehicles.

1.2 Background

Several stored forms of hydrogen could be considered for use as a transportation fuel: gas, liquid, slush, and metal hydrides. Two common methods of producing hydrogen are reforming of hydrocarbons such as methane and methanol, and electrolysis of water. Reforming of hydrocarbons, although today the most common and economical way of hydrogen production, results in carbon dioxide (a greenhouse gas) as a byproduct. Electrolysis of water produces only hydrogen and oxygen and is of interest to an electric utility company as a means of improving its load factor and increasing energy sales. In contrast to centralized manufacturing of hydrogen and use of tube trailers for delivery (as in gasoline distribution), the electrolysis process can be used with the existing electric distribution system to produce relatively small quantities of hydrogen during off-peak periods at the point of use. This provides the advantage of leveling electric energy usage and eliminating the need for tube trailer transportation.

Due to the very small number of hydrogen refueling stations, there are limited standards for their construction. Five other commercial hydrogen vehicle-refueling stations have been built in the United States: Sun Line Transit in Palm Springs, California; Ford Proving Ground in Dearborn, Michigan; California Fuel Cell Partnership in Sacramento, California; Las Vegas Transit in Las Vegas, Nevada; and the Honda Proving Ground in Torrance, California. Commercial hydrogen refueling stations have also been built in Germany and Iceland.

Due to the limited standards for the construction of hydrogen refueling stations, fueling station designers must rely on existing compressed gas industry standards and portions of existing building codes, while working very closely with local building inspection and safety departments as well as engineering experts with hydrogen experience. The viability of hydrogen as a transportation fuel depends on the speed and ease of working with local building inspectors, and on the costs associated with compliance to existing codes and standards governing fueling station construction.

1.3 Siting the Fueling Station

PNW and APS chose to construct the APS Alternative Fuel Pilot Plant in an urban setting to determine the full impact of existing codes and standards as well as building inspector requirements on station design and on the siting process. This approach is unique to fueling station design in the United States and provides unique insight into the requirements for hydrogen fueling stations to be constructed and operated in commercial, rather than industrial, areas.

1.3.1 Site Description

The APS Alternative Fuel Pilot Plant is located in downtown Phoenix, Arizona at 403 South 2nd Avenue. The facility is bordered on the west by 2nd Avenue (a City of Phoenix street) and an area zoned for commercial use, as shown in Figure 1.1. On the south and east, the facility is bordered by an active APS service yard. Meter readers and service men supporting APS electric distribution in the downtown Phoenix area use the yard. Figure 1.2 shows the eastern side of the facility, including the fuel dispensing station. The facility shares a building structure with the offices of Electric Transportation Applications, which is located immediately north. This building was constructed in the early 1900s and functioned to support lamp gas production from coal for use in streetlights located in downtown Phoenix. The portion of the building housing the APS Alternative Fuel Pilot Plant is constructed of unfired clay brick. The building is open on the east side, with a roof of sheet metal panels.

Figure 1.1. West Side of the APS Alternative Fuel Pilot Plant.

Figure 1.2. East Side of the APS Alternative Fuel Pilot Plant.

1.3.2 Siting Process

The process of siting the APS Alternative Fuel Pilot Plant began by conducting an occupancy review to determine zoning requirements that would impact design. This review also included analysis of applicable compressed gas standards, to determine the design requirements. Because the facility was to be located within an existing building, particular attention was given to requirements for indoor facilities. Numerous conflicts between code requirements and station objectives were revealed. In particular, requirements for setbacks between hydrogen and natural gas fuels, and between fuel storage equipment and occupied structures would, if followed, make construction of the APS Alternative fuel Pilot Plant on the site impossible. In addition, using the standards governing natural gas installations, the site was considered an outdoor facility (only 3 walls). However, using the standards governing hydrogen installations, the site was considered an indoor facility. Using the worst-case scenario (indoor facility), analyses were performed to determine if setback requirements could be eliminated and both hydrogen and compressed natural gas (CNG) processes co-located on the site and within the existing building.

The analyses consisted of plume modeling for leaks of various sizes to determine the maximum plume volume. Analyses were then conducted to determine the effects of both deflagration and detonation of the worst-case plume. The analyses showed that with minor reinforcement (surface mounted I-beams, as shown in Figure 1.3) and blow-off roof panels, the existing building would withstand the effects of a detonation of the worst-case plume. These analyses and the design for building reinforcement were reviewed with the chief fire inspector for the City of Phoenix and Dr. Robert Zalosh, consultant to the City of Phoenix and Factory Mutual on the effects of flammable gas detonations. After several rounds of questions on both the analyses and the facility design, the City of Phoenix approved the facility design, as presented in Sections 2, Hydrogen System; 3, Compressed Natural Gas System; and 4, Fuel Dispensing, of this report by issuing a construction permit for the APS Alternative Fuel Pilot Plant.

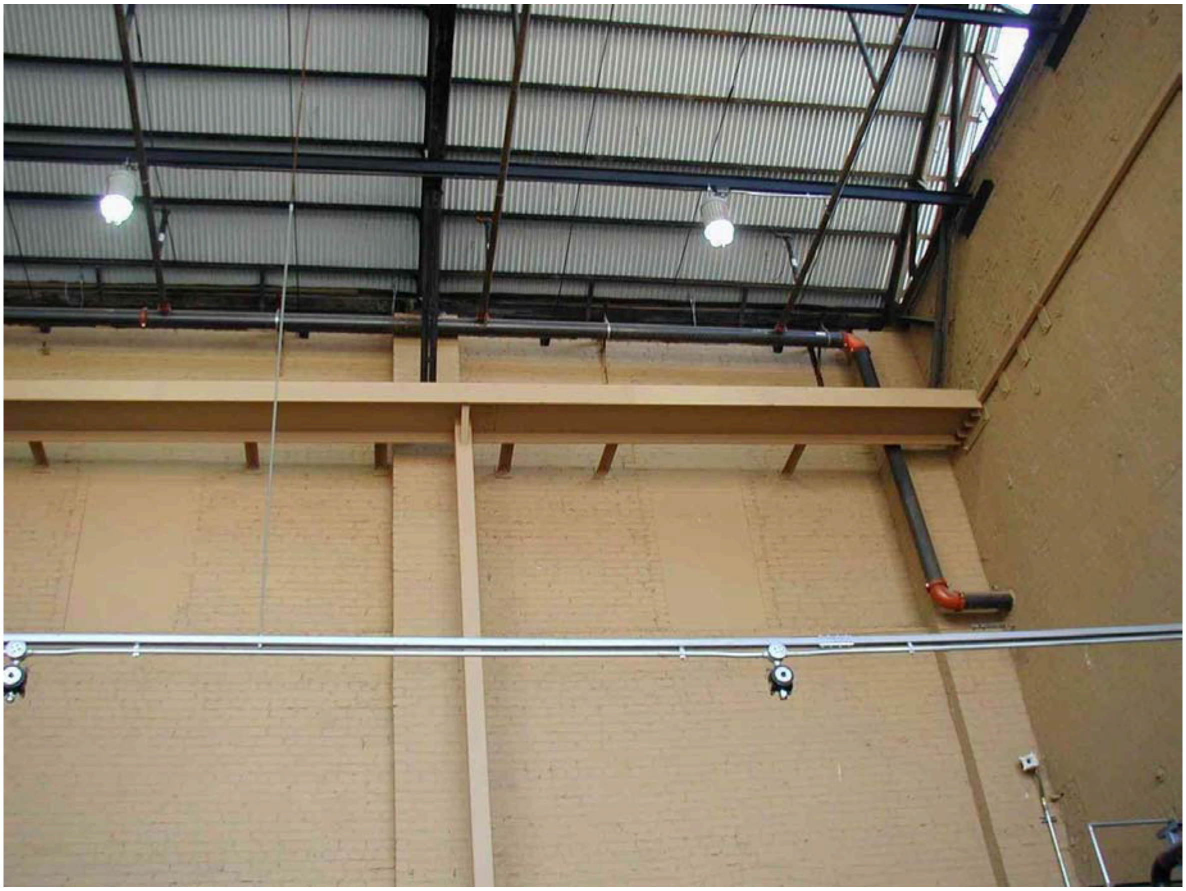


Figure 1.3. Building Reinforcement.

1.3.3 Permits

PNW and APS constructed the APS Alternative Fuel Pilot Plant under the close scrutiny and formal inspection of the City of Phoenix. Inspections were performed and releases issued for electrical, plumbing, structural, and piping systems. Inspections were typically performed on facility subsystems, and a final system release was awarded after construction completion. Upon overall facility completion, the City of Phoenix issued permits for both compressed gas storage and motor vehicle fueling.

1.4 Fueling Station Design

The APS Alternative Fuel Pilot Plant is a model alternative fuel refueling system, consisting of hydrogen, compressed natural gas (CNG), and CNG/hydrogen blends. Figure 1.2 shows the plant in plan view. The plant distinctly separates the hydrogen system from the natural gas system, but can blend the two fuels at the stationary filling system. Section 2 focuses on the hydrogen portion of the plant. Section 3 focuses on the natural gas portion of the plant, which is similar in various ways.

The plant's hydrogen system consists of production, compression, storage, and dispensing. The hydrogen produced is suitable for use in fuel cell-powered electric vehicles, for which the minimum hydrogen purity goal is 99.999%, and the upper limit of purity is 99.99999%. To obtain these purity levels, the facility uses two methods of production. One method takes advantage of the centralized manufacturing of hydrogen. The other method uses an electrolysis process that separates water into hydrogen and oxygen. At present, the hydrogen is compressed and stored at a maximum operating working pressure of 5,800 psi. The facility has over 17,000 scf of high-pressure storage capacity. The stationary filling system can dispense hydrogen at various pressures, up to the 5,800 psi maximum.

In addition to producing hydrogen, the plant also compresses natural gas for use as a motor fuel. CNG vehicles typically require 3,600 psi storage tanks. However, to fill vehicle onboard tanks, storage pressures must be higher. The APS system compresses natural gas to pressures up to 5,000 psi, using a three-stage cascade pressure arrangement.

2. HYDROGEN SYSTEM

2.1 Design Criteria

The hydrogen system has six primary functions: water purification, production, compression, storage, dispensing, and venting. Hydrogen is produced from high-purity water using electrolysis, which is compressed up to 5800 psi and stored in high-pressure-rated vessels. The high-pressure vessels supply the hydrogen to an automated refueling location where it is conveniently dispensed. Figure A-3 of Appendix A presents a plan view of the equipment locations for the hydrogen system. Figure A-2 presents a three-dimensional view of the hydrogen system components.

The electrolysis production process is a crucial element of the facility (see Section 2.3). Appendix B contains a Material Safety Data Sheet for hydrogen. The electrolysis equipment used at the facility is a HOGEN 300, manufactured by Proton Energy Systems. It produces 300 scf of hydrogen per hour at 150 psi, using high-purity water. The water purification process is one of the primary functions of the facility and significantly influences the purity level of the hydrogen within the system (see Section 2.2). The output of the electrolysis equipment is directed to the low-pressure storage vessel (see Section 2.5), which has a storage capacity of 8,955 scf of hydrogen. This vessel provides capacity when the hydrogen generator is not operating.

The pressure rating of the hydrogen generator and the low-pressure storage vessel is 150 psi. In order to provide the desirable dispensing pressures, a three-stage diaphragm compressor is used (see Section 2.6). The compressor is capable of compressing the hydrogen up to 6,000 psi at a rate of 300 scfh. At present, the high-pressure hydrogen system is regulated to 5,800 psi. The normal pipeline from the compressor output fills two high-pressure storage vessels (see Section 2.7). These vessels have a combined storage capacity of 17,386 scf and provide hydrogen for dispensing. The other pipeline from the compressor output provides hydrogen directly to the dispensers.

The capacities of all the storage vessels, the rate of hydrogen production, and the rate of compression can all be coordinated to achieve the required refueling demand. Though only a small mass of hydrogen is produced daily, the system offers model opportunity to evaluate system reliability, cost, and safety, and is a source of fuel for both fuel-cell and combustion engine testing.

The hydrogen system is a completely sealed, closed system. Specifications for hydrogen piping are presented in Appendix C. Proper piping design ensures that hydrogen is not inadvertently released. However, should a hydrogen leak occur, hydrogen gas detectors will signal an alarm and isolate the hydrogen system (see Section 2.9) with automatic shutdown of power to operating equipment (but control power, monitoring systems, and communication system remain energized).

Any venting or draining of the system is to the vent stack, where hydrogen is released above the roofline of the gas building (see Section 2.11). Design of the system eliminates any direct human contact with hydrogen. A helium purge is available to inert the vent stack (see Section 2.16). To quench fires in hydrogen vents is standard practice in the industry.

A nitrogen purge is used as an intermediary in any event that requires opening of the hydrogen system (see Section 2.10). Nitrogen purge points have been strategically designed into the system to adequately provide for safe operation and maintenance measures.

Because hydrogen fires are invisible, the entire equipment room containing the hydrogen system (see Appendix A, Figure A-3) is a controlled area, accessible only to those who are trained and certified to work around hydrogen systems. Arizona Public Service safety programs and procedures, defined in the

APS *Safety Manual*, have been applied to the pilot plant. Training programs prepared for the APS Alternative Fuel Pilot Plant are presented in Appendix D.

The gas building is continuously scanned for infrared and ultraviolet radiation, both typical signatures of a hydrogen flame (see Section 2.17). Combustible gas monitors are also used to monitor for hydrogen in the work area (see Section 2.17). These monitors will alarm at 25% LFL (lower flammability limit) of hydrogen. Equipment has been well grounded to eliminate static electricity as an ignition source (see Section 2.14). Hydrogen, unlike most fluids, does not build up a static charge when flowing; however, particles flowing in the hydrogen stream can create adequate energy to ignite the hydrogen if sufficient oxygen is present.

The EMS (emergency shutdown system) enables complete system shutdown, automatically or manually initiated (see Section 2.9). EMS alarm and annunciation visually and audibly indicate that the EMS has been initiated. If the hydrogen system isolation is breached, as detected by IR (infra-red) and UV (ultraviolet) scanners, gas detectors, or human intervention, the second contingency of isolation is automatically initiated by isolating all hydrogen storage, hydrogen production, and hydrogen dispensing; and by shutting off the power supply to the HOGEN 300 generator, dryer, and compressor.

Under the City of Phoenix ordinances, production of hydrogen gas must be performed in an area zoned A1, whereas retail sale of hydrogen gas can be in areas zoned C3. National Fire Protection Code (NFPA) 50A presents standards for constructing a hydrogen storage facility, but the code does not apply to hydrogen production facilities, per NFPA 50A, 1-3.3. The hydrogen production, compression, and storage equipment is physically located within the gas equipment building, while the water purification equipment, cooling equipment, nitrogen equipment, air compressor, and electrical panels are located in an adjacent room. The hydrogen electrical system within the gas building is engineered as Class 1, Division 2, in accordance with NFPA 70. Storage of hydrogen and related piping/tubing is in accordance with ASME Code B31.3.

Table 2.1 presents the specifications of the hydrogen production and storage system.

Table 2.1. Hydrogen production and storage.

Compressor: power	5 hp, 480V, 3ph	
DI Water: consumption	1.7 gal/hr	30 psi
Dryer: power	0.5 kVA, 120 V	
Effluent: DI water unit	DI water	
Effluent: dryer	hydrogen, DI water	
Effluent: HOGEN drains, vents,	DI water, oxygen	
HOGEN: chilled-water flow	72 gal/hr (supply)	72 gal/hr (return)
HOGEN: daily hydrogen production	7,200 scf/day	37.3 lb/day
HOGEN: hourly hydrogen production	300 scfh	1.55 lb/hr
HOGEN: make-up Air	1200 cfm air	
HOGEN: power	57 kW	480 volt
Instrument air	90 psi maximum	
Purge: nitrogen	130 psi maximum	
Storage: high pressure (6,000 psi)	17,386 scf	90.1 lb
Storage: low pressure (150 psi)	8,955 scf	46.4 lb
Storage: total hydrogen storage	26,341 scf	136.4 lb
Storage: energy release potential	8,560.5 MBTU	2,508.4 kWh

2.2 Water Purification

Potable water is supplied from a Phoenix street potable water supply (30 psi) to a water treatment system designed and manufactured by CIW Services, Inc. The CIW system has a 5-μ filter, carbon filter, stainless steel pump, reverse osmosis bank, 34-gal storage tank, mixed-bed demineralizer, and a 1.0-μ exit filter specifically built to accommodate Phoenix water. The maximum system flow rate is 215 gal/day.

The CIW system has two effluent lines: one 1" line from the RO (reverse osmosis) unit, and a second ¾" line from the storage tank bleed.

Deionized (DI) water flows to the drain until the minimum quality level is reached, as determined by an analyzer; about 30 gallons of DI water are consumed during startup. Once the water quality threshold has been achieved, the water drain-valve closes, and the supply to the HOGEN opens. During HOGEN shutdown, about 10 gal of DI water is discharged to the drain. A secondary DI water-polishing unit inside the HOGEN further purifies the water and provides backup to the primary DI water system.

2.3 Hydrogen Production

The HOGEN 300 is a proton exchange membrane-based system that produces hydrogen by electrolysis (Figure 2-1). It is similar to that used by the U.S. Navy in submarines. Hydrogen purity is between 99.999% and 99.99999%. The HOGEN uses electric potential across its membrane stack to produce a maximum pressure of 150 psi. Small increases in voltage will produce significant increases in pressure. Future systems may reach pressures of 2,000 psi. The HOGEN 300 was built following NFPA standards 496, 50A, and 70 and complies with NEMA 4. It is a one-of-a-kind unit, previously operated, continuously, at the STAR (Solar Test and Research) facility in Tempe, Arizona for 24 months without incident.

Figure 2-1. HOGEN 300 proton exchange system.

The HOGEN 300 is self-contained and weather proof, complete with control systems, polishers, dryer, and combustibles detector, located inside the gas building. In order to conform to NEC requirements, the unit uses the purge-and-pressurize technique to be acceptable in hazardous locations.

This requires a fresh air purge (from an unclassified area) at the rate of 1,200 scfm. The HOGEN 300 requires a chilled-water cooling system. This system provides cooling to the power electronics in the hydrogen generator. The chilled-water system is a separate unit located outside of the gas building. This closed-loop system has maximum potential to circulate at a rate of 72 gal/hr. A nitrogen purge port is incorporated into the HOGEN (there is no manufacturer's requirement to use the nitrogen purge for maintenance). The HOGEN needs 57 kW of electricity from a 480-V, 150-A, 3-phase supply, and ground. The electric installation is installed above ground and complies with NFPA 70. Communications allow remote system monitoring, with alarms and emergency shutdown. Table 2.2 describes the interfacing of all support systems for the HOGEN 300.

Table 2.2. HOGEN 300 systems interfacing.

Element	Required support
Combustible gas mixture detector	Master system alarm
Condensate drain	Blow-down tank and vent system
Control air	5 scf daily, 90-psi max pressure, clean dry air
Data line	Modem accessible
Electric power	57 kW (480 V, 150 A)
Electrical grounding	NFPA 70
Hydrogen vent (startup)	To vent stack
Local shutdown	Master system alarm
Oxygen vent	0.5 in. to building roof, min 25 ft from H_2 vent
Power electronics cooling	Chiller outside of gas building
Purge air	1,200 scfm, clean outside air
Purge nitrogen	0.5 in. manually activated
Remote shutdown	Emergency shutdown system and alarm

The hydrogen production rate is 300 scfh at 150 psi (8 NM^3/hr, 10 bars, 1.56 lb/hr). The HOGEN requires DI water conductivity better than 1-μ siemen (1MΩ-cm resistivity) and preferably better than 0.1-μS (10MΩ-cm). Water consumption is 1.7 gal/hr (or 6.4 l/hr) at an average supply pressure of 15 to 60 psi. During startup, hydrogen is initially vented to the vent stack until the quality level is achieved, upon which venting terminates. In normal operation, there is no leakage or venting of hydrogen gas. Oxygen is a byproduct of the HOGEN operation. Oxygen is vented to the outside in a separate vent stack at atmospheric pressure (150 scfh, 12.4 lb/hr) from a 0.5-in. connection on the HOGEN unit, through the gas-building roof. The HOGEN comes prepackaged with its own propriety control system.

2.4 Dryer and Filters

Hydrogen produced by the HOGEN 300 contains water. Although water contamination is not a problem for the storage vessels or fuel cells, it reduces the efficiency of the compressor and can result in excess maintenance of the compressor. Since the hydrogen must be compressed, water must be removed. The Lectrodryer, a hydrogen dryer, yields hydrogen with a -80°F dew point. The drain, vent, and safety valves of the dryer are piped to the hydrogen vent system. Isolation of the dryer from the rest of the hydrogen system is accomplished with manual isolation valves.

The Lectrodryer (Figure 2.2) is powered by a 120-V source. The electrical control panel enclosure is a NEMA 4x enclosure. To meet the requirements of Class 1, Division 2, Group B, of the *National*

Electrical Code, the enclosure uses purged nitrogen as a hazardous-location protection technique. Features of the dryer include electric reactivation heaters, thermostatic over-temperature protection, nonlubricated transflow valves, dial thermometer in the reactivation exhaust piping, and reactivation indicator lights.

Figure 2.2. Lectrodryer hydrogen dryer.

Hydrogen purity is controlled by the water quality entering the HOGEN unit and by removal of contamination particles (microscopic) from the interior surface of the gas system piping/equipment in contract with the gas stream. A coalescing filter, described in Table 2.3, is installed at the inlet to the dryer. Particulate filters, described in Table 2.3, are installed at outlets of the LPS (low-pressure storage), hydrogen compressor, HPS (high-pressure storage), and dryer. Filters have visual differential pressure indicators. Filters have isolation valves, nitrogen purge, and vents for maintenance.

Table 2.3. High-pressure hydrogen filters.

Filter	Dryer Outlet	HPS Outlet	LPS Outlet	Compressor Outlet	Dryer Inlet
Tag no.	F-102	F-401	F-103	F201	F-101
Size	0.5 in.	0.5 in.	0.5 in.	0.5-in.	0.5 in.
Port size & type	0.5-in. FPT	0.5-in. FPT	0.5-in. FPT	0.5-in. FPT	0.5-in. FPT
Design flow	12,000 scfh	400 scfh	12,000 scfh	400 scfh	400 scfh
Design pressure	6,000 psi	6,000 psi	6,000 psi	6,000 psi	6,000 psi
Type	Particulate	Particulate	Particulate	Particulate	Coalescing
Vendor	Norman	Norman	Norman	Norman	Norman

Model	Tee Type 535	Tee Type 535	Tee Type 535	Tee Type 535	In-line 4200 Series
Part No.	4535TP. 5ABSFNV	4535TP. 5ABSFNV	4535GP. 5ABSFNV	453GP. 5ABSFNV	42.5T-4PP
MAWP	6,000 psi	6,000 psi	6,000 psi	6,000 psi	6,000 psi
Burst pressure	24,000 psi	24,000 psi	24,000 psi	24,000 psi	24,000 psi
Filter rating	0.5-µm, sintered 316 SS	0.5-µm, sintered 316 SS	0.5-µm, sintered 316 SS	0.5-µm, sintered 316 SS	0.5-µm, sintered 316 SS
Temp. rating	800˚F	800˚F	800˚F	800˚F	800˚F
Body material	316 SS	316 SS	303 SS	303 SS	304 SS
Seal material	Viton	Viton	Viton	Viton	Viton

2.5 Low-Pressure Storage

The low-pressure storage (LPS) receives hydrogen from the HOGEN. It is a horizontal carbon steel cylindrical vessel measuring 6 ft 11 in. inside diameter, 19 ft. long. The LPS vessel has a water volume of 6,565 gal. The LPS (Figure 2.3) was manufactured under the *ASME Pressure Vessel Code*, Section VIII, Division 22, and is rated for 250-psi maximum pressure at 125°F. Appendix B presents Form UA-1, certifying compliance with the ASME Code (serial number 123982).

Figure 2.3. Hydrogen low-pressure storage vessel is the large tank on the bottom and the two high-pressure storage vessels are on top.

The vessel is protected against over pressurization by an ASME relief valve. Discharge from this valve is piped to the hydrogen vent stack. Hydrogen exits from the LFP to the hydrogen compressor.

The LPS receives dried 150-psi hydrogen gas from the HOGEN 300. About 46.4 lb or 8,955 scf of hydrogen can be contained in the LPS. The safety relief valve mounted on the LPS relieves pressure at 165 psi. Relief vents are piped to the vent stack. The LPS has powered isolation valves installed up- and downstream to permit full isolation of the LPS. These isolation valves can be activated manually or automatically by the EMS. Isolation of the LPS includes an activated ball valve (electrically operated) and a manual valve (open in normal operation). The LPS also has two vents: (1) a power-operated vent that discharges to the vent stack and (2) a manually actuated vent for purity control, which has also been piped to the vent stack. A manual drain for water at the low point of the LPS has been piped to the blow-down vent. The LPS is connected to the nitrogen purge system. The nitrogen purge includes isolation valves and check valves to eliminate back flow of hydrogen.

Pressure on the LPS is monitored with a pressure indicator gauge, pressure switch, and with a pressure transmitter for recording data. Should LPS system pressure exceed 165 psi, the HOGEN will ramp down to 130 psi, and then shut down, followed by an alarm. Should the LPS pressure be low, an alarm will be initiated, and the hydrogen compressor will shut down if compressing hydrogen. The moisture level in the gas delivered to the LPS is monitored using a dew point meter.

The LPS is electrically grounded. It is labeled with the fire diamond symbol for hydrogen (blue 0, red 4, yellow 0) and is visible from the building access. In the event of activation of the EMS, the LPS isolation valves will close. After resolving the conditions causing initiation of the EMS, the EMS will be reset, and the LPS isolation valves can be opened and HOGEN production resumed. If for some reason the LPS requires hydrogen dumping, the power vent can be opened and hydrogen will be released to the vent stack. If operation cannot resume, the nitrogen purge system will be activated after the hydrogen is released to vent, and the LPS will be filled with nitrogen.

2.6 Hydrogen Compressor

In the high-pressure system, a Pdc Machines, Inc. diaphragm compressor (Figure 2.4) with three stainless steel diaphragms raises the gas pressure to 6,000 psi (Table 2.4). The compressor motor and supporting electrical equipment have been designed to be rated Class 1, Division 2, Group B. The motor is of TEFC design.

The compressor control package monitors discharge pressure, temperature, and motor current. Pressure indicators are installed on the compressor suction, discharge, and DI water supply. The compressor has isolation valves, vents, and nitrogen purge. A discharge filter assembly includes a differential pressure monitor and indicator.

High and low discharge pressure switches are preset. The compressor package includes a leak detecting system that will detect leakage through the diaphragms and signal an alarm and will shut down the compressor.

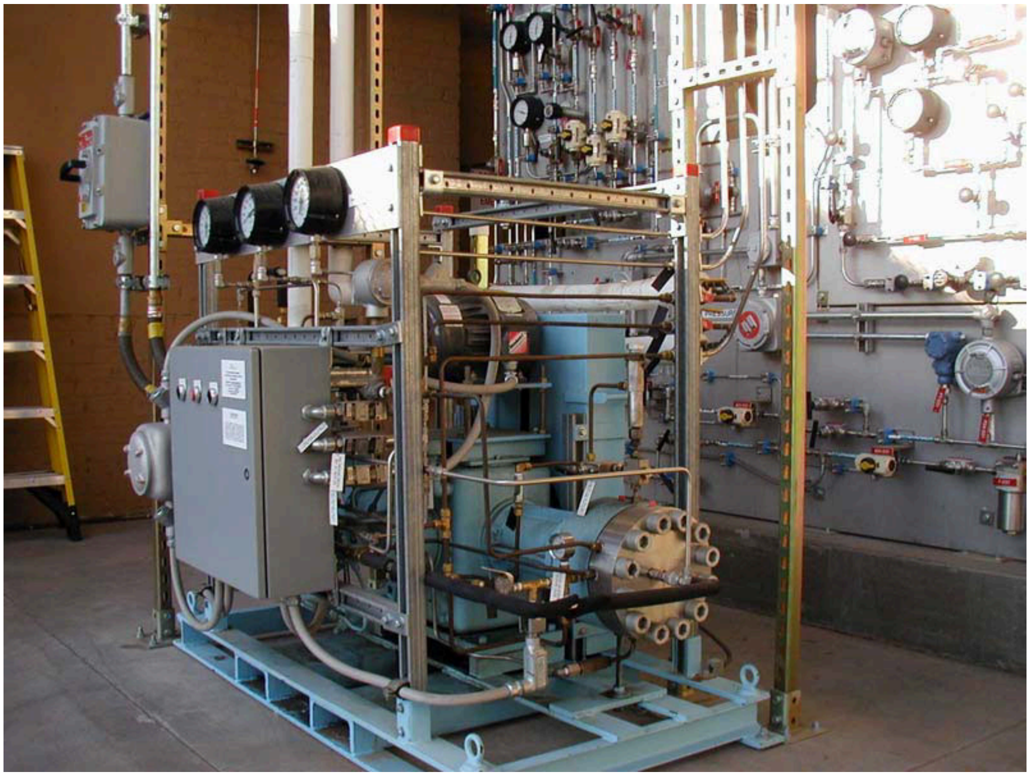


Figure 2.4. Pdc Machines, Inc. diaphragm hydrogen compressor.

