FINAL REPORT

VIII.D Energy Station

VIII.D Research and Development of a PEM Fuel Cell, Hydrogen Reformer, and Vehicle Refueling Facility

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City of Los Vegas, Las Vegas, NV

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Executive Summary

Air Products and Chemicals, Inc. has teamed with Plug Power, Inc. of Latham, NY, and the City of Las Vegas, NV, to develop, design, procure, install and operate an on-site hydrogen generation system, an alternative vehicle refueling system, and a stationary hydrogen fuel cell power plant, located in Las Vegas.

The facility will become the benchmark for validating new natural gas-based hydrogen systems, PEM fuel cell power generation systems, and numerous new technologies for the safe and reliable delivery of hydrogen as a fuel to vehicles. Most important, this facility will serve as a demonstration of hydrogen as a safe and clean energy alternative. Las Vegas provides an excellent real-world performance and durability testing environment.

The project has contributed to the achievement of two DOE technology milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 11 – Validate cost of producing hydrogen in quantity of $3.00/gge untaxed based on DOE's H2A model:** Results achieved and lessons learned from this project were applied to the Penn State Fueling Station, assisting in the progress on this milestone under that project.
- **Milestone 15 – Validate co-production system using 50 kW fuel cell, hydrogen produced at $3.60/gge and electricity at 8 cents/kW hr based on DOE's H2A model:** Results of the demonstrated testing of the distributed production of hydrogen for this project in concert with Detroit Edison (DTE) testing of a fuel cell in another DOE project validate the capability to achieve this milestone as defined by the HFCIT Multi-Year RD&D Plan.

The DOE Hydrogen Fuel Cells and Infrastructure Technology Program's Multi-Year Program Progress targets are obtainable when the technologies are adopted in sufficient numbers to achieve manufacturing economies of scale.

The Energy Station has proved to be a viable operational concept. To date, the station has safely serviced as many as 6 vehicles (fuel cell vehicles + HCNG converted, full-sized vans) for the CLV. In addition, the fuel cell has provided a use for hydrogen during low levels of vehicle fueling demand. Finally, the project has provided a significant source of development opportunities, given the applied technology demonstration in a real-world environment (see Design Issues and Recommendations below). Lessons learned have been incorporated into the Penn State Hydrogen Fueling Station project. Future directions are to support CLV fleet expansion as applicable and to continue to provide the public with a positive demonstration of the safety, convenience, and economical use of hydrogen as a fuel for vehicles.

Project Overview

Three organizations, Air Products a Chemicals, Inc., Plug Power Inc., and the City of Las Vegas, have teamed to develop, design, procure, install, and operate an alternative vehicle refueling station, and a stationary hydrogen fuel cell power plant, located in Las Vegas.

Small-scale, on-site hydrogen production technology that can operate on readily available fuels such as natural gas will be required to provide hydrogen fueling stations where delivered hydrogen is not readily available. Small-scale, natural gas-based hydrogen reformers are not fully developed, and will suffer from poor economics due to their scale and due to poor utilization rates. One approach to achieving high utilization rates on the reformer is to baseload it with a stationary fuel cell that produces electric power while the intermittent vehicle-fueling load, and resulting demand shortfall, is handled by diverting a portion of the hydrogen from the fuel cell to the fuel station. This co-production of hydrogen fuel and electric power is referred to as an "Energy Station."

The *objectives* of the project were to:

- Advance the technology and validate the viability of an alternative refueling station for dispensing H_2/CNG blends and pure H_2 to vehicles.
- Design, construct, install and operate a H_2-fueled stationary 50kW fuel cell.
- Maintain safety as a top priority for the fueling station and fuel cell.
- Evaluate operability, reliability, and economic feasibility of an integrated power-generation and vehicle-fueling system.
- Obtain adequate operational data on the fuel station to provide a basis for future commercial fueling station designs.

The *accomplishments* of the project were:

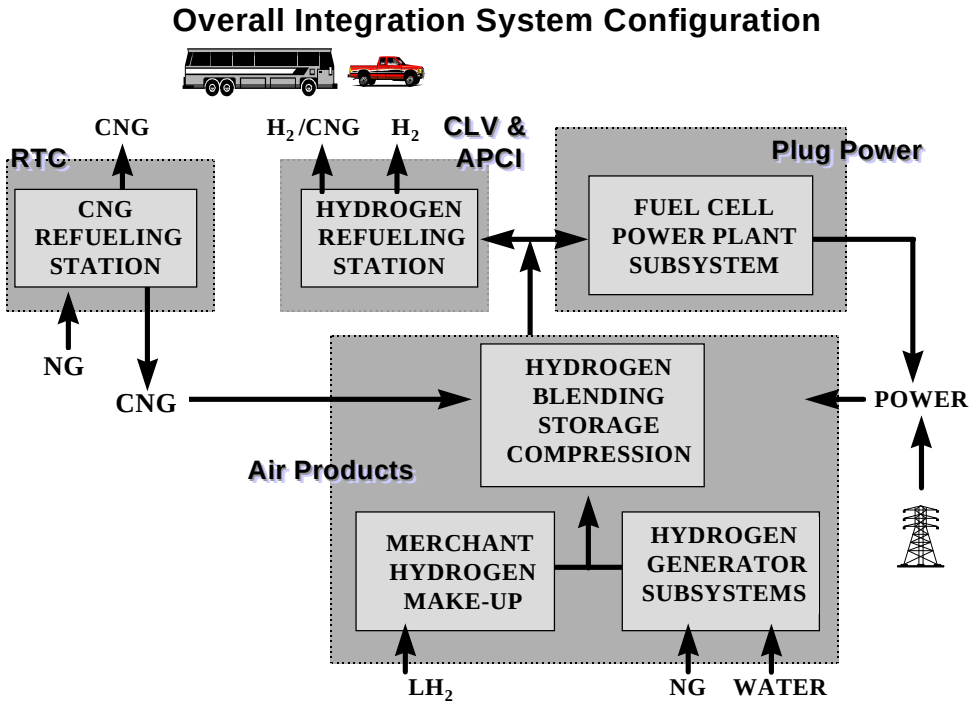
- Achievement of satisfactory process operation and product purity capability with the hydrogen generator, with one-button start and load-following capability.
- Achievement of aggregate hydrogen generator operation of over 4800 hours.
- Achievement of lower heating value (LHV) efficiency of 68%, with hydrogen purity at<1 ppm CO.
- Identification and implementation of system improvements under real-world performance and durability testing experience.
- Successful performance of over 200 HCNG blend and hydrogen vehicle fuelings.
- Achievement of safe operation during operating period; safe operation provided by the safe engineering, design, fabrication and utilization of the station.
- Updating of economic models to incorporate latest fuel cell data and reformer efficiencies. H_2 pricing of $3.54/kg and electricity pricing of $0.08/kWh are possible with a 1500 kg/day plant using H2A modeling. (H2A, which stands for Hydrogen Analysis, is a model developed by DOE to leverage the combined talents of industry analysts and stakeholders in order to improve transparency and consistency in the approach to analyzing a multitude of hydrogen pathways. The model provides a standardized approach and set of assumptions for estimating the life cycle costs of hydrogen production and delivery technologies and the resulting cost of hydrogen.)

Project Activity Summary

Introduction

Figure 1 is a block diagram of the refueling facility. In addition to the on-site hydrogen generation, a liquid hydrogen supply system was installed to satisfy initial demand for hydrogen at the refueling station, and to provide backup supply for additional system reliability. The hydrogen compression, storage, blending and dispensing system is capable of supplying pre-determined blends of H_2 and compressed natural gas (CNG) to be dispensed to trucks and buses with internal combustion engines (ICEs) that have been converted to run on H_2/CNG mixtures. The station is also able to dispense pure hydrogen to vehicles. Initially four light duty vehicle (LDVs) and one para-transit bus were being fueled with the H_2/CNG blend.

Figure 1



Approach

Early in the project, Air Products evaluated various small-scale developmental natural gas reformation technologies via extensive laboratory and field-testing. These technologies included partial oxidation, auto thermal reforming and steam methane reforming. The test results were the basis for technology selection for the steam methane reformer (SMR) fuel processor. These on-site options were evaluated on a total cost to serve proprietary economic model. The model includes capital, operating and maintenance costs. The steam methane reformer was determined to provide the lowest potential cost to serve. The SMR fuel processor was constructed by Harvest Energy Technologies and integrated with a PSA system supplied by QuestAir to develop the on-site system capable of generating pure hydrogen from natural gas.

Plug Power developed and provided a 50 kW fuel cell for the project. The fuel cell was built by assembling eight 7.5 kW residential fuel cell stacks that were being developed by Plug Power for the residential power market. The residential system was designed to operate on reformate, and thus modifications were required for the pure hydrogen service in this project. Extensive testing of the fully assembled module at Plug Power's Latham, NY facility was conducted to qualify individual systems and the final system configuration.

The fuel station design was based on previous H_2 and H_2/CHG fueling station experience. Extended duration operation of the fully integrated hydrogen-generation, fuel-cell, fuel-station system was conducted to address robustness, performance, and economic feasibility of the "Energy Station" concept.

Tasks Completed

Year 2000

Task 1 Design and Development

1.1 Finalize Project Plan

The final Project Management Plan was completed and submitted to DOE in June 2000. The Plan included the development of the hydrogen demand table based on vehicle buildup at the site and the proposed cost revisions that resulted from the project scope definition and re-evaluation. It was recommended to DOE that the Metal Hydride Compressor portion of the project be eliminated. Detailed economic reviews indicated that the compressor was technically feasible, but could not be made economically, even if it achieved its goals. In addition, it was recommended that a decision point to construct a commercial hydrogen generator be established for August 2001.

1.2 Reformer Design and Development

Prototype unit start-up, Operational Readiness Inspection (ORI) and shakedown were completed. Modifications to improve ignition and start-up control, initial and operational testing to complete detailed safety reviews and allow for unmanned operation, and testing to allow for demonstration of soot-free operation permitted the project to proceed through the initial key decision point. Testing of the reactor and the PSA achieved continuous operation records, and all runs exhibited good steady-state operating conditions during both attended and unattended periods of operation. Issues related to the generator's licensing and capital cost led to a revised objective to provide a scaleup generator smaller than the 6000-8000 scfh capacity unit specified in the original project proposal. The smaller unit was expected to be more in line with the hydrogen demand required by the refueling station and future commercial applications. The design specifications for the refueling station are provided in Appendix A (CLV Fact Sheet).

1.3 50 kW PEM Fuel Cell System

A major change in design concept for the fuel cell was made from "automotive" to "residential" to increase system reliability and reduce the development and production cycle. Plug Power completed the design of the power conditioning/grid interconnect subsystem.

1.4 CLV Refueling Station/Subsystem Integration
All major refueling components were fabricated, and the equipment arrangement and foundation design for the refuel station were developed and forwarded to the CLV for incorporation into the basic site and civil construction package. A hazard and operability safety review of the station piping and instrumentation design was also conducted. CLV began development of its overall site plan and utility connections for review with the city planning and permitting departments. For a detailed depiction of the equipment arrangement and utility supply for the site, refer to Appendix B.

Year 2001
Task 2 Construction and Installation
2.1 Reformer Subsystem
A fully integrated auto thermal (ATR)-based prototype H_2 generator was completed and successfully tested at Air Products' laboratories to demonstrate the technical viability of the technology. The unit ran for 150 and 120 hours, met design H_2 purity and burned tail gas sufficiently. Several operational issues around heat and waste gas management were resolved as part of meeting this major milestone. Steam coil replacement on the waste gas burner was necessary to bring the unit back to operation during testing; the problem was thought to have been related to the wastewater treatment system. In addition, there were control problems on the system, but they were resolved. Air Products also completed an internally funded study on the competitiveness of various reformer technologies, and concluded that the steam methane reformer (SMR) technology was more economical than ATR technology at this size range to generate pure hydrogen. Harvest Energy Technologies was identified as an SMR technology vendor, and procurement was initiated for the next-generation unit at a nominal 100 kW size.

2.2 50 kW PEM Fuel Cell
The design of the 50 kW fuel cell residential system recommended by Plug Power was completed. The design minimizes technical, schedule, field support and cost risk. Testing of the various parts of the system was completed. Nevada Power approved the grid interface, including the design of the interconnection of the fuel cell with the grid at the project site.

2.3 Refueling Station
Air Products completed the fuel station design, and various equipment components were fabricated. Refer to Appendix C for Piping and Instrumentation Diagrams and flow schematics for the fueling station. Process and design hazards and operability (HAZOP) reviews were completed, and CLV completed the electrical supply design for the project site. A typical demand profile is provided in Appendix D.

Year 2002
2.1 Reformer Subsystem
In 2001, the fully integrated auto thermal (ATR)-based prototype experienced ongoing operational issues requiring several changes. Following the changes, a full characterization of the ATR was completed at Air Products. However, based on both an economic analysis concluding that SMR technology was more economical than ATR to generate pure hydrogen at 50-100 kW and the recurring maintenance issues, it was decided not to install the ATR-based generator in Las Vegas. Instead a 100 kW, 3000 SCFH hydrogen SMR based on technology from Harvest Energy Technologies was developed and tested. Lessons learned in the ATR development were incorporated into

the SMR, including one-button start capability, improved PSA recovery and recycle of off-gas. The unit was installed, commissioned and placed into operation in the summer of 2002, and on-spec hydrogen production, with a purity of 99.5%, was established. Successful operation was achieved without process modification.

2.2 Fuel Cell

Full assembly and testing of the 50 kW fuel cell stack comprising eight 7.5 kW stack modules was carried out at Plug Power. Initial start-up and qualification testing yielded several design changes related to component selection, control and electronic equipment, software algorithms, and gas delivery systems. The fuel cell experienced stack degradation, the exact cause of which was unknown, but several causes were possible:

- An unknown contaminant in the stack
- Hydrogen not sufficiently wet
- Too large of a temperature rise across the stacks, causing the stacks to dry out or flood
- The stack cells pulling a negative voltage

Several changes to the fuel cell stack were implemented in June 2002 to mitigate the possible causes of the stack degradation, including:

- Revise stack piping
- Replace deionized water heat exchanger
- Install new stacks
- Change the location or recalibrate the temperature sensors in the fuel cell
- Rewire an electronic noise filter circuit into inverter to increase useable life of the fuel cell stacks
- Use only four of the eight stacks, since only 30 kW output was required from the system

Stack Degradation

Possible problems:

- Unknown contaminant
- Hydrogen not wet enough
- ΔT is too large – may result in membrane dehydration
- Stack cells pulling negative voltage

Solutions

- Replace deionized water heat exchange
- Install new stacks
- Change location or recalibrate temperature sensors
- Rewire circuit to eliminate current path
- Reduce minimum voltage
- Use 4 stacks instead of 8

Figure 2 provides a view of the hydrogen generator and fuel cell.

Figure 2
Hydrogen Generator (Left) and Fuel Cell (Right)



2.3 Refueling Station

Integration of a metal hydride "thermal" compressor to compress hydrogen for the fuel station was evaluated, but dropped from the project because there was insufficient waste heat from the reformer to provide the thermal energy required by the metal hydride compressor; in addition, the capital cost of the equipment made the technology uneconomical. Installation of the fueling equipment at the project site was delayed one year, awaiting completion of the CLV/CNG station, which was completed in March 2002. Figure 3 provides a view of the fuel station.

Figure 3
Fuel Station



Task 3 Systems/Station Integration
3.1 Permitting & Safety Review
Air Products personnel carried out the procedures required to obtain local codes and permitting for the hydrogen station. They met with local officials, performed hazard reviews per Air Products' standard procedures, and applied Air Products' codes and standards for design and construction. Site work began in March 2002.

Year 2003
2.1 Hydrogen Generator
The SMR achieved an aggregate run time of 2200 hours. The integrated generator system controls demonstrated the full range of expected operability control. In addition, remote operation and monitoring of the hydrogen generator was demonstrated. Produced hydrogen was used for electrical power production by the fuel cell power plant, and for blend H_2/CNG ICE (internal combustion engine) vehicle and hydrogen fuel cell vehicle fueling when required. However, fuel cell availability was not highly reliable.

2.2 Fuel Cell
Several operational issues were identified and addressed. Scanning of individual cell voltage was unreliable, and the scanner cards were redesigned, installed and operational in April 2003. In addition, inadequate draining of water was addressed with a successfully modified water drain valve. However, the fuel cell continued to have issues with cell voltage falloff that made continuous operation problematic. The fuel cell stack was replaced and restarted.

The fuel cell did not meet the durability objectives, and further extensive research would be required to determine the root cause of the degradation.

2.3 Fueling Station
Fueling station operation was established in July 2002. The H_2/CNG fuel dispensing unit was tied into the CLV fuel accounting system for seamless connectivity of data collection with their existing fleet of CNG vehicle operations. Satisfactory fueling functionality was demonstrated; fueling operations were performed for both hydrogen fuel cell vehicles and blend H_2/CNG ICE vehicles (Ford conversion vans and buses). Fully integrated control functionality of the Energy Station was demonstrated. Operational data from 2002 and 2003 are provided in Appendix E.

Year 2004
It was realized that there was a greater demand for hydrogen by other engine manufacturers. To support this need, the overall pressure had to be increased from 250 to 350 bar. Therefore plans to augment pressure at the site were developed in 2004.

