APPENDIX C – GASEOUS HYDROGEN PIPING SPECIFICATION

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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.