Table 2.4. Hydrogen compressor.

Model	Pdc-4
Motor	5 hp
Volts	480
Amperes	10
Phase	3
Hazardous class	Class I, Division 2, Group B
Inlet pressure range	100–150 psi, 200-psi max.
Output pressure	6,000 psi
Capacity, hydrogen	300 scfh

2.7 Hydrogen High-Pressure Storage

Hydrogen high-pressure storage (HPS) is provided in two high-pressure seamless carbon-steel horizontal storage vessels (Figure 2.3) manufactured under 1998 ASME Code, Section VIII, Division 1, Addendum 1999, Appendix 22 (SF3). Appendix B presents Form UA-1, certifying compliance with the ASME Code (serial numbers 46705 and 46708).

The vessels are 28.0 ft long, 16 in. outside diameter, and weigh 6,670 lb each. The design pressure is 6,667 psi at 200ºF. The water volume storage per vessel is 27.1 cubic feet, or 54.2 cubic feet total. The operating temperature range of the vessels is -20 to 200ºF. The vessel interiors were steam cleaned after being grit blasted to remove loose scale.

The HPS receives dry 6,000-psi hydrogen gas from the hydrogen compressor. About 90.1 lb, or 17,386 scf, of hydrogen can be contained in the HPS. A safety relief valve mounted to the HPS will relieve pressure at 6,667 psi. The relief valve discharge is piped to the vent stack. The HPS has powered isolation valves installed up- and downstream to permit full isolation of the HPS. These isolation valves can be activated manually or automatically by the EMS. The HPS also has two vents that are piped to the vent stack: (1) a solenoid-operated vent valve piped to the vent stack and (2) a manually operated vent valve for purity control. There is a manual water drain at the low point of the HPS, which is piped to the blow-down vent. The HPS is connected to the nitrogen purge system, which includes isolation and check valves to eliminate backflow of hydrogen.

Pressure on the HPS is monitored with a pressure indicator gauge and with a pressure transmitter for electronic data recording and control. Should the HPS system pressure exceed 6,200 psi, the system will alarm an early warning. If the pressure exceeds 6,300 psi, the EMS will shut down the entire hydrogen system and activate the high-pressure alarm.

The HPS is grounded electrically. The HPS is labeled using the fire diamond symbol for hydrogen (blue 0, red 4, yellow 0) and is visible from the building access. In the event of activation of the EMS, the HPS isolation valves will close. After resolving the conditions causing the initiation of the EMS, the EMS will be reset and the HPS isolation valves can be opened. If for some reason the HPS requires dumping of hydrogen, the power vent can be opened and hydrogen will be released to the vent stack. If operation cannot resume, the nitrogen purge system will be activated after the hydrogen is released to vent, and the HPS will be filled with nitrogen.

There is a 0.5-μ filter in the exit tubing from the HPS and an excess flow control valve and flow switch to detect excess flow, either of which can initiate shutdown of the HPS isolation valves. If tubing or hoses fail downstream of the HPS, the excess flow valve will automatically close. The filter and excess flow valve can be isolated for maintenance.

2.8 Fuel Dispensing

The APS Alternative Fuel Pilot Plant has two dual output dispensers (Figure 2.4) manufactured by Fueling Technologies, Inc. One of these units dispenses CNG only at each output. The other unit has a hydrogen output and a CNG/hydrogen blend output. Dispensers are more fully described in Section 4 of this report.

Appendix E presents hydrogen system and hydrogen dispenser operating procedures.

Figure 2.4. CNG only dispenser and hydrogen and CNG/hydrogen blend dispenser.

2.9 Emergency Shutdown System – EMS

The EMS is the second-level process control safety system, which reacts after the detected failure of the primary safety system. The primary safety system for hydrogen is isolation; the second level safety system is shutdown. The following components constitute the system.

- Ultra-fast IR/UV detectors
- Combustible gas detector
- Manual and remote trip
- Vent stack temperature monitor
- Alarms horns and strobe lights
- Calibration and testing of the system
- Vent stack fire suppression.

If a hydrogen event is detected or perceived to have occurred, the EMS will isolate sections of the system and de-energize all operating equipment, including the CNG compressor. Audible alarms and visual lights will notify personnel in the area that activation of the EMS has occurred. An alarm located at the PNW security station at the 502 Building will also indicate that an EMS activation has occurred. Activation of the EMS will be a failsafe action.

A hydrogen event is defined as constituting any of the nine items listed below. Any one of the hydrogen events listed will result in activation of audible alarms, strobe lights, and a Security Station alarm. The EMS map will indicate which activation device authorized activation. The EMS will reset itself after a hydrogen event has cleared.

- Any of the four IR/UV scanners located in the process area testing positive
- The IR/UV scanner located at the fuel-dispensing island testing positive
- Manual activation from the fuel-dispensing island.
- Manual activation from the east side of the control building
- Manual activation from inside the control building
- High-pressure switch activated on the LPS vessel.
- High-pressure switch activated on the HPS vessels
- Flammable gas detects gas leak
- Loss of control of air pressure.

The EMS will activate warning strobe lights when in any of the following incidents:

- The combustible gas detectors detect 25% of LFL
- High temperature is detected on the vent stack.
- Incipient flame is detected.

The EMS will provide a process system alarm on any of the following conditions:

- Authorization by the vent stack thermocouple to activate helium purge into vent stack
- Activation of the excess flow switch
- Low-pressure switch activated on hydrogen compressor
- Failure of the hydrogen compressor to start
- Low-pressure on the vent stack helium system
- Compressor leak detected
- High pressure detected on LPS
- High pressure detected on HPS.

The EMS has a scanner lockout, which permits calibration of the IR/UV scanners without activating the EMS. Negative scan readings should occur within 5 minutes after activation of the EMS. The EMS alarms will be reset, and the system remains down until released for operation by the authorizing engineer. If the IR/UV scanners continue to scan positive after 5 minutes, the authorizing engineer will be contacted.

2.10 Auxiliary Systems

2.10.1 Control Air

The control air system consists of a 100-cfm air compressor, 500-scf storage vessel, and piping network. The control system provides clean dry 90-psi air for the hydrogen system.

2.10.2 Chiller

The dual-compressor closed-loop chiller provides 293,000 Btu/h (at 80°F ambient) cooling water to the HOGEN and Pdc compressor. The Drake model PACT240D unit requires 480 V, 3-phase power, and produces 12 hp at a flow rate of 66 gpm.

2.10.3 Nitrogen

Nitrogen is used as a buffer gas between the air and hydrogen. The nitrogen system consists of a production unit, compressor, storage tank, and piping network. Atmospheric air is processed by the nitrogen generator (PSA type system), which produces 97% purity nitrogen. Nitrogen is compressed to 100 psi and stored in a 600-scf vessel. A piping network distributes nitrogen to purge locations on the hydrogen system.

2.10.4 Vacuum

During a startup of the hydrogen system, it is necessary to attain the required hydrogen purity, which consumes a minimum duration of time and hydrogen gas. A portable vacuum pump is used to evacuate the pressure vessels of nitrogen before introduction of hydrogen, to reduce the number of purge cycles in meeting the purity goal.

2.11 Drains, Vents, Tubing, Vent Stack, and Blowdown Tank

The system of vents and drains constitutes a significant safety system. The vent stack and blowdown tank control the release of hydrogen into the atmosphere. It is assumed that once the hydrogen gas reaches the vent stack, or is released from it, it will react with air and burn. Burning could occur in the stack but is most likely to react at the stack exit. Probably, there will be no reaction, but the design assumption is that it will. The reaction of hydrogen with oxygen produces water; hence, in the worst-case scenario there are no environmentally hazardous emissions from the release of hydrogen into the atmosphere. The release is 10 feet above the Gas Building roofline. The design of the vent stack exit prevents nesting of birds or forces of nature blocking the exit of the gas.

The oxygen vent from the HOGEN unit does not go into the vent stack but is routed separately away from the stack. The oxygen vent is fabricated from 0.5-in. 304 stainless steel tubing and is identified as an oxygen vent.

The vent stack begins at the top of the blowdown tank. Drains are piped into the blowdown tank. Vents are piped into the Vent Stack. The blowdown tank is fully open to the vent stack. At the low point of the blowdown tank, a self-closing drain valve permits safe removal of condensate or oil. The vent stack and blowdown tank are normally under atmospheric pressure. The vent stack posts a sign reading "Venting Hydrogen Gas May Ignite." A helium injection system is installed in the vent stack.

Table 2.5 lists the hydrogen system vents. Vents are fabricated from 0.5-in. 304 stainless steel Swaglock tubing. A 1-in. color-coded tape is used at 5-foot intervals to identify the tubing as a hydrogen system vent line. Flow direction arrows are also mounted on the vent lines. The vent stack utilized weldolets for vent attachment. The blowdown tank has similar attachments for drains. The vent stack is 3-in. schedule 40 stainless steel pipe for the intended duty. The blowdown tank is 6-in. schedule 80 stainless steel pipe. The vent stack is securely anchored to the Gas Building to restrain any thrust from dislodging it, and it is electrically grounded.

Table 2.5. Hydrogen system vents.

Vent No.	From	To	Size	
OV1	HOGEN	Top of gas bldg	0.5-in. 304 SS	Oxygen vent
HV1	HOGEN	Vent stack	0.5-in. 304 SS	HOGEN vent
HV2	Dryer	Vent stack	0.5-in. 304 SS	Dryer vent
HV3	LPS – Powered	Vent stack	0.5-in. 304 SS	Powered LPS vent
HV4	LPS	Vent stack	0.5-in. 304 SS	Purity LPS vent
SRV2	LPS – SRV	Vent stack	0.5-in. 304 SS	LPS safety relief

SRV2	LPS – SRV	Vent stack	0.5-in. 304 SS	LPS safety relief
HV5	F1	Vent stack	0.5-in. 304 SS	Filter bleed
HV6	H_2 Compressor	Vent stack	0.5-in. 304 SS	Compressor bleed
HV7	HPS	Vent stack	0.5-in. 304 SS	HPS vent
HV8	HPS	Vent stack	0.5-in. 304 SS	HPS vent
SRV3	HPS – SRV	Vent stack	0.5-in. 304 SS	HPS safety relief
SRV4	HPS – SRV	Vent stack	0.5-in. 304 SS	HPS safety relief
HV9	Dispenser filter	Vent stack	0.5-in. 304 SS	Filter bleed
HV10	Dispenser vent	Vent stack	0.5-in. 304 SS	Dispenser nozzle vent

2.12 Hydrogen System Valves

Appendix A, Figure A-4, presents the hydrogen system piping and instrumentation diagram. Table 2.6 shows the specifications for low-pressure valves shown in Figure A-4. Table 2.7 shows the specifications for high-pressure hydrogen system valves. All valves are certified by their manufacturers to be suitable for use with hydrogen.

Table 2.6. Low-pressure hydrogen.

Device	Check Valve	Manual Valve
Tag No.	CV-XXX	V-XXX
Size	0.5 in.	0.5 in.
Cv	1.8	0.73
Port size and type	0.5-in. Swagelok	0.5-in. Swagelok
Design flow	400 scfh	400 scfh
P1	100 psi	100 psi
P2	99 psi	99 psi
P drop	1 psid	1 psid
Vendor	Swagelok	Swagelok
Model	CH Series	1 Series
Part no.	SS-CHS8-1-SC11	SS-1KS8-SC11
Cracking pressure	1 psid	N/A
MAWP	6000 psi	5000 psi
Burst pressure	24,000 psi	24,000 psi
Temp. rating	400°F	100°F
Temp. derating	N/A	4295 psi @ 200˚F
Seat material	Viton	Kel F
Body material	316 SS	316 SS
Valve style	in-line check	Bonnet needle
Seal material	N/A	TFE Packing
Seat leak rate	N/A	0.1 scc/min N2 @ 1000 psi

Table 2.7. High-pressure hydrogen valve specification.

Device	Check Valve	Solenoid Valve	Solenoid Valve	Manual Valve	Manual Valve	Solenoid Valve	Manual Valve	Slow-Open Actuated Valve
Tag No.	CV-XXX	SV-XXX	SV-XXX	V-XXX	V-XXX	SV-XXX	V-XXX	AOV-XXX
Size	0.5 in.	0.375 in.	0.5 in.	0.5 in.	0.5 in.	0.5 in.	0.5 in.	0.5 in.
Cv	7.4	0.096	0.64	1.2	1.2	0.64	1.2	1.2
Port size and type	0.5 in. fem. pipe	0.375 in FPT	0.5 in. FPT	0.5 in. pipe socket	0.5 in. pipe socket	0.5 in. FPT	0.5 in. pipe socket	0.5 in. pipe SW
Design flow	400 scfh	>400 scfh	>400 scfh	400 scfh	400 scfh	12000 scfh	400 scfh	12,000 scfh
P1	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi	5900 psi
P2		5999 psi	5999 psi	5999 psi	5999 psi	5999 psi	5999 psi	5899 psi
P drop	0.2 psid	1 psid	1 psid	1 psid	1 psid	1 psid	1 psid	1 psid
Vendor	Circle seal	Circle seal	Circle seal	Circle seal	Circle seal	Circle seal	Circle seal	Circle seal
Model	H200	SV20	SV400	MV Series	MV Series	SV400	MV Series	CMV60 Series
Part No.	H220T-4PP	SV21T2NC6P33	SV462T2NC8P33	MV60T08PW	MV60T108PW	SV462T2NC8P3S	MV60T108PW	CMV60T108PWNC
Electrical class	N/A	115 Vac, X-proof	115 Vac, X-proof	N/A	N/A	115 Vac, X-proof	N/A	115 Vac, X-proof
Cracking pressure	8 psi	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MAWP	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi	6000 psi
Burst pressure	>15,000 psi	>15,000 psi	>15,000 psi	24,000 psi	24,000 psi	>15,000 psi	24,000 psi	24,000 psi
Temp. rating	450°F	165°F	165°F	250°F	250°F	165°F	250°F	250°F
Seat material	Teflon	Viton	Viton	Teflon	Teflon	Viton	Teflon	Teflon
Body material	303 SS	303 SS	303 SS	303 SS	316 SS	303 SS	316 SS	316 SS
Valve style	Check	Direct acting S.V.	Direct acting S.V.	Globe	Globe	Direct acting S.V.	Globe	Globe
Outboard leak rate	N/A	N/A	N/A	Bubble tight	Bubble tight	N/A	Bubble tight	Bubble tight
Seal material	N/A	Viton	Viton	Teflon packing	Teflon packing	Viton	Teflon packing	Teflon packing
Seat leak rate	N/A	Zero	Zero	Bubble tight	Bubble tight	Zero	Bubble tight	Bubble tight

2.13 Control and Instrumentation

Table 2.8 lists the hydrogen system controls and instrumentation.

Table 2.8. Controls and instrumentation.

Device	ID	Local	Indicate[a]	Monitor[b]
DI water quality	N/A	DI skid	Yes	No
DI water pressure	N/A	DI skid	Yes	No
Pressure LPS vessel	PT-104	LPS tank	Yes	Yes
Pressure LPS Vessel	PI-109	LPS panel	Yes	No
Hydrogen sample	PI-106	HOGEN outlet	Yes	No
HOGEN amps	N/A	HOGEN skid	Yes	No
Compressor inlet pressure	PI-108	Pdc panel	Yes	No
Compressor outlet pressure	PT-112	HPS panel	Yes	Yes
Temperature HPS vessel 1	TI-101	HP tank 1	Yes	No
Temperature HPS vessel 1	TI-102	HP tank 1	Yes	No
Pressure HPS vessel 1	PT-113	HP tank 1	Yes	Yes
Pressure HPS vessel 2	PT-114	HP tank 2	Yes	Yes
H2 pressure to dispenser	PT-402	HPS Panel	Yes	Yes
Diff pressure filter F-101	DPI-101	Filter 101	Yes	No
Diff pressure filter F-102	DPI-102	Filter 102	Yes	No
Diff pressure filter F-103	DPI-103	Filter 103	Yes	No
Diff pressure filter F-201	DPI-201	Filter 201	Yes	No
Diff pressure filter F-401	DPI-401	Filter 401	Yes	No
Vent stack temperature	TE-104	Vent stack tee	No	Yes
Combustibles analyzer 1	AIT-101	Roof Gas Building	Yes	Yes
Combustibles analyzer 2	AIT-102	Roof Gas Building	Yes	Yes
IR/UV scanner 1	BE-101	Gas Building	Yes	Yes
IR/UV scanner 2	BE-102	Gas Building	Yes	Yes
IR/UV scanner 3	BE-103	Gas Building	Yes	Yes
IR/UV scanner 4	BE-104	Gas Building	Yes	Yes
IR/UV scanner 5	BE-105	Gas Building	Yes	Yes
IR/UV scanner 6	BE-106	Gas Building	Yes	Yes
EMS status	N/A	Control room	Yes	No
Control air pressure	N/A	Compressor skid	Yes	No
Dispenser 1 status	N/A	Dispenser	Yes	No
Flow through dispenser	N/A	Dispenser	Yes	No
Helium pressure	PT-501	Helium storage	No	Yes
Nitrogen pressure	N/A	Nitrogen skid	Yes	No
City water pressure	N/A	DI skid	Yes	No

a. Indicate = local visual indication only; no electrical signal to control panel.

b. Monitor = provides an electrical signal to the control panel and produces a visual indication at the control panel; used to generate alarms and shutdowns.

2.14 Electrical

The electrical energy supply is through a 48-V, 600-A, 3-phase load center located in the auxiliary equipment area (unclassified). The interior of the building is considered to be a Class 1, Division 2, area. Wherever possible, electric equipment is placed in an unclassified area outside of the building. Purge air from the control air system is used in panels within the building. Conduits are sealed.

Grounding is with a 2/0 copper grounding grid placed in the concrete floor slab. This grid is bonded to the building steel. The grounding system also extends to the fueling island and its canopy

2.15 Color Coding of Fluid Lines

All gas and liquid piping has color-coded labels (Table 2.9) that indicate the kind of fluid in the line and the direction of flow. Labels are at 10-ft intervals, on both sides of wall penetrations. Labeling is as follows:

- Safe colors: white, black
- Danger/fuel: blue (sky, dark), red, yellow
- Inert gas: orange

Table 2.9. Gas and liquid piping labeling used.

Fluid	Color
Deionized water	White/black strip
Chilled water	White
Potable water	White
Compressed air	Black
Helium	Orange/2 white stripes
Nitrogen	Orange/1 white stripe
Hydrogen	Sky blue
Hydrogen vent	Sky blue/2 red stripes
Hydrogen drain	Sky blue/1 red stripe
Compressed natural gas	Dark blue/2 red stripes
CNG vent	Dark blue/2 red stripes
CNG drain	Dark blue/1 red stripe
Hydrogen/natural gas blend	Dark blue/sky blue stripe
Oxygen	Green
Oxygen vent	Green

2.16 Helium and Fire Sprinkler System

The gas building is protected with a fuse-link-type fire sprinkler system.

The vent stack has a helium purge system for extinguishing any extensive fires that may develop in the vent stack. A thermocouple installed at the top (exit) of the vent stack triggers an alarm condition if exit gas temperatures reach 250ºF. Release of helium into the vent stack is manually initiated.

2.17 Flame and Flammable Gas Detection

Flame detectors are Spectrex Model 20/20LB units. They scan both for IR and UV wavelength or flame signature. Factory Mutual certifies the units. The scanners produce a series of outputs that allow an visual/audible alarm to sound at an *incipient* fire condition and initiate system shutdown once the detector senses a high level of IR/UV. The unit can sense flames up to 50 feet away. The gas building has five or more detectors located to completely scan the facility. Appendix F presents the coverage envelops for both the IR and UV detectors. A single unit is located at the fuel dispenser island. In this application, this UV/IR device is an industry standard. The scanners have built-in automatic testing to ensure proper operation.

The gas building has two types of gas detectors: hydrogen and natural gas. The technology and vendor for each is different. Both detectors provide an audible/visual alarm at 25% LFL for hydrogen and initiate system shutdown at 50% LFL for hydrogen.

3. COMPRESSED NATURAL GAS SYSTEM

3.1 Fueling Station Overview

The APS Alternative Fuel Pilot Plant is a model alternative fuel refueling system supplying compressed natural gas (CNG), hydrogen, and a blend of CNG/hydrogen. Figure A-1 of Appendix A shows a plan of the plant. The hydrogen and natural gas systems are distinctly separate; the stationary filling station blends the two fuels. This section focuses on the natural gas portion of the plant. Section 2 discusses the hydrogen portion, which is similar in various ways.

In addition to hydrogen, the plant also compresses natural gas for use as a motor fuel. CNG vehicles typically require 3,600-psi storage tanks. However, to fill vehicle onboard tanks, storage pressures must be higher. The APS system compresses natural gas to pressures up to 5,000 psi using a three-stage cascade pressure arrangement.

The objectives of constructing and operating the natural gas system are to:

- Evaluate the cost and benefit ratio of operating a natural gas fueling system
- Evaluate the safety of a natural gas fueling system
- Provide a fuel source for APS-operated CNG and hydrogen enriched CNG (HCNG) vehicles.

3.2 CNG System Design Criteria

The CNG system has four primary functions: compression, storage, dispensing, and venting. Natural gas provided by Southwest Gas is delivered at 30 psi; it is then filtered, compressed to 5,200 psi, and stored in three pressure vessels. Figure A-3 of Appendix A presents a plan of equipment locations for the natural gas system. Figure A-2 presents a three-dimensional view of the CNG system components.

Natural gas is received from Southwest Gas at 30 psi and is then filtered through two filters (see Section 3.10) before being routed to the compressor. The main compressor for the CNG system is a 4-stage 300-cfm Gemini model HPSS-4, described in Table 3.1. It compresses the gas to 5,000 psi. Originally, it was thought that raising the inlet pressure above 30 psi could optimize the Gemini's performance. This led to including an additional compressor in the design.

Table 3.1. Gemini compressor operating conditions.

Gemini Compressor	Normal	Shutdown
Oil pressure	45–55 psi	25 psi
Gemini suction pressure	55 psi	30 psi
Gemini suction temperature	80ºF	100˚F
Gemini 1st stage discharge pressure	237 psi	Lo 180: Hi 300
Gemini 1st stage discharge temperature	300ºF	N/A
Gemini 2nd stage suction temperature	120ºF	@
Gemini 2nd stage discharge pressure	593 psi	Lo 500: Hi 600
Gemini 2nd stage discharge temperature	249ºF	N/A
Gemini 3rd stage suction temperature	120ºF	@
Gemini 3rd stage discharge pressure	1674 psi	Lo 1550: Hi 1800
Gemini 3rd stage discharge temperature	266ºF	N/A
Gemini 4th stage suction temperature	120ºF	@
Gemini 4th stage discharge pressure	5069 psi	@
Gemini 4th stage discharge temperature	277ºF	N/A
CNG compressor discharge temperature	120ºF	@
CNG compressor discharge pressure	5000 psi	@

A Hy-Bon model AC-8DB boost compressor (Figure 3.1), as described in Table 3.2, was added to the design. The natural gas was routed through this compressor before it was sent to the Gemini (Figure 3.2). The purpose of the Hy-Bon was to raise the pressure of the gas at the inlet of the Gemini with the hope of optimizing Gemini's performance. The Hy-Bon is capable of compressing natural gas to 60 psi. The necessity of the Hy-Bon unit is now being questioned, and tests are underway to determine if the unit adds any benefit to the system.

Figure 3.1. Hy-Bon - CNG boost compressor.

Table 3.2. Hy-Bon boost compressor operating conditions.

Hy-Bon	Normal
Booster suction pressure	30 psi
Booster discharge pressure	55 psi

After the natural gas is compressed, it is once again filtered in preparation for storage (Figure 3.3) and dispensing. The compressed gas is stored at three pressures (low, medium, and high), which allows the dispensing pressure to be more closely matched to the receiving pressure, avoiding the thermodynamic losses associated with excessive gas throttling. After filtration, the natural gas control system (see Section 3.11) directs the gas to either the low-pressure vessel (see Section 3.3), the medium-pressure vessel (see Section 3.4), or the high-pressure vessel (see Section 3.5), depending on which vessel requires filling. Solenoid valves (Section 3.9) control the flow of gas to each vessel.

Under normal operations, CNG is not released into the surrounding area. The entire system is completely sealed to prevent human contact with natural gas. In the event of a CNG leak, combustible detectors will signal an alarm and isolate the entire system by automatically shutting down (see Section 3.8) the power to the operating equipment (control power, monitoring systems, and communication system remain energized).

All venting of natural gas is piped to the vent stack (separate vent stack than for hydrogen). The vent stack releases natural gas above the roofline of the plant.

Figure 3.2. Gemini - main CNG compressor.

3.3 Low-Pressure Storage

The low-pressure storage system consists of three pressure tanks, each 20 feet long, at 3600 psi. Each tank has a capacity of 11,079 scf, or 262 gallons. The tanks were manufactured under the 1989 ASME code, Section VIII, Division 1, Addendum 1990, Appendix 22 (SF3). Form UA-1, certifying compliance with the ASME Code, is presented in Appendix B (serial numbers 42301, 42302 and 42303). The maximum allowable pressure is 4,000 psi at 200ºF. Each tank is equipped with an ASME safety relief valve, set at 4,000 psi, piped to the CNG vent stack. The tank is equipped with a manual drain at its low point to drain off any oil or moisture that may be in the CNG.

Figure 3.3. CNG storage tanks. The top tank is the high-pressure tank and the two lower tanks are the medium-pressure tanks in the near rack. The three low-pressure tanks are in the far rack.

3.4 Medium-Pressure Storage

The medium-pressure storage system consists of two pressure tanks, each 11 feet long, at 4,500 psi. The tanks have a capacity of 5,711 scf, or 120 gallons. They were manufactured under 1992 ASME code, Section VIII, Division 1, Appendix 22 (SF3). Form UA-1, certifying compliance with the ASME Code, is presented in Appendix B (serial numbers 43390 and 43400). Maximum allowable pressure is 5,500 psi at 200ºF. Each tank is equipped with a safety relief valve, set at 5,500 psi, piped to the vent stack. The tank is equipped with a manual drain at its low point to drain off any oil or moisture that may be in the CNG.

3.5 High-Pressure Storage

The high-pressure storage system consists of a single pressure tank, 11 feet long, at 5,000 psi. The tank has a capacity of 5,711 scf, or 120 gallons. It was manufactured under 1992 ASME code, Section VIII, Division 1, Appendix 22 (SF3). Form UA-1, certifying compliance with the ASME Code, is presented in Appendix B (serial number 43401). The tank's maximum allowable pressure is 5,500 psi at 200ºF. It is equipped with a safety relief valve, set at 5,500 psi, piped to the vent stack. The tank is equipped with a manual drain at its low point to drain off any oil or moisture that may be in the CNG.

3.6 Storage Filling

Each pressure tank in the CNG storage system is equipped with air-actuated solenoid valves (see Section 3.9). Under normal operation, these valves are open. The valves close in the event of failure of the instrument air system. When the air-actuated solenoid valves are closed, no gas can flow into or out of the pressure vessels. The valves will also close if the EMS is activated.

The natural gas can be dispensed to the storage vessels in one of two ways: hand mode or automatic mode. Each mode is controlled by an FW Murphy Mark III control system.

3.6.1 Hand Control

The high-pressure tank is filled first. The control system opens the high-pressure-tank air-operated valve (AOV) if the pressure is below 5,000 psi. The AOV directing the high-pressure tank closes when the pressure reaches 5,200 psi. The safety valves for the high-pressure vessels are set at 5,500 psi.