3.1 Permitting and Safety Review
A better than satisfactory assessment of the site was made by the DOE Safety Panel in March 2004. No critical or deficient items concerning safety were found.

Year 2005
2.1 Hydrogen Generator
The unit had achieved a run time of over 4800 hours. During 2005 hydrogen generator operation efficiency achieved 68%, with hydrogen produced at purities of less than 1 ppm

CO. Economic analysis confirmed the technology's ability to achieve an integrated, co-production result of less than $3.60/kg cost of hydrogen and $0.08/kWh cost of power.

Because of the excellent real-world performance and durability testing environment provided by Las Vegas, several improvement opportunities were identified. These learnings are captured in the lessons learned section and Appendix F of this report.

2.3 Fueling Station

Satisfactory fueling functionality was demonstrated. Over 200 fuelings were safely performed. Tables 1 and 2 summarize the hydrogen demand profiles for the fuelers from February 2004 through December 2005 and from January through December 2006, respectively.

Table 1 – Hydrogen Profile Demands for 2004/2005

	Las Vegas Hydrogen	**Las Vegas Blend**
Total	136 kg	49 kg
Monthly Average	6.48 kg	2.24 kg

Table 2 – Hydrogen Profile Demands for 2006

	Las Vegas Hydrogen	**Las Vegas Blend**
Total	118 kg	263 kg
Monthly Average	10.55 kg	21.45 kg

The fueling pressure was upgraded from 250 bar fueling capability to 350 bar. This upgrade operated reliably. The upgrade was made as a move to accommodate the need to increase dispensing pressure by the OEMs and thus the capacity on board the vehicle. The increased pressure capability to dispense has attracted interest from OEMs such as Honda to place vehicles at the CLV. General performance observations are provided in Appendix F.

Major Lessons Learned

Equipment Operational Issues

Since the original charge of catalyst lasted less than 2200 hours, a run of 2000 hours was repeated with modifications. The Boiler Level control logic was primarily responsible for the catalyst degradation; the new logic reduced but did not eliminate the problem. The GC was used to document the baseline performance after other issues below were corrected. The GC was taken back to the site at the end of the 2000-hour operating period, since the manual data showed apparent performance drop-off.

Operating issues:

- There were significant temperature variations throughout the reformer due to BFW control logic. The temperature variation was removed with improved control strategy.

- The shift inlet temperature could not be controlled to be hot enough, resulting in poor catalyst activity - high CO in the syngas to the PSA. This could be solved by modifying the E-1 Feed Preheat Exchanger Bypass Line size; this is a design issue.

- The K621 Syngas compressor recycle line leaked. This was threaded pipe with standard unions, and it was in syngas service and under high vibrations due to the syngas compressor vibration issue. While the leak was not bad enough to set off the combustible gas monitor, this line should be changed to welded with Hart Unions (o-ring unions), which would be required per Air Products pipe specs.

- The fire eye was apparently experiencing intermittent faults, causing the plant to shut down. The fire eye was replaced, and the installation was modified to independently bring the detector fault signal back to the PLC. These steps improved the reliability of the operation of the H2 generator.

- Day to night process variation – The air flow correction was changed to follow burner core temperature instead of the container temperature. The reformer temperatures and conversion and production dropped when the container doors were opened each morning and the TI-110 temperature dropped which reduced air flow to the reformer and reduced firing.

After 5 days of operation, the plant tripped. Based on the enclosure fan stopping and then starting sometime later, the trip was caused by the Fire Detector indication (FIH-101). The Fire Detector is wired to trip either on a detected fire or on a fault of the Fire Detector Unit. After talking to the manufacturer, the Air Products technical support person for the unit, it was determined that the unit is a relatively old model number and should be replaced or repaired and upgraded. Additionally, new wiring and detector option setup is recommended, which will make the unit more reliable.

The plant was left in a shutdown state, and recommendations were made on how to proceed and confirm the process performance.

Design Issues

Hydrogen Generator

- *Desulfurizers* were too large for one-man operation, and were sized for too short a period onstream; it would be better to size them for 9 to 12 months before change-out.
- For the *reformer/boiler*, the controls package around the boiler control should be further improved as previously stated, and optimized to obtain extended unit operations and catalyst life.
- The *syngas compressor* experienced too much vibration; the vendor should change to provide a more balanced, stable design. Options for lube or non-lube machine may be better and should be investigated. Compressor rebuilds are an expensive item and need to be considered in the total cost to deliver HP gas.
- Catalyst activity in the *shift reactor* should be improved to significantly reduce the size of the reactor, and thus reduce the cost of the component.
- Investigate *PSAs* with higher hydrogen recovery to reduce cost and footprint. The current PSA exhibited much lower recovery than large plant PSAs, and a project should be undertaken to improve recovery and lower the footprint. Novel designs need to be considered.
- *Utilities*: a more robust nitrogen supply for purging is needed, as is a better reverse osmosis water treatment system. In addition, the cooling water refrigeration system should be removed from the roof.
- Upgrade the *water pump.* Reliability was poor, causing outages. Several designs should be investigated based on a total cost to delivery basis.
- Improve the aesthetics and reduce the footprint of the *container*. The existing container was chosen from a cost and availability standpoint. A design that would fit a less industrial look is recommended.
- Eliminate the huge stack to improve the aesthetics of the *safety systems*.
- Improve *efficiency* to above 65%, preferably to 68% on an LHV basis. This small system exhibits very poor efficiency. Further investigation would improve efficiency and the potential to be commercially viable.
- Optimize *controls*; include better data collection capability and include test instrumentation. The lack of detailed data affected the ability to troubleshoot in a timely fashion.

Hydrogen Compressor and Hydrogen Storage

- Investigate *compressor vendor* to achieve lower cost, lower noise and a smaller footprint.
- Enclose *compressor* to improve aesthetics.
- Simplify *control system* to save cost and integrate it with the reformer control system into a single package.

Dispenser

- Reduce *cost*. A first of a kind dispensor needs value engineering to obtain costs comparable to today's gasoline dispensors. This would include improving the aesthetics for a more commercial vs. industrial look.
- Improve *aesthetics*.
- Simplify *user interface* (computer control screen) and make the control panel more user friendly. As a first design, the industrial interface will be too cumbersome for the average public user.
- A more accurate means of metering is needed.

Recommendations/Conclusions
Recommendations for future R&D include continuing to reduce the cost of systems and subsystems by simplifying the manufacturing of each of the components and subsystems to effect capital cost reductions.

From a commercial standpoint, the unit is currently too expensive to be a product offering; therefore, further significant cost reductions and integration are needed to make the facility commercially attractive. The system was put together as an integration of test components; further development is required for a total integrated turnkey system to have a viable offering in the marketplace. We suggest a next-generation, turnkey fueling system and/or "Energy Station" be pursued as the next phase toward developing a hydrogen fueling station capable of being operated by an average vehicle driver.

Publications/Presentations/Recognition
Presentations on the "Energy Station" concept and the Las Vegas project have been given to various audiences separately or in conjunction with a discussion of developing hydrogen infrastructure, including:

- Energy Frontiers International, Marcos Island, FL, February 1-2, 2000
- 11th Annual NHA Conference, Tyson's Corner, VA, March 1-2, 2000
- IQPC Fuel Cells 2000 Conference, Palm Springs, CA, May 24-25, 2000
- Florida's Hydrogen Summit, Tallahassee, FL, October 24-25, 2000
- Merrill-Lynch Global Energy Technology Conference – New York City, May 2001
- California Fuel Cell Partnership Steering Team – Diamond Bar, CA, October 2001
- The EVAA Electric Transportation Industry Conference & Exposition – Sacramento, CA, December 2001 NRC Hydrogen Study Team Meeting - Washington D.C. CHALLENGES FOR THE CHEMICAL SCIENCES IN THE 21ST CENTURY – January 2002
- Globe 2002 – Vancouver, Canada, March 2002
- H2 Investor Forum – Washington, D.C., April 2002
- Hydrogen Expo 2002, Hamburg, Germany, October 10-12, 2002 - "Pathways to Building Infrastructure to Support the Hydrogen Economy"
- U.S. - Australian Climate Action Partnership Opportunities Roundtable, Washington, DC, November 4, 2002 - "Role of Hydrogen as an Energy Resource for the United States"
- Hydrogen Energy Systems Society of Japan Symposium, Tokyo Institute of Technology, Tokyo, Japan, December 11, 2002 – "Hydrogen Economy Strategies- a U.S. Perspective"
- SAE Telephone/Webcast, April 3, 2003 - The Path to the Emission-Free Vehicle through the Use of Hydrogen as a Fuel – "Hydrogen Fuel Infrastructure - Creating the Future"
- DOE Regional Meeting in Annapolis, MD, 2004
- SAE Annual Meeting, 2004
- Annual NHA Meeting, March 2005

Project participants received a special member award from the National Hydrogen Association for "… development of the Las Vegas Refueling Station, the world's first energy station featuring the co-production of hydrogen and electricity."

APPENDICES

Appendix A
Equipment Specifications for the Fueling Station
(CLV Fact Sheet)

CLV Fact Sheet

Summary / Purpose

Air Products and Chemicals, Inc. is performing work for the DOE to develop, design, procure, install, and operate an on-site hydrogen generation system, an alternative vehicle refueling station, and a stationary hydrogen fuel cell power plant, to be located in Las Vegas, Nevada. Air Products and Chemicals, Inc. has teamed with Plug Power Inc., of Latham, NY, and the City of Las Vegas, Nevada for this effort.

The facility will serve as a commercial demonstration of hydrogen as a safe and clean energy alternative. Integral to this will be the validation of new natural gas based hydrogen production systems, PEM fuel cell power generation systems, and numerous new technologies for the safe and reliable delivery of hydrogen as a fuel to vehicles.

The facility consists of a H2 generator, fuel station, and stationary PEM fuel cell. The fuel station includes hydrogen compression, liquid and gaseous hydrogen storage, hydrogen and natural gas blending and pure hydrogen and CNG/H2 blend dispensing systems.

System Attributes

1500 Gallon Liquid H2 Storage Vessel

- *Holds approx. 170,000 scf of H2 product; 930 lbs of H2 product*
- *Cryogenic, double walled, vacuum annular space insulated vessel, ASME Stn 8 Code*
- *Manufactured by ACME*
- *Monitored via telemetry for refill rqmts*
- *Refill product hauled from New Orleans or Sacramento*

Hydril Storage Tubes

- *ASME Stn 8 Code Storage tubes*
- *Product stored at 5200 psig*
- *Tubes store approx. 54,000 total scf*
- *Manufactured by CPI*

Product Compression

- *Henderson / Greenfield Compressor*
- *50 psig suction pressure / 5400 psig discharge pressure*
- *85 scfm (5100 scfm) capacity*
- *575 rpm*
- *60 HP*
- *5 stages / 6 cylinders*
- *6000 MAWP*

CNG / H2 Blend Dispenser

- *Built by Kraus*

H2 Dispenser

- *Built by QMP*

Note: This was subsequently changed out to a new dispenser, rated for 350 Bar fueling

H2 Generator

- *Fuel Processor and Assembly Integration by Harvest Engineering Technologies, Burbank, CA*
- *Specified to Produce 2600 scfh H2, 99.95 purity: product at approx. 100 – 110 psig*

  Fuel Processor

  - *Traditional SMR at low pressure*
  - *3% CO from Fuel Processor*

- *Desulfurizer (activated carbon [mercaptans]/ copper impreg act crbn[H2S]) – to – Feed Preheater – to – SMR Tubes (6 ea) [concentric tubes w/ catalyst in annular space; tubes arranged around central radiant burner mounted at top of reformer shell] – to – Shift Reactor – to – Condensate Separator [V2]*
- *Reformer catalyst = Nickel on Alumina*
- *Shift catalyst = Copper and Chromium on Iron*

Compressor

- *Mehrer Compressor packaged by UAPC*
- *Vertical, 2 stage, oil free*
- *Water cooled*
- *Suction @ 2 psig; Discharge @ 120 psig*
- *Flow = 75.9 scfm*
-

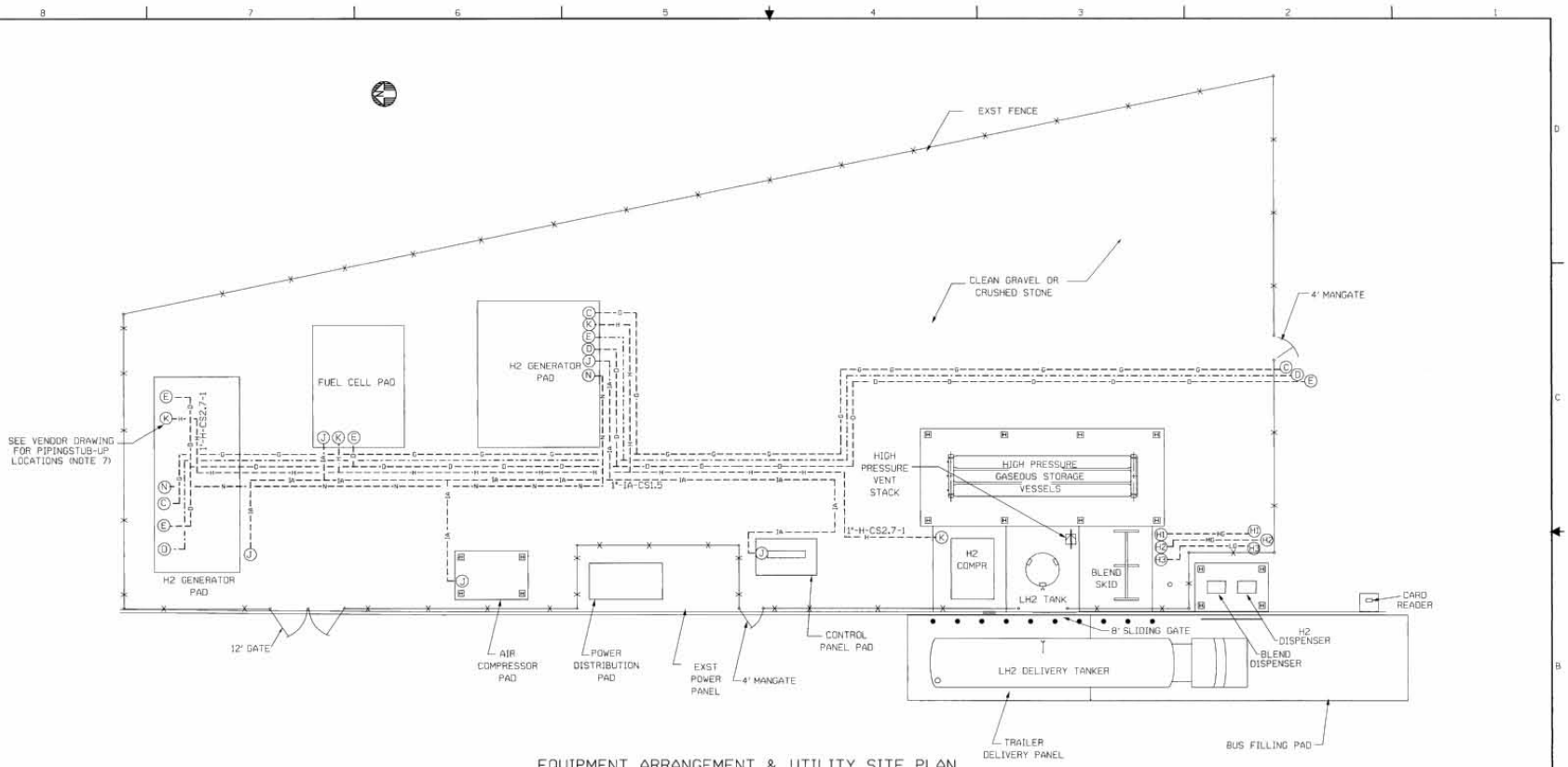
PSA

- *Provided by QuestAir*
- *Six beds*
- *Two rotary cycling valves*
- *Zeolite Catalyst (UOP Molecular Sieve – Sodium/Calcium Aluminosilicate)*
- *Approx. 5'Wx7.5'Lx7.5'H*
- *Vessels = 6 in. diameter x 49 in. long*

Plug Power Fuel Cell

- *Specified to generate 50 kW on 1629 scfh H2 feedstock*

Appendix B
Equipment Arrangement and Utility Supply



EQUIPMENT ARRANGEMENT & UTILITY SITE PLAN

CLV SUPPLIED UTILITIES

- (C) NATURAL GAS
- (D) POTABLE WATER
- (E) PROCESS DRAIN
- (H1) COMPRESSED NATURAL GAS (HIGH)
- (H2) COMPRESSED NATURAL GAS (MEDIUM)
- (H3) COMPRESSED NATURAL GAS (LOW)

AIR PRODUCTS PROCESS PIPING

- (J) INSTRUMENT AIR
- (K) LOW PRESSURE HYDROGEN
- (N) LOW PRESSURE NITROGEN

LIQUID HYDROGEN INSTALLATION NOTES

1. LOCATE AND INSTALL PER NFPA 50-B, "LIQUID HYDROGEN SYSTEM AT CONSUMER SITES", LATEST EDITION, OR LOCAL CODES, WHICHEVER ARE MORE STRINGENT.
2. COMPLETE APCI FORM 3493, "SITE EVALUATION", FOR APPROVAL.
3. DETERMINE EXACT LOCATION OF ALL EXST UNDERGROUNDS BEFORE BEGINNING EXCAVATION.
4. SECURE VENT STACK TO BRACKETS ATTACHED TO THE TANK OR TO GUY WIRES SPACED 90 DEGREES APART AND 8' FROM THE VENT STACK BASE.
5. BARRICADE PLANT ROADS WITHIN 25 FEET OF THE TANK DURING OFF-LOADING OPERATIONS.
6. INSTALLATION MUST BE COMPLETELY FENCED, EVEN WHEN LOCATED WITHIN A FENCED INDUSTRIAL COMPLEX.
7. REFERENCE VENDOR DRAWING # F-1 TITLED: "SMR FOUNDATION PLOT" FROM HARVEST ENERGY TECHNOLOGY FOR PIPING STUB-UP'S ON H2 GENERATOR PAD.