Upon closure of the high-pressure AOV, the medium-pressure tank AOV opens. Once the medium-pressure tank reaches 4,700 psi, the low-pressure AOV opens, and the medium-pressure tank AOV closes. Safety valves for the medium-pressure vessels are set at 5,500 psi.

Upon closure of the medium-pressure AOV, the low-pressure tank AOV opens. The low-pressure AOV remains open until the storage pressure reaches 3,800 psi. At this pressure, the AOV closes, and the Gemini shuts down. Safety valves for the low-pressure vessels are set at 4,000 psi.

3.6.2 Automatic Control

If the high-pressure tank is below 4,000 psi (fill pressure point), no other tank will be filled. At 4,000 psi, the compressor starts. Once the start sequence is complete, the AOV opens, permitting flow of the compressed gas into the high-pressure storage vessel. Once the pressure reaches 5,200 psi, the medium-pressure tank AOV opens, permitting filling of the medium-pressure storage. When the medium-pressure tank reaches 4,700 psi, the medium-pressure AOV closes, and the low-pressure AOV opens, permitting filling of the low-pressure vessels. When the low-pressure vessels reach 3,800 psi, FV 2 closes, and the compressor returns to standby.

If the medium-pressure tank reaches 3,600 psi and the high-pressure storage has not reached 4,000 psi, then the compressor auto start sequence will begin. Once the sequence is complete, the medium-pressure AOV opens, permitting filling of the medium-pressure tank. Once the medium-pressure tank reaches 4,700 psi, the medium-pressure AOV closes, and the high-pressure AOV opens, permitting filling of the high-pressure vessel. Once the high-pressure tank reaches 5,200 psi, the high-pressure AOV closes, and the low-pressure AOV opens, permitting filling of the low-pressure vessels. Once the low-pressure tanks reach 3800 psi, the low-pressure AOV closes, and the compressor shuts down and returns to standby.

If the low-pressure tank reaches 2,800 psi and the medium-pressure tank has not reached 3,600 psi, and the high pressure tank has not reached 4000 psi, then the compressor auto start will begin. Once the start sequence is complete, the low-pressure AOV opens, permitting filling of the low-pressure vessels. Once the low-pressure vessels have reached 3,800 psi, the low-pressure AOV closes, and the medium-pressure AOV opens, permitting filling of the medium-pressure tank. Once the medium-pressure tank has reached 4,700 psi, the medium-pressure AOV closes and the high-pressure AOV opens, permitting filling of the high-pressure vessel. Once the high-pressure vessel has reached 5,200 psi, the high-pressure AOV closes, and the compressor shuts down and returns to standby.

3.7 Fuel Dispensing

There are two dual-output dispensers, manufactured by Fueling Technologies, Inc., at the Arizona Public Service Alternative Fuel Pilot Plant. One unit dispenses CNG only, at each output. CNG can be dispensed from the low-, medium-, or high-pressure storage tanks or directly from the Gemini. The other unit has a hydrogen output and a CNG/hydrogen blend output. The dispensers are more fully described in Section 4 of this report.

3.8 Emergency Shutdown System

The CNG compression/storage system is equipped with pressure transducers, on each compressor stage, that detect low pressures within the system, which could indicate a gas leak. If the pressure drops within a stage to the low pressure shown in Table G-1 of Appendix G, the system will automatically shut down. In addition, natural gas detectors have been installed that will signal the system to shut down if the natural gas present in the air reaches 2%.

The EMS offers both manual and automatic methods of safely and rapidly shutting down the operation of the CNG system and CNG dispensing in the case of an event that could cause harm.

3.8.1 Emergency Shutdown System Initiation

- Manual push buttons (5)
  - East side of the fueling island
  - West side of the fueling island
  - East access door to the equipment building
  - South access door to the equipment building
  - East side access door to the auxiliary room
- Methane Gas detectors (9); 50% lower flammability limit is detected by any one detector
- Flame detectors (6); UV/IR radiation is detected by any one of the detectors
- Sprinkler system, flow activated

3.8.2 Emergency Shutdown System Automatic Actuations

- Emergency horn activation
- Emergency Light Activation
- CNG low-pressure storage tank isolation
- CNG medium-pressure storage tank isolation
- CNG high-pressure storage tank isolation
- Compressor inlet closes
- Fuel maker supply closes
- Compressor blow down opens
- Buffer tank blow down opens
- Dispenser 1 inlet valve closes
- Dispenser 2 inlet valve closes
- Dispenser 1 LP, MP, HP tank supply closes
- Dispenser 2 LP, MP HP tank supply closes
- Breaker for compressor opens
- Breaker for instrument air compressor opens
- Breaker for blower opens
- Breaker for dispenser 1 opens

- Breaker for dispenser 2 opens
- Breaker for equipment building lighting opens

3.9 CNG System Valves

Appendix A, Figure A-5, presents the CNG system piping and instrumentation diagram. Table 3.3 describes the CNG system safety relief valves. Table 3.4 describes the CNG air-operated solenoid valves and control valves. Table 3.5 describes the manual valves.

Table 3.3. CNG system safety relief valves.

Tag No.	Description	Location
SRV 5	Safety Hy-Bon outlet	Hy-Bon compressor
SRV 10	Safety buffer tank	Set at 250 psi
SRV 11	Safety Gemini compressor 1^{st} stage	Set at 500 psi
SRV 12	Safety Gemini compressor 2^{nd} stage	Set at 1000 psi
SRV 13	Safety Gemini compressor 3^{rd} stage	Set at 2200 psi
SRV 14	Safety Gemini compressor 4^{th} stage	Set at 5500 psi
SRV 15	Mercer, 0.75-in. inlet, 1-in. outlet, set at 4000 psi	Low-pressure storage
SRV 16	Mercer, 0.75-in. inlet, 1-in. outlet, set at 4000 psi	Low-pressure storage
SRV 17	Mercer, 0.75-in. inlet, 1-in. outlet, set at 4000 psi	Low-pressure storage
SRV 18	Mercer, 0.75-in. inlet, 1-in. outlet, set at 4000 psi	Medium-pressure storage
SRV 19	Mercer, 0.75-in. inlet, 1-in. outlet, set at 4000 psi	Medium-pressure storage
SRV 20	Mercer, 0.75-in. inlet, 1-in. outlet, set at 4000 psi	High-pressure storage

Table 3.4. CNG system solenoid valves and control valves.

Tag Number	Description	Location
SV-11	Swagelok 1-in. CFM3, 2200 psi	SWG supply to FM
SV-12	Swagelok, SS68TF32-35C	Inlet Gemini Comp
SV-13	Nutron/Hytork-70	Startup diverting, Gemini
SV-14	Nutron/Hytork-70	Startup diverting, Gemini
SV 20	Swagelok, 0.5-in. CF8M	Direct vehicle fill, Desp 1
SV 21	Swagelok, 0.5-in CF8M	LP Vessel inlet, Panel 1
SV 22	Swagelok, 0.5-in CF8M	MP Vessel inlet, Panel 1
SV 23	Swagelok, 0.5-in CF8M	HP Vessel inlet, Panel 1
SV 24	Nutron, 0.5-in 6000 psi WOG	No. 1 dispenser LPS, Panel 1
SV 25	Nutron, 0.5-in 6000 psi WOG	No. 1 dispenser MPS, Panel 1
SV 26	Nutron, 0.5-in 6000 psi WOG	No. 1 dispenser HPS, Panel 1
SV 27	Parker, 0.5-in 8Z(A)-B8L-T-SS PCTFE 6000 psi	No. 2 dispenser LPS, Panel 2
SV 28	Parker, 0.5-in 8Z(A)-B8L-T-SS PCTFE 6000 psi	No. 2 dispenser MPS, Panel 2
SV 29	Parker, 0.5-in 8Z(A)-B8L-T-SS PCTFE 6000 psi	No. 2 dispenser HPS, Panel 2
SV 30	Parker, 0.5-in 8Z (A)-B8L-T-SS PCTFE 6000 psi	No. 3 dispenser LPS, Panel 2
SV 31	Parker, 0.5-in 8Z (A)-B8L-T-SS PCTFE 6000 psi	No. 3 dispenser MPS, Panel 2
SV 32	Parker, 0.5-in 8Z (A)-B8L-T-SS PCTFE 6000 psi	No. 3 dispenser HPS, Panel 2
SV 33	Habonim, 0.5-in body: F318L ball, class 5000	No. 1 dispenser trip, FTI
SV 34	Habonim, 0.5-in body: F318L ball, class 5000	No. 2 dispenser trip, FTI
SV 35	Habonim, 0.5-in body: F318L ball, class 5000	No. 3 dispenser trip, FTI
SV 40	Swagelok,	LPS Isolation trip
SV 41	Swagelok,	LPS Isolation trip
SV 42	Swagelok,	LPS Isolation trip
SV 43	Swagelok,	MPS Isolation trip
SV 44	Swagelok,	MPS Isolation trip
SV 45	Swagelok,	HPS Isolation trip
PCV 10	Gemini compressor suction	Set 55 psi at 70ºF
CV 10	Check valve	Blower discharge
CV 11	Check valve	N2 compressor discharge
CV 35	Parker, 0.5-in 8Z(A) C8L-1BN-SS	Panel 2
CV 36	Parker, 0.5-in 8Z(A) C8L-1BN-SS	Panel 2
CV 37	Parker, 0.5-in 8Z(A) C8L-1BN-SS	Panel 2
CV 38	Parker, 0.5-in 8Z(A) C8L-1BN-SS	Panel 2
CV 39	Parker, 0.5-in 8Z(A) C8L-1BN-SS	Panel 2
CV 40	Parker, 0.5-in 8Z(A) C8L-1BN-SS	Panel 2

Table 3.5. Manual valves.

Tag No.	Description	Location
V 1	Jomar 2-in. T-100 N ball valve-brass, 150 psi	SWG supply
V 10	Jomar 2-in. T-100 N ball valve brass, 150 psi	SWG supply to F10
V 11	Jomar 3-in. T-100 N ball valve-brass, 150 psi	SWG supply to F11
V 12	Jomar 3-in. T-100 N ball valve-brass, 150 psi	SWG supply to F12
V 13	Jomar 3-in. T-100 N ball valve-brass, 150 psi	Isolation for F11
V 14	Jomar 3-in. T-100 N ball valve-brass, 150 psi	Isolation for F12
V 15	Jomar 2-in. T-100 N ball valve-brass, 150 psi	Isolation for F10
V 16	Jomar 2-in. T-100 N ball valve-brass, 150 psi	By-pass for F10
V17	Jomar 1-in. T-100 N ball valve-brass, 150 psi	Booster supply to FM
V17A	Jomar 1-in. T-100 N ball valve-brass, 150 psi	Isolation for PVC
V17B	Jomar 1-in. T-100 N ball valve-brass, 150 psi	Isolation for PVC
V 18A	Jomar 2-in. T-100 N ball valve-brass, 500 psi	Isolation
V 19	Swagelok 0.75-in. SS-12-NBS12, 6000 psi	CF 14 isolation, disch hrdr
V 20	Swagelok 0.75-in. SS-12-NBS12, 6000 psi	CF 14 isolation, disch hrdr
V 20A	Parker 0.5-in. 8Z(A)-B8LJ2-SSP-PCTFE, 6000 psi	Disch hrdr iso., and test point
V 20B	Swagelok 0.5-in. SS 1KS8 SC11, 5000 psi	Disch hrdr N2 purge
V 21	Parker 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	CF 15 and 16 isolation
V 21 A	Parker 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	CF 15 BD
V 21B	Parker 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	CF 16 DB
V 22	Swagelok 0.5-in. SS 83KS8-PCTFE, 6000 psi	CF 15 and 16 isolation
V 23	Parker 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	CF 17 and 18 isolation
V 23A	Parker 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	CF 17 BD
V 23B	Parker 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	CF 18 BD
V 24	Swagelok 0.5-in. SS 83KS8-PCTFE, 6000 psi	CF 17 and 18 isolation
V 25	Parker, 0.5-in. IDBT	Isolation, supply to panel 1
V 26	Parker, 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	Isolation, LPS
V 27	Parker, 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	Isolation, LPS
V 28	Parker, 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	Isolation, LPS
V 29	Parker, 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	Isolation, MPS
V 30	Parker, 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	Isolation, MPS
V 31	Parker, 0.5-in. 8Z(A)-B8LJ-SSP-PCTFE, 6000 psi	Isolation, HPS
V 32	Not used	
V 33	Not used	
V 34	Not used	
V 35	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2
V 36	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2
V 37	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2
V 38	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2
V 39	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2
V 40	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2
V 41	Parker, 0.5-in. IDBF	Panel 1

V 42	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2, supply to disp 2
V 43	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Isolation F 19 and F 20
V 43A	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F 19 BD
V 43B	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F20 BD
V 44	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Isolation F 19 and F 20
V 45	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Isolation F 21 and F 22
V 45A	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F21 BD
V 45B	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F 22 BD
V 46	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Isolation F 21 and F 22
V 47	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Panel 2, supply to disp 3
V 48	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Isolation F23, F24, and F25
V 48A	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F 23 BD
V 48B	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F 24 BD
V 48C	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	F 25 BD
V 49	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Isolation F
V 50	Habonim, 0.5-in. body: F318L ball, class: 5000	FTI, dispenser 1 isolation
V 51	Habonim, 0.5-in. body: F318L ball, class: 5000	FTI, dispenser 2 isolation
V 52		FTI, dispenser 3 isolation
V 53	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Low-pressure storage drain
V 54	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Low-pressure storage drain
V 55	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Low-pressure storage drain
V 56	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Medium-pressure storage drain
V 57	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	Medium-pressure storage drain
V 58	Parker, 0.5-in. 8Z(A) B8LJ-SSP-PCTFE, 6000 psi	High-pressure storage drain
V 60	Nutron, 0.75-in. ball	Low-pressure storage SRV isolation
V 61	Nutron, 0.75-in. ball	Low-pressure storage SRV isolation
V 62	Nutron, 0.75-in. ball	Low-pressure storage SRV isolation
V 63	Nutron, 0.75-in. ball	Medium-pressure storage SRV isolation
V-64	Nutron, 0.75-in. ball	Medium-pressure storage SRV isolation
V 65	Nutron, 0.75-in. ball	High-pressure storage SRV isolation
PCV 10	Gemini compressor suction	Set 55 psi at 70ºF
CV 10	Check valve	Blower discharge
CV 11	Check valve	N2 compressor discharge
CV 35	Parker, 0.5-in. 8Z(A) C8L-1BN-SS	Panel 2
CV 36	Parker, 0.5-in. 8Z(A) C8L-1BN-SS	Panel 2
CV 37	Parker, 0.5-in. 8Z(A) C8L-1BN-SS	Panel 2
CV 38	Parker, 0.5-in. 8Z(A) C8L-1BN-SS	Panel 2
CV 39	Parker, 0.5-in. 8Z(A) C8L-1BN-SS	Panel 2
CV 40	Parker, 0.5-in. 8Z(A) C8L-1BN-SS	Panel 2

3.10 Compressed Natural Gas System Filters

Filters in the CNG system remove particulate matter and water. They are positioned as noted in Table 3.6.

Table 3.6. Compressed natural gas system filters

Tag No.	Description	Process Fluid
F 10	Filter Inc., Model V-1422W, MAWP 50 psi	SWG supply
F 11	Parker Model HF3-801, element 60US1-280, MAWP 185 psi at 225°F	SWG supply
F 12	Parker Model HF3-801, element 60US1-280, MAWP 185 psi at 225°F	SWG supply
F 5	Hy-Bon	Booster compressor
F 13	Coalescence filter	Gemini Comp discharge
F 14	Coalescing filter	Gemini Comp discharge
F 15, 16 F 17,18	Parker, P/N: J4NF-10CWC15-070B, element 4CWC15-070, MAWP 5000 psi at 350°F	Compressor discharge header
F 19, 20 F 21, 22 F 23, 24, 25	Parker, P/N: J2SD-10CWC11-035, element 10CWC11-035B, MAWP 5000 psi at 350°F	Dispenser 1 CNG supply Dispenser 2 CNG supply Dispenser 3 CNG supply
F 26	FTI, P/N: S71, MAWP 5000 psi at 275°F	Dispenser 1
F 27	FTI, P/N: S71, MAWP, 5000 psi at 275°F	Dispenser 2

3.11 Control and Instrumentation

CNG system operation is controlled by the FW Murphy Mark III control system. The Murphy system provides system shutdown as shown in Table 3.7.

Table 3.7. Shutdown display messages.

Class	Shut Down/Alarm	Description
B	Shut down	Low suction pressure
A	Shut down	High suction pressure
P	Shut down	Low discharge 1 pressure
A	Shut down	High discharge 1 pressure
P	Shut down	Low discharge 2 pressure
A	Shut down	High discharge 2 pressure
P	Shut down	Low discharge 3 pressure
A	Shut down	High discharge 3 pressure
S	Shut down	Run signal failure
A	Shut down	Plant emergency shutdown system
A	Shut down	Common short cycle SD

The Murphy control system provides cascade control of CNG system storage based on the control parameters shown in Table 3.8 and 3.9 (Program 50-34-2101, Rev. C).

Table 3.8. Murphy Mark III settings; access code 61.

Point ID	Description	Setting (psi)	Actual (psi)	Default (psi)	Range (psi)
P-0	Circle to exit	—	—	—	—
P-1	Line 1 selection	—	—	—	—
P-2	Last shutdown	—	—	—	—
P-3	Stop pressure	5500		3600	-100 – 5000
P-4	LP tank fill pressure	2600		2700	-100 – 5000
P-5	LP tank full pressure	3800	3800	3000	-100 – 5000
P-6	MP tank fill pressure	3900	3900	2900	-100 – 5000
P-7	MP tank full pressure	4700		3200	-100 – 5000
P-8	HP tank fill pressure	4500		3100	-100 – 5000
P-9	HP tank full pressure	5200		3400	-100 – 5000
P-10	Veh 1 max pressure	NA		3000	3000/ 3600
P-11	Veh 2 max pressure	NA		3000	3000/ 3600
P-12	Slow fill max pressure	3600		3000	3000/ 3600
P-13	Slow fill min pressure	300		300	0 – 5000
P-14	Low inlet pressure	45		5	-100 – 5000
P-15	High inlet pressure	75		20	-100 – 5000
P-16	Low discharge pressure stage 1	180		-3	-100 – 5000
P-17	High discharge pressure stage 1	300		150	-100 – 5000
P-18	Low discharge pressure stage 2	500		-3	-100 – 5000
P-19	High discharge pressure stage 2	600		750	-100 – 5000
P-20	Low discharge pressure stage 3	1550		-3	-100 – 5000
P-21	High discharge pressure stage 3	1800		1750	-100 – 5000
P-22	Activity delay	5		5	0 – 3600
P-23	Motor start delay	2		2	0 - 3600
P-24	Motor stop delay	0		0	0 – 3600
P-25	Prelube/accum	30		30	0 – 999
P-26	Lockout delay	15		15	0 – 999
P-27	Idle lockout delay	30		30	0 – 999
P-29	Low Vehicle flow delay	10		10	0 – 60
P-30	Veh stop delay	10		10	0 – 60
P-32	Power up delay	30		60	0 – 300
P-33	Blow down on start	20		20	1 – 30
P-34	Blow down during delay	5		5	1 – 20
P-35	Blow down interval delay	3600		2700	1 – 3600
P-36	Blow down after stop delay	10		10	5 – 30
P-37	Close inlet after stop	5		5	1 – 30
P-38	Common short cycle	8		5	1 – 20
P-28	Vehicle minimum flow rate	125		125	0 – 1000 SCFM
P-31	Vehicle stop flow rate	100		100	0 – 1000 SCFM

Table 3.9. Settings for Murphy Mark III, access code 64.

S No.	Description	Setting	Default	Range
S-0	Circle to exit	—	—	—
S-1	Line 1 selection	—	—	—
S-2	Set time (minutes)	—	—	—
S-3	Set time (hours)	—	—	—
S-4	Set date (day)	—	—	—
S-5	Set date (month)	—	—	—
S-6	Set date (year)	—	—	—
S-7	Set day of week	—	—	—
S-8	Reset 1K hours	—	—	—
S-9	Reset hours	—	—	—
S-10	Inlet pressure maximum	75	300	0–1000 psi
S-11	Inlet pressure offset	0	0	-100–1000 psi
S-12	Discharge 1 pressure maximum	300	500	0–6000 psi
S-13	Discharge 1 pressure offset	0	0	-100–6000 psi
S-14	Discharge 2 pressure maximum	600	1000	0–6000 psi
S-15	Discharge 2 pressure offset	0	0	-100–6000 psi
S-16	Discharge 3 pressure maximum	1800	2000	0–6000 psi
S-17	Discharge 3 pressure offset	0	0	-100–6000 psi
S-18	Slow fill pressure maximum	4000	5000	0–6000 psi
S-19	Slow fill pressure offset	0	0	-100–6000 psi
S-20	Low tank pressure maximum	3600	5000	0–6000 psi
S-21	Low tank pressure offset	0	0	-100–6000 psi
S-22	Medium tank pressure maximum	4500	5000	0–6000 psi
S-23	Medium tank pressure offset	0	0	-100–6000 psi
S-24	High-pressure tank pressure maximum	5000	5000	0–6000 psi
S-25	High-pressure pressure offset	0	0	-100–6000 psi
S-26	NA – Veh 1 pressure max	---	5000	0–6000 psi
S-27	NA – Veh 1 pressure offset	---	0	-100–6000 psi
S-28	NA – Veh 1 flow maximum	---	800	0–2000 SCFM
S-29	NA – Veh 1 flow offset	---	0	-100–2000 SCFM
S-30	NA – Veh 2 pressure maximum	---	5000	0–6000 psi
S-31	NA – Veh 2 pressure offset	---	0	-100–6000 psi
S-32	NA – Veh 2 flow maximum	---	800	0–2000 SCFM
S-33	NA - Veh 2 flow offset	---	0	-100–2000 SCFM
S-34	Ambient temperature maximum	140	170	0–1000 F
S-35	Ambient temperature offset	0	-20	-150–1000 F

The Murphy control system displays system status using front panel display messages, as shown in Table 3.10.

Table 3.10. Murphy control system displays.

Front Display Messages
Program 50-34-2101
CNG Package
{DATE}
{TIME}
INLET: { x PSI}
DSCH 1: { x PSI}
DSCH 2: { x PSI}
DSCH 3: { x PSI}
LO TANK: { x PSI}
MID TANK: { x PSI}
HI TANK: { x PSI}
(TC) SF STOP: {x PSI} (temperature compensated stop pressure)
SLOWFILL: { x SCFM}
(TC) VEH 1 STP: { X PSI} (temperature compensated stop pressure)
VEH 1: { x PSI}
DISP 1 FLW: { x SCFM}
(TC) VEH 2 STP: { x PSI} (temperature compensated stop pressure)
VEH 2: { x PSI)
DISP 2 FLW: { x SCFM}
AMBIENT TMP: { x F}
STATUS = OFF
STANDBY
FAIL
PURGE
START
RUN SIG?
RUNNING
LOADED
STOPPING
(SELECTOR)
SELECTOR – OFF
SELECTOR - HAND
SLECTOR - AUTO
TOT HRS = {x.x HRS}
JP4 2 – 11 OOOO OOOO
JP4 14 – 23 OOOOO OOOOO
JP5 1 – 10 OOOOO OOOOO
JP5 11 – 20 OOOOO OOOOO
JP6 1 – 9 OOOOO OOOO
JP6 10 – 18 OOOOO OOOO
JP7 1 - 7 OOOOO OO
JP7 9 – 15 OOOOO OO

Table 3.11 list the inputs to the Murphy control system.

Table 3.11. CNG System Instrumentation.

Tag No.	Description	Location
PI 12		
PI 13	Ashcroft 2.5 in., 0-60 psi	SWG supply
PI 14		
PI 5	Murphy	Booster compressor
PI 6	Murphy	Booster compressor
PI 17	Ashcroft 4 in., 0–400 psi	Gemini panel, suction pressure
PI 18	Ashcroft, 4 in., 0–400 psi	Gemini panel, 1^{st} stage
PI 19	Ashcroft 4 in., 0–1000 psi	Gemini panel, 2^{nd} stage
PI 20	Ashcroft 4 in., 0–3000 psi	Gemini panel, 3^{rd} stage
PI 21	Ashcroft 4 in., 0–10000 psi	Gemini panel, 4^{th} stage
PI 22	Ashcroft 2.5 in., 0–6000 psi	Panel 1, compressor discharge
PI 23	Ashcroft 2.5 in., 0–6000 psi	Panel 1, tank low-pressure
PI 24	Ashcroft 2.5 in., 0–6000 psi	Panel 1, tank medium-pressure
PI 25	Ashcroft 2.5 in., 0–6000 psi	Panel 1, tank high-pressure
PI 26	Ashcroft 2.5 in., 0–6000 psi	Panel 1, dispenser 1
PI 35		Panel 2, dispenser 2 low-pressure system
PI 36		Panel 2 dispenser 2 medium-pressure system
PI 37		Panel 2, dispenser 2 high-pressure system
PI 38		Panel 2, dispenser 3 low-pressure system
PI 39		Panel 2, dispenser 3 medium-pressure system
PI 40		Panel 2, dispenser 3 high-pressure system
LG 10	Level glass,	Gemini buffer tank
LG 11	Level glass,	
PSL 5	Murphy	Hy-Bon compressor
PSL 6	Murphy	Hy-Bon compressor
PT 10	Press. Xmitter,	1^{st} stage Gemini, Murphy
PT 11	Press. Xmitter	2^{nd} stage Gemini, Murphy
PT 12	Press. Xmitter	3^{rd} stage Gemini, Murphy
PT 13	Press. Xmitter	4^{th} stage Gemini, Murphy
PT 14	Press Xmitter	LP Storage, Murphy
PT 15	Press Xmitter	MP Storage, Murphy
PT 16	Press Xmitter	HP Storage, Murphy
PS 14	Pressure switch, lube oil	Gemini compressor
VS 10	Vibration switch	Gemini compressor
TI 5		Hy-Bon compressor
TI 6	Murphy	Hy-Bon compressor
TCV 6	Murphy	Hy-Bon compressor
TI 7		Hy-Bon
TS 10	Temperature switch	Gemini compressor
TS 11	Temperature switch	Gemini compressor
TS 12	Temperature switch	Gemini compressor
TS 13	Temperature switch	Gemini compressor

4. FUEL DISPENSING

The APS Alternative Fuel Pilot Plant is located within the boundaries of the APS service yard, located at 501 South 2nd Avenue, in Phoenix, Arizona. Fuel is dispensed at the (APS) 501 facility in support of its operating fleet of light- and heavy-duty trucks performing electrical system maintenance and meter reading for APS. The liquid and electric fueling infrastructure was already in place at the 501 facility (described in Sections 4.1.1 and 4.1.2) before the gaseous refueling infrastructure was constructed (described in Section 4.1.3).

4.1 Refueling Equipment at the 501 Facility

4.1.1 Existing Liquid Refueling Systems

The previously existing petroleum vehicle refueling system is aboveground and dispenses both unleaded gasoline and diesel fuels. It has existed for several years and replaced belowground tanks. It has one 2,000-gallon aboveground gasoline storage tank and one 2,000-gallon aboveground diesel tank. The petroleum refueling equipment is centrally located in the southern parking area, which also serves as an assembly area at the start and at the end of the day shift. No vapor recovery system has been installed on the tank or on dispenser hoses. Tank vent stacks are protected to prevent blockage by insects or birds and from entry of foreign objects. The tanks are free to vent to the atmosphere. A spill prevention dike is installed, but no bollards exist to protect the tanks from vehicle intrusion (hazard exists because maneuvering space in the area for large vehicle operation is limited). The physical and open-air distance between the tanks is 66 inches. No fire containment or barrier wall exists between the tanks. No fire detection equipment or alarms exist on the tank and fuel dispensing systems. And no fire fighting or fogging systems are installed. Flammable material is stored within the fuel dispenser spill containment area (two garbage cans with flammable trash). Hand-held fire extinguishers are mounted on the south outboard canopy post supports, about 21 inches from the longitudinal axis of the tanks. Electrical junction boxes in the fuel dispensing control are not Class 1, explosion proof. There have been no reported safety incidents, fires, or explosions since installation of this system.

4.1.2 Existing Electric Refueling Systems

There is an electric vehicle recharging area (area 401) approximately 400 feet north of the 501 fueling area and north of the meter reader parking area. This area is equipped with the following systems:

- One 150-kW Minit charger (24 to 400 V, 400 amp max., all battery chemistries, non-2293 vehicles)
- One 150-kW Minit charger compatible with 2293 DaimlerChrysler vehicles (model year 1999–2003, 400 amp maximum, all battery chemistries, including NMH)
- One 120-kW Minit charger (24 to 455 V, 500 amp maximum, all battery chemistries, all vehicles, including 2293 DaimlerChrysler),
- One 33-kW SuperCharge (all vehicles except 2293 DaimlerChrysler)
- Four GM Level II inductive chargers
- One SCI Level II conductive charger
- One Avcon Level II conductive charger.

There are hand-held fire extinguishers in the charging area. There are no emissions from this refueling system, and there is no hazardous material in storage. There have been no safety incidents or fires since installation of these systems.

4.1.3 New Gaseous Refueling

A gaseous refueling area has been constructed west of the meter reader parking area and southwest of the electric vehicle refueling area. There is one dispensing island with two dispensers and each dispenser has dual dispenser hoses. One dispenser is dedicated to CNG and it provides CNG at pressures up to 3,600 psi. The other dispenser provides pure hydrogen at pressures up to 5,000 psi via one dispensing hose, and HCNG at pressures up to 3,600 psi via the second dispensing hose. The dispensers are located a minimum of 50 feet from the closest storage vessel. Gas storage uses pressure vessels built to ASME Code (ASME Code - Section VIII, Appendix 22).

Table 4.1 shows the quantities of gaseous fuel storage. These gases are lighter than air and disperse rapidly. Based on mass weight, the gaseous facility is primarily a typical CNG refueling system such as are found in operation at City of Phoenix facilities east and west of the 501-building complex. In the unlikely event of complete release of all of the energy of the combined gases, it would amount to 22% of the energy stored in aboveground gasoline tanks at the 501 complex, and 10% of the combined aboveground petroleum fuel storage at the 501 complex.

Table 4.1. Fuel storage at the 501 facility.

Fuel Type	Volume (gallons)	Capacity (SCF)	Weight (pounds)	Release Potential (kWh)	Emissions (ft^3/day)
Electric	0	0	0	0	0
Hydrogen	6,646	26,340	136.4	2,152	720+
HCNG (70% CNG, 30% H_2)	0	0	0	0	0*+
CNG	1,145	50,370	2,443	14,771	0*+
Diesel	2,000	NA	13,583	75,792	**
Gasoline	2,000	NA	12,018	70,593	**

* Natural gas trapped in the filling hose is vented to the atmosphere after vehicle filling. Since venting occurs after vehicle refueling, no leakage is considered to have occurred.

** APS was granted an exemption for the 501 gasoline and diesel refueling system by the ADEQ in 1995. The aboveground tanks are located within 66 inches of each other; no vapor recovery system is installed on either the fuel tank or the dispenser hose. Spill prevention containment is installed, but no barrier protection exists.

+ Note: The CNG and hydrogen systems may vent on occasion, as part of the safety relief system.

Table 4.2 shows the chemical properties of fuels present at the 501 Complex.

Table 4.2. Fuel properties.

Property	Hydrogen	Methane	Propane	Gasoline	Diesel	Methanol	Acetylene
Density (20ºC, 1 atm)							
lb/ft^3	0.00518	0.0485	0.1168	44.95	50.8	49.4	0.0704
Kg/l	0.000083	0.00078	0.00187	0.72			
Specific gravity							
air = 1.0	0.0696	0.554	1.562	3.90			0.92
water = 1.0				0.733	0.814	0.791	
Diffusion coefficient							
(m/sec)	0.0061	0.0016	0.0012	0.008			
ft/sec	0.0200	0.0052	0.0039	0.026			
Heat energy (weight basis)							
Wh/kg	39,472	15,425	13,891	12,922	12,276	6,332	13,892
BTU/lb	61,095	23,875	21,500	20,000	19,000	9,800	21,502
Heat Energy (volume basis)							
Wh/l	3	10	27	8,890			
BTU/Ft^3	325	1,012	2,524	860		752	1,477
Flammability limits (% volume in air)	4 to 75	5 to 16	2 to 12	1.4 to 7.6		6.7 to 36	2.5 to 81
Optimum air/fuel (% volume in air)	2.38	9.53	23.8	1.76			11.9
Ignition temperature							
º*F*	1,062	1,170	919	536	490-560	725	581
º*C*	572	632	493	280	254-293	385	305
Ignition energy, air							
watt	6×10^{-9}	8×10^{-8}	7×10^{-8}	7×10^{-8}			
BTU	2×10^{-8}	3×10^{-7}	3×10^{-7}	2×10^{-7}			
Flame temperature							
º*F*	3,713	3,416	3,573	4,190		3,460	4,207
º*C*	2,045	1,880	1,967	2,310		1,904	2,319
Flame speed							
ft/sec	9.3	1.5	1.5	1.31			8.8
m/sec	2.83	0.46	0.46	0.40			2.68

Fuel From Water, eighth edition, Michael A. Peavey, Merit Inc., p. 225.
Petroleum Engineers Handbook, 5th edition, McGraw Hill

4.2 Fuel Dispensing System Description

Both hydrogen and CNG vehicular dispensing is performed in the same manner. Fueling Technologies Inc. manufactured the fuel dispensers for each fuel. The hydrogen dispenser is a dual station. One hose dispenses hydrogen into a vehicle with a pressure rating of up to 5,000 psi. The other hose dispenses a hydrogen-enriched CNG at a vehicle pressure rating of up to 3,600 psi.

Each of the dispensers has individual displays. The displays indicate the amount of fuel dispensed in GGE (gasoline gallon equivalent), the total cost for the fuel dispensed, and the unit cost by gallon. The output hose assemblies and the nozzle that connects to the vehicle are coordinated with the type of fuel that is to be dispensed. Thereby, the nozzle from the hydrogen dispenser can be connected only to a vehicle designed for hydrogen, and the nozzle from the CNG dispenser can be connected only to a vehicle designed for CNG.

4.2.1 Hydrogen Dispenser Operation

The hydrogen dispensers have a maximum inlet pressure rating of 5,000 psi. Special nozzle and hose assemblies designed and manufactured by WEH (Germany) provide a mechanical guarantee that CNG vehicles cannot obtain fuel from the hydrogen or HCNG refueling system. In addition to the mechanical incompatibility of fueling nozzles, the system is authorized by an interlocking commercial access system provided by Pickens Fuel. All hose assemblies are also equipped with a breakaway connection at the output of the dispenser housing.

The fuel dispensing system also provides cascade control of the high-pressure storage vessels during refueling. Independent of the fueling control system and emergency shutdown system, excess flow valves in the hydrogen piping to the dispenser protect against pipe and hose failures. If hydrogen flow exceeds a predetermined amount, the flow control will shut off the flow of hydrogen to the dispenser.

4.2.2 CNG Dispenser Operation

The natural gas dispensers have a maximum inlet pressure rating of 5,000 psi, a service pressure rating of 3,600 psi, and a flow rate of 0.5 lb/min. Each hose is equipped with a Shurex, NGV1, Type 1, Class A nozzle. These nozzles are unique and are commonly used for compressed natural gas vehicles. The output assembly combines two hoses in one. One hose is used for the process gas. The other hose is used for venting. The process gas hose is Furon/Synflex, 35NG-06, 3/8-in. ID, with a maximum pressure rating of 5,000 psi. The vent hose is Furon/Synflex, 35NG-03, 3/16-in. ID, with a maximum pressure rating of 5,000 psi, and is considered electrically conductive for CNG. These hoses meet the standard, AGA 1-93. All hose assemblies are also equipped with a breakaway connection at the output of the dispenser housing.

5. LESSIONS LEARNED

During the siting process, detailed design, and construction of the APS Alternative Fuel Pilot Plant, numerous lessons were learned that will improve the performance and reduce the cost of the next generation of fueling stations. These lessons learned are presented in the following sections.

5.1 Codes And Standards

Existing codes for storage of compressed hydrogen gas present significant obstacles to developing commercial hydrogen fueling stations (Appendix H). The definition of indoor facilities and setback distances are two examples of requirements that will make the size of fueling stations using existing design concepts unacceptable for commercial application. These standards have been developed based on years of experience and a significant body of expertise. They represent best-practice requirements to protect the public from the hazards of stored gas. Future designs will require novel concepts to accommodate these standards within the constraints imposed by a commercial fueling station site. Both new designs and analyses will be required to accomplish the requisite objectives.

5.2 Facility Layout

The current state of the art for facility arrangement is represented by industrial gas facilities. These facilities typically use a flat arrangement, where equipment and piping are located at near-ground level. For commercial hydrogen fueling stations, significant reductions in hazards can be achieved by using a three-dimensional layout, including the following design features:

- Elevated or vertical tanks, with penetrations and piping at a level to prevent flame jet impingement on personnel in the event of a high-pressure leak.
- Physical separation of piping associated with different storage vessels to prevent cascading failures resulting from flame jet impingement.

5.3 Piping

The current state of the art for piping design of commercial compressed gas facilities is represented by compressed natural gas fueling stations. The standards used by the natural gas industry were found to be inadequate in the following areas:

- Vents and drains are typically open to the atmosphere in a natural gas design. In a hydrogen fueling station, the vents and drains must be piped to a blowdown tank and vent stack to prevent any gas release in occupied areas of the facility.
- Compression fittings are used extensively in the natural gas industry. These fittings are not adequate to ensure the long-term integrity of high-pressure hydrogen piping. All high-pressure hydrogen piping must be welded and inspected as appropriate to ensure weld integrity.
- Care must be taken to ensure that all pressure boundary components are certified by their manufacturer for hydrogen service at the pressures and temperatures required. Many commonly used fittings and valves advertised for hydrogen use are not certified by their manufacturers for such duty.

5.4 Electrical Grounding

Elimination of static or lighting-induced sparks in a hydrogen fueling station is imperative. Careful attention must be given to equipment grounding and earth grounding of the facility.

5.5 Construction

Construction of a hydrogen fueling station requires the accommodation of several unique processes:

- A significant amount of high-pressure welding is required. Arrangements for qualified welders and machine welding equipment must be made to facilitate construction.
- Piping system cleanliness must be maintained during construction by the use of precleaned tubing and vessels and exercise of due care during construction to maintain cleanliness.
- Hydrostatic pressure testing of completed piping must be accomplished while maintaining cleanliness requirements.

5.6 Fuel Dispensing

Existing fuel dispensers for hydrogen fuel and blends of hydrogen fuel and CNG are not adequate to support commercial hydrogen fueling. Cost reliability and safety must be significantly improved to allow commercial fueling.

6. LIST OF APPENDICES

APPENDIX A – SYSTEM DRAWINGS

APPENDIX B - FORMS AND LISTS

APPENDIX C – GASEOUS HYDROGEN PIPING SPECIFICATION

APPENDIX D - TRAINING PROGRAMS

APPENDIX E – HYDROGEN SYSTEMS OPERATIONS

APPENDIX F – FLAME SCANNERS AND SENSORS

APPENDIX G – COMPRESSED NATURAL GAS SYSTEM OPERATIONS

APPENDIX H – CODES AND STANDARD

APPENDIX A – SYSTEM DRAWINGS

Figure A-1. APS Alternative Fuel Pilot Plant Facility Plan View

Figure A-2. APS Alternative Pilot Plant Production Equipment Plan

Figure A-3. APS Alternative Pilot Plant Production And Control Room Plan View

Figure A-4. APS Alternative Pilot Plant Production Hydrogen System Piping and Instrument Diagram

Figure A-5. APS Alternative Pilot Plant Production CNG System Piping and Instrument Diagram

Figure A-1. APS Alternative Fuel Pilot Plant Facility Plan View

REVISION	0
DATE	4/8/03
JOB NUMBER	C0130
DRAWN BY:	A. TURNER
CHECKED:	S. McCAMMAN

ALTERNATIVE FUELS PILOT PLANT FACILITY

NORTH EAST CORNER OF 2nd AV. & BUCHANAN
APS 501 SOUTH 2nd AV. CAMPUS.
PHOENIX, ARIZONA

PINNACLE WEST CAPITAL CORPORATION

S1

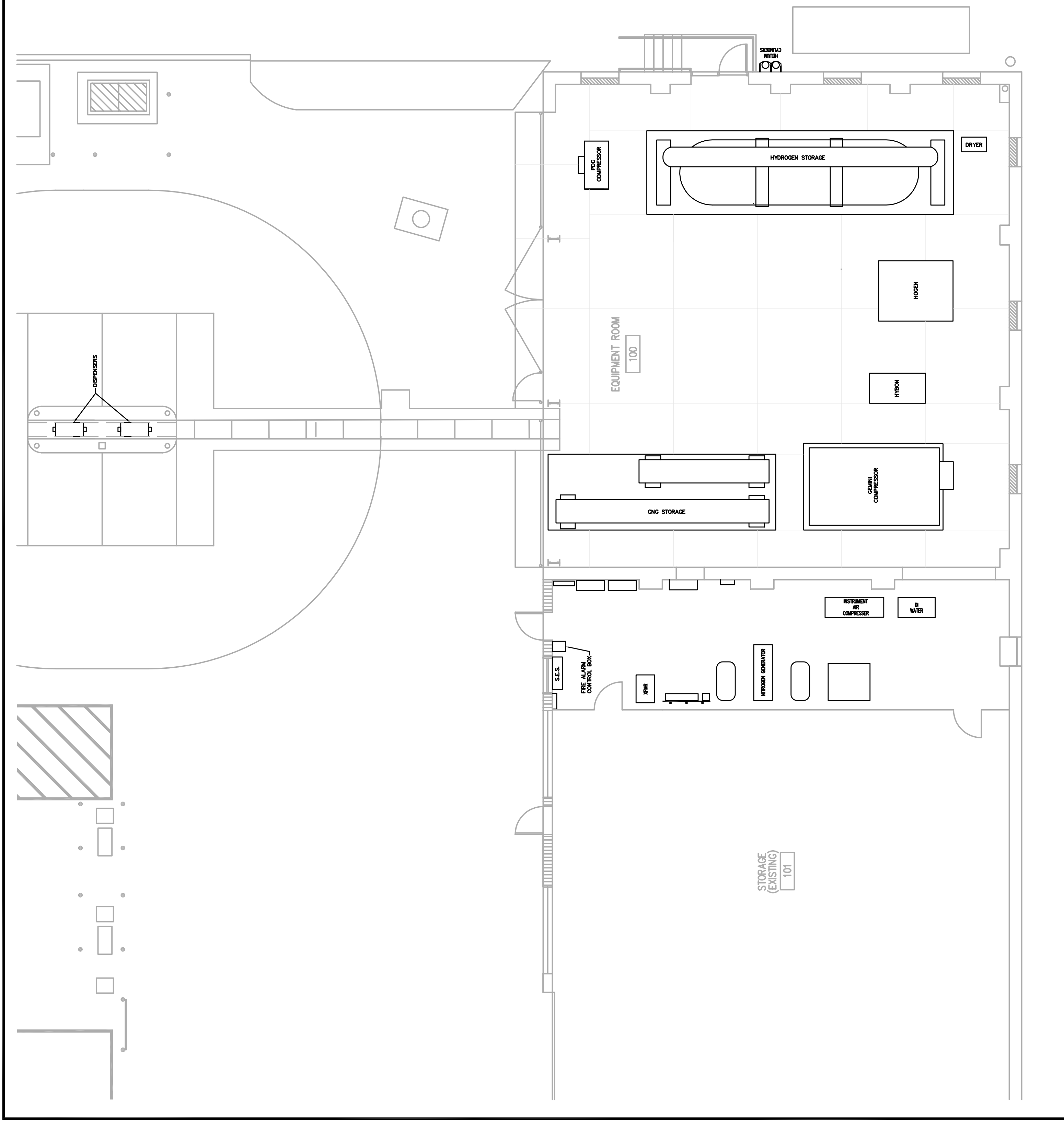


Figure A-2. APS Alternative Pilot Plant Production Equipment Plan

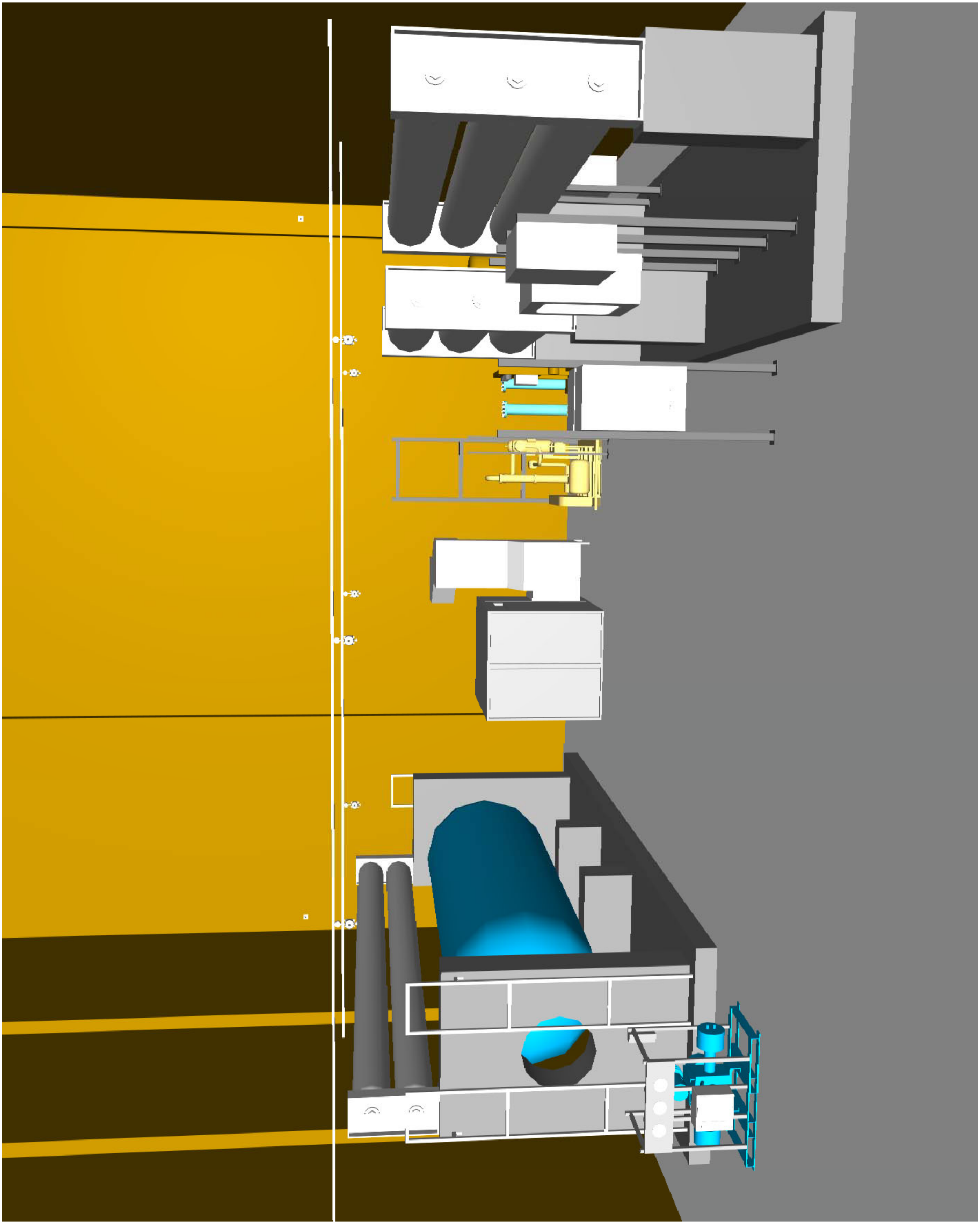
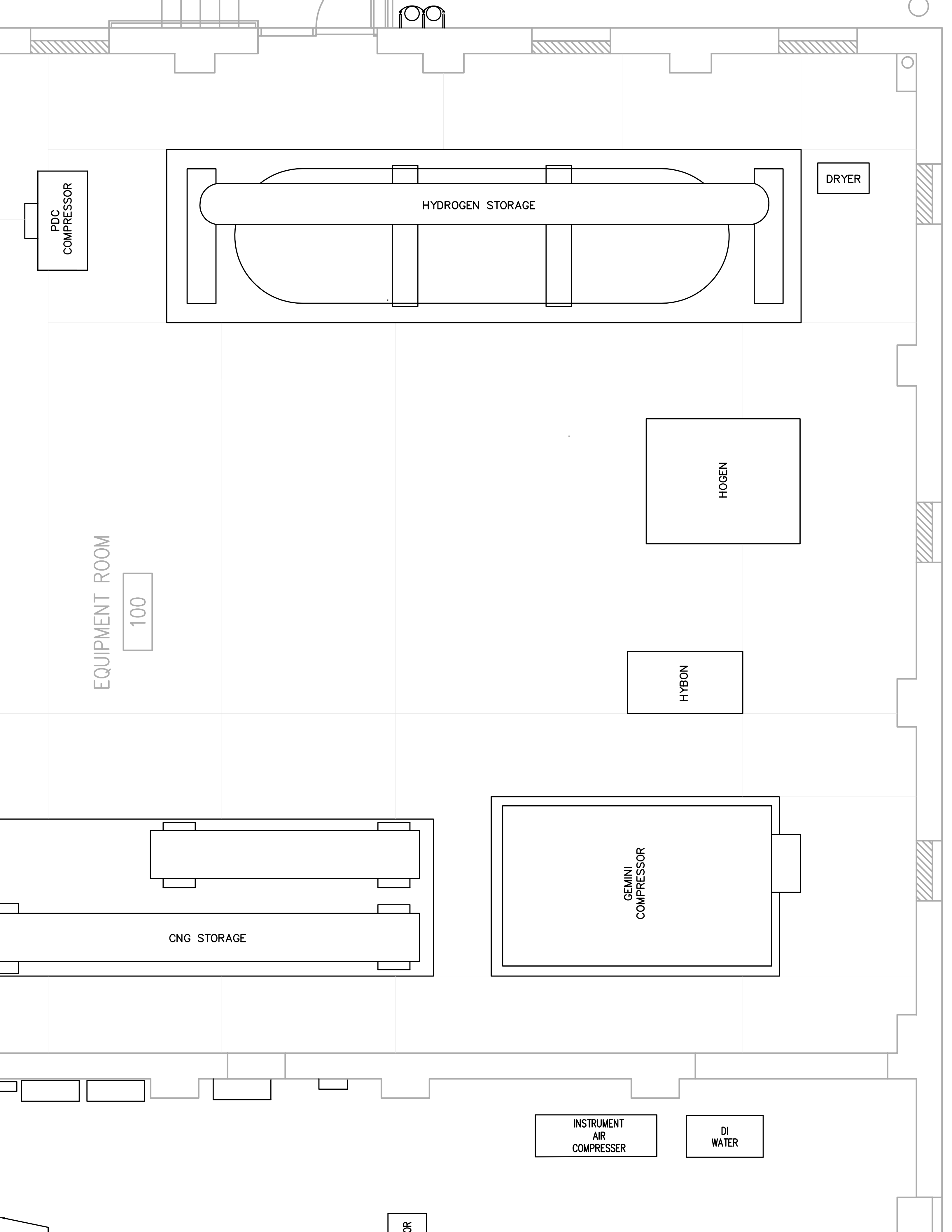
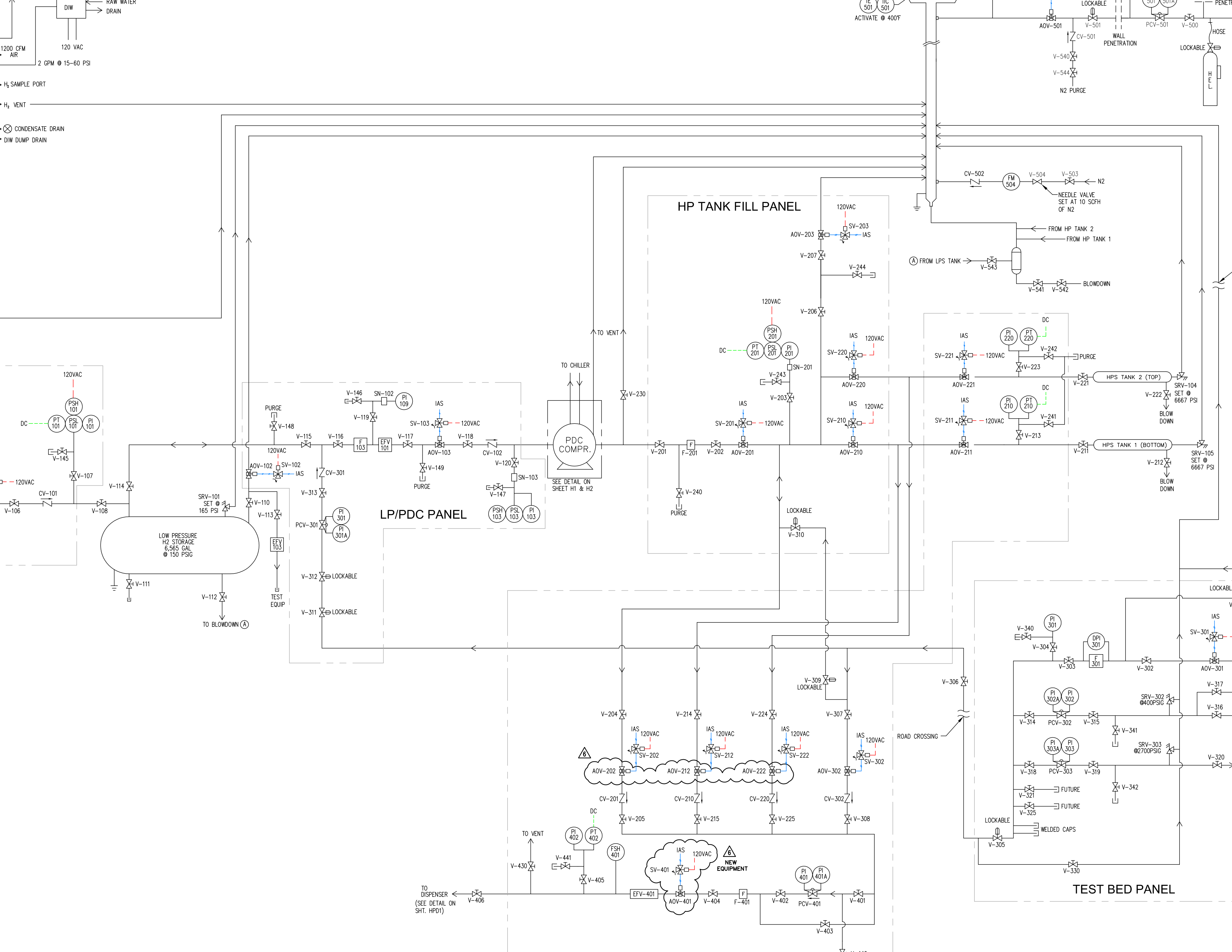