REFERENCE INFORMATION

ATT1042 CIVST 0001	FOUNDATION PLAN & DETAILS
ATT1042 CIVST 0002	UNDERGROUND SITE TRENCH PLAN
ATT1042 ELEC 0004	UNDERGROUND GROUNDING GRID PLAN
ATT1042 ELEC 0005	UNDERGROUND CONDUIT PLAN & DETAIL

ECN NO.	REV.	ZONE	REVISION DESCRIPTION	DATE	BY	CHK'D	APPD.
	1		RELOCATED GENERATOR & FUEL PADS & PIPING	28SEPT01	HLW		

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE: FRACTION ± DECIMAL ± ANGLE ± HOLE LOCATION ± HOLE SIZE ±

FIRST USED ON: ATT1042

WEDDIGEN-WEIKERT DRAWN: J FISCHL, CHECKED: 7/13/01 — DATE: 13JUL01

D E IMLER, ENGINEER: 7/16/01

J R FARESE, APPD.: 7/17/01

TITLE: EQUIPMENT ARRANGEMENT & UTILITY SITE PLAN CNG/HYDROGEN FUELING STATION DOE LAS VEGAS, NV

AIR PRODUCTS

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FILE: ATT1042MECH0001.DGN — DWG NO. ATT1042 MECH 0001 — D — REV. 1

SCALE NOTED — WT. — SHEET 1 OF 1

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Appendix C
Piping and Instrumentation Diagrams and Flow Schematics

Piping and Instrumentation Diagram
ATT1042121E
Hydrogen Generation Facility
2600 SCFH for
DOE Fueling Station
Las Vegas, Nevada

PIPING AND INSTRUMENTATION DIAGRAM
ATT1042121E
HYDROGEN GENERATION FACILITY
2600 SCFH FOR
DOE FUELING STATION
LAS VEGAS, NV

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NOTES:
1. REFER TO INDEX SHEET FOR ACTUAL, INDIVIDUAL SHEET REVISION STATUS.

REVISIONS					APPROVED														
REV. NO.	ECN/PFD, P&ID CHANGE NOTE	DATE	DRAWN	CHECKED	PROCESS SYSTEMS	PROJECT	PROCESS	CRYOGENIC SYSTEMS	YARD AREA	PROCESS CONTROL	SAFETY	ENG. TECH./ PROC. TECH.	PSO/ START-UP	MACHINERY ENGINEERING	CRYO MACHINERY	EQUIPMENT ENGINEERING	ELECTRONICS	MECHANICAL SYSTEMS	PRODUCT OWNER	
Ø		1-10-02	C.R.S.	RLC		MFW	GRK			KHS 1-11-02	KSW		JRS						RLC	
ØA	ATT1042121-FCN-005 ATT1042121-FCN-006	2-26-02	FENNELLY	RLC	DG	MFW 3-1-02	GRK 3-2-02			KHS 2-27-02	KSW 3-1-02		JRS						RLC 2-28-02	
1	ATT1042121-FCN-007 ATT1042121-FCN-008	5-28-02	FENNELLY	RLC		MFW 5-30-02	CTS 5-30-02			KHS 5-30-02	KSW 5-30-02		JRS 5-30-02						RLC 5-25-02	
2	ATT1042121-FCN-009 ATT1042121-FCN-010	9-4-02	PUTNAM	RLC		MFW 9-12-02	CTS 9-12-02			KHS 9-11-02	KSW 9-13-02								RLC 9-12-02	