Figure A-3. APS Alternative Pilot Plant Production And Control Room Plan View



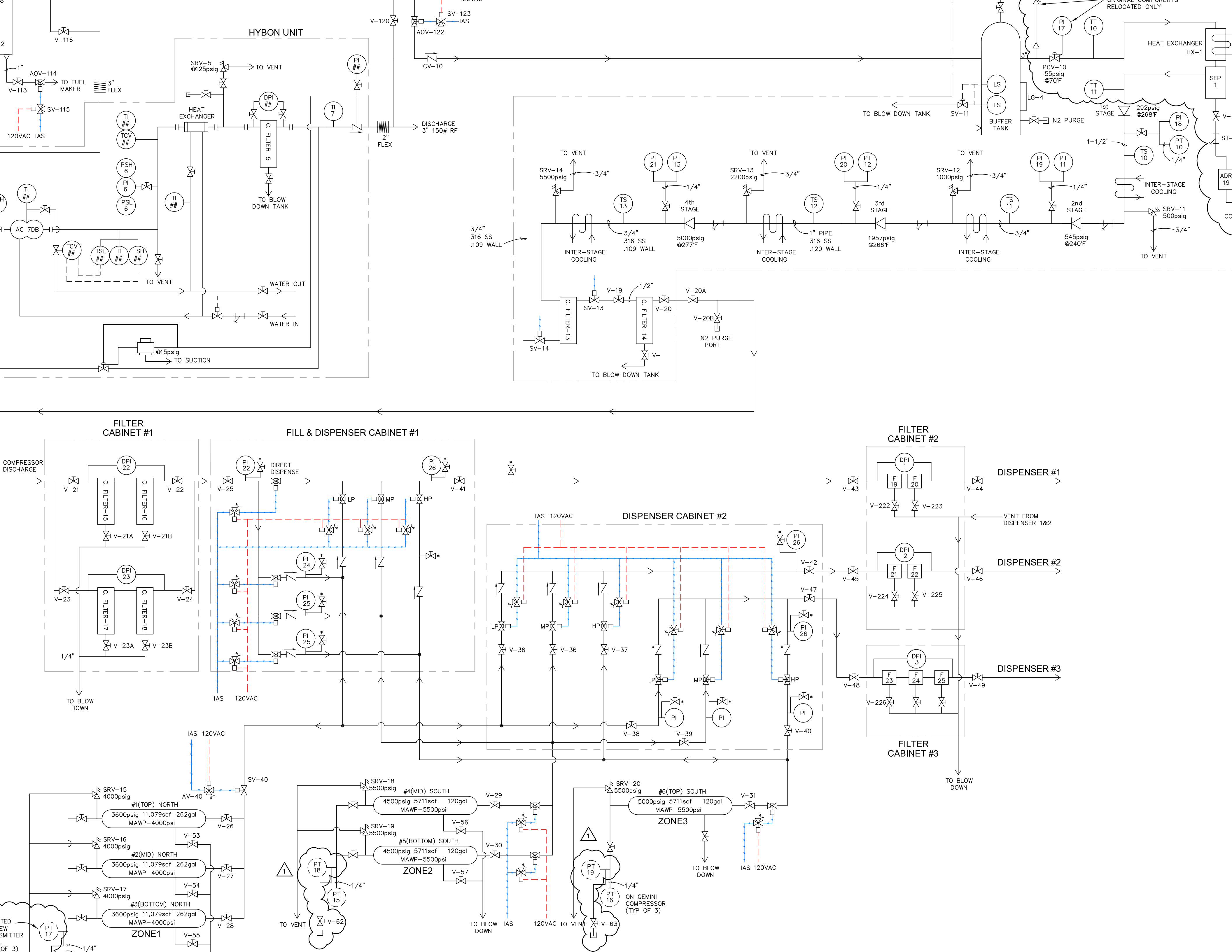
PDC COMPRESSOR
HYDROGEN STORAGE
DRYER
HOGEN
EQUIPMENT ROOM
100
HYBON
CNG STORAGE
GEMINI COMPRESSOR
INSTRUMENT AIR COMPRESSER
DI WATER

Figure A-4. APS Alternative Pilot Plant Production Hydrogen System Piping and Instrument Diagram



HP TANK FILL PANEL
LP/PDC PANEL
TEST BED PANEL
PDC COMPR.
SEE DETAIL ON SHEET H1 & H2
LOW PRESSURE H2 STORAGE 6,565 GAL @ 150 PSIG
HPS TANK 2 (TOP)
HPS TANK 1 (BOTTOM)
SRV-104 SET @ 6667 PSI
SRV-105 SET @ 6667 PSI
SRV-101 SET @ 165 PSI
SRV-302 @400PSIG
SRV-303 @2700PSIG
TO CHILLER
TO VENT
TO BLOWDOWN
FROM LPS TANK
FROM HP TANK 2
FROM HP TANK 1
BLOWDOWN
BLOW DOWN
PURGE
N2 PURGE
NEEDLE VALVE SET AT 10 SCFH OF N2
WALL PENETRATION
ROAD CROSSING
TEST EQUIP
NEW EQUIPMENT
WELDED CAPS
FUTURE
LOCKABLE
TO DISPENSER (SEE DETAIL ON SHT. HPD1)
ACTIVATE @ 400°F
RAW WATER DRAIN
DIW
1200 CFM AIR
120 VAC
2 GPM @ 15-60 PSI
H_2 SAMPLE PORT
H_2 VENT
CONDENSATE DRAIN
DIW DUMP DRAIN
HOSE

Figure A-5. APS Alternative Pilot Plant Production CNG System Piping and Instrument Diagram



HYBON UNIT
HEAT EXCHANGER
C. FILTER-5
TO BLOW DOWN TANK
SRV-5 @125psig
TO VENT
TO FUEL MAKER
AOV-114
V-113
SV-115
120VAC IAS
V-116
3" FLEX
2" FLEX
DISCHARGE 3" 150# RF
AC 7DB
WATER OUT
WATER IN
@15psig
TO SUCTION
V-120
AOV-122
SV-123
IAS
CV-10
BUFFER TANK
LG-4
N2 PURGE
SV-11
TO BLOW DOWN TANK
HEAT EXCHANGER HX-1
SEP 1
PCV-10 55psig @70°F
1st STAGE
292psig @268°F
2nd STAGE
545psig @240°F
3rd STAGE
1957psig @266°F
4th STAGE
5000psig @277°F
INTER-STAGE COOLING
SRV-11 500psig
SRV-12 1000psig
SRV-13 2200psig
SRV-14 5500psig
TO VENT
1" PIPE 316 SS .120 WALL
3/4" 316 SS .109 WALL
C. FILTER-13
C. FILTER-14
SV-13
SV-14
V-19
V-20
V-20A
V-20B
N2 PURGE PORT
FILTER CABINET #1
C. FILTER-15
C. FILTER-16
C. FILTER-17
C. FILTER-18
COMPRESSOR DISCHARGE
TO BLOW DOWN
FILL & DISPENSER CABINET #1
DIRECT DISPENSE
DISPENSER CABINET #2
FILTER CABINET #2
FILTER CABINET #3
DISPENSER #1
DISPENSER #2
DISPENSER #3
VENT FROM DISPENSER 1&2
TO BLOW DOWN
#1(TOP) NORTH
3600psig 11,079scf 262gal
MAWP-4000psi
#2(MID) NORTH
#3(BOTTOM) NORTH
ZONE1
#4(MID) SOUTH
4500psig 5711scf 120gal
MAWP-5500psi
#5(BOTTOM) SOUTH
ZONE2
#6(TOP) SOUTH
5000psig 5711scf 120gal
ZONE3
SRV-15 4000psig
SRV-16 4000psig
SRV-17 4000psig
SRV-18 5500psig
SRV-19 5500psig
SRV-20 5500psig
AV-40
SV-40
IAS 120VAC
ON GEMINI COMPRESSOR (TYP OF 3)
TO VENT

APPENDIX B - U-1A FORMS

FORM U-1A MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS

(Alternative Form for Single Chamber, Completely Shop-Fabricated Vessels Only)

As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

07/17/1998 S/O X-714231

PLANT:#23

1. Manufactured and certified by TRINITY INDUSTRIES, INC. 617 E. SYCAMORE, TX 76205 (NAME AND ADDRESS OF MANUFACTURER)

2. Manufactured for PROTON ENERGY SYSTEMS, 50 INWOOD RD. ROCKY HILL, CT (NAME AND ADDRESS OF PURCHASER)

3. Location of installation Phoenix, Arizona (NAME AND ADDRESS)

4. Type HORIZ (HORIZ OR VERT TANK) 123982 (MFGR'S SERIAL NO.) (CRN) 714231 r- (DRAWING NO.) 23729 (NAT'L BD NO.) 1998 (YEAR BUILT)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1995 (YEAR)

to A97 (ADDENDA (DATE)) (CODE CASE NOS.) (SPECIAL SERVICE PER UG 120 (D))

6. Shell SA612 (MAT'L (SPEC NO., GRADE)) 0.517" (NOM. THK. (IN.)) 0" (CORR. ALLOW (IN.)) 6'-10.966" (DIAM. I.D. (FT. & IN.)) 19'-0" (LENGTH (OVERALL) (FT. & IN.))

7. Seams: WELD, DBL (LONG (WELDED DBL., SNGL., LAP, BUTT)) FULL (R.T. (SPOT OR FULL)) 100% (EFF. (%)) ---- (H.T. TEMP (F)) ---- (TIME (HR.)) WELD, DBL (GIRTH (WELDED DBL., SNGL., LAP, BUTT)) UW-11a(5(b (R.T. (SPOT, PARTIAL, OR FULL)) 2 (NO. OF COURSES)

8. Heads: (a) Mat'l. SA455 HOT FORMED, NORM. (SPEC NO., GRADE) (b) Mat'l. (SPEC NO., GRADE)

Seg. Seams: WELD, DBL H.T.: R.T.: SPOT Eff: 85%

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	ENDS	0.327"	0"					41.673		CONCAVE
(b)								I.S.		

If removable, bolts used (describe other fastenings) (MAT'L., SPEC NO., GR., SIZE, NO.)

9. MAWP 250 psi at max. temp. 125 °F

Min. design metal temp. -3 °F at 250 psi. Hydrostatic test pressure 375 psi.

10. Nozzles, inspection and safety valve openings:

UW-16.1

Purpose (Inlet, Outlet, Drain)	No.	Diam or Size	Type	Mat'l.	Nom Thk	Reinforcement Mat'l.	How Attached	Location
MANWAY	1	15"	PTFLG	SA516-70N	2.50"	INTERGRAL	(1)	HEAD
FLOAT, ROT.	1,1	2.5",2"	CPLG	SA105	3000#		(y-2)	
TW, LL/PG	1,1	.75"	CPLG	SA105	6000#		(y-2)	
L.O., SPARE	1,1	3",.25"	CPLG	SA105	6000#		(z-1)	
VAP, RELIEF	1,1	2"	CPLG	SA105	3000#		(y-1)(z-1)	
FILL, VAPOR	1,1	2"	CPLG	SA105	3000#		(z-1)	

11. Supports: Skirt NO (YES OR NO) Lugs (NO.) Legs (NO.) Other SADDLES (DESCRIBE) Attached SHELL, WELDED (WHERE AND HOW)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report: Shell Assy S/N 2298085, Head S/N T373-37-H13, S/N 969-72 Trinity Plts #22 and #373 (NAME OF PART, ITEM NUMBER, MFGR'S NAME AND IDENTIFYING STAMP) Ft. Worth, TX and Frontera, Coahuila, Mexico

714231 SHT 1 REV.0, SHT 2 REV.0

TANK, HORIZONTAL, LPG STORAGE: 84" OD x 6,565 NOM WG

TO BE USED IN A NON-CORROSIVE SERVICE. MDMT -20 @ 207 PSI.

LINE 9: MDMT/PSI BASED ON UCS-66(a), UCS-66(b) AND UG-20 (f).

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No. 10,920 which expires Jan. 15, 20 01

Date 9-21-98 Co. Name TRINITY INDUSTRIES, INC. (MANUFACTURER) Signed Mike Stanford (REPRESENTATIVE)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by TRINITY INDUSTRIES, INC. at DENTON TX 76205

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of TEXAS and employed by OLD REPUBLIC INS., CO.-DALLAS, TX

have inspected the component described in this Manufacturer's Data Report on 9-21, 19 98, and state that to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied concerning the pressure vessel described in the Manufacturers' Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 9-21-98 Signed [signature] (AUTHORIZED INSPECTOR) Commissions 9723 A 1126 TX (NAT'L BOARD (INCL. ENDORSEMENTS), STATE, PROV. AND NO.)

TRI 437-CON2 (7/97)

FORM U-1A MA[illegible] ACTURER'S DATA REPORT FOR PRE[illegible] RE VESSELS

(Alternative Form [illegible]or Single Chamber, Completely Shop-Fabricate[illegible] Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT, 2214 WALNUT STREET, McKEESPORT, PA 15132
(Name and address of Manufacturer)

2. Manufactured for PINNACLE WEST CAPITAL CORP., P.O. BOX 53999, MS 8948, PHOENIX, AZ 85072
(Name and address of Purchaser)

3. Location of installation NOT KNOWN
(Name and address)

4. Type HORIZ. (Horiz. or vert. tank) 46705 (Mfgr's serial No.) (CRN) 8X15993 REV. 1 (Drawing No.) 46705 (Nat'l Bd. No.) 2000 (Year Built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER and PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME rules, Section VIII, Division 1 1998 (Year)
to 1999 AND APPENDIX 22 (SF=3)
Addenda (Date) Code Case Nos. Special Service per UG-120(d)

6. Shell: SA372 GRADE J, CLASS 70 Mat'l. (Spec. No., Grade) 1.250" Min. Thk. (in.) 0 Corr. Allow. (in.) 16" Diam. O.D. (in.) 28'-0" Length (overall) (ft. & in.)

7. Seams: SEAMLESS Long. (Welded, Dbl., Sngl., Lap, Butt) NONE R.T. (Spot or Full) 100 Eff. (%) H.T. Temp(F) Time(hr) SEAMLESS Girth (welded, Dbl., Sngl., Lap, Butt) NONE R.T (Spot, Partial or Full) 1 No. of Courses

8. Heads: (a) Matl. SAME AS 6. (Spec No., Grade) (b) Matl. SAME AS 6. (Spec No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	ENDS	1.250"	0					8"		CONCAVE
(b)	(INTEGRALLY FORGED HEADS AND NECKS)									

If removable, ends used (describe other fastenings)
(Matl., Spec. No., Gr., Size, No.)

9. MAWP 6667 psi at max. temp. +200 °F
Min. design metal temperature -20 ° F at 6667 psi. Hydrostatic test pressure 10001 psi.

10. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain)	No.	Diam. or Size	Type	Matl.	Nom. Thk.	Reinforcement Matl.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD				FORMED IN	HEADS
OUTLET	1	1/2" NGT	THREAD				IN	HEAD

11. Supports: Skirt NO (Yes or no) Lugs 0 (No.) Legs 0 (No.) Other NONE (Describe) Attached N/A (Where and how)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report:
(Name of part, item number, Mfgr's. name and identifying stamp)
CONSTRUCTED IN ACCORDANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS. DRY GAS STORAGE, NON CORROSIVE SERVICE.
VESSEL MATERIAL IMPACT TESTED PER UHT-6. LIQUID Q&T PER SA 372. SC 16045
UT NDT VESSEL OAL: 30'-0" PIPE NO: E838 MO 7412

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No 1127 expires 3/30 20 03.

Date: 9/26/00 Co. Name: CP INDUSTRIES, INC. (Manufacturer) Signed: [signature] (Representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at McKEESPORT, PA. I, the undersigned, holding a valid Commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of PENNSYLVANIA and employed by ABS GROUP INC., HOUSTON, TX. have inspected the component described in this Manufacturer's Data Report on 9/28, 20 00, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 9/28/00 Signed Michael F. Wink (Authorized Inspector) Commissions NB 11193 AB PA2630 (Nat'l Board (Incl. endorsements, State, Prov. and No.)

FORM U-1A MAN ACTURER'S DATA REPORT FOR PRE RE VESSELS

(Alternative Form for Single Chamber, Completely Shop-Fabricated Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT, 2214 WALNUT STREET, McKEESPORT, PA 15132
(Name and address of Manufacturer)

2. Manufactured for PINNACLE WEST CAPITAL CORP., P.O. BOX 53999, MS 8948, PHOENIX, AZ 85072
(Name and address of Purchaser)

3. Location of installation NOT KNOWN
(Name and address)

4. Type HORIZ. (Horiz. or vert. tank) 46708 (Mfgr's serial No.) (CRN) 8X15993 REV. 1 (Drawing No.) 46708 (Nat'l Bd. No.) 2000 (Year Built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER and PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME rules, Section VIII, Division 1 1998 (Year)
to 1999 AND APPENDIX 22 (SF=3) Addenda (Date) Code Case Nos. Special Service per UG-120(d)

6. Shell: SA372 GRADE J, CLASS 70 Mat'l. (Spec. No., Grade) 1.250" Min. Thk. (in.) 0 Corr. Allow. (in.) 16" Diam. O.D. (in.) 28'-0" Length (overall) (ft. & in.)

7. Seams: SEAMLESS Long. (Welded, Dbl., Sngl., Lap, Butt) NONE R.T. (Spot 0r Full) 100 Eff.(%) H.T. Temp(F) Time(hr) SEAMLESS Girth (welded, Dbl., Sngl., Lap, Butt) NONE R.T. (Spot, Partial or Full) 1 No. of Courses

8. Heads: (a) Matl. SAME AS 6. (Spec No., Grade) (b) Matl. SAME AS 6. (Spec No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	ENDS	1.250"	0					8"		CONCAVE
(b)	(INTEGRALLY FORGED HEADS AND NECKS)									

If removable, ends used (describe other fastenings)
(Matl., Spec. No., Gr., Size, No.)

9. MAWP 6667 psi at max. temp. +200 °F
Min. design metal temperature -20 ° F at 6667 psi. Hydrostatic test pressure 10001 psi.

10. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain)	No.	Diam. or Size	Type	Matl.	Nom. Thk.	Reinforcement Matl.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD				FORMED IN	HEADS
OUTLET	1	1/2" NGT	THREAD				IN	HEAD

11. Supports: Skirt NO (Yes or no) Lugs 0 (No.) Legs 0 (No.) Other NONE (Describe) Attached N/A (Where and how)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned inspectors have been furnished for the following items of the report:
(Name of part, item number, Mfgr's. name and identifying stamp)
CONSTRUCTED IN ACCORDANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS. DRY GAS STORAGE, NON CORROSIVE SERVICE.
VESSEL MATERIAL IMPACT TESTED PER UHT-6. LIQUID Q&T PER SA 372. SC 16045
UT NDT VESSEL OAL: 30'-0" PIPE NO: E842 MO 7412

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No. 1127 expires 3/30 20 03.

Date: 9/26/00 Co. Name: CP INDUSTRIES, INC. (Manufacturer) Signed: [signature] (Representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at McKEESPORT, PA. I, the undersigned, holding a valid Commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of PENNSYLVANIA and employed by ABS GROUP INC., HOUSTON, TX. have inspected the component described in this Manufacturer's Data Report on 9/28, 20 00, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 9/28/00 Signed Michael F. Hink (Authorized Inspector) Commissions NB 11193 AB PA2630 (Nat'l Board (Incl. endorsements, State, Prov. and No.)

FORM U-1A MANUFACTURERS' DATA REPORT FOR PRESSURE VESSELS
(Alternate Form for Single Chamber, Completely Shop-Fabricated Vessels Only)
as required by the provisions of the ASME Code rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT 2214 WALNUT STREET, MCKEESPORT, PA 15132
(name and address of manufacturer)

2. Manufactured for TREN FUELS INC., 320 AUSTIN CENTRE, 701 BRAZOS, AUSTIN, TX .78701
(name and address of purchaser)

3. Location of installation NOT KNOWN
(name and address)

4. Type: HORIZ. (horiz. or vert., tank) 42301 (mfr's serial no.) ______ (CRN) 8X15261Y R.7 (drawing no.) 42301 (Nat'l Bd. No.) 1992 (year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction and workmanship conform to ASME Code, Section VIII, Division 1; 1989 (year)
A90 AND APPENDIX 22 (SF=3) (addenda (date)) ______ (code cases) ______ (special service per UG-120(d))

6. Shell: SA372 TYPE IV (mat'l (spec. no., grade)) 1.093 MIN. (nom. thickness (in.)) 0 (corr. allow. (in.)) 20" O.D. (diameter) 22' 4" (length overall (ft. & in.))

7. Seams: SEAMLESS (long. (welded, dbl., sngl., lap, butt)) NONE (RT (spot or full)) 100 (eff. (%)) ______ (H.T. temp. (°F)) ______ (time (hr)) SEAMLESS (girth (welded, dbl., sngl., lap, butt)) NONE (RT (spot, partial, or full)) 1 (no. of courses)

8. Heads: (a) SAME AS 6 (mat'l (spec. no., grade)) (b) SAME AS 6 (mat'l (spec. no., grade))

	Location (top, bottom, ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (convex or concave)
(a)	ENDS	1.093"	0					10"		CONCAVE
(b)		(INTEGRALLY FORGED HEADS AND NECKS)								

If removable, bolts used (describe other fastenings) ______ (mat'l, spec. no., gr., size, no.)

9. MAWP 4000 (psi) at max. temp. 200 (°F) Min design metal temp. -20 (°F) at 6000 (psi) Hydro., ~~pneu. or combination~~ test pressure 6000 (psi)

10. Nozzles, inspection and safety valve openings:

Purpose (inlet, outlet, drain, etc.)	No.	Dia. or Size	Type	Mat'l	Nom. Thickness	Reinforcement Mat'l	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD				FORMED	IN HEADS
OUTLET	1	1/2" NPT	THREAD					IN HEAD

11. Supports: Skirt NO (yes or no) Lugs 0 (no.) Legs 0 (no.) Other NONE Attached NA

THIS IS A CERTIFIED COPY OF [illegible] REPORT REGISTERED WITH THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS.

12. Remarks: Manufacturers' Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report: ______
(name of part, item number, mfr's. name and identifying stamp)

CONSTRUCTED IN CONFORMANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS
DRY GAS STORAGE - NON CORROSIVE SERVICE
[signature] EXECUTIVE DIRECTOR
PIPE NO. A856 M05192
SC06565

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization no 1127 expires 3/30 19 94
Date 7-23-92 Name CP INDUSTRIES, INC. (manufacturer) Signed [signature] (representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at MCKEESPORT, PA
I, the undersigned, holding a valid commission issued by The National Board of Boiler and Pressure Vessel Inspectors and the state or province of PENNSYLVANIA and employed by KEMPER NATIONAL INSURANCE COMPANIES of LONG GROVE, IL have inspected the component described in this Manufacturers' Data Report on 8-11 19 92 and state that, to the best of my knowledge and belief, the manufacturer has constructed this pressure vessel in accordance with the ASME Code Section VIII, Division 1. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in the Manufacturers' Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.
Date 8-11 19 92 Signed [signature] (authorized inspector) Commissions NB 11153 PA 2127 (Nat'l Bd. (incl. endorsements) state, prov. and no.)

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229

THIS IS A CERTIFIED COPY OF ORIGINAL DATA REPORT REGISTERED WITH THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS.

EXECUTIVE DIRECTOR

FORM U-1A MANUFACTURERS' DATA REPORT FOR PRESSURE VESSELS

(Alternate Form for Single Chamber, Completely Shop-Fabricated Vessels Only)

as required by the provisions of the ASME Code rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT 2214 WALNUT STREET, MCKEESPORT, PA 15132 (name and address of manufacturer)

2. Manufactured for TREN FUELS INC., 520 AUSTIN CENTRE, 701 BRAZOS, AUSTIN, TX .78701 (name and address of purchaser)

3. Location of installation NOT KNOWN (name and address)

4. Type: HORIZ. (horiz. or vert., tank) 42302 (mfr's. serial no.) ____ (CRN) 8X15261Y R.7 (drawing no.) 42302 (Nat'l. Bd. no.) 1992 (year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction and workmanship conform to ASME Code, Section VIII, Division 1; 1989 (year), A90 (addenda (date)) AND APPENDIX 22 (ST-3) (Code Case nos.) ____ (special service per UG-120(d))

6. Shell: SA372 TYPE IV (mat'l. (spec. no., grade)) 1.093 MIN. (nom. thickness (in.)) 0 (corr. allow. (in.)) 20" O.D. (diameter) 22' 4" (length overall (ft. & in.))

7. Seams: SEAMLESS (long. (welded, dbl., sngl., lap, butt)) NONE (RT (spot or full)) 100 (eff. (%)) ____ (HT temp. (°F)) ____ (time (hr.)) SEAMLESS (girth (welded, dbl., sngl., lap, butt)) NONE (RT (spot, partial or full)) 1 (no. of courses)

8. Heads: (a) SAME AS 6 (mat'l. (spec. no., grade)) (b) SAME AS 6 (mat'l. (spec. no., grade))

	Location (top, bottom, ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (convex or concave)
(a)	ENDS	1.093"	0					10"		CONCAVE
(b)		(INTEGRALLY FORGED HEADS AND NECKS)								

If removable, bolts used (describe other fastenings): ____ (mat'l. (spec. no., gr., size, no.))

9. MAWP: 4000 (psi) at max. temp. 200 (°F). Min design metal temp. -20 (°F) at 4000 (psi). Hydro., ~~pneu., or comb.~~ test pressure 6000 (psi)

10. Nozzles, inspection and safety valve openings:

Purpose (inlet, outlet, drain, etc.)	No.	Dia. or Size	Type	Mat'l.	Nom. Thickness	Reinforcement Mat'l.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD				FORMED	IN HEADS
OUTLET	1	1/2" NPT	THREAD					IN HEAD

11. Supports: Skirt NO (yes or no) Lugs 0 (no.) Legs 0 (no.) Other NONE (describe) Attached NA (where & how)

12. Remarks: Manufacturers' Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report: ____ (name of part, item number, mfr's. name and identifying stamp)

CONSTRUCTED IN CONFORMANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS.
DRY GAS STORAGE - NON CORROSIVE SERVICE UHT-6
PIPE NO. A880 N05192
8C06585

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization no. 1127 expires 3/30 19 94

Date 7-22-92 Name CP INDUSTRIES, INC. (manufacturer) Signed [signature] (representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at MCKEESPORT, PA.

I, the undersigned, holding a valid commission issued by The National Board of Boiler and Pressure Vessel Inspectors and the state or province of PENNSYLVANIA and employed by KEMPER NATIONAL INSURANCE COMPANIES of LONG GROVE, IL have inspected the component described in this Manufacturers' Data Report on 7-21 19 92 and state that, to the best of my knowledge and belief, the manufacturer has constructed this pressure vessel in accordance with the ASME Code Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in the Manufacturers' Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 8-11 19 92 Signed [signature] (Authorized Inspector) Commissions NB8153 PA2227 (Nat'l Bd. (incl. endorsements) state, prov. and no.)

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229

THIS IS A CERTIFIED COPY OF [illegible] REGISTERED WITH THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS.

[signature] EXECUTIVE DIRECTOR

FORM U-1A MANUFACTURERS' DATA REPORT FOR PRESSURE VESSELS
(Alternate Form for Single Chamber, Completely Shop-Fabricated Vessels Only)

as required by the provisions of the ASME Code rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT 2214 WALNUT STREET, MCKEESPORT, PA 15132 (name and address of manufacturer)

2. Manufactured for TREN FUELS INC., 520 AUSTIN CENTRE, 701 BRAZOS, AUSTIN, TX .78701 (name and address of purchaser)

3. Location of installation NOT KNOWN (name and address)

4. Type: HORIZ. (horiz. or vert. tank) 42303 (mfr's. serial no.) ____ (CRN) 8X15261Y R.7 (drawing no.) 42303 (Nat'l. Bd. no.) 1992 (year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction and workmanship conform to ASME Code, Section VIII, Division 1: 1989 (year)
A90 AND APPENDIX 22 (SP-3) (addenda (date)) (Code Case nos.) ____ (special service per UG-120(d))

6. Shell: SA372 TYPE IV (mat'l. (spec. no., grade)) 1.093 MIN (nom. thickness (in.)) 0 (corr. allow. (in.)) 20" O.D. (diam. (ID)(ft. & in.)) 22' 4" (length (overall)(ft. & in.))

7. Seams: SEAMLESS (long. (welded, dbl., sngl., lap, butt)) NONE (R.T. (spot or full)) 100 (eff. (%)) ____ (H.T. temp. (°F)) ____ (time (hr.)) SEAMLESS (girth (welded, dbl., sngl., lap, butt)) NONE (R.T. (spot, partial, or full)) 1 (no. of courses)

8. Heads: (a) SAME AS 6 (mat'l. (spec. no., grade)) (b) SAME AS 6 (mat'l. (spec. no., grade))

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	ENDS	1.093"	0					10"		CONCAVE
(b)		(INTEGRALLY FORGED HEADS AND NECKS)								

If removable, bolts used (describe other fastenings): ____ (Mat'l., spec. no., gr., size, no.)

9. MAWP 4000 (psi) at max. temp. 200 (°F). Min design metal temp. -20 (°F) at 4000 (psi). Hydro., ~~pneu., or comb.~~ test pressure 6000 (psi)

10. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain, etc.)	No.	Dia. or Size	Type	Mat'l.	Nom. Thickness	Reinforcement Mat'l.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD				FORMED	IN HEADS
OUTLET	1	1/2" NGT	THREAD					IN HEAD

11. Supports: Skirt NO (yes or no) Lugs 0 (no.) Legs 0 (no.) Other NONE (describe) Attached NA (where & how)

12. Remarks: Manufacturers' Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report: ____ (name of part, item number, mfr's. name and identifying stamp)

CONSTRUCTED IN CONFORMANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS.
DRY GAS STORAGE - NON CORROSIVE SERVICE UHT-6
PIPE NO. A864 MO5192
SC06565

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization no. 1127 expires 3/30 19 94

Date 7-23-92 Name CP INDUSTRIES, INC. (manufacturer) Signed [signature] (representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at MCKEESPORT, PA

I, the undersigned, holding a valid commission issued by The National Board of Boiler and Pressure Vessel Inspectors and the state or province of PENNSYLVANIA and employed by KEMPER NATIONAL INSURANCE COMPANIES of LONG GROVE, IL have inspected the component described in this Manufacturers' Data Report on 7-23 19 92 and state that, to the best of my knowledge and belief, the manufacturer has constructed this pressure vessel in accordance with the ASME Code Section VIII, Division 1. By signing this certificate neither the inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in the Manufacturers' Data Report. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 7-23 19 92 Signed [signature] (Authorized Inspector) Commissions NB8153 PA2227 (Nat'l. Bd. (incl. endorsements) state, prov. and no.)

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229

FORM U-1A MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS
(Alternative Form for Single Chamber, Completely Shop-Fabricated Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT, 2214 WALNUT STREET, MCKEESPORT, PA 15132
(Name and address of manufacturer)

2. Manufactured for [illegible] COMPANY, P.O. BOX 9758, CORPUS CHRISTI, TX 78469
(Name and address of purchaser)

3. Location of installation NOT KNOWN
(Name and address)

4. Type HORIZ. | 45310 | | 4215657 Rev. 1 | 45310 | 1993
(Horiz. or vert. tank) (Mfg's serial No.) (CRN) (Drawing no.) (Nat'l Bd. No.) (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1992
Year

to 1992 AND APPENDIX 22 (93?)
Addenda (Date) Code Case Nos. Special Service per UG 120(d)

6. Shell: SA372 TYPE V, CL.5, CL. B 1.303 Min. 0 30" O.D. 11'-6"
Matl. (Spec. No., Grade) Nom. Thk. (in.) Corr. Allow. (in.) Diam. I.D. (ft & in.) Length (overall) (ft & in.)

7. Seams: SEAMLESS NONE 100 SEAMLESS NONE 1
Long. (Welded, Dbl., Sngl., Lap, Butt) R.T. (Spot or Full) Eff. (%) H.T. Temp (F) Time (hr) Girth (welded, Dbl., Sngl., Lap, Butt) R.T. (Spot, Partial, or Full) No. of Courses

8. Heads: (a) Matl. SAME AS 6 (b) Matl. SAME AS 6
(Spec. No., Grade) (Spec. No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	ENDS	1.303"	0					14"		CONCAVE
(b)	(INTEGRALLY FORGED HEADS AND NECKS)									

If removable, bolts used (describe other fastenings)
(Matl., Spec. No., Gr., Size, No.)

9. MAWP 5500 psi at max. temp. 200 °F
Min. design metal temp. -20 °F at 5500 psi. Hydro., pneu., or comb. test pressure 8250 psi

10. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain)	No.	Diam. or Size	Type	Matl.	Nom. Thk.	Reinforcement Matl.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD				FORGED IN HEADS	
OUT	1	1/2" NPT	THREAD					IN HEAD

11. Supports: Skirt NO Lugs 0 Legs 0 Other NONE Attached NO
(Yes or no) (No.) (No.) (Describe) (Where and how)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report
(Name of part, item number, Mfg's name and identifying stamp)

CONSTRUCTED IN CONFORMANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS
NOT GAS STORAGE, NON CORROSIVE SERVICE
PIPE No.: C165

CERTIFIED COPY OF ORIGINAL ON FILE WITH THE NATIONAL BOARD OF BOILER & PRESSURE VESSEL INSPECTORS
[signature]
EXECUTIVE DIRECTOR

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No. 1127 expires 1/16, 19 96.

Date 8/27/93 Co. name CP INDUSTRIES, INC. Signed [signature]
(Manufacturer) (Representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at MCKEESPORT, PA

I, the undersigned, holding a valid commission issued by The National Board of Boiler and Pressure Vessel Inspectors and the State or Province of PENNSYLVANIA and employed by KEMPER NATIONAL INSURANCE COMPANIES, LONG GROVE, IL have inspected the component described in this Manufacturer's Data Report on 9-7, 19 93, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 9-7-93 Signed [signature] Commissions NB 8153 A,B PA 2237
(Authorized Inspector) (Nat'l Board (incl. endorsements) State, Prov. and No.)

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229

NB-18
Rev. 10

FORM U-1A MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS
(Alternative Form for Single Chamber, Completely Shop-Fabricated Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT, [illegible] STREET, MCKEESPORT, PA [illegible]
(Name and address of manufacturer)

2. Manufactured for [illegible] COMPANY, P.O. BOX [illegible], CORPUS CHRISTI, TX [illegible]
(Name and address of purchaser)

3. Location of installation NOT KNOWN
(Name and address)

4. Type HORIZ. | [illegible] | | [illegible] Rev 1 | [illegible] | 1993
(Horiz. or vert. tank) (Mfg's serial No.) (CRN) (Drawing no.) (Nat'l Bd. No.) (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 [illegible] Year

to [illegible] APPENDIX 22 (UF-1)
Addenda (Date) Code Case Nos. Special Service per UG 120(d)

6. Shell: [illegible] | [illegible] min. | 0 | [illegible] O.D. | [illegible]
Mat'l. (Spec. No., Grade) Nom. Thk. (in.) Corr. Allow (in.) Diam. ID (ft. & in.) Length (overall) (ft. & in.)

7. Seams: SEAMLESS | NONE | 100 | | | SEAMLESS | NONE | 1
Long. (Welded, Dbl., Sngl., Lap, Butt) R.T. (Spot or Full) Eff. (%) H.T. Temp. (F) Time (hr) Girth (welded, Dbl., Sngl., Lap, Butt) R.T. (Spot, Partial, or Full) No. of Courses

8. Heads: (a) Mat'l. SAME AS 6 (b) Mat'l. SAME AS 6
(Spec No., Grade) (Spec No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	ENDS	[illegible]"	0					[illegible]"		CONCAVE
(b)	(INTEGRALLY FORGED HEADS AND SHELL)									

If removable, bolts used (describe other fastenings)
(Mat'l., Spec. No., Gr., Size, No.)

9. MAWP 5500 psi at max. temp. [illegible] °F
Min. design metal temp. [illegible] °F at 5500 psi. Hydro., pneumatic, test pressure [illegible] psi.

10. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain)	No.	Diam. or Size	Type	Mat'l	Nom. Thk.	Reinforcement Mat'l.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD					FORGED IN HEADS
OUT	1	1/2" NPT	THREAD					IN HEAD

11. Supports: Skirt NO (Yes or no) Lugs 0 (No.) Legs 0 (No.) Other NONE (Describe) Attached NA (Where and how)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report:
(Name of part, item number, Mfg's name and identifying stamp)

CONSTRUCTED IN CONFORMANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS
[illegible] STORAGE, NON CORROSIVE SERVICE

THIS IS A CERTIFIED COPY OF ORIGINAL DATA REPORT REGISTERED WITH THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS [illegible]
[signature]
EXECUTIVE DIRECTOR
FILE NO.: [illegible] [illegible]

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No. [illegible] expires [illegible], 19 94

Date [illegible] Co. name CP INDUSTRIES, INC. Signed [signature]
(Manufacturer) (Representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at MCKEESPORT, PA

I, the undersigned, holding a valid commission issued by The National Board of Boiler and Pressure Vessel Inspectors and the State or Province of PENNSYLVANIA and employed by KEMPER NATIONAL INSURANCE COMPANIES, LONG GROVE, IL have inspected the component described in this Manufacturer's Data Report on 9-7, 1993, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 9-7-93 Signed [signature] (Authorized Inspector) Commissions NB[illegible] PA[illegible]
(Nat'l Board (incl. endorsements) State, Prov. and No.)

This form may be obtained from The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229

NB-15
Rev. 10

FORM U-1A MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS
(Alternative Form for Single Chamber, Completely Shop-Fabricated Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

1. Manufactured and certified by CP INDUSTRIES, INC., CHRISTY PARK PLANT, 2214 WALNUT STREET, MCKEESPORT, PA 15132
(Name and address of manufacturer)

2. Manufactured for [illegible] COMPANY, P.O. BOX 9250, CORPUS CHRISTI, TX [illegible]
(Name and address of purchaser)

3. Location of installation NOT KNOWN
(Name and address)

4. Type HORIZ. | [illegible] | | [illegible] REV. 1 | [illegible] | 1993
(Horiz. or vert. tank) (Mfg's serial No.) (CRN) (Drawing no.) (Nat'l Bd. No.) (Year built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 [illegible] (Year)

to [illegible] AND APPENDIX 22 ([illegible])
Addenda (Date) — Code Case(s) — Special Service per UG-120(d)

6. Shell: [illegible] | 1.345 MIN. | 0 | [illegible]" O.D. | 11'-6"
Matl. (Spec. No., Grade) — Nom. Thk. (in.) — Corr. Allow. (in.) — Diam. ID (ft & in.) — Length (overall) (ft & in.)

7. Seams: INTEGRAL | NONE | 100 | | | INTEGRAL | NONE | 1
Long. (Welded, Dbl., Sngl., Lap, Butt) — R.T. (Spot or Full) — Eff. (%) — H.T. Temp (F) — Time (hr) — Girth (welded, Dbl., Sngl., Lap, Butt) — R.T. (Spot, Partial, or Full) — No. of Courses

8. Heads: (a) Matl. SAME AS 6 (Spec No., Grade) (b) Matl. SAME AS 6 (Spec No., Grade)

	Location (Top, Bottom, Ends)	Minimum Thickness	Corrosion Allowance	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a)	BOTH	1.345"	0					[illegible]"		CONCAVE
(b)	(INTEGRALLY FORGED HEADS AND NECKS)									

If removable, bolts used (describe other fastenings)
(Matl., Spec. No., Gr., Size, No.)

9. MAWP 5500 psi at max. temp. [illegible] °F
Min. design metal temp. -20 °F at 5500 psi. Hydro., pneu., or comb. test pressure [illegible] psi.

10. Nozzles, inspection and safety valve openings:

Purpose (Inlet, Outlet, Drain)	No.	Diam. or Size	Type	Matl.	Nom. Thk.	Reinforcement Matl.	How Attached	Location
INLET/OUTLET	2	2 3/4"	THREAD					FORGED IN HEADS
[illegible]	1	1/2" NPT	THREAD					IN HEAD

11. Supports: Skirt NO (Yes or no) Lugs 0 (No.) Legs 0 (No.) Other NONE (Describe) Attached NO (Where and how)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of this report

THIS IS A CERTIFIED COPY OF ORIGINAL DATA REPORT REGISTERED WITH THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS.

(Name of part, item number, Mfg's name and identifying stamp)

CONSTRUCTED IN CONFORMANCE WITH APPENDIX 22, INTEGRALLY FORGED VESSELS
FOR GAS STORAGE, NON CORROSIVE SERVICE

[illegible] EXECUTIVE DIRECTOR

CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No. [illegible] expires [illegible], 19 [illegible]

Date 9/3/93 Co. name CP INDUSTRIES, INC. (Manufacturer) Signed [signature] (Representative)

CERTIFICATE OF SHOP INSPECTION

Vessel constructed by CP INDUSTRIES, INC. at MCKEESPORT, PA

I, the undersigned, holding a valid commission issued by The National Board of Boiler and Pressure Vessel Inspectors and the State or Province of PENNSYLVANIA and employed by KEMPER NATIONAL INSURANCE COMPANIES, LONG GROVE, IL have inspected the component described in this Manufacturer's Data Report on 9-7, 1993, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 9-7-93 Signed [signature] (Authorized Inspector) Commissions NB [illegible] PA [illegible] (Nat'l Board (incl. endorsements) State, Prov. and No.)

APPENDIX C – GASEOUS HYDROGEN PIPING SPECIFICATION

February 19, 2001, Rev. 0

C.1 GENERAL

This specification provides guidelines for designing and installing the gaseous low-pressure (<275 psig) and high-pressure (276 to 7,000 psig) high-purity hydrogen process piping. For both low- and high-pressure, stainless steel (303, 304, 316) tubing, piping, fittings, and components are preferred. Piping systems should be designed and built to meet ANSI/ASME B31.3 for process piping. Specifications for the tubing are ASTM A269 TP 304 and 316. Maximum hardness is 80 Rb.

C.2 MAXIMUM ALLOWABLE WORKING PRESSURE

Maximum allowable working pressures (MAWP) for commercially available tubing and piping are given below. Piping systems must be designed so that the process pressure of the gas will not exceed the MAWP of the pipe, tubing, or components.

C.2-1 LOW-PRESSURE HYDROGEN (<275 PSIG)

For all sizes from 0.25- to 1-in. OD stainless steel tubing, 0.035-in. wall thickness is acceptable. Schedule 10S to Schedule 80S stainless steel pipe is also acceptable for both plain end and threaded end styles. Threaded ends should be 80S.

C.2-2 HIGH-PRESSURE HYDROGEN (275 TO 7000 PSIG)

See the Tables below. The hydrogen system downstream of the compressor will operate at 6,000 psig. The high-pressure storage tubes are designed to a maximum allowable working pressure of 6,667 psig. The tubing or piping for these high-pressure circuits should be selected to meet or exceed this pressure. To this end, the high-pressure hydrogen piping/tubing will be designed for 7,000 psig. Acceptable sizes and wall thicknesses are:

1/4-in. OD tubing:	0.049 and 0.065-in. wall thickness; 0.065-in.
3/8-in. OD tubing:	0.065 and 0.083-in. wall thickness; 0.083-in.
1/2-in. OD tubing:	0.083 and 0.095-in. wall thickness; 0.095-in.
3/4-in. OD tubing:	Not Allowed
1-in. OD tubing:	Not Allowed
3/4-in. Schedule 80 piping:	Limited to 6,550 psig with plain ends

The components specified in the Instrument Summary are primarily 1/2-in. and are configured with either 1/2-in. female pipe ports or compression style tube fittings, depending on availability. The piping designer/contractor may choose to modify the specified end connection when ordering the components to facilitate installation. If the end connections are modified, then confirm with the supplier that the pressure rating for the component with the new end connection still meets the required MAWP for the system (7,000 psig).

Maximum Allowable Working Pressure 304 and 316 Stainless Steel Annealed Seamless Tubing (-20 to 100ºF)						
Tubing	Wall Thickness (in.)					
OD (in.)	0.028	0.035	0.049	0.065	0.083	0.095
1/4	4,600	5,891	8,602	11,688		
3/8		3,777	5,460	7,517		
1/2		2,768	3,976	5,423	7,162	
3/4		1,814	2,581	3,478	4,544	5,273
1		1,346	1,907	2,562	3,329	3,582

Maximum Allowable Working Pressure 304 and 316 Stainless Steel Annealed Seamless Pipe (-325 to 100ºF)					
	Wall Thickness, Pipe Schedule				
Pipe Nominal Size	Schedule 10S	Schedule 40S	Schedule 80S	Schedule 160S	Schedule XXS
1/2-in. plain ends	3,483	4,600	6,550	7,800	12,200
1/2-in. threaded	Not Allowed	1,760	3,399		
3/4-in. plain ends	2,745	3,820	5,370	7,300	10,200
3/4-in. threaded	Not Allowed	1,549	2,921		
1-in. plain ends	2,887	3,580	4,940	6,600	9,500
1-in. threaded	Not Allowed	1,361	2,600		

C.3 FITTINGS

C.3-1 TUBE FITTINGS

Several suppliers of tube fittings will meet the required 7000-psig design pressure for 1/4-in., 3/8-in., and 1/2-in. tubing. Cajon (Swagelok), Parker, and Hoke all can supply Stainless Steel tube fittings for this application. Cajon fittings were used, as they were the only manufacturer to certify their products for use in hydrogen and CNG service.

Parker Hannifin Triple-Lok 37 degree flared tube compression fittings having a pressure rating of 7000 psig are acceptable in sizes up to 1-in. OD. Cone-and-thread style fittings such as the BuTech M/P fittings are also acceptable up to 1-in. OD.

C.3-2 PIPE FITTINGS

Cajon (Swagelok) manufactures a line of 10,000-psig pipefittings in 1/4 to 1/2-in. configurations. These fittings are manufactured from bar stock or forgings and are designated suitable for 10,000-psig services by a -10K suffix on the end of the standard Cajon part number. BuTech also offers a line of fittings with a working pressure of 7000 psig or higher. Flowline manufactures a line of butt weld fittings, many of which are available in Schedule 160 and XXS configurations.

C.4 JOINING TECHNIQUES

In general, with high-pressure hydrogen systems, welded joints are preferred over threaded or brazed connections, but threaded connections cannot be eliminated entirely. Many components are not available except as NPT end connections. Threaded connections should be kept to a minimum. Compression fittings are acceptable if rated for the operating pressure of the system and if properly installed and leak tested. Welded joints may be socket welds or butt welds. They should be accomplished using GTAW (TIG) welding techniques for either manual or automated (orbital welding). All welding must be completed by qualified welders following qualified procedures per ASME B31.3. A liquid source of argon gas should be used for purging the piping system ID and for shielding on the OD of the weld area. Purging is required to minimize oxidation and contamination in the weld zone. Purging also helps to control the weld bead profile. Minimum purge rate for 1/2-in. tubing and smaller is 10 SCFH. A welding log should be maintained that catalogs the welding parameters (date, time, purge flow rate, size and type of weld, welder name and identification number, inspector name, weld schedule, weld number, and drawing number). Mill certifications and test reports should be requested from the component supplier and maintained by the contractor as part of the welding log.

The maximum allowable diameter misalignment for butt welds should be less than 0.005 in. Pipe/tube ends should be cut and prepped so that there are no nicks, burrs, chamfers, or sharp edges and no reduction in diameter or wall thickness. The ends should be square and perpendicular within 0.003 in. The weld must have 100% penetration and show no points of discontinuity. The weld may have no undercut that will render the weld wall thickness thinner than the pipe/tube nominal wall thickness. The weld bead should be 2–5% thicker than the nominal wall thickness and should not be 10% thicker than the nominal wall thickness. The welds should have no porosity or inclusions when inspected under magnification and under white light. The weld bead should have uniform width and should not be more than three times the nominal wall thickness. Discoloration of the weld should be kept to a minimum through proper purging with argon. All socket weld joints must have a 1/16-in. gap between the pipe end and the socket bottom (ASME B31.3, Fig. 328.5.2C).

It is recommended that 5% of each welder's joints should be 100% radiographed in accordance with ASME B31.3. For each failed weld, two additional welds made by the same welder should be radiographed. Radiographs will be made until no defects are found or until all welds have been examined and repaired. All socket weld final passes will be 100% dye penetrant tested.

The performance of the welder and the weld machine should be checked periodically by performing a sample weld, sectioning the weld lengthwise, and inspecting the weld under bright white light. Weld performance should be checked when there are substantial changes to the welds being made: change in pipe/tube diameter, new welder, after maintenance of welding unit, after power failure, after a change in weld program/schedule, after any defective weld.

C.5 BENDING

Tubing may be bent where needed. The minimum mandrel bend radius must be equal to or greater than five times the OD of the tubing.

C.6 CLEANING

The internal gas-wetted surfaces of the piping system and components should be cleaned to remove any contaminants that could compromise the performance of fuel cells, gas turbines, or other applications equipment. Cleaning the system piping and components to an oxygen clean level is acceptable. Applicable standards include:

- Compressed Gas Association Pamphlet G-4.1, "Cleaning Equipment for Oxygen Service"
- ASTM Pamphlet G23, "Practice for Cleaning Methods for Material and Equipment Used in Oxygen Enriched Environments."

These documents describe in general terms how to clean and inspect equipment that will be placed into oxygen service. The procedure below provides more specific detail for cleaning to oxygen clean standards.

Oxygen cleaning should be conducted in a clean, dust free area. The cleaning can be accomplished with a range of acceptable cleaners (see CGA Pamphlet G-4.1). The detergent Blue Gold, used with hot water (140ºF minimum) or steam, is an effective, environmentally safe method. Components that are not cleaned by the equipment manufacturer should be disassembled, and the internal parts and surfaces cleaned. Piping, tubing, and fittings should be soaked in the Blue Gold solution (detergent in water in a 1:20 ratio) and cleaning swabs pushed through the piping/tubing. Continue to swab the pipe/tube ID until the swabs show no discoloration after passing through the tube. After cleaning, the parts should be rinsed with clean warm water and allowed to dry.

The parts should be inspected after they are cleaned and dried. Under a bright white light, there should be no indication of discoloration, oils, grease, nor indication of particulate matter (dust, fiber, chips, etc.). Finally, inspect the parts under an ultraviolet (UV, 3660 angstrom wavelength) lamp. The UV lamp will cause any hydrocarbon contaminants to fluoresce. Any contaminants found under either white or UV light should be removed by recleaning and then re-inspected. Parts that have been cleaned and that pass inspection should be tagged as "Cleaned and Inspected" and stored in 4-mil-thick polyethylene bags and sealed until ready to use. Pipes or tubes that are cleaned and accepted should also be tagged and the ends capped with plastic caps and stored in a secure, clean area.

C.7 TESTING

All circuits of the piping system must be tested before putting the system into operation. Testing should consist of both a pressure retention test and a leak test. Testing should be conducted using utmost caution. The process lines will contain in excess of 6,000 psig. *Failure of a joint or component will expose test personnel to high-pressure gas, which could result in injury.* The number of testing personnel should be kept to a minimum in the test area. A pressure test supervisor should be appointed to direct all pressure tests and to control the access of personnel into the test areas. Maintain a minimum distance of 25 feet from the test circuit while the circuit is being pressurized and while it is under pressure. Test personnel should continually monitor the test until it is completed and the test circuit is depressurized. Post test warning signs around the test area to warn personnel that high-pressure pneumatic testing is underway.

Clean dry nitrogen should be used for the test gas. Be sure that the testing is done in a ventilated area. Nitrogen is an asphyxiant. Leakage of nitrogen into the test area may create an oxygen-deficient atmosphere that can asphyxiate personnel in the area. Isolate or remove any components from the system that are not rated for 1.1 times the maximum allowable working pressure of the system. Slowly pressurize the circuit, increasing the pressure in stages. Pressurize the system to 1.1 times the MAWP from a remote location, using an approved pressure testing control system. Hold the pressure in the system for 15 minutes. If the pressure declines more than a few psig then there is likely a leak in the section of pipe/tube. Depressurize the circuit to about 150 psig and locate the leak using an approved leak detection solution such as SNOOP. Apply the SNOOP solution to each joint (welded, threaded, compression fitting, brazed) and look for the formation of bubbles. If no bubbles form within 30–60 s, the joint is acceptable. If bubbles form, the joint must be repaired and retested. After the system passes the 15-minute pressure retention test at 1.1 times MAWP, reduce the pressure to 90% of MAWP. Record the pressure and the temperature. Hold at this pressure for 24 hours; then, observe the test pressure gauge for any loss of pressure. Loss of pressure that cannot be attributed to a change in temperature is an indication of a leak. Locate the leak point and repair the leak.

C.7-1 PRESSURE TEST MANIFOLD

The pressure test manifold should include an isolation valve, a flow control valve, restrictive orifice, pressure gauge and bleed valve, and a relief valve set to relieve slightly above the test pressure assembled in the same sequence as above. The relief valve should be sized to relieve more gas flow than can flow through the restrictive flow orifice.

Conduct the pressure test at 110% of the design pressure of the system. The test supervisor will be responsible for controlling access to the area during testing, which is off limits to everyone except test personnel. A Safety Work Permit is required before testing may begin. This permit will be issued to the test supervisor after the test procedures have been completely reviewed and understood by all test personnel. The facility manager is the only person authorized to issue a Safety Work Permit.

Devices that are not rated to the full test pressure (relief devices) may be temporarily removed for the test. The openings will be plugged for testing. Upon completion of the test, these devices will be reinstalled.

C.8 LABELING

All process gas lines should be clearly marked to show the type of gas contained in the line and to show the flow direction of the gas. Where possible, the normal operating pressure should also be indicated on the labeling. Lab Safety Supply labels P/N OA-5339, “Hydrogen”; OA-51835, “High Pressure”; OA-18194, “Nitrogen”; and OA-5349, “Natural Gas,” are suitable labels. All piping is color coded and labeled.

APPENDIX D - TRAINING PROGRAMS

In accordance with the *APS Safety Manual*, training programs have been prepared for the APS Alternative Fuel Pilot Plant. A video-based program has been developed to provide general information concerning the APS Alternative Fuel Pilot Plant. This program is used to provide general information concerning the facility to personnel working in the general area. A second computer-based training program has been developed to train personnel fueling vehicles at the APS Alternative Fuel Pilot Plant. This program includes a post-training test.

These training programs are available from Arizona Public Service.

APPENDIX E – HYDROGEN SYSTEMS OPERATIONS

Rev. 3, July 9, 2001

E.1 HYDROGEN SYSTEM ALARMS

E.1.1 Process Alarm

A process alarm indicates that the process is deviating from the normal condition but does not represent a hazardous or incipient hazardous condition. An example would be a high-pressure switch on the PDC compressor that hits the high set point that shuts down the compressor as part of normal operation. Indicator lights will be on both the local (near the equipment) control panel(s) and at the remote control room panel.

E.1.2 Safety Alarm Level 1

A safety alarm level 1 (S-1) results from a condition that is not normal but does not require immediate response by local fire or emergency response teams. The condition does, however, require input from plant management. Plant management would be notified of an S-1 alarm by a paging system or cellular call out that would identify the type of alarm. The page would specify the alarm as an S-1 type, "Incipient Flame Detected in H2 Room." Examples of an S-1 alarm would be the UV/IR detectors detecting an "incipient" flame, which is one that may or may not be present and that requires investigation by trained personnel. An S-1 alarm can shut down part or all of the H_2 and CNG systems to the normally closed, safe condition.

E.1.3 Safety Alarm Level 2

A safety alarm level 2 (S-2) indicates a major deviation from normal process parameters and requires immediate notification of plant management and local fire and emergency response teams. Both would be notified by pager or cellular call outs that would identify the type of alarm. The page would specify the alarm as an S-2 type, "Flame Detected in H2 Room." An example of an S-2 is the UV/IR detectors detect a flame in the storage or dispensing area.

E.1.4 Alarm Actions

E.1.4.1 UV/IR Detects an Incipient Fire

This is an S-1 alarm. There may be a flame, or the detector may be fooled by another signal. There is no definite flame detected. This should generate an audible alarm (horn, tone 1) and a visual alarm (yellow light/beacon) in both the storage room and the control room. The alarm also generates a pager/cellular call out to plant management that describes the event as an S-1, "possible fire detected."

The alarm will:

1. Shut down the HOGEN 300, the PDC compressor, the dryer, and all fueling dispensers
2. Close all H_2 and CNG-actuated valves
3. Maintain power to the gas detectors, UV/IR detectors, sprinkler
4. Flow detection, all pressure and temperature transmitters, TIC, and SV-104 on the helium purge system.

E.1.4.2 UV/IR detects a fire

This is an S-2 type alarm, requiring immediate response by system controls, plant personnel, and local emergency teams. The alarm will generate a red flashing beacon and horn (tone type 2) in both the storage area and the control room. The system will send a page/cellular call out to plant management and emergency response teams, describing the type (S-2) alarm and the source, "Fire detected."

The alarm will:

1. Shut down the HOGEN 300, the PDC compressor, the dryer, and all fueling dispensers
2. Close all H_2 and CNG-actuated valves
3. Maintain power to the gas detectors, UV/IR detectors, sprinkler
4. Flow detection, all pressure and temperature transmitters, TIC, and SV-104 on Helium purge system.

E.1.4.3 Emergency Shutdown

When an emergency shutdown (ESD) is initiated, either at the control panel or by depressing any of the ESD pushbuttons, it will initiate an S-2 alarm, requiring immediate response by the system controls, plant personnel, and local emergency teams. The alarm will generate a red flashing beacon and horn (tone type 2) in both the storage area and the control room. The system will send a page/cellular call out to plant management and emergency response teams, describing the type (S-2) alarm and the source, "Fire detected."

The alarm will:

1. Shut down the HOGEN 300, the PDC compressor, the dryer, and all fueling dispensers
2. Close all H_2 and CNG-actuated valves
3. Maintain power to the gas detectors, UV/IR detectors, sprinkler
4. Flow detection, all pressure transmitters and temperature transmitters, TIC, and SV-104 on the helium purge system.

E.1.4.4 Combustible Gas Detector Detects Either CNG or H_2 at 25% of LFL

This is an S-1 alarm with response similar to the "incipient fire" shown in C.1.2 above.