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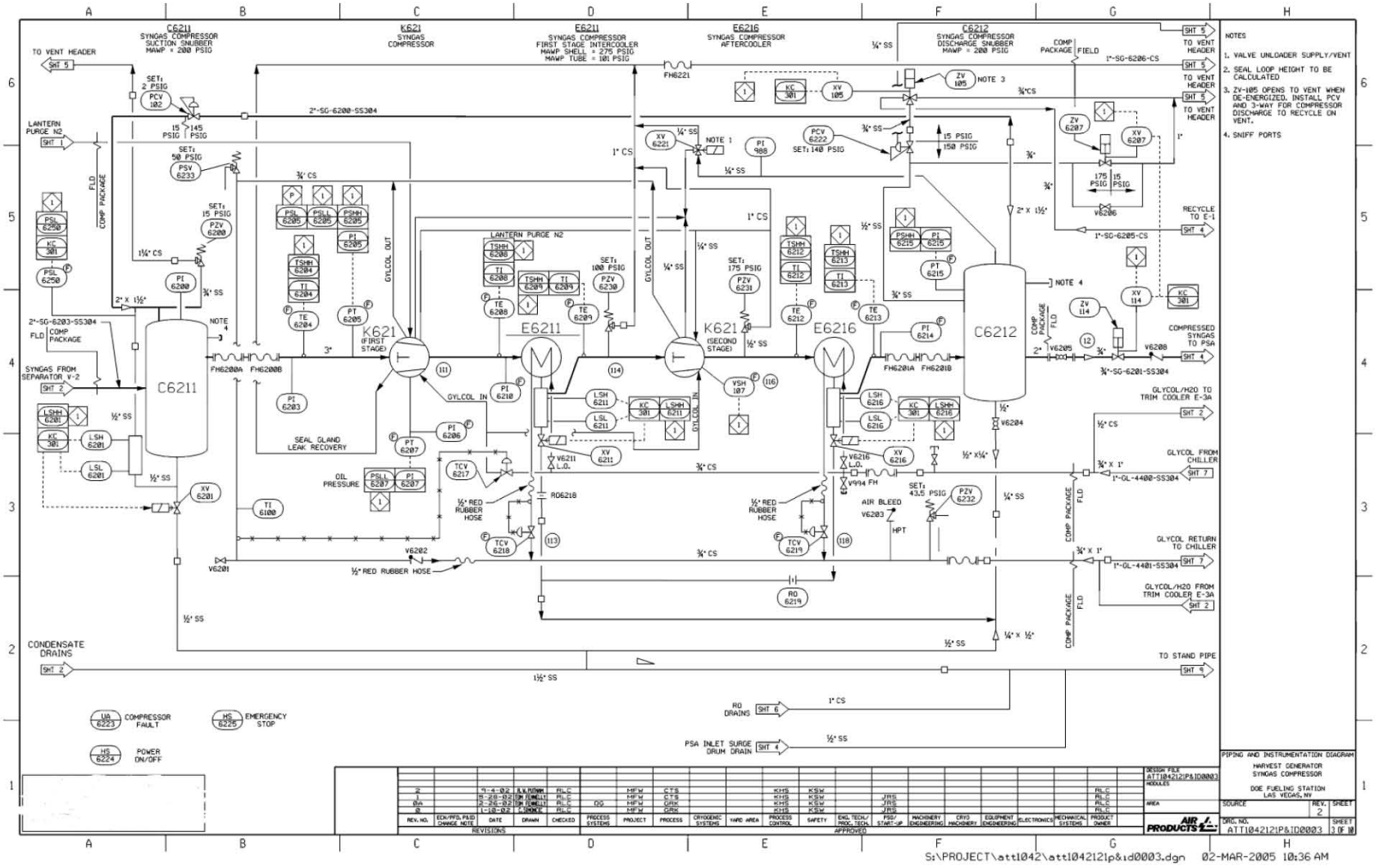
C6211
SYNGAS COMPRESSOR
SUCTION SNUBBER
MAWP = 200 PSIG
K621
SYNGAS
COMPRESSOR
E6211
SYNGAS COMPRESSOR
FIRST STAGE INTERCOOLER
MAWP SHELL = 275 PSIG
MAWP TUBE = 101 PSIG
E6216
SYNGAS COMPRESSOR
AFTERCOOLER
C6212
SYNGAS COMPRESSOR
DISCHARGE SNUBBER
MAWP = 200 PSIG
TO VENT HEADER
SYNGAS FROM SEPARATOR V-2
CONDENSATE DRAINS
TO STAND PIPE
COMPRESSED SYNGAS TO PSA
GLYCOL/H2O TO TRIM COOLER E-3A
GLYCOL FROM CHILLER
GLYCOL RETURN TO CHILLER
GLYCOL/H2O FROM TRIM COOLER E-3A
RECYCLE TO E-1
SEAL GLAND LEAK RECOVERY
LANTERN PURGE N2
COMPRESSOR FAULT
EMERGENCY STOP
POWER ON/OFF
NOTES
1. VALVE UNLOADER SUPPLY/VENT
2. SEAL LOOP HEIGHT TO BE CALCULATED
3. ZV-105 OPENS TO VENT WHEN DE-ENERGIZED. INSTALL PCV AND 3-WAY FOR COMPRESSOR DISCHARGE TO RECYCLE OR VENT.
4. SNIFF PORTS
PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR
SYNGAS COMPRESSOR
DOE FUELING STATION
LAS VEGAS, NV
AIR PRODUCTS
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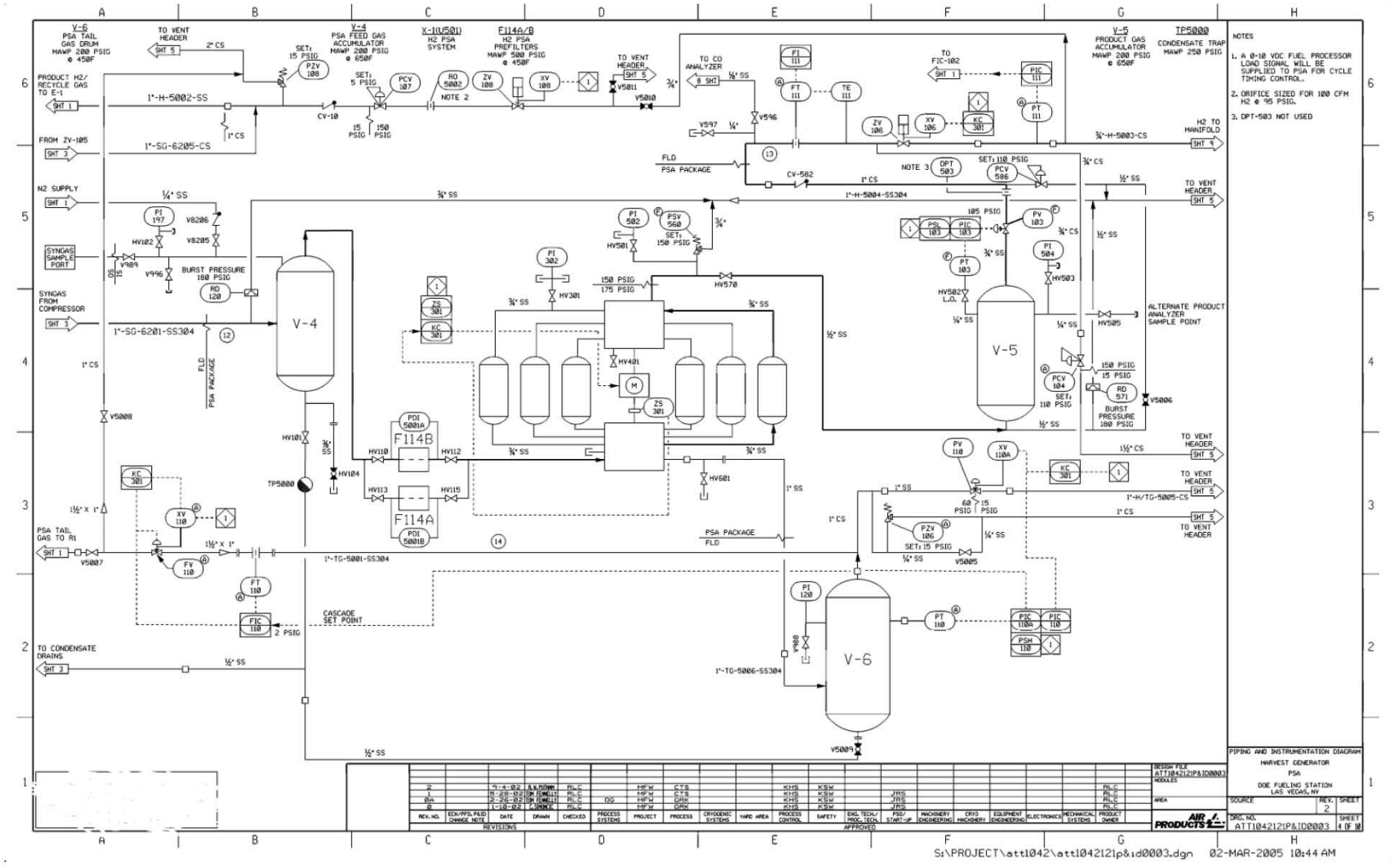
V-6
PSA TAIL GAS DRUM
MAWP 200 PSIG
@ 450F
V-4
PSA FEED GAS ACCUMULATOR
MAWP 200 PSIG
@ 650F
X-1(U501)
H2 PSA SYSTEM
F114A/B
H2 PSA PREFILTERS
MAWP 500 PSIG
@ 450F
V-5
PRODUCT GAS ACCUMULATOR
MAWP 200 PSIG
@ 650F
TP5000
CONDENSATE TRAP
MAWP 250 PSIG
NOTES
1. A 0-10 VDC FUEL PROCESSOR LOAD SIGNAL WILL BE SUPPLIED TO PSA FOR CYCLE TIMING CONTROL.
2. ORIFICE SIZED FOR 100 CFM H2 @ 95 PSIG.
3. DPT-503 NOT USED
PRODUCT H2/ RECYCLE GAS TO E-1
FROM ZV-105
N2 SUPPLY
SYNGAS SAMPLE PORT
SYNGAS FROM COMPRESSOR
PSA TAIL GAS TO R1
TO CONDENSATE DRAINS
TO VENT HEADER
TO CO ANALYZER
TO FIC-102
H2 TO MANIFOLD
ALTERNATE PRODUCT ANALYZER SAMPLE POINT
BURST PRESSURE 180 PSIG
CASCADE SET POINT
PSA PACKAGE FLD
1"-H-5002-SS
1"-SG-6205-CS
1"-SG-6201-SS304
1"-TG-5001-SS304
1"-TG-5006-SS304
1"-H-5004-SS304
1"-H/TG-5005-CS
PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR
PSA
DOE FUELING STATION
LAS VEGAS, NV
AIR PRODUCTS
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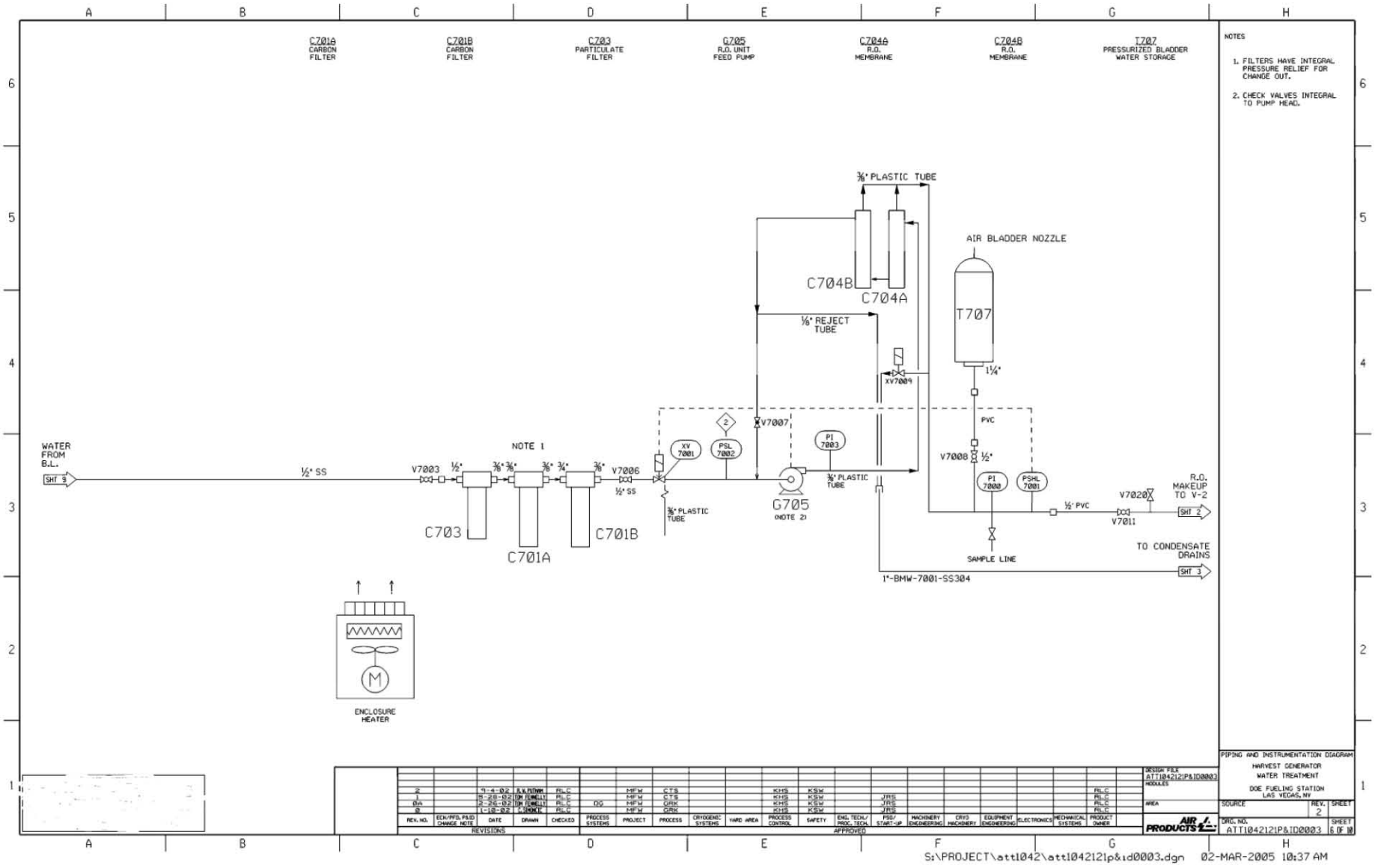
C701A CARBON FILTER
C701B CARBON FILTER
C703 PARTICULATE FILTER
G705 R.O. UNIT FEED PUMP
C704A R.O. MEMBRANE
C704B R.O. MEMBRANE
T707 PRESSURIZED BLADDER WATER STORAGE
NOTES
1. FILTERS HAVE INTEGRAL PRESSURE RELIEF FOR CHANGE OUT.
2. CHECK VALVES INTEGRAL TO PUMP HEAD.
3/8" PLASTIC TUBE
AIR BLADDER NOZZLE
C704B
C704A
T707
1/8" REJECT TUBE
XV7009
1 1/4"
PVC
V7007
PI 7003
V7008 1/2"
PI 7000
PSHL 7001
WATER FROM B.L.
SHT 9
1/2" SS
V7003
NOTE 1
V7006
1/2" SS
XV 7001
PSL 7002
3/8" PLASTIC TUBE
G705 (NOTE 2)
3/8" PLASTIC TUBE
1/2" PVC
V7020
V7011
R.O. MAKEUP TO V-2
SHT 2
C703
C701A
C701B
SAMPLE LINE
TO CONDENSATE DRAINS
SHT 3
1"-BMW-7001-SS304
ENCLOSURE HEATER
PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR
WATER TREATMENT
DOE FUELING STATION
LAS VEGAS, NV
DESIGN FILE ATT1042121P&ID0003
MODULES
AREA
SOURCE
REV. 2
SHEET
DRG. NO. ATT1042121P&ID0003
SHEET 6 OF 10
AIR PRODUCTS
REVISIONS
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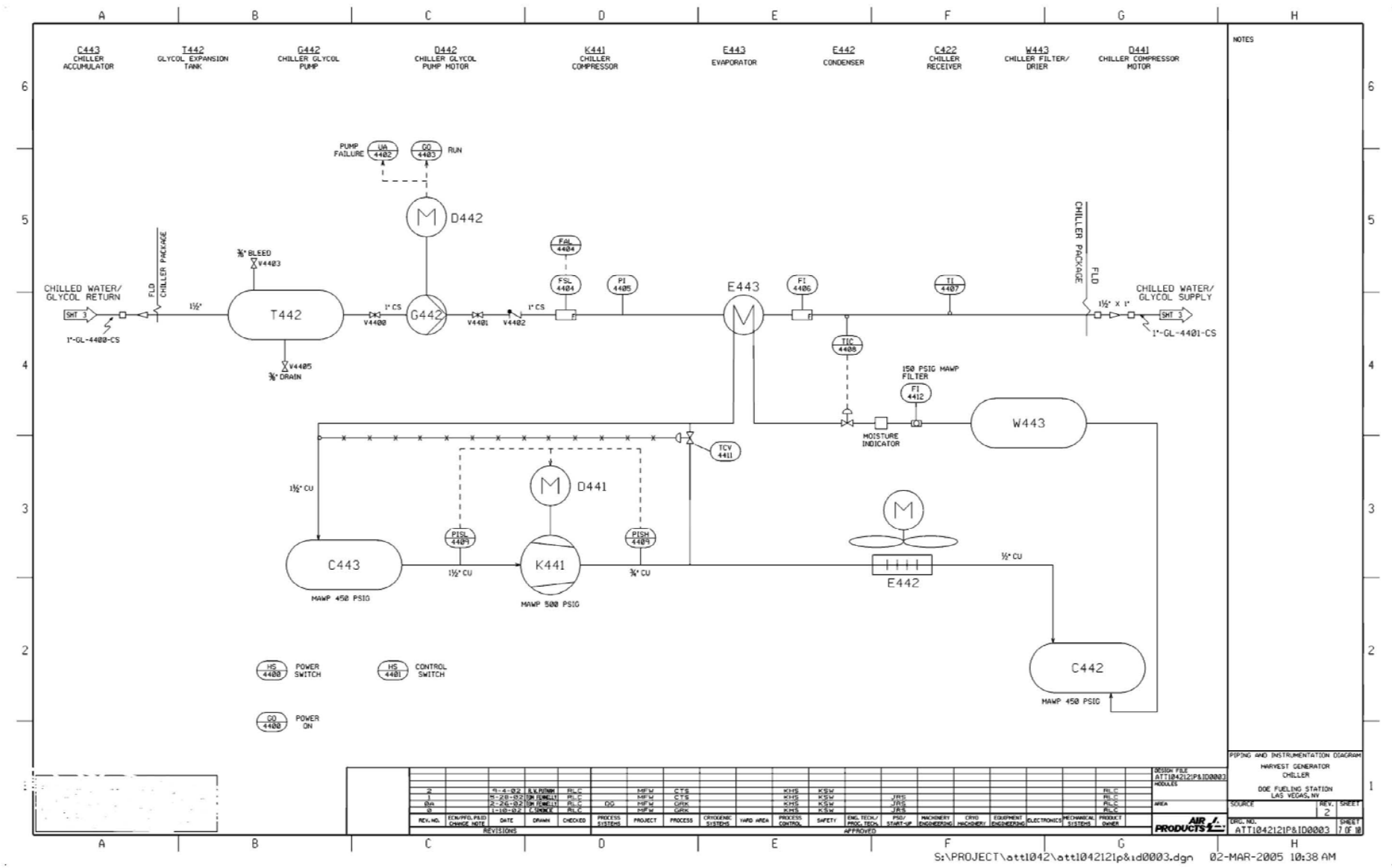
C443 CHILLER ACCUMULATOR
T442 GLYCOL EXPANSION TANK
G442 CHILLER GLYCOL PUMP
D442 CHILLER GLYCOL PUMP MOTOR
K441 CHILLER COMPRESSOR
E443 EVAPORATOR
E442 CONDENSER
C422 CHILLER RECEIVER
W443 CHILLER FILTER/ DRIER
D441 CHILLER COMPRESSOR MOTOR
NOTES
PUMP FAILURE
UA 4402
GO 4403
RUN
D442
CHILLER PACKAGE
FLD
3/8" BLEED
V4403
CHILLED WATER/ GLYCOL RETURN
SHT 3
1"-GL-4400-CS
1½"
T442
3/8" DRAIN
V4405
1" CS
V4400
G442
V4401
V4402
1" CS
FAL 4404
FSL 4404
PI 4405
E443
FI 4406
TIC 4408
TI 4407
CHILLER PACKAGE
FLD
1½" x 1"
CHILLED WATER/ GLYCOL SUPPLY
SHT 3
1"-GL-4401-CS
150 PSIG MAWP FILTER
FI 4412
MOISTURE INDICATOR
W443
TCV 4411
D441
1½" CU
PISL 4409
PISH 4409
C443
MAWP 450 PSIG
1½" CU
K441
MAWP 500 PSIG
¾" CU
E442
½" CU
C442
MAWP 450 PSIG
HS 4400 POWER SWITCH
HS 4401 CONTROL SWITCH
GO 4400 POWER ON
PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR
CHILLER
DOE FUELING STATION
LAS VEGAS, NV
AIR PRODUCTS
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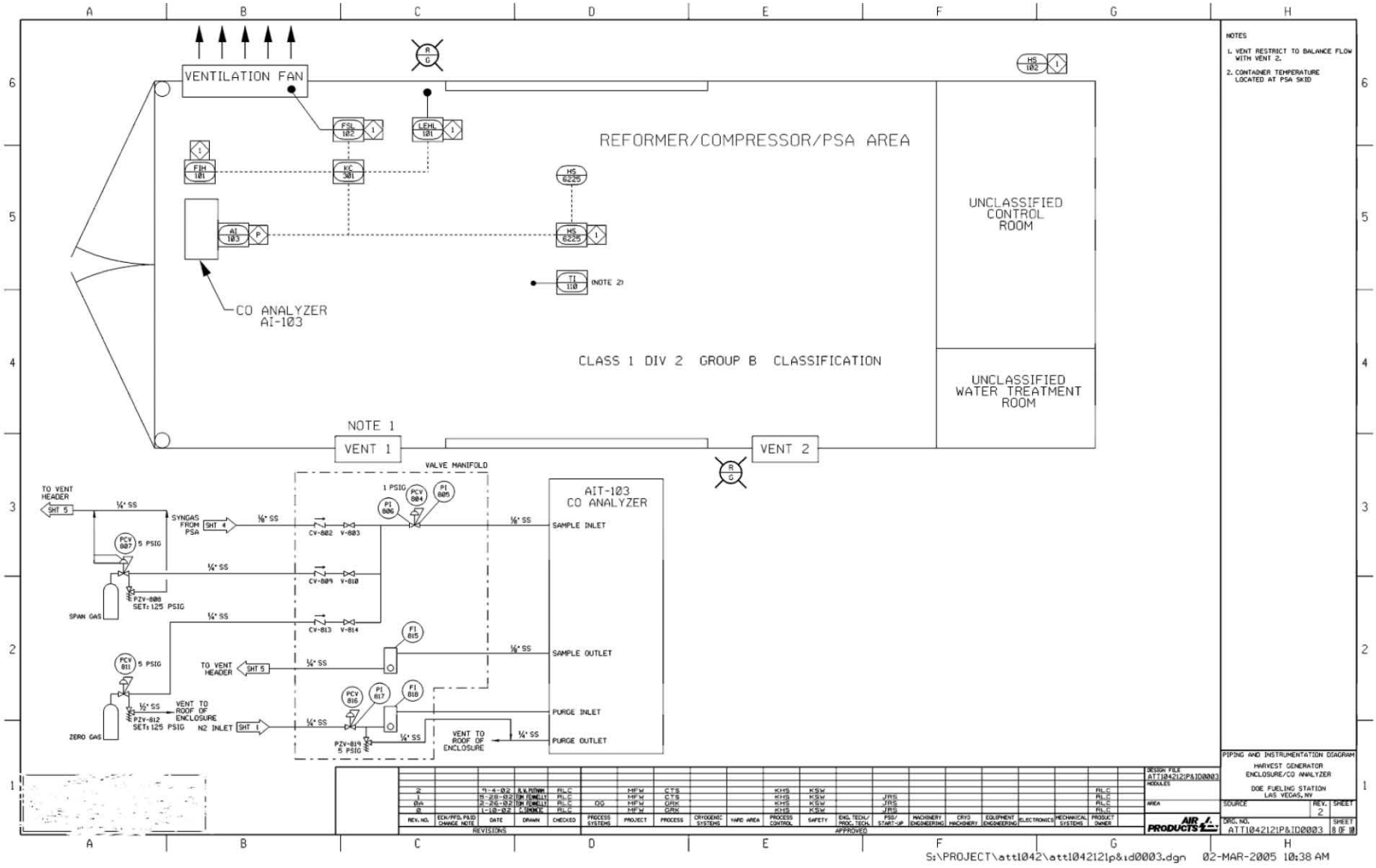
VENTILATION FAN
REFORMER/COMPRESSOR/PSA AREA
UNCLASSIFIED CONTROL ROOM
UNCLASSIFIED WATER TREATMENT ROOM
CLASS 1 DIV 2 GROUP B CLASSIFICATION
CO ANALYZER AI-103
NOTE 1
VENT 1
VENT 2
VALVE MANIFOLD
AIT-103 CO ANALYZER
SAMPLE INLET
SAMPLE OUTLET
PURGE INLET
PURGE OUTLET
SYNGAS FROM PSA
TO VENT HEADER
SPAN GAS
ZERO GAS
N2 INLET
VENT TO ROOF OF ENCLOSURE
NOTES
1. VENT RESTRICT TO BALANCE FLOW WITH VENT 2.
2. CONTAINER TEMPERATURE LOCATED AT PSA SKID
PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR ENCLOSURE/CO ANALYZER
DOE FUELING STATION LAS VEGAS, NV
AIR PRODUCTS
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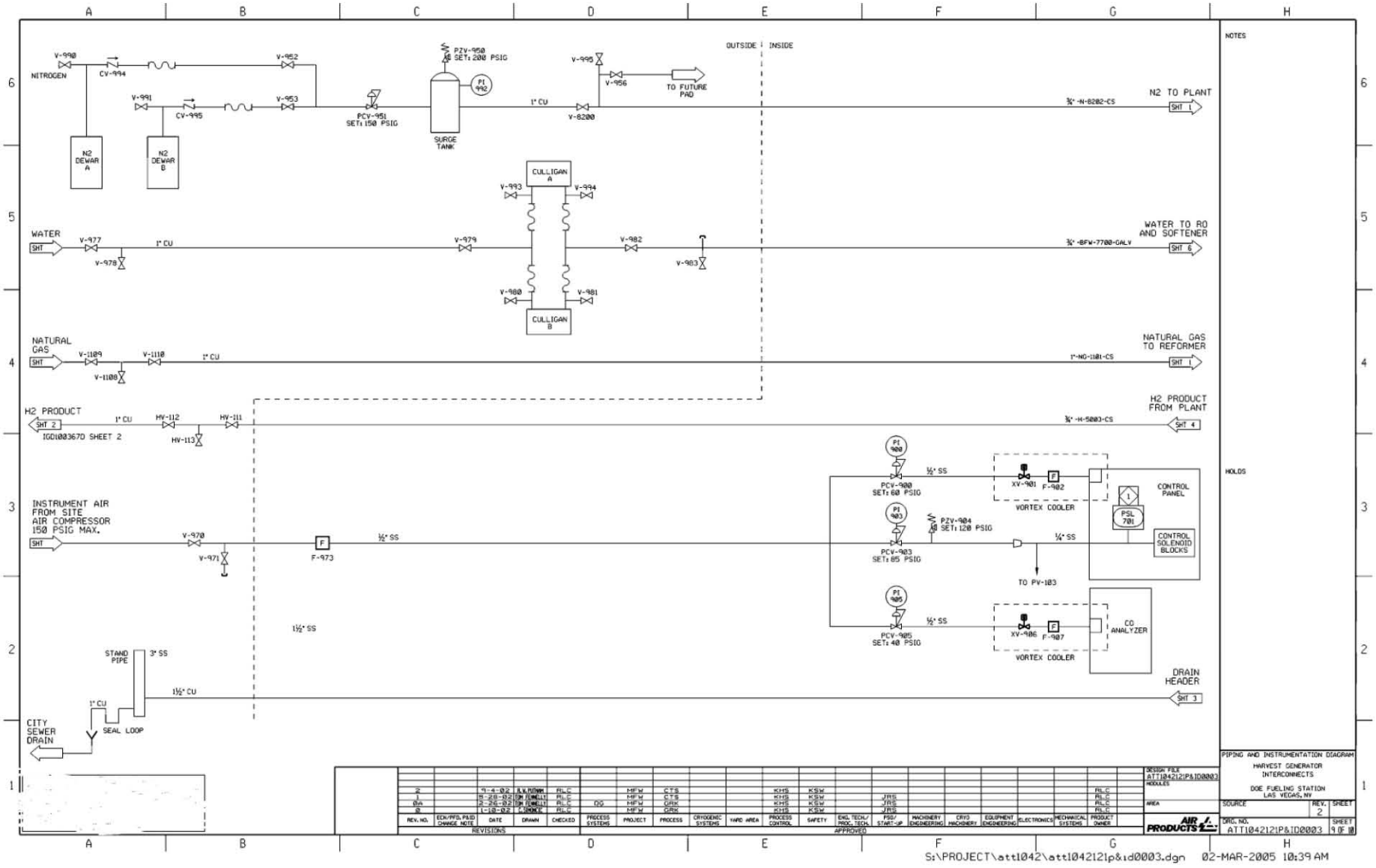
NITROGEN
V-990
CV-994
V-952
V-991
CV-995
V-953
PCV-951
SET: 150 PSIG
PZV-950
SET: 200 PSIG
PI 992
SURGE TANK
V-995
V-956
TO FUTURE PAD
1" CU
V-8200
¾" -N-8202-CS
N2 TO PLANT
SHT 1
N2 DEWAR A
N2 DEWAR B
OUTSIDE
INSIDE
CULLIGAN A
CULLIGAN B
V-993
V-994
V-980
V-981
WATER
SHT
V-977
V-978
1" CU
V-979
V-982
V-983
¾" -BFW-7700-GALV
WATER TO RO AND SOFTENER
SHT 6
NATURAL GAS
V-1109
V-1110
V-1108
1" CU
1"-NG-1101-CS
NATURAL GAS TO REFORMER
H2 PRODUCT
SHT 2
IGD100367D SHEET 2
1" CU
HV-112
HV-111
HV-113
¾" -H-5003-CS
H2 PRODUCT FROM PLANT
SHT 4
INSTRUMENT AIR FROM SITE AIR COMPRESSOR 150 PSIG MAX.
V-970
V-971
F-973
½" SS
1½" SS
PI 900
PCV-900
SET: 60 PSIG
PI 903
PCV-903
SET: 85 PSIG
PZV-904
SET: 120 PSIG
PI 905
PCV-905
SET: 40 PSIG
XV-901
F-902
VORTEX COOLER
¼" SS
TO PV-103
XV-906
F-907
VORTEX COOLER
CONTROL PANEL
PSL 701
CONTROL SOLENOID BLOCKS
CO ANALYZER
DRAIN HEADER
SHT 3
STAND PIPE
3" SS
1½" CU
1" CU
SEAL LOOP
CITY SEWER DRAIN
NOTES
HOLDS
PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR INTERCONNECTS
DOE FUELING STATION
LAS VEGAS, NV
AIR PRODUCTS
DESIGN FILE
ATT1042121P&ID0003
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SD	DESCRIPTION	IL	SHUTDOWN CAUSE			
			TAG	DESCRIPTION	IL	PID
1			TSH-101A	HIGH INVERSION TEMPERATURE		1
1			TSH-101B	HIGH INVERSION TEMPERATURE		1
1			PSH-198	HIGH FUEL GAS TO REFORMER PRESSURE		1
1			TSH-102A	HIGH BURNER FACE TEMPERATURE		1
1			TSH-102B	HIGH BURNER FACE TEMPERATURE		1
1			TSL-102A	LOW BURNER FACE TEMPERATURE		1
1			TSL-102B	LOW BURNER FACE TEMPERATURE		1
1			TSH-103A	HIGH TUBE WALL TEMPERATURE		1
1	HARD WIRE CRITICAL		TSH-103B	HIGH TUBE WALL TEMPERATURE		1
1			TSH-109	HIGH BURNER CORE TEMPERATURE		1
1			PSL-101	LOW FUEL GAS PRESSURE (BC-101)		1
1			PSH-102	HIGH REFORMER FEED PRESSURE		1
1			ZSC-111	MAIN FUEL VALVE CLOSED (BC-101)		1
1			ZSO-112	FUEL VENT OPEN (BC-101)		1
1			BC-101	BURNER CONTROL		1
1	HARDWIRE CRITICAL		FSL-101	REFORMER AIR FLOW		1
1			PSH-101	NG FEED SUPPLY PRESSURE		1
1			PSL-700	LOW NITROGEN PRESSURE		1
1			LSLL-102	CONDENSATE SEPARATOR LOW LEVEL		2
1			TSHH-104	SHIFT REACTOR HIGH INLET TEMPERATURE		2
1			TSHH-105	SHIFT REACTOR HIGH OUTLET TEMPERATURE		2
1			TSHH-106	HIGH BOILER TEMPERATURE		2
1			TSL-106	LOW BOILER TEMPERATURE		2
1			LSLL-101	LOW BOILER WATER LEVEL		2
1			LSHH-101	HIGH BOILER WATER LEVEL		2
1			LSHH-102	CONDENSATE HIGH LEVEL		2
1			LSHH-6201	SYNGAS COMPRESSOR SUCTION BOTTLE HIGH LEVEL		3
1	HARDWIRE CRITICAL		PSLL-6250	SYNGAS COMPRESSOR LOW SUCTION PRESSURE		3
1			TSHH-6204	SYNGAS COMPRESSOR HIGH SUCTION TEMPERATURE		3
1			PSLL-6205	SYNGAS COMPRESSOR LOW SUCTION PRESSURE		3
1			PSHH-6205	SYNGAS COMPRESSOR HIGH SUCTION PRESSURE		3
1			TSHH-6208	SYNGAS COMPRESSOR HIGH INTERSTAGE TEMPERTURE		3
1			TSHH-6209	SYNGAS COMPRESSOR HIGH INTERSTAGE TEMPERTURE		3
1			TSHH-6212	SYNGAS COMPRESSOR SECOND STAGE DISCHARGE TEMPERATURE		3
1			TSHH-6213	SYNGAS COMPRESSOR AFTERCOOLER EXIT		3
1			PSHH-6215	SYNGAS COMPRESSOR HIGH DISCHARGE PRESSURE		3
1			PSLL-6207	SYNGAS COMPRESSOR LOW OIL PRESSURE		3
1			LSHH-6211	SYNGAS COMPRESSOR INTERCOOLER LEVEL		3
1			LSHH-6216	SYNGAS COMPRESSOR AFTERCOOLER LEVEL		3
1			VSH-107	SYNGAS COMPRESSOR HIGH VIBRATION		3
1			PSL-6205	LOW SYSTEM PRESSURE		3
1			PSH-110	TAILGAS DRUM HIGH PRESSURE		4
1			PSL-103	LOW PRODUCT GAS PRESSURE		4
1			ZS-301	PSA ROTARY VALVE FAILURE		4
1			FSL-102	VENTILATION FAN LOW FLOW		8
1			LEHL-101	COMBUSTION ANALYZER HIGH/LOW		8
1			FIH-101	FIRE EYE HIGH		8
1			HS-6225	COMPRESSOR STOP		8
1			HS-102	EMERGENCY STOP		8
1			PSL-701	LOW INSTRUMENT AIR PRESSURE		9
1			T/C BURN	THERMOCOUPLE BURNOUT		
2	R.O. SYSTEM TRIP		PSL-7002	PUMP SUCTION PRESSURE		6