E.1.4.5 Combustible Gas Detector Detects Either CNG or H_2 at 50% of LFL

This is an S-2 alarm with the same response as an ESD alarm or flame detection alarm.

E.1.4.6 High Low-Pressure Storage Tank Pressure Alarm

This is a two-level alarm. High pressure detected by PSH-104 initiates a P-1 alarm with no page outs. The alarm will close valves SV-101 and -103 on the inlet and outlet side of the LPS and will initiate a horn (tone 1) and an amber light beacon in the storage area and control room. If the pressure in the low-pressure storage continues to climb, then PT-104 high-high setpoint will trigger an S-1 alarm: horn tone 2, red flashing beacon, call out to plant management, and shutdown:

1. Shut down the HOGEN 300, the PDC compressor, the dryer, and all fueling dispensers
2. Close all H_2 and CNG-actuated valves
3. Maintain power to the gas detectors, UV/IR detectors, sprinkler

4. Flow detection, all pressure transmitters and temperature transmitters, TIC, and SV-104 on the helium purge system.

EF.1.4.7 PDC Leak Detected in Either Stage 1 or 2

This indicates there is a diaphragm leak in the compressor. The leak is captured within the leak detection system and vented to the H_2 vent stack at low pressure. The alarm is a process alarm, P-1. The alarm should initiate an amber indicator light and an audible tone in the storage area and the control room, shut down the PDC compressor, and close the inlet and outlet valves on the PDC, valves SV-101, -104, and -105.

EF.1.4.8 PDC Loss of Chilled Water Flow

This is a process alarm, P-1. It will shut off the PDC compressor, close valves SV-103, -104, and -105, and provide a tone and amber light at the control panel.

E.1.4.9 PDC High Outlet Pressure

This condition is initiated by PSH-203 and is the normal sequence to shut down the PDC compressor when the outlet pressure reaches 6,000 PSIG. The signal should also close SV-103 and -104, feeding H_2 to the PDC.

E.1.4.10 PDC High-High Outlet Pressure

This condition is initiated by PSHH-203, set at 6,100 PSIG. This is also a process alarm, P-1, and will shut down the PDC. It will also close SV-103 and -105.

E.1.4.11 High-Pressure in H_2 Process Line from PDC to HPS Tanks

This alarm is initiated by PSH-112, set at 6,500 PSIG, and is an S-1 type alarm. It will shut down the PDC, initiate an audible and visual alarm, and close SV-103 and -105.

E.1.4.12 Low Pressure in H_2 Process Line from PDC to HPS Tank

This alarm is initiated by PSL-112. The alarm indicates a possible leak from the H_2 line, which should be operating at 4,000–6,000 psig. If the pressure drops below 4,000 psig, it is possible that the line has a leak. This is a P-1 or S-1 type alarm that initiates an audible and visual alarm in the control room. Operators should take steps to check for leaks through system diagnostics and by visual checks of the line with portable gas detectors.

E.1.4.13 HPS Tanks 1 and 2 High-Pressure Detected by PT-113 and -114

There are two high alarm set points for each transmitter. The high-pressure alarm is set at ~6,200 psig. When this set point is reached, it will illuminate an indicator light on the control panel, and it will close SV-109 and -107 and shut off the PDC compressor. If the pressure continues to increase and reaches the second, or high-high pressure alarm set point at ~6,500 psig, then the system will initiate an S-1 alarm and keep SV-107 and -109 deenergized and the PDC shut down.

E.1.4.14 High H_2 Pressure to the Dispenser

This alarm will be initiated by PT-110 and will have two set points: high and high-high. The high-pressure alarm will be set at ~5,200 psig, which will initiate a process alarm, P-1, warning the operators that the dispenser feed pressure is high. This alarm will not shut down any equipment or close any valves. The alarm will be an amber indicator light and a tone. When the pressure increases to ~5,500 psig at PT-110, then the system will initiate an S-1 alarm, and will close SV-106, -110, -111, -112, thereby preventing H_2 flow to the dispenser.

E.1.4.15 High CNG Pressure to the Dispenser

This alarm will be initiated by PT-111 and will have two set points: high and high-high. The high-pressure alarm will be set at ~5,200 psig, which will initiate a process alarm, P-1, warning the operators that the dispenser feed pressure is high. The alarm will not shut down any equipment or close any valves. It will be an amber indicator light and a tone. When the pressure increases to ~5,500 psig at PT-111, then the system will initiate an S-1 alarm and will close SV-113, thereby preventing CNG flow to the dispenser.

E.1.4.16 High H_2 Flow from the High-Pressure System

This alarm indicates there is a likely break in the H_2 line between the HPS tanks and the dispenser. The alarm is actuated by flow switch FSH-101. This is an S-2 type alarm, generating a red beacon light and horn (tone 2). The alarm shuts down the HOGEN, dryer, PDC, and compressor. It also closes all actuated valves

E.2 INITIAL STARTUP OR STARTUP AFTER EXTENDED SHUTDOWN

E.2.1 Sensors/Detectors

1. Run a test of the UV/IR flame detectors to ensure that they are operating properly. Initiate a manual built in test (BIT) by pressing in momentarily on push button "BIT Manual Test" on the central control panel. The UV/IR detectors will run through a manual diagnostic test, checking the electrical circuitry, the sensors, and the sensing window cleanliness. A successful manual BIT activates the following: the fault relay is closed, the alarm relay activates for 3 s, the accessory relay is activated for 3 s, the 4–20-mA output will go to 20 mA (or 16 mA if only SW1-7 = on and SW1-6 = off). An unsuccessful BIT activates the following: fault relay is released, and the 4–20-mA output goes to zero. If the BIT is unsuccessful, the plant operators *must* determine why it was unsuccessful and correct the problem. The BIT must be run again until a successful test is completed.
2. *Warning*: Failure to complete a successful BIT means that the flame detection system is not working properly, and it will not detect a flame. Failure of the flame detectors will put personnel and property at risk and may result in injury or death to personnel. Do not proceed with the hydrogen system startup until the flame detector system is fully operational and has passed a successful BIT test.
3. If the BIT test is successful (4 to 20-mA output goes to 20 mA), then the detector status returns to normal, and the flame detector system is ready to scan the area and detect a flame. Each detector must be tested and pass a successful BIT before starting the hydrogen or CNG systems. The UV/IR system must pass the BIT before you proceed.
4. Run a check of the flammable gas detection system. Ensure that the detector(s) is properly calibrated and that the alarm output is functioning properly. The detector should initiate a visual and audible alarm (S-1 type alarm) at 25% of the hydrogen LFL and initiate a system shutdown and alarm (S-2 type) at 50% LFL of the hydrogen LFL.

E.2.2 Nitrogen Generator

1. Start the nitrogen generator (N-20). Turn the main power switch on the nitrogen generator control panel to the OFF position. Turn on the compressed air supply, following the air compressor's operating instructions. Check that the air pressure out of the compressor is 90–150 psig. Open the air supply valve to the nitrogen gas generator. Turn on the power circuit for the nitrogen generator at its disconnect box. Turn the main power switch on the generator control panel to the ON position. The power indicator light should be lit ON. Pressure (90–150 psig) should show on the Peak Pressure gauge. Nitrogen should begin to flow into the product tank. Initially, the product tank is filled with air. The air must be purged out of the product tank by the product nitrogen. This is accomplished by opening the drain valve on the bottom of the product tank and venting the air/nitrogen mix to the atmosphere until the product reaches 97% nitrogen (<3% oxygen as measured using an oxygen detector on the product venting from the drain valve).
2. When the product pressure reaches 75 to 80 psig, the amber light on the N-20 control panel will illuminate, and nitrogen production will stop until the product pressure falls below 55 to 60 psig. Check the product purity using the integral oxygen analyzer. Purity should be >97% nitrogen before the nitrogen is used as a purge gas. If the purity is less than 97%, vent the product from the storage tank until 97% purity is achieved. Once purity is reached and the product pressure has reached 75–80 psig, the nitrogen may be used to purge the hydrogen production, compression, and storage system.

> WARNING: Nitrogen purity must be >97% (<3% oxygen) for the gas to be used as a safe purge gas. If purity is less than 97%, a flammable mix can occur when the purge gas mixes with the hydrogen gas.

E.2.3 Hydrogen System Inert Purging

E.2.3.1 Vent Stack Nitrogen Purge

1. As part of the APS HAZOP, it was recommended to maintain a constant nitrogen purge on the vent stack. This purge is normally a low-flow purge of about 10 scfh, which will generate a nitrogen velocity in the vent stack of about 0.1 ft/s. The purge will keep ambient air from diffusing into the vent stack.
2. First, purge the hydrogen dryer. Connect the nitrogen source to valve V-169 on the inlet side of the dryer. Open valves V-104 ,-105, -107, and -108. Connect an oxygen monitor onto valve V-106 and open this valve. Flow nitrogen through both adsorber beds in the dryer. Monitor the oxygen level at V-106 until the oxygen reads 3%. At this point, the dryer has been adequately purged with inert nitrogen. Close V-169 and disconnect the nitrogen source from this valve. Replace the cap on the end of valve V-169. Close V-169 and –106, then disconnect the nitrogen source from V-169 and remove the oxygen detector from V-106.
3. Purge the remainder of the hydrogen system with the nitrogen generated by the nitrogen generator. Connect the nitrogen supply to V-109. Close V-103. Connect the oxygen detector to valve V-111, and open it to sample the contents of the LPS. Open V-109, allowing nitrogen into the piping system. Open manual valves (V-104, -105, -107). Open actuated valve SV-101, using the control system PLC (programmable logic controller) to force the outputs to the ON or OPEN status for this valve. With the manual and solenoid valves open, the LPS can be purged with the nitrogen gas. Open V-109 to start nitrogen flow into the low-pressure storage (LPS) tank.

4. Allow the nitrogen to flow into the low-pressure storage tank (Note that this tank must be purged of all hydrogen before being moved to the new hydrogen production location). The nitrogen generator can generate about 300 scfh of 97% nitrogen (3% oxygen). At this production rate, it will take about 5 days to fill the low-pressure tank to 90 psig. This amount of nitrogen is needed to purge the high-pressure storage tubes. Continue to fill the LPS with nitrogen. Connect the oxygen analyzer to valve V-111 on the LPS. Open V-111 and monitor the oxygen content of the LPS tank. The LPS should eventually reach 3% oxygen. It may be necessary to vent some of the tank content to the vent stack by opening V-110 and SV-102.

5. Once the LPS tank reaches 3% oxygen, the remainder of the hydrogen system can be purged with the nitrogen contained in the LPS. Open valves V-103, -116, -127, -128, -136, -138, -140, -141, -144, and -145 and energize actuated valves SV-103, -105, -106, -107, -109, -110, and –111, using the PLC control system. Continue to operate the nitrogen generator to keep the LPS filled with nitrogen.

6. Open valves V-132 and -133 on the chilled water supply for the PDC compressor. Allow chilled water to begin flowing through the compressor. Turn on the PDC compressor. This will pull low-pressure nitrogen out of the low-pressure storage tank and boost the nitrogen to about 6000 psig. The high-pressure nitrogen will flow to the high-pressure storage tanks (HPS) and to the process piping between the HPS tubes and the fueling dispensers. The high-pressure tubes will fill with nitrogen. These tubes have a storage capacity of about 8,900 scf per tube. They are shipped with air inside the tubes. The air must be purged out of the tubes until the oxygen level reaches 3% before hydrogen is introduced into the tube. To reduce the oxygen level in the tubes to a level that will not allow a reaction between the hydrogen and oxygen, the tubes need to be filled to at least 2000 psig with nitrogen gas. Monitor the fill pressure on PT-113 and -114. This fill pressure requires a minimum of 3,000 scf per tube to properly inert the storage tubes. The PDC compressor is capable of delivering 300 scfh of 6,000-psig gas. The flow rate of nitrogen will be somewhat lower, due to its material properties. At this flow rate, it will take a minimum of 10 hours per hydrogen storage tube to fill the tubes to 2,000 psig of nitrogen.

7. Once the high-pressure tubes are filled with nitrogen to ~2,000 psig, the PDC compressor can be shut down manually by pressing the STOP button, SW-1, on the PDC control panel. This will stop the flow on high-pressure nitrogen to the high-pressure storage tubes. Use the control system PLC to force solenoid valves, SV-101, -103, -104, -105, -107, and -109 to the closed position by deenergizing the outputs to these valves. Connect the oxygen detector to purge valve V-161. Open V-142 and adjust PCV-115 to match the inlet pressure required by the detector (2–15 psig). Close V-144 and SV-110. Begin to vent the nitrogen from the high-pressure tubes by opening manual valve V-159 and -139. Vent HPS tank 1 by opening the solenoid valves and SV-106, -108 and -111. Allow the pressure in the high-pressure storage to decrease to about 30–45 psig, then close the vent solenoid valve SV-108 and close the manual valves SV-110 and V-144. Use an oxygen detector to validate that the oxygen concentration in the gas in tube 1 is not greater than 3%. If the gas has 3% oxygen or less, the storage tank has been properly purged and is ready to be filled with flammable hydrogen. If the oxygen level is >3%, the tubes must be filled with nitrogen again and the purge/vent procedure repeated until the oxygen level is <3%. Repeat this procedure for tube 2. Close V-145 and SV-111. Open V-144 and SV-110. Energize SV-108 to the open position and begin venting the gas in tube 2 into the vent stack. Monitor the oxygen level with the oxygen detector. If the oxygen level is <3%, the tank is adequately purged. If the level is >3%, repeat the fill, purge, and vent procedure. Once tube 2 reaches <3%, vent the pressure to 30–45 psig. De-energize SV-108 to close this actuated vent valve. Close valves V-139, -142, and V-159.

E.2.3.2 Dispenser Purging

Close V-142. Connect the nitrogen supply to V-161 and open this valve. Open V-148 and -149, which supply gas to the dispenser. Open the lower door on the dispenser and adjust PR-1 to allow

N2 flow through the dispenser. Slowly (3–5 s), open PCV-3 on the instrument air supply. Open BV-1 and -2. Use the dispenser control system (DCS) to open ABV-1, -3, and -4 on the hydrogen flow run in the dispenser and allow nitrogen to flow through the dispenser and fueling hose/nozzle. Use the oxygen detector to check the oxygen level of the purge gas exiting the fueling nozzle. Continue to purge until the oxygen level is <3%. Close BV-1 and -2. Use the DCS to close ABV-1, -2, -3, -4. Adjust PR-1 to zero psig. Repeat this process for the CNG flow line in the dispenser.

E.2.3.3 Low-Pressure Storage Venting

Release the nitrogen purge from the LPS by closing V-104, -105, -109, and -116. De-energize SV-101, -103 to close these valves. Open V-110 and energize SV-102 to vent the tank to the vent stack. Watch the LPS tank pressure on OI-104 and PT-104. Allow the LPS tank pressure to drop to 15–25 psig of nitrogen. Close SV-102 and V-110 when the pressure reaches 15–25 psig. Recheck the oxygen level in the LPS by sampling at V-111. Close V-111 when sampling is completed.

E.2.4 Starting Hydrogen Generation

1. Start the Proton HOGEN 300 hydrogen generator. Switch the HOGEN's power disconnect to the ON position. Check that valves V-101 and –102, which supply instrument air and nitrogen to the HOGEN, are open. Set the pressure regulators on these supply lines by adjusting PCV-101 and -102. Open the deionized water valves that feed DI water into the HOGEN 300. Initiate start of the HOGEN by resetting the controller. Press the RESET switch on the control panel on the HOGEN. Start the generator by pressing the START button on the HOGEN panel. The generator begins an automated 5-minute start up sequence that includes an enclosure air purge for 180 s, fluids level check, ramp up of operating current to 1000 amp, start of electrolysis current and vent for 120 s, and start and check of the circulating pump for 30 s. Once this 5-minute sequence is complete, the generator will produce 300 scfh of hydrogen gas at 150 psig.
2. Start the hydrogen dryer by pressing the ON button on the dryer control panel. The dryer will set the actuated switching valves to the initial position. Saturated hydrogen from the HOGEN will enter the primary adsorber vessel, where moisture will be removed from the hydrogen.
3. Open V-104, -105, -107, -108 to the LPS. Begin hydrogen flow into the inerted low-pressure storage by opening SV-101 (initiate the START H_2 FLOW sequence or force SV-101 open with the PLC). Allow hydrogen to flow into this tank until the tank pressure (PI-104) reaches about 150 psig. At this point, the operator chooses whether to continue generating hydrogen or to shut down the generator. The HOGEN automatically begins to ramp down production as the outlet pressure nears 150 psig and will automatically shut down hydrogen production at 150 psig. The operator can continue to generate gas by starting the PDC compressor and drawing some hydrogen (300 scfh) out of the low-pressure tank. Removing this amount of hydrogen will keep the tank pressure below 150 psig and will allow the HOGEN to continue to generate (~300 scfh) hydrogen. If the operator does not start the PDC compressor, the HOGEN will automatically shut down when the tank pressure reaches 150 psig. If the operator chooses to stop the production of hydrogen, solenoid valve SV-101 should be closed (de-energized).

E.2.5 Hydrogen Fill to the High-Pressure Storage System

1. Open valves V-116, -103, -127, -128, -136, -140, -141, -144, and -145. Start the PDC compressor by pressing the START button, SW-2, on the PDC control panel. Open solenoid valves SV-103, -105 (PDC inlet and outlet) and inlet valves SV-107 and -109 on the high-pressure tubes. At this point, hydrogen will begin to flow into the high-pressure storage tubes. The pressure indicated on PI-113 and -114 and on PT-113, -114 will begin to increase. During the first fill with hydrogen, the tubes should only be filled to 150 psig. Then shut off the PDC compressor. Vent the HPS tubes to the

vent stack until the tube pressure drops to 30–45 PSIG. The vented gas will be a mix of nitrogen and hydrogen and therefore must be vented safely to the hydrogen vent stack. *Do not fill the tubes with hydrogen beyond 150 psig at first fill. The tube contains a low (3%) oxygen content. Mixing low-percentage oxygen in high-pressure hydrogen (>300 psig) can be hazardous.* Refill the tubes to 150 psig and again purge out to the vent stack. Repeat a third cycle to reduce the nitrogen content to below 1%. As the tubes are then filled to 6,000 psig with hydrogen, the nitrogen content will drop below 0.1%.

2. Once the initial hydrogen fill is completed, continue to operate the PDC to fill the tubes to 6000 psig. The PDC compressor will continue to operate and deliver high-pressure hydrogen to the storage tubes until the pressure in the tubes reaches 6,000 psig. Pressure switch PSH-203 (6,000 psig) and PSHH-203 (6,100 psig) on the compressor skid will shut off the PDC when the pressure at the outlet of the compressor reaches 6,000–6,100 psig. PSH-112 and PT-112 provide additional shutoff for the PDC at 6500 psig. PSH-112 will initiate an S-1 alarm if the pressure reaches 6,500 psig. PT-113 and PT-114 will also shut down the PDC compressor at 6,200 psig. Once the HPS tubes have reached 6,000 psig, the system is ready to deliver hydrogen to the dispenser.

E.2.5.1 Initial Hydrogen Dispensing

As with the HPS tubes, the dispenser and piping to the dispenser must be carefully filled and purged with low-pressure hydrogen to flush the nitrogen and 3% oxygen from the process lines. Open V-142 and -145 and energize SV-111. Adjust the pressure at PCV-115 to 150 psig. Open V-148 and -149 and SV-112. Start the dispenser and allow hydrogen to flow to the dispenser and out the vent line to the vent stack. Allow the hydrogen to flow for about 5 minutes at 10 scfm. This flow and duration should be adequate to flush the line of nitrogen and trace oxygen. Shut down the dispenser. The dispenser is now ready for the first vehicle fill.

E.3 STEADY-STATE OPERATION

When the system is operating at steady state, the HOGEN produces ~300 scfh of saturated hydrogen. The dryer produces 270 scfh of -80°F dew point hydrogen, and vents 30 scfh of wet hydrogen to the hydrogen vent stack. The PDC compressor delivers ~270 scfh of high-pressure hydrogen to the high-pressure storage tubes. This steady state will continue until the high-pressure tubes reach 6,000 psig. At this point, the PDC compressor will shut down. The HOGEN will continue to produce hydrogen and refill the low-pressure storage until this tank reaches ~150 psig, at which pressure the HOGEN will ramp down its production of hydrogen.

E.4 DISPENSER OPERATION

The hydrogen-fueling dispenser has two fueling hoses. One hose is set to deliver only 100% hydrogen at a maximum pressure of 5,000 psig. The second hose is set to deliver a blend of hydrogen and CNG. The driver/fueler can select either a low-hydrogen blend (H_2/CNG) or a high-hydrogen blend (H_2/CNG) for a 3,600-psig-vehicle CNG tank. The blend ratios are programmable within the control panel PLC to deliver a 5 to 50% H_2/CNG blend. Only authorized system operators can program the two (high and low) blend ratios. Once programmed, the selector switch on the fueling dispenser will only allow the driver/fueler to deliver a low or a high-hydrogen blend to the vehicle. The driver/fueler cannot change the preprogrammed H_2/CNG blend ratios at the fueling dispenser but can only select LOW or HIGH on the dispenser. This design is similar to a conventional gasoline dispenser—the driver can select the grade of gasoline desired (high test or regular) but cannot change the octane rating of the selection.

Fueling can be accomplished while the PDC compressor is operating. Hydrogen can be delivered to the fueling dispenser from either the high-pressure storage tube, from both tubes at the same time, or from the PDC compressor. Normally, the system operates as a *priority sequencing* system. The HPS tubes are filled by the PDC compressor in priority, with tube 2 filled first through SV-109, then tube 1 is filled through SV-107. In this way, tube 2 is maintained at the highest pressure to ensure sufficient high-pressure hydrogen is available to complete the vehicle fill to 5,000 psig. Sequencing valves SV-110 and -111 control the flow of hydrogen from the HPS to the dispenser. The PDC will continue to fill whichever tube is not dispensing hydrogen to the fuel dispenser until the 6,000-psig pressure switch trip point is reached. The sequencing valves are pneumatically actuated and are controlled by the dispenser control system (DCS). The selection of tube 1 or 2 depends on the flow rate required and pressure available in each tube. The system also allows direct supply of hydrogen from the PDC compressor to the dispenser through SV-106.

E.4.1 Initializing the Hydrogen Dispenser

1. Set the H2/CNG blend ratios in the control panel PLC logic. This ratio set point is password protected, so only authorized operators may change the setting.
2. Open valves V-144 and -142 and solenoid valve SV-110. This allows hydrogen to flow to PCV-115. PI-115A should read ~6,000 psig. Set the delivery pressure on PI-115 by adjusting PCV-115 to about 5,200 psig.
3. Remove the lower door on the dispenser and adjust PR-1 to 5,000 psig. Open the pneumatic ball valve (PCV-3) on the instrument air supply slowly (3 to 5 s to full open), allowing instrument air to enter pneumatic valves ABV-1, -2, -3, and -4. Replace the door and turn power to the dispenser to ON.

E.5 VEHICLE FUELING

1. Swipe the credit card through the credit card reader and wait for acknowledgement that the card has been read. Once the card is read, the control system will open solenoid valve SV-112. This allows hydrogen to flow from both storage tubes to the hydrogen fueling dispenser. (Note that the control system PLC can be programmed to draw hydrogen from one or both tubes or directly from the compressor.)
2. The card reader will verify what type of fuel the operator is authorized to use and will only enable refueling for the fuel specified. No other dispensers or nozzles will be enabled.
3. Select either the 100% H_2 nozzle or the H_2/CNG blend nozzle from the dispenser and connect the nozzle to the vehicle fueling port. If the fuel is H_2/CNG blend, select either the LOW or HIGH HYDROGEN position on the dispenser selector switch.
4. Move the ON/OFF lever to the ON position. The dispenser will sense the pressure in the fuel tank and measure the ambient temperature. The system will calculate the criteria for each fill based on the initial measurements. The dispenser then initiates the purge cycle through the fill nozzle. The blended fuel hose also opens a solenoid valve to deliver a fuel sample to the blended gas FUEL GAS ANALYZER, which checks the composition and fuel value of the blend. Once the nozzle purge sequence is completed, hydrogen or H_2/CNG starts to flow to the vehicle. The dispenser continuously monitors the pressure and temperature of the gas as it enters the fuel tank to ensure that the right amount of fuel is delivered.
5. Once the vehicle is filled to the required pressure, the dispenser will shut off the gas flow and will purge the fill nozzle. A signal from the dispenser controls also de-energizes SV-112 in the hydrogen feed line from the high-pressure storage to the dispenser. The vehicle operator may then disconnect the fill hose. The vehicle operator will then cap the fill port and hang up the hose.

E.6 STARTUP AFTER NORMAL SHUTDOWN

1. Run a test of the UV/IR flame detectors to ensure they are operating properly. Initiate a manual built in test (BIT) by pressing momentarily on push button BIT Manual Test on the central control panel. The UV/IR detectors will run through a manual diagnostic test, checking the electrical circuitry, the sensors, and the sensing window cleanliness. A successful manual BIT activates the following: fault relay is closed, the alarm relay activates for 3 s, the accessory relay is activated for 3 s, the 4 to 20-mA output will go to 20 mA (or 16 mA if only SW1-7 = on and SW1-6 = off). An unsuccessful BIT activates the following: the fault relay is released, and the 4 to 20-mA output goes to zero. And if the BIT is unsuccessful, the plant operators *must* determine why it was unsuccessful and correct the problem. The BIT must be run again until a successful test is completed.
2. Warning: *Failure to complete a successful BIT means that the flame detection system is not working properly and it will not detect a flame. Failure of the flame detectors will put personnel and property at risk and may result in injury or death to personnel. Do not proceed with the hydrogen system startup until the flame detector system is fully operational and has passed a successful BIT test.*
3. If the BIT is successful (4 to 2-mA output goes to 20 mA), the detector status returns to normal, and the flame detector system is ready to scan the area and detect a flame. Each detector must be tested and pass a successful BIT before starting the hydrogen or CNG systems. The UV/IR system must pass the BIT before you proceed.
4. Run a check of the flammable gas detection system. Ensure that the detector(s) are properly calibrated and that the alarm output is functioning properly.
5. Start up the nitrogen generator. Turn on the compressed air supply, following the air compressor's operating instructions. Check that the air pressure out is 90 to 150 psig. Open the air supply valve to the generator. Turn the main power switch to the OFF position. Turn on the power circuit for the nitrogen generator at its disconnect box. Turn the main power switch on the generator control panel to the ON position. The power indicator light should be lit ON. The pressure should show on the *peak pressure* gauge. Nitrogen should begin to flow into the product tank.
6. When the product pressure reaches 75 to 80 psig, an amber light will illuminate, and nitrogen production will stop until the product pressure falls below 55–60 psig. Check product purity, using the integral oxygen analyzer. Purity should be >97% nitrogen before the nitrogen is used as a purge gas. Once the purity is reached and product pressure has reached 75–80 psig, the nitrogen may be used to purge the hydrogen production, compression, and storage system.
7. Start the Proton HOGEN 300 hydrogen generator. Switch the HOGEN's power disconnect to the ON position. Check that valves V-101 and –102, which supply instrument air and nitrogen to the HOGEN, are open. Set the pressure regulators on these lines by adjusting PCV-101 and -102. Open the de-ionized water valves that feed DI water into the HOGEN 300. Initiate start up of the HOGEN by resetting the controller. Press the RESET switch on the control panel on the HOGEN. Start the generator by pressing the START button on the HOGEN panel. The generator begins an automated 5-minute start up sequence that includes an enclosure air purge for 180 s, fluids level check, ramp up of operating current to 1000 amps, start of electrolysis current and vent for 120 s, and start and check of the circulating pump for 30 s. Once this 5-minute sequence is complete, the generator will produce 300 scfh of hydrogen gas at 150 psig.
8. Start the hydrogen dryer by pressing the ON button on the dryer control panel. The dryer will set the actuated switching valves to the initial position. Saturated hydrogen from the HOGEN will enter the primary adsorber vessel where moisture will be removed from the hydrogen.