SHUTDOWN EFFECT SD-1					
NOTES	TAG	DESCRIPTION	IL	PID	NOTES
	ZV-109	MAIN GAS SHUTOFF VALVE		1	CLOSE
	TV-101	FUEL GAS SUPPLY VALVE		1	CLOSE
	ZV-111	MAIN FUEL GAS VALVE		1	CLOSE
	ZV-112	FUEL VENT VALVE		1	OPEN
	ZV-102	FEED GAS SHUTOFF VALVE		1	CLOSE
	ZV-113	NITROGEN PURGE TO FEED		1	OPEN POST F-1A/B SHUTDOWN
	ZV-108	PIPELINE HYDROGEN TO FEED		1	CLOSE
	F-1A/F-1B	COMBUSTION AIR FANS		1	SHUT DOWN AFTER 10 MINUTES
	ZV-103	BOILER DRAIN VALVE		2	CLOSE
	P-1	FEEDWATER PUMP		2	SHUT DOWN
	AC-1	AIR COOLER FAN		2	SHUT DOWN
	ZV-104	MAKE-UP WATER VALVE		2	CLOSE
	ZV-7102	BOILER PURGE VALVE		2	OPEN POST ZV-113 CLOSURE
	ZV-114	PSA BLOCK VALVE		3	CLOSE
	ZV-6207	COMPRESSION BLEED VALVE		3	OPEN FOR 20 MINUTES POST SHUTDOWN
	K621	SYNGAS COMPRESSOR		3	SHUT DOWN
	FV-110	TAILGAS TO REFORMER		4	CLOSE
	ZV-105	PRODUCT/RECYCLE VALVE		4	SWITCH TO VENT
	ZV-106	PRODUCT BLOCK VALVE		4	CLOSE
	PV-103	SYSTEM BACKPRESSURE VALVE		4	CLOSE
	PV-110	TAILGAS PRESSURE VALVE		4	CLOSE

SHUTDOWN EFFECT SD-2					
NOTES	TAG	DESCRIPTION	IL	PID	NOTES
		SHUTDOWN R.O. SYSTEM			

NOTES

HOLDS

REV. NO.	ECN/PFD, P&ID CHANGE NOTE	DATE	DRAWN	CHECKED
2		9-4-02	R.K.PUTNAM	RLC
1		5-28-02	TOM FLORELLI	RLC
0A		2-26-02	TOM FLORELLI	RLC
0		1-10-02	J.SMOKE	RLC

REVISIONS

PROCESS SYSTEMS	PROJECT	PROCESS	CRYOGENIC SYSTEMS	YARD AREA	PROCESS CONTROL	SAFETY	ENG. TECH./ PROC. TECH.	PSS/ START-UP	MACHINERY ENGINEERING	CRYO MACHINERY	EQUIPMENT ENGINEERING	ELECTRONICS	MECHANICAL SYSTEMS	PRODUCT OWNER
	MFW	CTS			KHS	KSW								RLC
	MFW	CTS			KHS	KSW		JRS						RLC
DG	MFW	GRK			KHS	KSW		JRS						RLC
	MFW	GRK			KHS	KSW		JRS						RLC

APPROVED

DESIGN FILE: ATT1042121P&ID0003
MODULES:
AREA:

AIR PRODUCTS

PIPING AND INSTRUMENTATION DIAGRAM
HARVEST GENERATOR
SHUTDOWN TABLE
DOE FUELING STATION
LAS VEGAS, NV

SOURCE | REV. 2 | SHEET

DRG. NO. ATT1042121P&ID0003 | SHEET 10 OF 10

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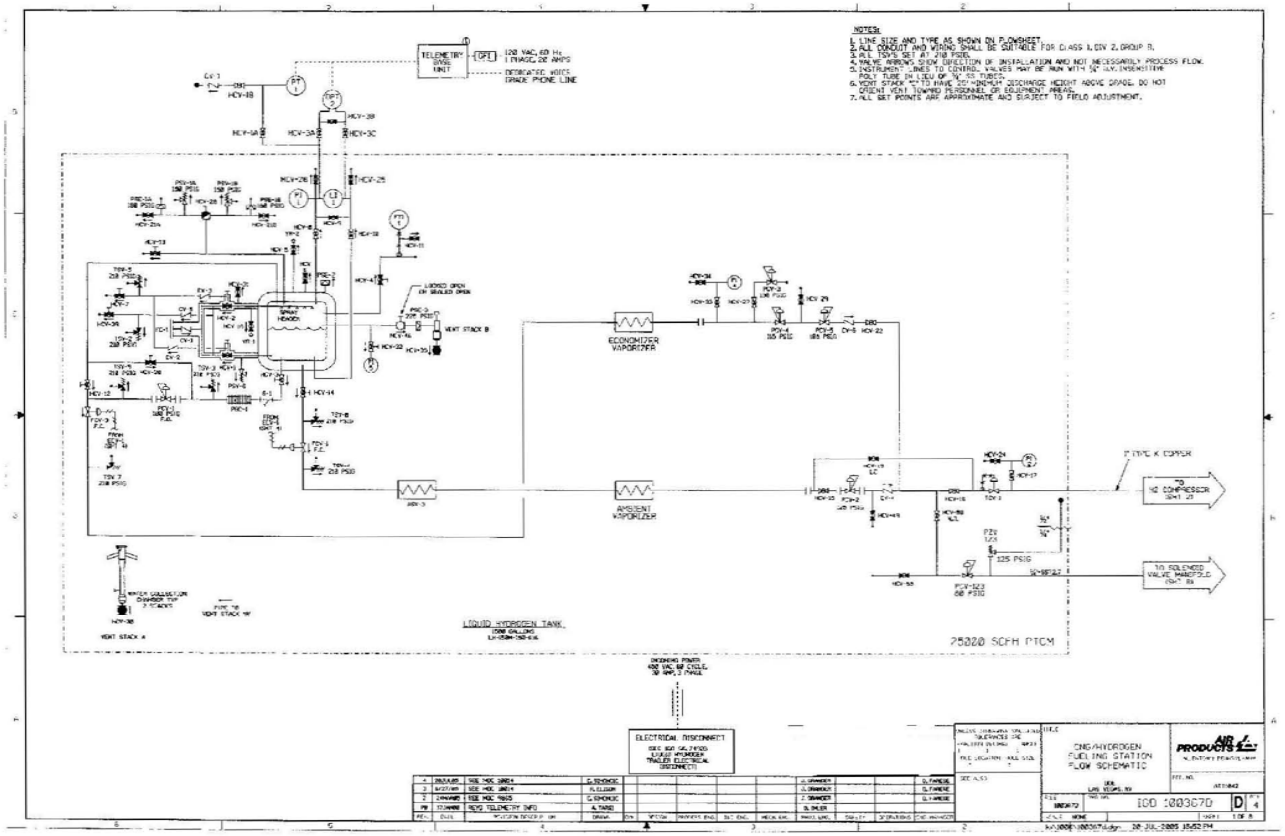
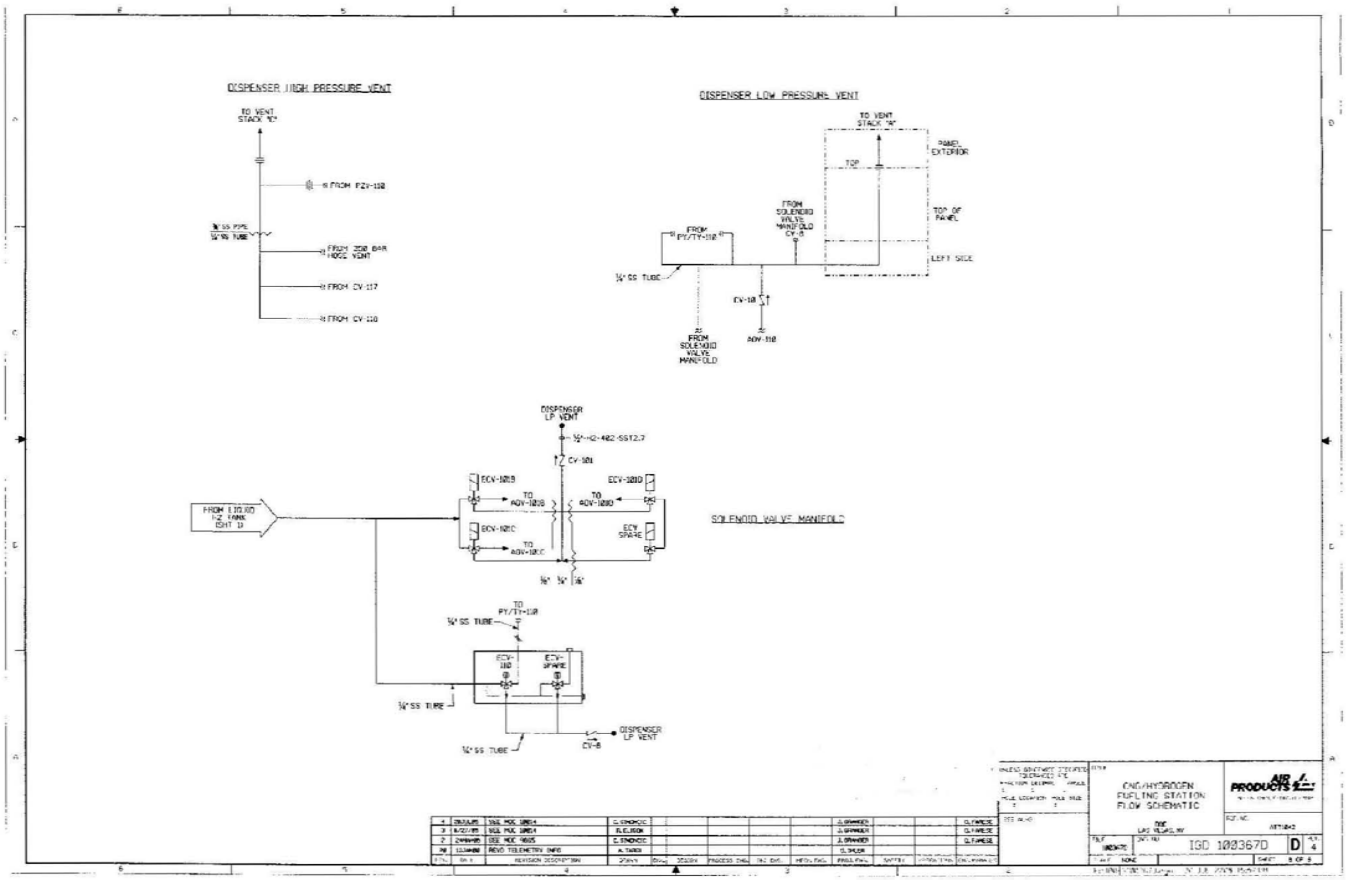
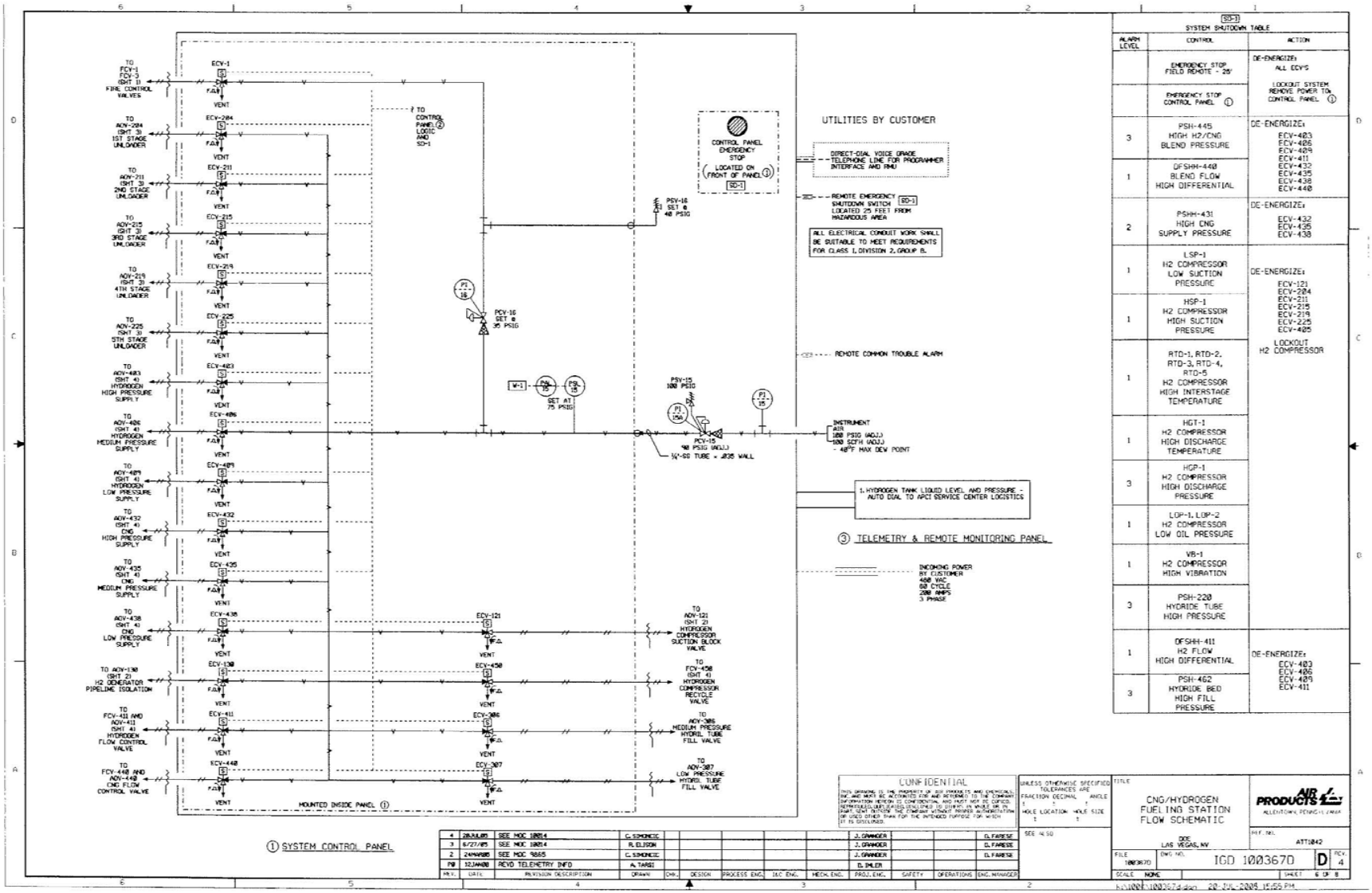

NOTES:
1. LINE SIZE AND TYPE AS SHOWN ON FLOWSHEET.
2. ALL CONDUIT AND WIRING SHALL BE SUITABLE FOR CLASS 1, DIV 2, GROUP B.
3. ALL TSV'S SET AT 210 PSIG.
4. VALVE ARROWS SHOW DIRECTION OF INSTALLATION AND NOT NECESSARILY PROCESS FLOW.
5. INSTRUMENT LINES TO CONTROL VALVES MAY BE RUN WITH 1/4" O.V. INSENSITIVE POLY TUBE IN LIEU OF 1/4" SS TUBES.
6. VENT STACK "A" TO HAVE 20' MINIMUM DISCHARGE HEIGHT ABOVE GRADE. DO NOT ORIENT VENT TOWARD PERSONNEL OR EQUIPMENT AREAS.
7. ALL SET POINTS ARE APPROXIMATE AND SUBJECT TO FIELD ADJUSTMENT.
TELEMETRY BASE UNIT
120 VAC, 60 Hz
1 PHASE, 20 AMPS
DEDICATED VOICE GRADE PHONE LINE
ECONOMIZER VAPORIZER
AMBIENT VAPORIZER
LIQUID HYDROGEN TANK
25000 SCFH PTCM
VENT STACK A
VENT STACK B
ELECTRICAL DISCONNECT
CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC
AIR PRODUCTS
ID0 1003670
D

Flow schematics follow


DISPENSER HIGH PRESSURE VENT
DISPENSER LOW PRESSURE VENT
SOLENOID VALVE MANIFOLD
CNG/HYDROGEN
FUELING STATION
FLOW SCHEMATIC
IGD 100367D


SD-1
SYSTEM SHUTDOWN TABLE
ALARM LEVEL
CONTROL
ACTION
EMERGENCY STOP FIELD REMOTE - 25'
EMERGENCY STOP CONTROL PANEL (1)
DE-ENERGIZE: ALL ECV'S
LOCKOUT SYSTEM REMOVE POWER TO CONTROL PANEL (1)
3
PSH-445 HIGH H2/CNG BLEND PRESSURE
1
DFSHH-440 BLEND FLOW HIGH DIFFERENTIAL
DE-ENERGIZE: ECV-403 ECV-406 ECV-409 ECV-411 ECV-432 ECV-435 ECV-438 ECV-440
2
PSHH-431 HIGH CNG SUPPLY PRESSURE
DE-ENERGIZE: ECV-432 ECV-435 ECV-438
1
LSP-1 H2 COMPRESSOR LOW SUCTION PRESSURE
1
HSP-1 H2 COMPRESSOR HIGH SUCTION PRESSURE
1
RTD-1, RTD-2, RTD-3, RTD-4, RTD-5 H2 COMPRESSOR HIGH INTERSTAGE TEMPERATURE
1
HGT-1 H2 COMPRESSOR HIGH DISCHARGE TEMPERATURE
3
HGP-1 H2 COMPRESSOR HIGH DISCHARGE PRESSURE
1
LOP-1, LOP-2 H2 COMPRESSOR LOW OIL PRESSURE
1
VB-1 H2 COMPRESSOR HIGH VIBRATION
DE-ENERGIZE: ECV-121 ECV-204 ECV-211 ECV-215 ECV-219 ECV-225 ECV-405
LOCKOUT H2 COMPRESSOR
3
PSH-220 HYDRIDE TUBE HIGH PRESSURE
1
DFSHH-411 H2 FLOW HIGH DIFFERENTIAL
3
PSH-462 HYDRIDE BED HIGH FILL PRESSURE
DE-ENERGIZE: ECV-403 ECV-406 ECV-409 ECV-411
UTILITIES BY CUSTOMER
DIRECT-DIAL VOICE GRADE TELEPHONE LINE FOR PROGRAMMER INTERFACE AND RMU
REMOTE EMERGENCY SHUTDOWN SWITCH SD-1 LOCATED 25 FEET FROM HAZARDOUS AREA
ALL ELECTRICAL CONDUIT WORK SHALL BE SUITABLE TO MEET REQUIREMENTS FOR CLASS I, DIVISION 2, GROUP B.
CONTROL PANEL EMERGENCY STOP LOCATED ON FRONT OF PANEL (2) SD-1
REMOTE COMMON TROUBLE ALARM
INSTRUMENT AIR 100 PSIG (ADJ.) 1000 SCFH (ADJ.) -40°F MAX DEW POINT
1. HYDROGEN TANK LIQUID LEVEL AND PRESSURE - AUTO DIAL TO APCI SERVICE CENTER LOGISTICS
(3) TELEMETRY & REMOTE MONITORING PANEL
INCOMING POWER BY CUSTOMER 460 VAC 60 CYCLE 200 AMPS 3 PHASE
PSV-16 SET @ 40 PSIG
PCV-16 SET @ 35 PSIG
PSV-15 100 PSIG
PCV-15 90 PSIG (ADJ.) 1/4"-SS TUBE x .035 WALL
SET AT 75 PSIG
ECV-1
ECV-204
ECV-211
ECV-215
ECV-219
ECV-225
ECV-403
ECV-406
ECV-409
ECV-432
ECV-435
ECV-438
ECV-121
ECV-450
ECV-386
ECV-387
ECV-440
VENT
MOUNTED INSIDE PANEL (1)
TO FCV-1, FCV-3 (SHT 3) FIRE CONTROL VALVES
TO AOV-204 (SHT 3) 1ST STAGE UNLOADER
TO AOV-211 (SHT 3) 2ND STAGE UNLOADER
TO AOV-215 (SHT 3) 3RD STAGE UNLOADER
TO AOV-219 (SHT 3) 4TH STAGE UNLOADER
TO AOV-225 (SHT 3) 5TH STAGE UNLOADER
TO AOV-403 (SHT 4) HYDROGEN HIGH PRESSURE SUPPLY
TO AOV-406 (SHT 4) HYDROGEN MEDIUM PRESSURE SUPPLY
TO AOV-409 (SHT 4) HYDROGEN LOW PRESSURE SUPPLY
TO AOV-432 (SHT 4) CNG HIGH PRESSURE SUPPLY
TO AOV-435 (SHT 4) CNG MEDIUM PRESSURE SUPPLY
TO AOV-438 (SHT 4) CNG LOW PRESSURE SUPPLY
TO AOV-130 (SHT 2) H2 GENERATOR PIPELINE ISOLATION
TO FCV-411 AND AOV-411 (SHT 4) HYDROGEN FLOW CONTROL VALVE
TO FCV-440 AND AOV-440 CNG FLOW CONTROL VALVE
? TO CONTROL PANEL LOGIC AND SD-1
TO AOV-121 (SHT 2) HYDROGEN COMPRESSOR SUCTION BLOCK VALVE
TO FCV-450 (SHT 4) HYDROGEN COMPRESSOR RECYCLE VALVE
TO AOV-386 MEDIUM PRESSURE HYDRIL TUBE FILL VALVE
TO AOV-387 LOW PRESSURE HYDRIL TUBE FILL VALVE
(1) SYSTEM CONTROL PANEL
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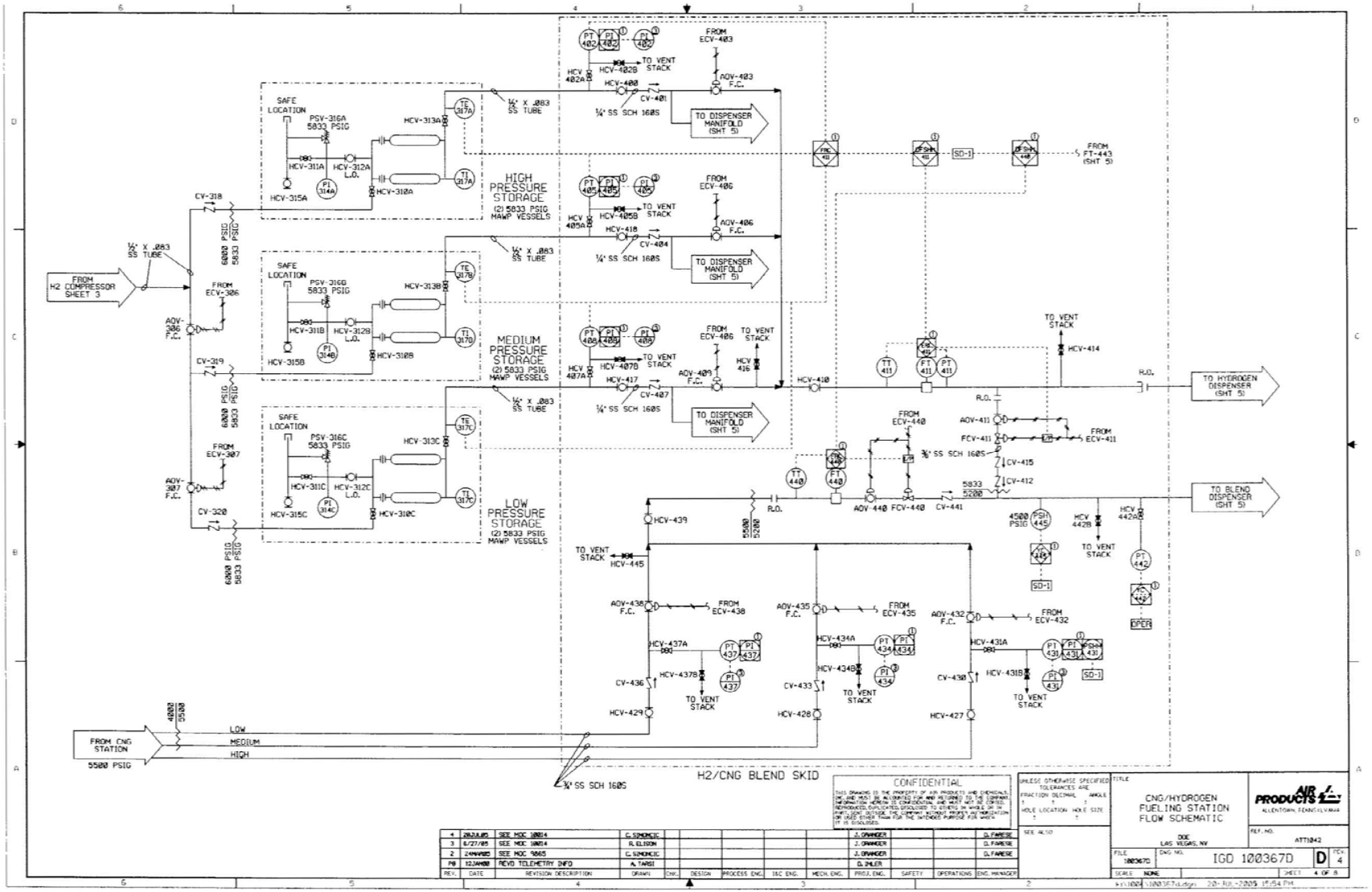
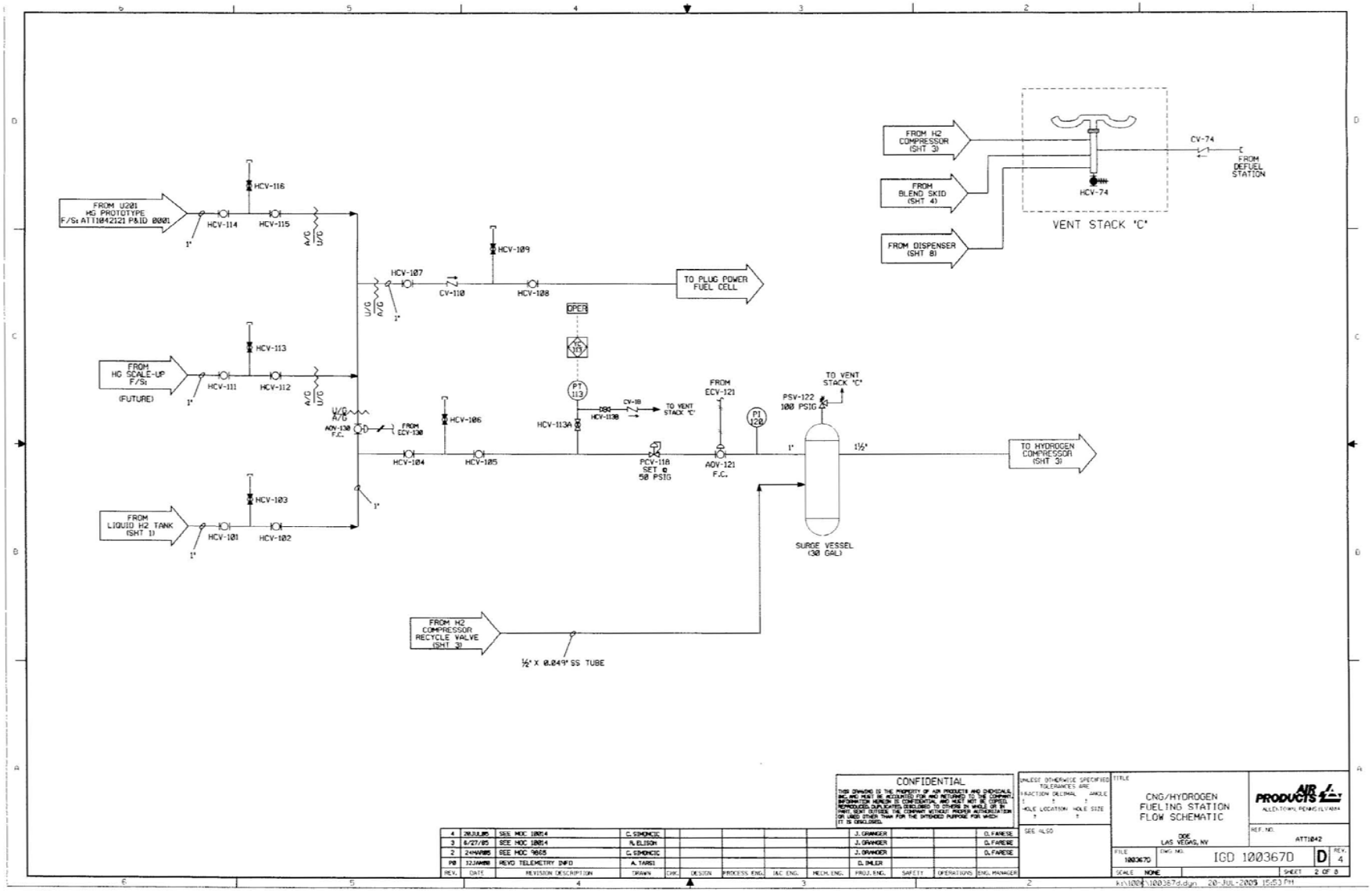
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE FRACTION DECIMAL ANGLE
HOLE LOCATION HOLE SIZE
SEE ALSO
TITLE
CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC
DOE LAS VEGAS, NV
AIR PRODUCTS
ALLENTOWN, PENNSYLVANIA
REF. NO. AT10842
FILE 1003670
DWG. NO. IGD 1003670
D
REV. 4
SCALE NONE
SHEET 6 OF 8
4 28JUL09 SEE MOC 10014 C. SIMONSIC J. GRANGER D. FARESE
3 6/27/09 SEE MOC 10014 R. ELSON J. GRANGER D. FARESE
2 24MAR09 SEE MOC 9865 C. SIMONSIC J. GRANGER D. FARESE
P8 12JAN08 REVD TELEMETRY INFO A. TARSI D. EMLER
REV. DATE REVISION DESCRIPTION DRAWN CHK. DESIGN PROCESS ENG. I&C ENG. MECH. ENG. PROJ. ENG. SAFETY OPERATIONS ENG. MANAGER
h:\1003\1003670.dgn 20-JUL-2009 15:55 PM