9. Begin hydrogen flow into the low-pressure storage by opening manual valves V-4, -5, -7, and -8 and actuating valve SV-101 (initiate the START H_2 FLOW sequence or force SV-101 open with the PLC). Hydrogen will begin to flow out of the HOGEN and through the dryer adsorber bed and then into the LPS tank. Allow hydrogen to flow into this tank until the tank pressure (PI-104) reaches about 150 psig. At this point, choose whether to continue generating hydrogen or to shut down the generator. The HOGEN automatically begins to ramp down production as the outlet pressure nears 150 psig and will automatically shut down hydrogen production at 150 psig. You can continue to generate hydrogen gas by starting the PDC compressor and drawing some hydrogen (300 scfh) out of the low-pressure tank. Removing this amount of hydrogen will keep the LPS tank pressure below 150 psig and will allow the HOGEN to continue to generate hydrogen (~300 scfh). If you do not start the PDC compressor, the HOGEN will automatically shut down when the LPS tank pressure reaches 150 psig. If you choose to stop the production of hydrogen, then close solenoid valve SV-101 (to de-energize).
10. Open valves V-116, -103, -127, -128 , -136, -140, -141, -144, and -145. Start the PDC compressor by pressing the START button, SW-2, on the PDC control panel. Open solenoid valves SV-103, -105 (PDC inlet and outlet) –107, and -109 (the inlet valves on the high-pressure tubes. At this point, hydrogen will begin to flow into the high-pressure storage tubes. The pressure indicated on PI-113 and -114 and on PT-113 and -114 will begin to increase.
11. The PDC compressor will continue to operate and deliver high-pressure hydrogen to the storage tubes until the pressure in the tubes reaches 6,000 psig. Pressure switch PSH-203 (6,000 psig) and PSHH-203 (6100 psig) will shut off the PDC when the pressure at the outlet of the compressor reaches 6,000–6,100 psig. PSH-112 provides an additional shut off for the PDC at 6,000 psig. PSH-112 and PT-112 provide an additional shutoff for the PDC at 6,500 psig. PSH-112 will initiate an S-1 alarm if the pressure reaches 6,500 psig. PT-113 and -114 will also shut down the PDC compressor at 6,200 psig. Once the HPS tubes have reached 6000 psig, the system is ready to deliver hydrogen to the dispenser.

E.7 EMERGENCY SHUTDOWN

1. Emergency shutdown (ESD) can be initiated from the control room or from any of the remote ESD red mushroom head ESD buttons located throughout the facility
2. When an emergency shutdown is initiated, it will:
    - De-energize and close all actuated valves in the hydrogen system, isolating and capturing the hydrogen within the storage vessels and process piping.
    - Stop the PDC compressor drive motor (if operating).
    - Shut off the fueling dispenser, closing all valves in the dispenser.
    - Shut off the air compressor feeding the nitrogen generator.
    - Shut down the HOGEN 300 by interrupting the signal into the unit on terminal/port J102. This will cause the generator to shut down and vent the hydrogen out of the unit into the vent stack.
    - Keep the UV/IR flame detectors energized and operating.
    - Keep all visual and audible alarms operating.
    - Keep the flammable gas detector operating.
    - Maintain all pressure transmitters and switches, temperature transmitters and switches, flow transmitters and switches operating, so that the operators in the control room can monitor the process conditions in the hydrogen system.

- Maintain the data output from the HOGEN 300 through data port J101.
- Maintain power to the nitrogen generator except for the feed air compressor. The nitrogen generator may be shut down by turning the main power switch on the generator to the OFF position.
- Maintain lighting in the area.
- Maintain power to the control room panel and communication system.
- Initiate an S-2 alarm with callouts to APS plant management and local emergency response personnel. See Alarms above (Section C.1.4).

In the event of an emergency shutdown, plant personnel should attempt to determine its cause and then determine what emergency response actions are required. This may include evacuation of the site and surrounding areas if deemed necessary by plant personnel. The ESD will initiate an immediate emergency response by Arizona Public Service security and plant personnel to assist emergency response teams into the facility and provide them with information regarding the nature of the cause for the ESD.

E.7.1 OPERATION OF THE HELIUM PURGE SYSTEM

The helium purge system is used for fire suppression in the event a fire occurs in the hydrogen vent stack. System operation can be initiated from a remote location by pressing the Helium Purge ON button on the control panel. This will open the actuated valve on the purge system, allowing helium to flow into the vent stack. This inert gas purge will suppress the hydrogen flame. There is also a backup nitrogen purge that can be manually opened to maintain an inert purge to the stack.

E.7.2 OPERATION OF THE FIRE SPRINKLER SYSTEM

The gas building and the adjoining auxiliary equipment room are equipped with a water sprinkler system in the event of a fire. A fusible link in the sprinkler head ensures automatic flow of water into the area of a fire. This system is not intended as a fire fighting measure but rather provides a means to keep equipment and storage vessels cool until the supply of fuel is exhausted. If the system is tripped, it will initiate an automatic call to local fire companies.

E.7.3 CONNECTIONS FOR FIRE DEPARTMENT HOOKUPS

There are two fire hydrants available to the fire department. The first hydrant is about 100 ft east of the gas building and about 50 ft east of the dispensing station. This hydrant is located on Arizona Public Service property within the 501 facility yard area. A second hydrant is located on 2nd Avenue, immediately south of the gas building.

E.8 NORMAL SHUTDOWN

Normal shutdown is defined as a system shutdown conducted in a managed, controlled fashion to bring the hydrogen system to a static condition in which the HOGEN is not generating hydrogen, the PDC compressor is not operating, and the storage and dispensing systems are inactive. In normal shutdown, the sensing devices and control circuits remain active so that the operators in the control room can monitor the status of the hydrogen system and the flame and flammable gas detectors. In normal shutdown, the active elements of the subsystems will be shut down (hydrogen cell stack, dryer, compressor, fuel dispenser).

In normal shutdown, follow this sequence:

1. Shut down the HOGEN 300 hydrogen generator by depressing the red STOP button on the control panel of the generator (or from a remote location by interrupting the J102 terminal). This will remove all dc power from the cell stack, preventing generation of any hydrogen. The hydrogen gas in the generator will vent to atmospheric pressure through the hydrogen vent stack. The water in the generator will drain if the ambient temperature is below 40ºF. All valves in the generator will revert to their unpowered state, resulting in venting and depressurization of the HOGEN.
2. Allow the HOGEN to complete its shutdown and cool down (about 15 to 30 minutes); then, turn off the chiller.
3. Close all solenoid valves in the hydrogen process piping by de-energizing these valves. Close select manual valves if the shutdown is for an extended time (weekend) such as V-103, -108, -110, -111, -116, -127, -142, -148, -149. These valves will isolate the storage tanks and the fuel dispenser.
4. Turn off the power to the fueling dispenser by turning the power switch on the dispenser to the OFF position (note that this will de-energize all electrical items in the dispenser and will de-energize the electrical output from the sensors in the dispenser.
5. Shut down the PDC compressor by pressing the STOP button. This will allow all controls and sensors to remain active in the compressor skid. *You may completely de-energize the PDC by switching the electrical disconnect for the PDC to the OFF position.*
6. Turn off the feed air compressor to the generator. Turn off the nitrogen generator by turning the main power switch to the OFF position.
7. Turn off the hydrogen dryer by pressing the STOP button on the control panel.

E.9 EXTENDED SHUTDOWN

An *extended shutdown* is one that will persist for an undetermined length of time but greater than 2 weeks. It is not a shutdown for weekends or holidays. Generally, in an extended shutdown the storage tanks and tubes that contain hydrogen will be de-pressurized to about 10–15 psig of hydrogen gas. For a very long shutdown period, or for major maintenance, the storage tubes/tanks should be de-pressurized and then purged with nitrogen until the atmosphere in the process piping and tanks/tubes is below 3% oxygen and below 25% of the LEL for hydrogen. The nitrogen pressure in the system should be set at about 10–15 psig.

All safety systems, UV/IR detectors, and flammable gas detectors should remain active during the extended shutdown until or unless the hydrogen system is completely shut down and purged with nitrogen. Only then should the safety systems, flame detectors, and flammable gas detectors be decommissioned (note that if the CNG system is still active, all of the safety systems, flame detectors, flammable gas detectors must remain active. It is recommended that these systems remain active even if the hydrogen and CNG systems have both been shut down and nitrogen purged. Operators must make an informed decision as to whether to shut off the safety systems, gas detectors, and flame detectors).

1. Turn off power to each subsystem.
   - Turn the main power switch on the nitrogen generator to OFF. Switch the power disconnect to OFF.
   - Turn the power switch on the fueling dispenser to OFF. Switch the power disconnect to OFF.
   - Press the STOP button on the PDC compressor. Switch the control panel power disconnect handle to OFF. Switch the main power disconnect to OFF.

- De-energize all solenoid valves.
- De-energize all process gas sensors, transmitters, and switches.

2. Close all manual valves. Check the pressure in each subsystem by looking at the local gauge and reading the pressure on the transmitters at the control panel. If there is excess pressure, then safely bleed the pressure to vent until the pressure is 10–15 psig.
3. Lock out and tag out all electrical disconnects.
4. Lock out select manual valves.
5. Secure the area.

APPENDIX F – FLAME SCANNERS AND SENSORS

Figures F.1 and F.2 depict the gas detector scan footprint (blue). The six combustible gas detectors monitor both hydrogen and natural gas levels in the equipment room in 1% increments of lower flammability limit (LFL). An alarm condition exists if 25% of LFL for either hydrogen or natural gas is reached. An emergency shutdown (ESD) is initiated when 50% LFL is reached for either hydrogen or natural gas.

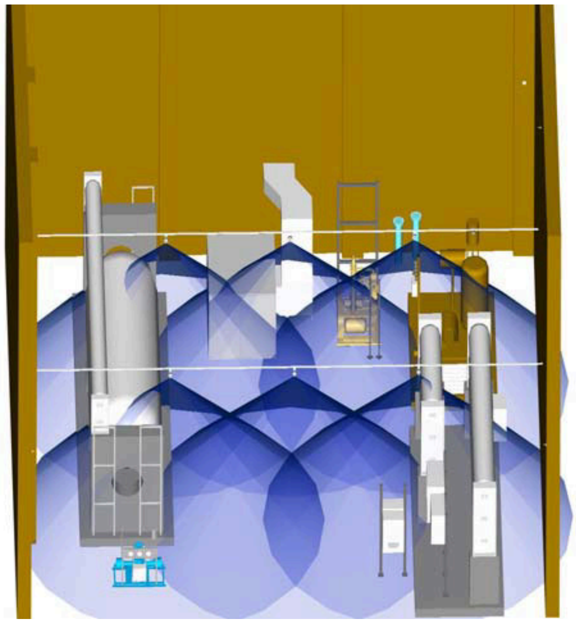


Figure F.1. Gas detector scan footprint (overhead).

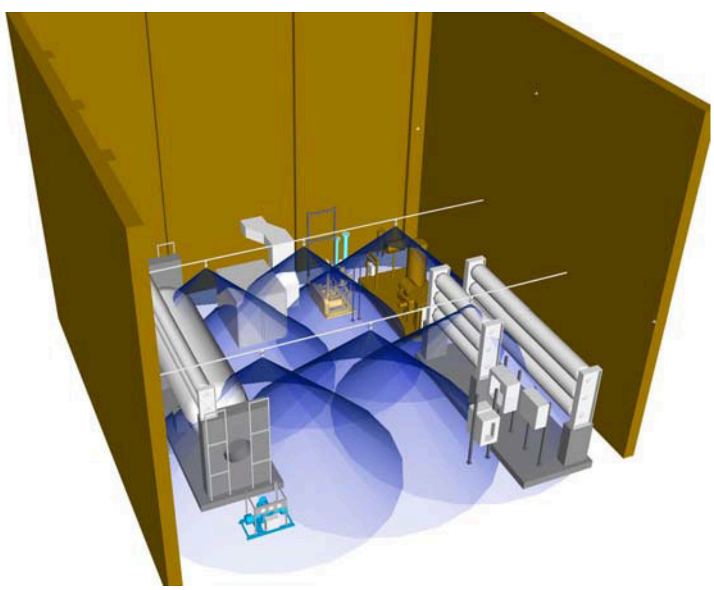


Figure F.2. Gas detector scan footprint (oblique).

Figure F.3 depicts the high-level IR/UV flame scanner footprint (red). The two scanners located mid-depth at a level of 35 ft above the floor elevation monitor the foot print space for sources of infrared or ultraviolet radiation. If a flame is detected, an ESD is initiated within 3 milliseconds.

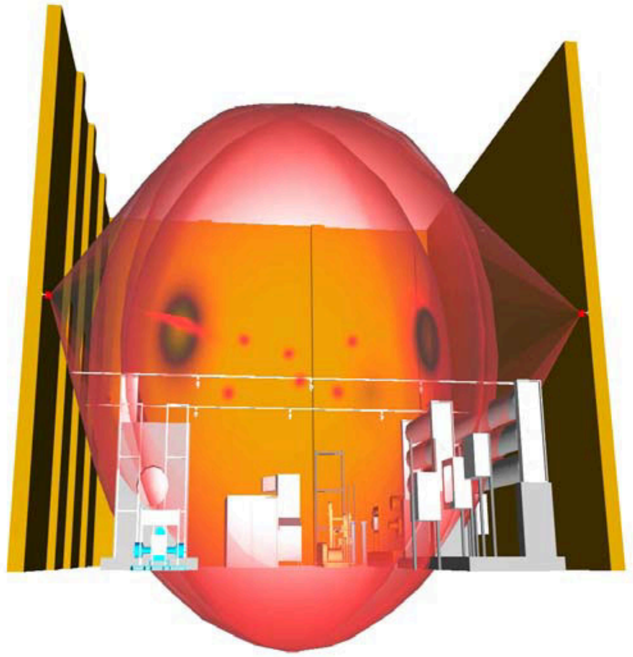


Figure F.3; IR/UV High Level Scanner Footprint (ground level)

Figure F.4 depicts the high-level IR/UV flame scanner footprint (red). The two scanners located mid-depth at a level of 35 ft above the floor elevation monitor the foot print space for sources of infrared or ultraviolet radiation. If a flame is detected, an ESD is initiated within 3 milliseconds.

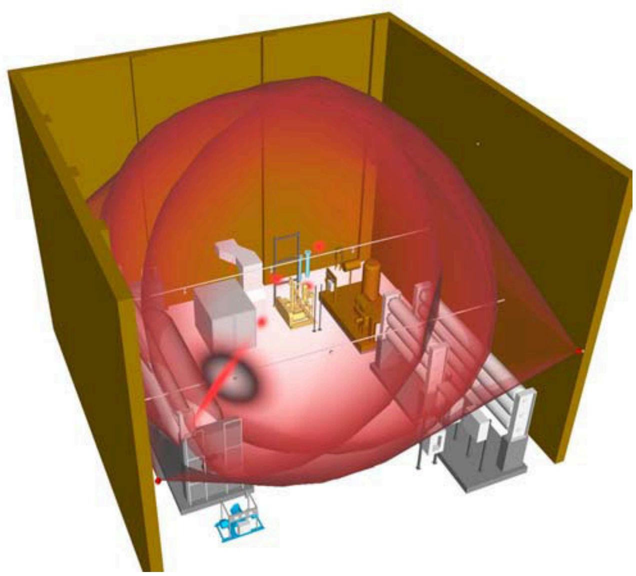


Figure F.4. IR/UV high-level scanner footprint (oblique).

Figure F.5 depicts the corner IR/UV flame scanner footprint (red). The four scanners located at the room corners at a level of 13 ft above the floor elevation monitor the foot print space for sources of infrared or ultraviolet radiation. If a flame is detected, an ESD is initiated within 3 milliseconds.

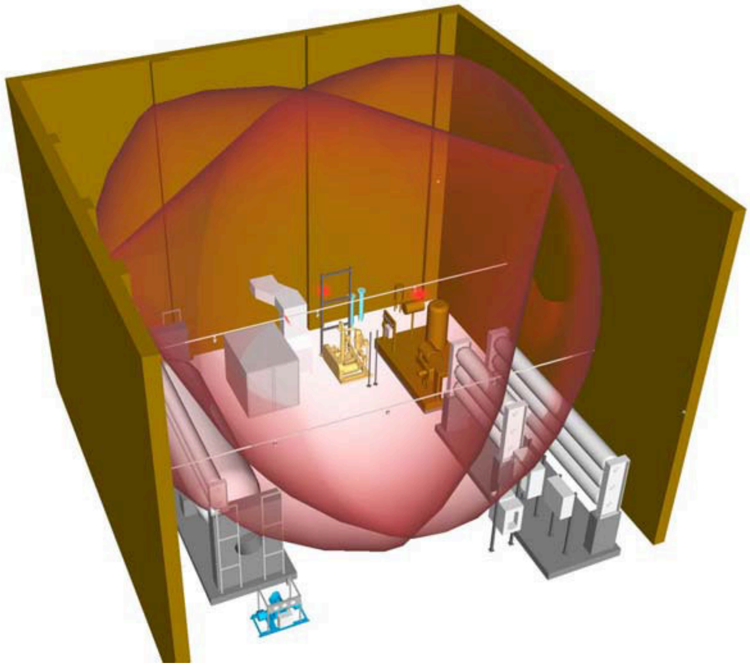


Figure F.5. IR/UV corner scanner footprint (oblique).

Figure F.6 depicts the corner IR/UV flame scanner footprint (red). The four scanners located at the room corners at a level of 13 ft above the floor elevation monitor the foot print space for sources of infrared or ultraviolet radiation. If a flame is detected, an ESD is initiated within 3 milliseconds.

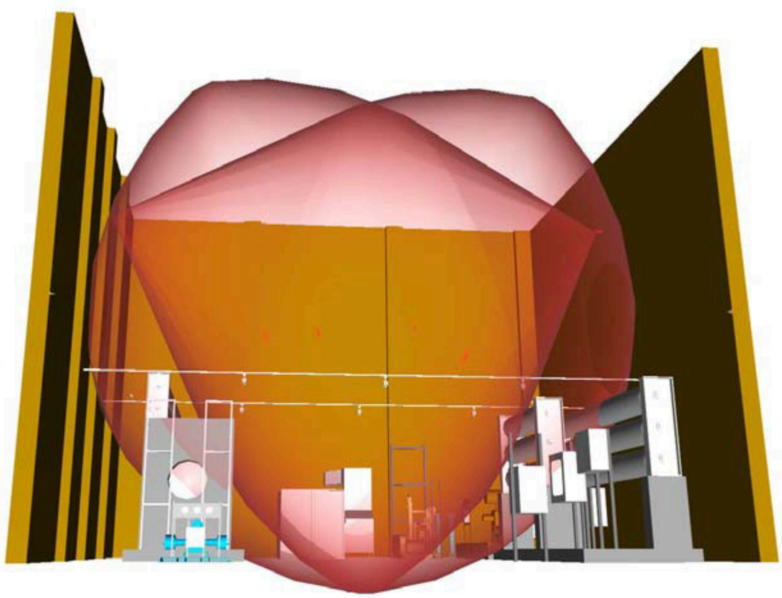


Figure F.6. IR/UV corner scanner footprint (ground level).

APPENDIX G – COMPRESSED NATURAL GAS SYSTEM OPERATIONS

Rev. 0, July 9, 2001

G.1 NORMAL STARTUP

To conduct normal startup, proceed as follows:

1. Open the supply from Southwest Gas (V-101) and activate AOV-102.
   a. Open one filter (V-105/V-108 or V-109/V-112), with the other filter line closed and filter drains closed.
   b. Verify that the SWG supply pressure is 30 psi (PI 104 and PI 118).
   c. Verify that the blowdown filter is set to drain.
2. Open the by-pass supply to Gemini V-119 and V-18.
3. Gemini discharge valve configuration:
   a. Open V-19, -20, -20A.
   b. Valve into operation one set of coalescening filters:
      Open V-21 and V-22 and Close V-23 and V-24
      Or Close V-21 and V-22 and Open V-23 and V-24.
4. Open V-25 at fill and dispenser cabinet 1.
5. Optional the booster blower or Hy-Bon compressor:
   a. Open the suction valve to the booster compressor (V- 116) and booster compressor discharge valve V-120.
   b. Go to electric panel HB; put breaker 7 to ON, local disconnect to ON at Hy-Bon compressor.
   c. Start the booster compressor by pushing ON at the compressor; observe discharge pressure at 55 psig.
6. Go to electric panel H1; put switch breaker to ON, local disconnect switched to ON.
7. Go to the Murphy panel; reset the alarm panel, switch key to H (hand) or A (automatic).
   a. When power is first applied to the Murphy panel, there is a power up delay of 30 s. This delay is to ensure that line voltage is within parameters; if there is a momentary loss of power during this delay, the sequence will reset and start over automatically.
   b. The air-operated valve on the Gemini compressor will activate the buffer tank to by-pass.
   c. The compressor inlet valve will open and the compressor will start. The first stage should reach 180 psi immediately.
   d. The Gemini compressor output bypass to the buffer tank will open SV 13.
   e. The compressor starts (run signal failure timer is 5 s, fixed). The hour meter is started after the run signal failure timer expires.
   f. The inlet valve opens SV-14.
   g. The buffer tank blowdown valve closes SV-11 (blowdown timer is 30 s, adjustable).
   h. The compressor output by-pass closes SV-13, and SV-12 opens.

i. The compressor is now running loaded.

j. The blowdown valve (SV-14) will automatically open after 45 minutes (adjustable) for 5 seconds (adjustable), and then close. The blowdown valve will continue to automatically cycle through the compressor operation. While the blowdown valve is open, the Class P shutdowns will be disarmed; when the blowdown valve closes, the Class P timer will time and rearm the Class P shutdowns.

k. The compressor will operate until a Stop signal is initiated at the Murphy panel, or there is an automatic shut down, or the key switch on the Murphy panel is turned to OFF.

l. The Stop signal will initiate the cool-down timer (5 s), as the blowdown valve is opened. The compressor suction inlet closes (time adjustable) with the command to close the blowdown valve. By adjusting these delays, the inlet valve can be closed while the motor is still running, or after the motor stops. The blowdown valve can be closed any time after the motor stops.

To resume operation after an abnormal shutdown, the condition creating the shutdown must be corrected. Then, the system must be reset by turning the OFF/HAND/AUTO from the AUTO or HAND position to the OFF position; wait for at least 2 s, then switch back to AUTO or HAND.

When more than five complete START – STOP cycles occur, a common short-cycle shutdown will initiate (number of cycles is adjustable. High START-STOP cycles usually indicate a leak in the downstream piping.

System parameters under normal and shutdown conditions are shown in Table G-1.

Table G-1. Normal operation.

	Normal	Shutdown
Booster Blower		
Booster suction pressure	30 psi	
Booster discharge pressure	55 psi	
Gemini Compressor		
Oil pressure	45–55 psi	25 psi
Gemini suction pressure	55 psi	30 psi
Gemini suction temperature	80ºF	
Gemini 1st stage discharge pressure	237 psi	Lo 180 psi; Hi 300 psi
Gemini 1st stage discharge temperature	300ºF	
Gemini 2nd stage suction temperature	120ºF	
Gemini 2nd stage discharge pressure	593 psi	Lo 500 psi; Hi 600 psi
Gemini 2nd stage discharge temperature	249ºF	
Gemini 3rd stage suction temperature	120ºF	
Gemini 3rd stage discharge pressure	1674 psi	Lo 1550 psi; Hi 1800 psi
Gemini 3rd stage discharge temperature	266ºF	
Gemini 4th stage suction temperature	120ºF	
Gemini 4th stage discharge pressure	5069 psi	
Gemini 4th stage discharge temperature	277ºF	
CNG compressor discharge temperature	120ºF	
CNG compressor discharge pressure	5000 psi	

G.2 ROUTINE MAINTENANCE

Daily maintenance requirements are as follows:

- Check the Gemini compressor oil level in the sight glass and makeup tank. Add oil as required.
- Check the Gemini lubricator cycle indicator for operation. Adjust as necessary.
- Check the Gemini oil pressure. If it is below 25 psi, shut down the compressor and contact a service representative.
- Check the differential pressure in the natural gas supply filters and blowdown.
- Check each discharge temperature gauge of the Gemini Compressor for abnormal operating temperature. If it is consistently above 325ºF, contact a service representative.
- Check the compressors for oil and gas leaks. If leaks are detected, identify the location, shut down equipment, and repair the leak.
- Check the differential pressure across the compressor outlet filters and blowdown.
- Check for normal operating pressures from each compressor stage and storage tanks.
- Blow down each tank of gas storage as needed.
- Check the differential pressure across dispenser filters and blowdown.

Table G-2 lists the equipment lubrication requirements.

Table G-2. Equipment lubrication.

Equipment Mfg	Model	Lubricant	Quantity
Compressor Gemini	Model HPSS-125 Unit No. 11316 SN C4708 4-stage, 300 cfm	Normal operation: SAE 40 weight, ISO 150 grade rust and corrosion inhibited, anti-wear.	Crankcase: 23 quarts
Compressor Motor U.S. Motors	125 hp, 1760 rpm 480 V, 200 amp, 3 phase SN X783119	Grease:	As required
Blower ac compressor (Hy-Bon Assembly)	Model 8 DB (AC8DB) SN 4002-79606-1 Hy Bon SN 7302	Normal operation: ISO 50 grade, rust and corrosion inhibited	Crankcase 8 quarts
Motor Blower Worldwide Electric Corporation (China)	40 hp, 1775 rpm 480 V, 46 amp, 3 phase TEFC Class F Model WW40 324T	Grease:	As required
Instrument Air Quincy Compressor	Model 0005012D00173 SN 5143613 5 hp, 120-gal storage vessel Duplex 3 phase	0–32 F SAE 10W ISO 32 32–80 F SAE 20 ISO 68 60–104 F SAE 30 ISO 100	1.5-liter each
Motor Instr. Air (2) Baldor	Model EM3218T SN F0103264539 SN F0103264594 5 hp, 480 V 3-phase 6.4 amps	Grease:	As required

APPENDIX H – CODES AND STANDARDS

Research into the applicability of codes and standards for a facility to generate hydrogen shows that there is no comprehensive standard governing the design of such facilities. The Idaho National Engineering and Environmental Laboratory (INEEL) reports that "There are no specific codes pertaining to the generation of hydrogen and few recommended practices dealing with hydrogen refueling; however, there are numerous standards dealing with hydrogen as an industrial gas." There are several industry standards and recommended practices, however, that apply to the components of such systems, such as the ASME Boiler and Pressure Vessel Code, Section VIII, "Rules for the Construction of Pressure Vessels." In some cases, these standards are referenced by other codes, and in other cases have been adopted based on the judgment of the design professional or Pinnacle West.

No comprehensive standard exists for dispensing gaseous hydrogen fuel. Some limited research has been completed by the National Energy Laboratories in Idaho and Colorado; however, this new technology does not yet have a corresponding common set of rules. The INEEL report goes on to state that "Guidance from natural gas vehicular fuel codes is considered appropriate for ensuring safety of hydrogen handling, as long as hydrogen's unique physical and combustion properties are accounted for when following that guidance." This project has, therefore, adopted NFPA 52, applying the CNG dispensing standards to the hydrogen dispensing, based on the fact that both are "lighter than air, low-energy, spark-ignitable gases."

The Alternative Fuels Pilot Plant was designed in accordance with the requirements of the following codes and standards:

American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII, "Rules for the Construction of Pressure Vessels."

American Society of Mechanical Engineers Code for Chemical Plant and Petroleum Refinery Piping, B31.3.

Compressed Gas Association Standard for Hydrogen Piping at Consumer Locations, G5.4.

Compressed Gas Association Standard for Hydrogen Vent Systems, G5.5.

Compressed Natural Gas Vehicular Fuel Systems Code, NEPA 52, 1998 edition.

Guide for Venting of Deflagrations, NFPA 68, 1998 edition, where the basic assumptions of the NFPA 69 model for evaluating a deflagration apply to this structure.

National Electric Code, NFPA 7, 1996 edition, as adopted by the City of Phoenix.

Standard for Gaseous Hydrogen Systems at Consumer Sites, NEPA 50A, 1999 edition, with selective application to a hydrogen generation process.

Uniform Building Code, 1997 edition, as adopted by the City of Phoenix.

Uniform Fire Code, 1997 edition, as adopted by the City of Phoenix, Articles 52, 80, and Standard 52-1.

Uniform Mechanical Code, 1997 edition, as adopted by the City of Phoenix.

Uniform Plumbing Code, 1997 edition, as adopted by the City of Phoenix.

At the outset of this project, a code analysis site plan was developed, showing all of the existing buildings on the east side of Second Avenue at the 501 Facility of Arizona Public Service. As part of this effort, each of the buildings was examined visually to determine its construction type, occupancy, and fire protection features. This analysis was given to the City of Phoenix for review and comment, and the comments received from the City of Phoenix were incorporated into the design of the Alternative Fuels Pilot Plant.