HIGH PRESSURE STORAGE
(2) 5833 PSIG MAWP VESSELS
MEDIUM PRESSURE STORAGE
(2) 5833 PSIG MAWP VESSELS
LOW PRESSURE STORAGE
(2) 5833 PSIG MAWP VESSELS
SAFE LOCATION
FROM H2 COMPRESSOR SHEET 3
FROM CNG STATION
5500 PSIG
LOW
MEDIUM
HIGH
TO DISPENSER MANIFOLD (SHT 5)
TO VENT STACK
TO HYDROGEN DISPENSER (SHT 5)
TO BLEND DISPENSER (SHT 5)
FROM FT-443 (SHT 5)
H2/CNG BLEND SKID
CONFIDENTIAL
CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC
AIR PRODUCTS
ALLENTOWN, PENNSYLVANIA
DOE
LAS VEGAS, NV
IGD 100367D
ATT1842


FROM U201
H2 PROTOTYPE
F/St ATT1042121 P&ID 0001
HCV-116
HCV-114
HCV-115
A/G
U/G
1"
HCV-107
HCV-109
CV-110
HCV-108
TO PLUG POWER
FUEL CELL
OPER
XS 10
FROM
H2 SCALE-UP
F/St
(FUTURE)
HCV-113
HCV-111
HCV-112
PT 113
CV-18
080
HCV-113B
TO VENT
STACK 'C'
HCV-113A
FROM
ECV-130
HCV-106
HCV-104
HCV-105
PCV-118
SET @
50 PSIG
FROM
ECV-121
PI 120
AOV-121
F.C.
PSV-122
100 PSIG
TO VENT
STACK 'C'
1½"
TO HYDROGEN
COMPRESSOR
(SHT 3)
SURGE VESSEL
(30 GAL)
FROM
LIQUID H2 TANK
(SHT 1)
HCV-103
HCV-101
HCV-102
FROM H2
COMPRESSOR
RECYCLE VALVE
(SHT 3)
½" X 0.049" SS TUBE
FROM H2
COMPRESSOR
(SHT 3)
FROM
BLEND SKID
(SHT 4)
FROM DISPENSER
(SHT 8)
HCV-74
CV-74
FROM
DEFUEL
STATION
VENT STACK 'C'
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UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:
FRACTION DECIMAL ANGLE
HOLE LOCATION HOLE SIZE
SEE ALSO
TITLE
CNG/HYDROGEN
FUELING STATION
FLOW SCHEMATIC
AIR PRODUCTS
ALLENTOWN, PENNSYLVANIA
DOE
LAS VEGAS, NV
REF. NO. ATT1042
FILE 1003670
DWG NO. IGD 1003670
D
REV. 4
SCALE NONE
SHEET 2 OF 8
4 28JUL05 SEE MOC 10014 C. SIMONCIC J. GRANGER D. FARESE
3 6/27/05 SEE MOC 10014 N. ELISON J. GRANGER D. FARESE
2 24MAR05 SEE MOC 9665 C. SIMONCIC J. GRANDER D. FARESE
P8 22JAN04 REVD TELEMETRY INFO A. TARSI D. EMLER
REV. DATE REVISION DESCRIPTION DRAWN CHK DESIGN PROCESS ENG. I&C ENG. MECH. ENG. PROJ. ENG. SAFETY OPERATIONS ENG. MANAGER
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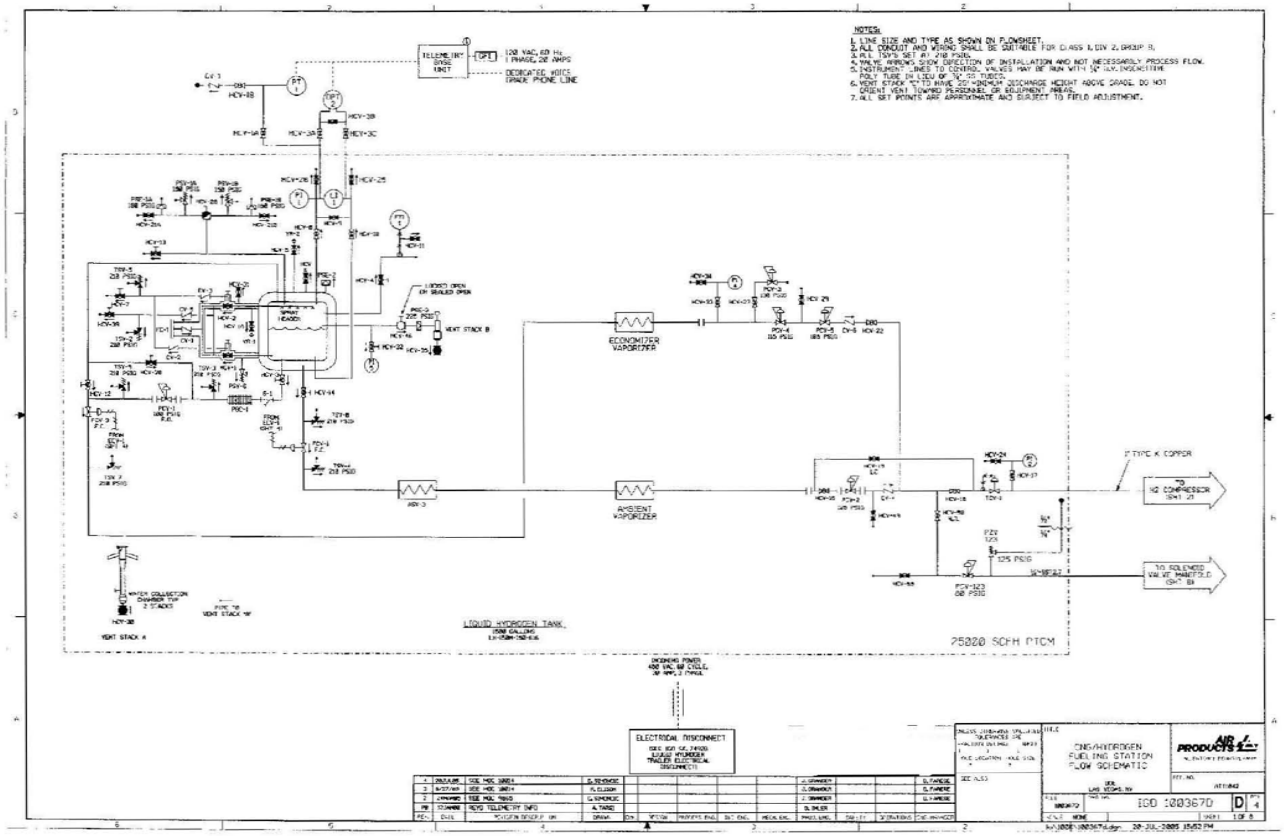
NOTES:
1. LINE SIZE AND TYPE AS SHOWN ON FLOWSHEET.
2. ALL CONDUIT AND WIRING SHALL BE SUITABLE FOR CLASS 1, DIV 2, GROUP B.
3. ALL TSV'S SET AT 210 PSIG.
4. VALVE ARROWS SHOW DIRECTION OF INSTALLATION AND NOT NECESSARILY PROCESS FLOW.
5. INSTRUMENT LINES TO CONTROL VALVES MAY BE RUN WITH 1/4" O.D. INSCRIPTIBLE POLY TUBE IN LIEU OF 1/4" SS TUBES.
6. VENT STACK "C" TO HAVE 20'-0"MINIMUM DISCHARGE HEIGHT ABOVE GRADE. DO NOT ORIENT VENT TOWARD PERSONNEL OR EQUIPMENT AREAS.
7. ALL SET POINTS ARE APPROXIMATE AND SUBJECT TO FIELD ADJUSTMENT.
TELEMETRY BOSE UNIT
120 VAC, 60 Hz, 1 PHASE, 20 AMPS
DEDICATED HOTCS TRADE PHONE LINE
ECONOMIZER VAPORIZER
AMBIENT VAPORIZER
LIQUID HYDROGEN TANK
VENT STACK A
VENT STACK B
2" TYPE K COPPER
TO H2 COMPRESSOR
TO SOLENOID VALVE MANIFOLD
25000 SCFH PTCM
ELECTRICAL DISCONNECT
CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC
AIR PRODUCTS
ISO 1003670
D
4
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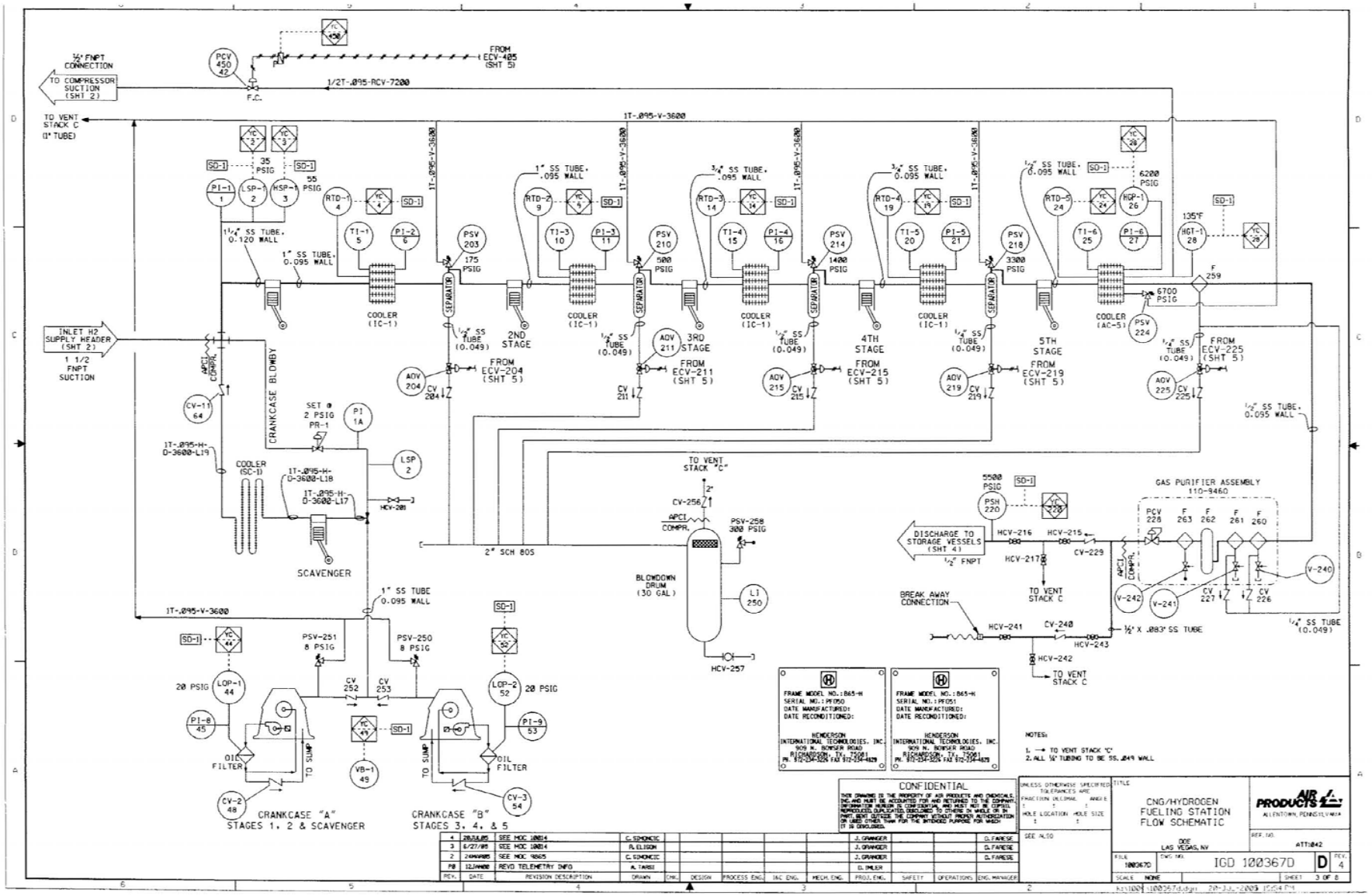
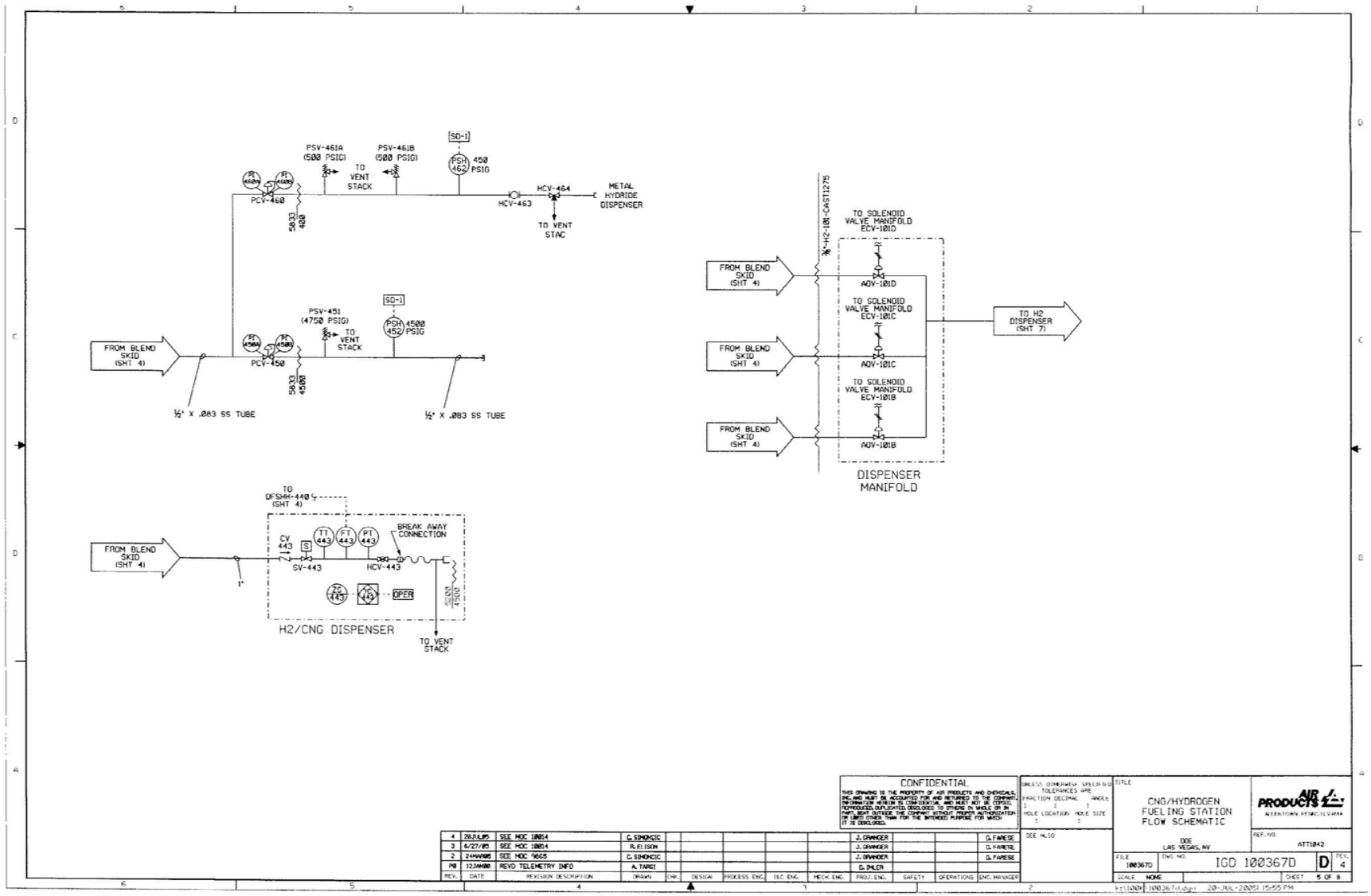
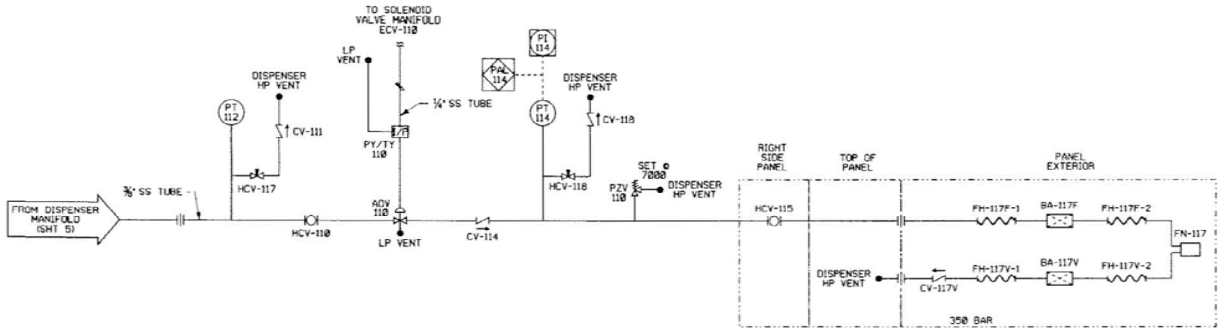

TO COMPRESSOR SUCTION (SHT 2)
FROM ECV-405 (SHT 5)
1/2T-.095-RCV-7200
TO VENT STACK C (1" TUBE)
1T-.095-V-3600
INLET H2 SUPPLY HEADER (SHT 2)
1 1/2 FNPT SUCTION
COOLER (IC-1)
2ND STAGE
3RD STAGE
4TH STAGE
5TH STAGE
COOLER (AC-5)
FROM ECV-204 (SHT 5)
FROM ECV-211 (SHT 5)
FROM ECV-215 (SHT 5)
FROM ECV-219 (SHT 5)
FROM ECV-225 (SHT 5)
CRANKCASE BLOWBY
SCAVENGER
COOLER (SC-1)
2" SCH 80S
BLOWDOWN DRUM (30 GAL)
GAS PURIFIER ASSEMBLY 110-9460
DISCHARGE TO STORAGE VESSELS (SHT 4)
BREAK AWAY CONNECTION
TO VENT STACK C
CRANKCASE "A" STAGES 1, 2 & SCAVENGER
CRANKCASE "B" STAGES 3, 4, & 5
OIL FILTER
TO SUMP
CONFIDENTIAL
CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC
AIR PRODUCTS
IGD 100367D


PSV-461A (500 PSIG)
PSV-461B (500 PSIG)
TO VENT STACK
SD-1
PSH 462 450 PSIG
PCV-460
HCV-463
HCV-464
METAL HYDRIDE DISPENSER
TO VENT STAC
PSV-451 (4750 PSIG)
PSH 452 4500 PSIG
FROM BLEND SKID (SHT 4)
PCV-450
½" X .083 SS TUBE
½" X .083 SS TUBE
TO SOLENOID VALVE MANIFOLD ECV-101D
AOV-101D
TO SOLENOID VALVE MANIFOLD ECV-101C
AOV-101C
TO SOLENOID VALVE MANIFOLD ECV-101B
AOV-101B
TO H2 DISPENSER (SHT 7)
DISPENSER MANIFOLD
TO DFSHM-440 (SHT 4)
BREAK AWAY CONNECTION
CV 443
SV-443
HCV-443
OPER
H2/CNG DISPENSER
TO VENT STACK
CONFIDENTIAL
CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC
AIR PRODUCTS
DOE LAS VEGAS, NV
IGD 100367D
SCALE NONE
SHEET 5 OF 8



PIPING FABRICATION/ASSEMBLY NOTES:

1. ALL MAJOR PIECES OF MECHANICAL EQUIPMENT (VALVES, TRANSMITTERS, FLOW ELEMENTS, I/P's, ETC.) SHALL BE TAGGED WITH THE EQUIPMENT IDENTIFICATION NUMBER.
2. PIPING WILL BE INSPECTED BY AN API INSPECTOR PRIOR TO SHIPMENT. PIPING SHALL BE INSPECTED PER DRAWINGS BY PANEL VENDOR PRIOR TO API INSPECTION. ALL DEVIATIONS DETERMINED IN INSPECTION WILL BE CORRECTED PRIOR TO API INSPECTION.
3. INTERIOR LAYOUT SHALL BE DETERMINED BY PANEL VENDOR. LAYOUT MUST CONSIDER EASE OF ACCESS AND MAINTAINABILITY OF EQUIPMENT. LAYOUT MUST ALSO CONSIDER ELECTRICAL COMPONENT PLACEMENT SUCH AS ROUTING OF CONDUIT AND POURING OF CONDUIT SEALS.
4. PANEL VENDOR MAY AND IS STRONGLY ENCOURAGED TO SUBSTITUTE, ADD, AND/OR CHANGE COMPONENTS WHERE NECESSARY TO FACILITATE THE EASE OF ASSEMBLY, ACCESS AND MAINTAINABILITY - FOR EXAMPLE SUBSTITUTING A MALE ELBOW FOR A MALE CONNECTOR SO A TUBE BEND IS NOT NECESSARY OR ADDING A UNION TO FACILITATE DISSEMBLY.
5. ⅜" SS TUBE USED IN HIGH PRESSURE APPLICATIONS SHALL HAVE A THICKNESS OF 0.086".
6. ¼" SS TUBE USED FOR INSTRUMENTATION SHALL HAVE A THICKNESS OF 0.035".
7. ALL PIPING SHALL BE SCHEDULE 40.

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UNLESS OTHERWISE SPECIFIED TOLERANCES ARE: FRACTION DECIMAL ANGLE ± ± ± HOLE LOCATION: HOLE SIZE ± ±

SEE ALSO

REV.	DATE	REVISION DESCRIPTION	DRAWN	CHK.	DESIGN	PROCESS ENG.	I&C ENG.	MECH. ENG.	PROJ. ENG.	SAFETY	OPERATIONS	ENG. MANAGER
4	28JUL05	SEE MOC 10014	G. SIMONSIC						J. GRANGER			D. FARESE
3	6/27/05	SEE MOC 10014	R. ELISON						J. GRANGER			D. FARESE
2	24MAR05	SEE MOC 9685	G. SIMONSIC						J. GRANGER			D. FARESE
PB	12JAN05	REVD TELEMETRY INFO	A. TARSI						D. ENLER			

TITLE: CNG/HYDROGEN FUELING STATION FLOW SCHEMATIC

DOE LAS VEGAS, NV

AIR PRODUCTS AND CHEMICALS, INC. ALLENTOWN, PENNSYLVANIA

REF. NO. ATT1042

FILE 1003670 | DWG. NO. IGD 1003670 | D | REV. 4

SCALE NONE | SHEET 7 OF 8

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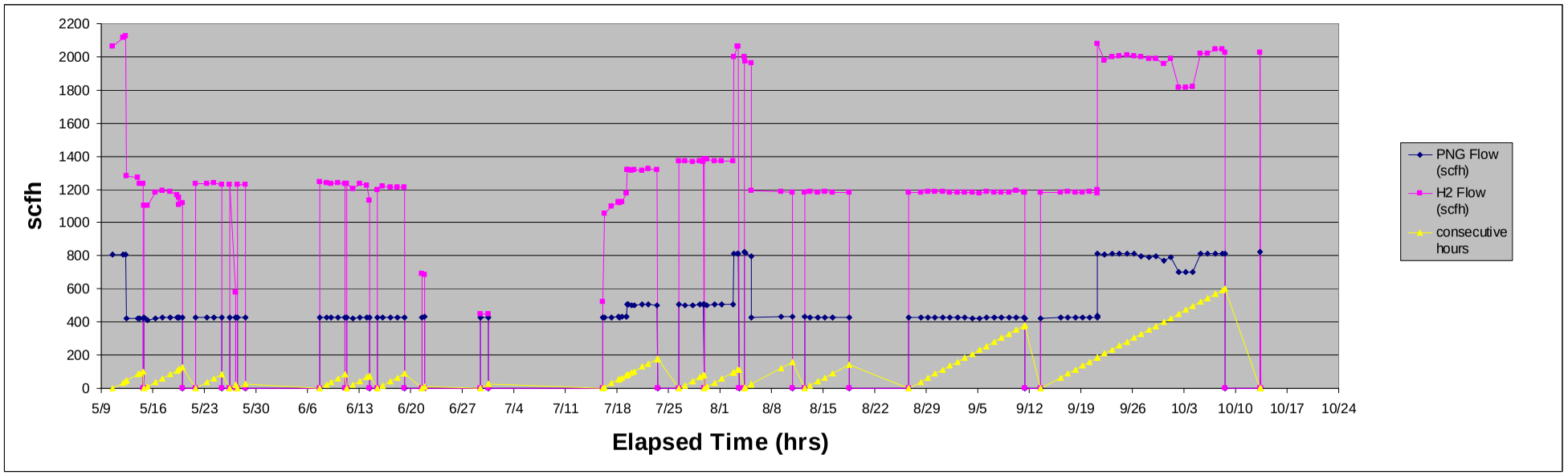
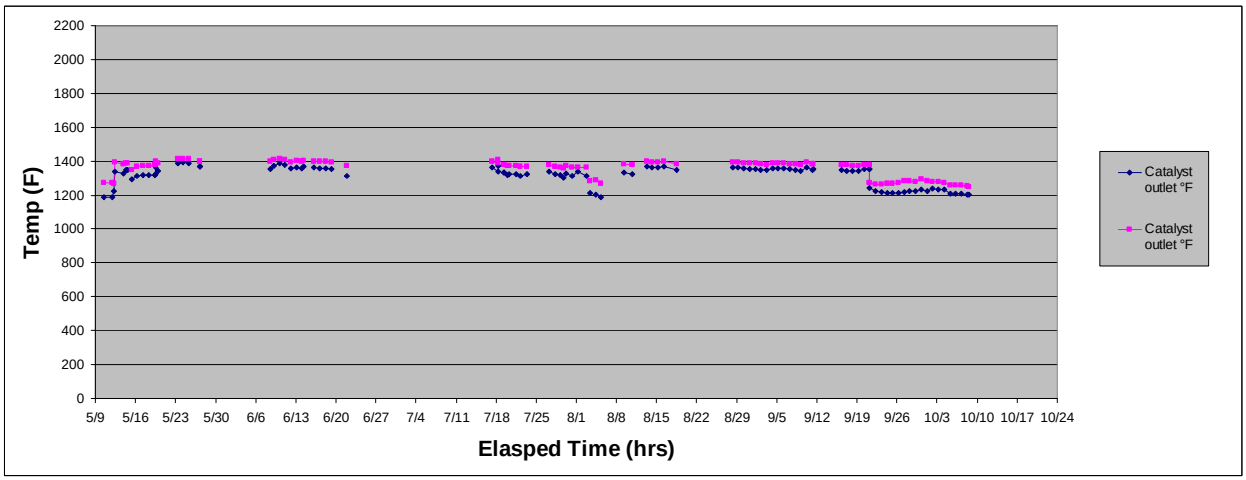
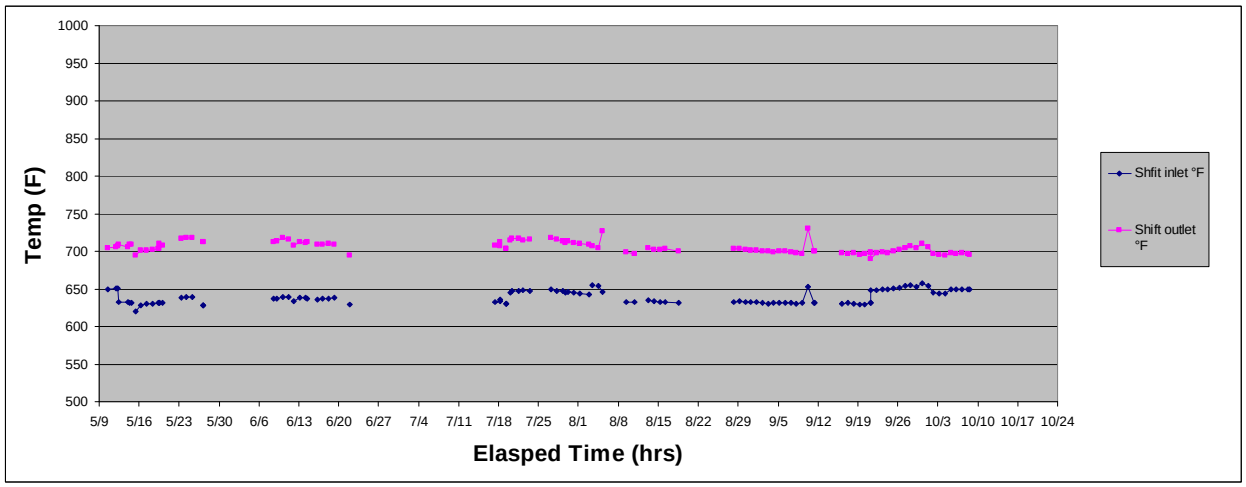
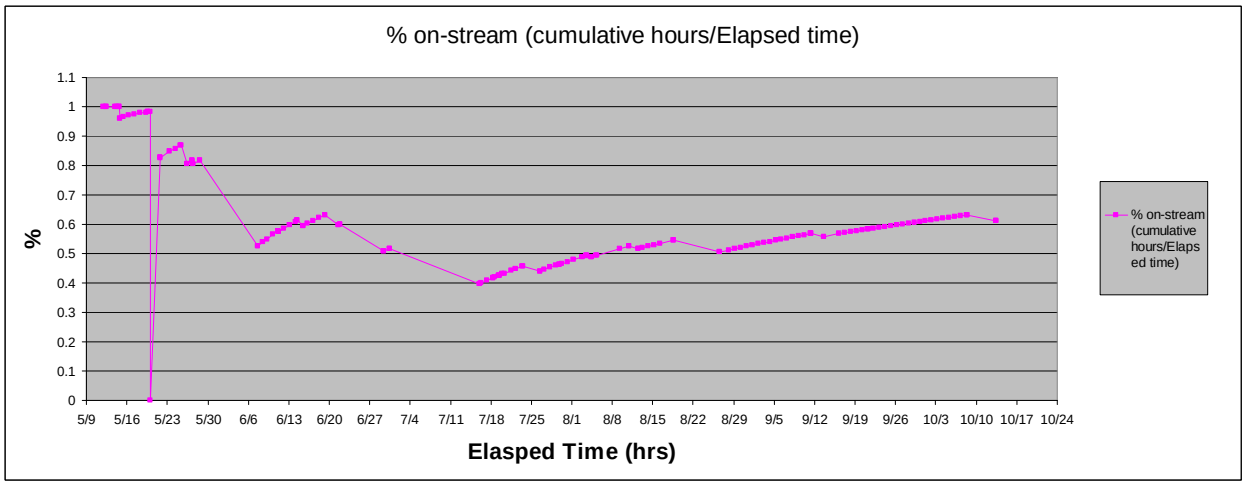
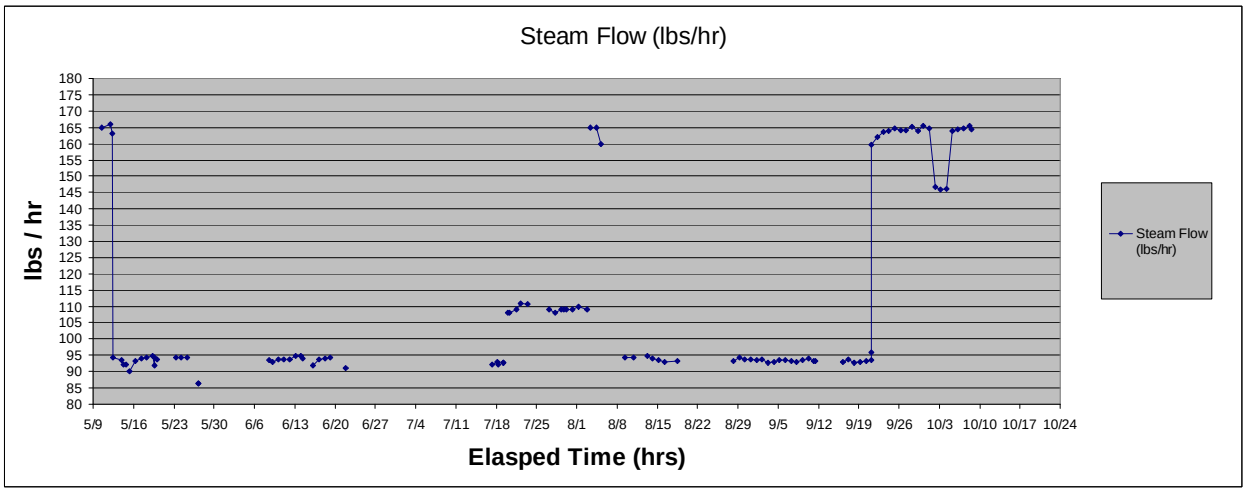
Appendix D
Hydrogen Production History

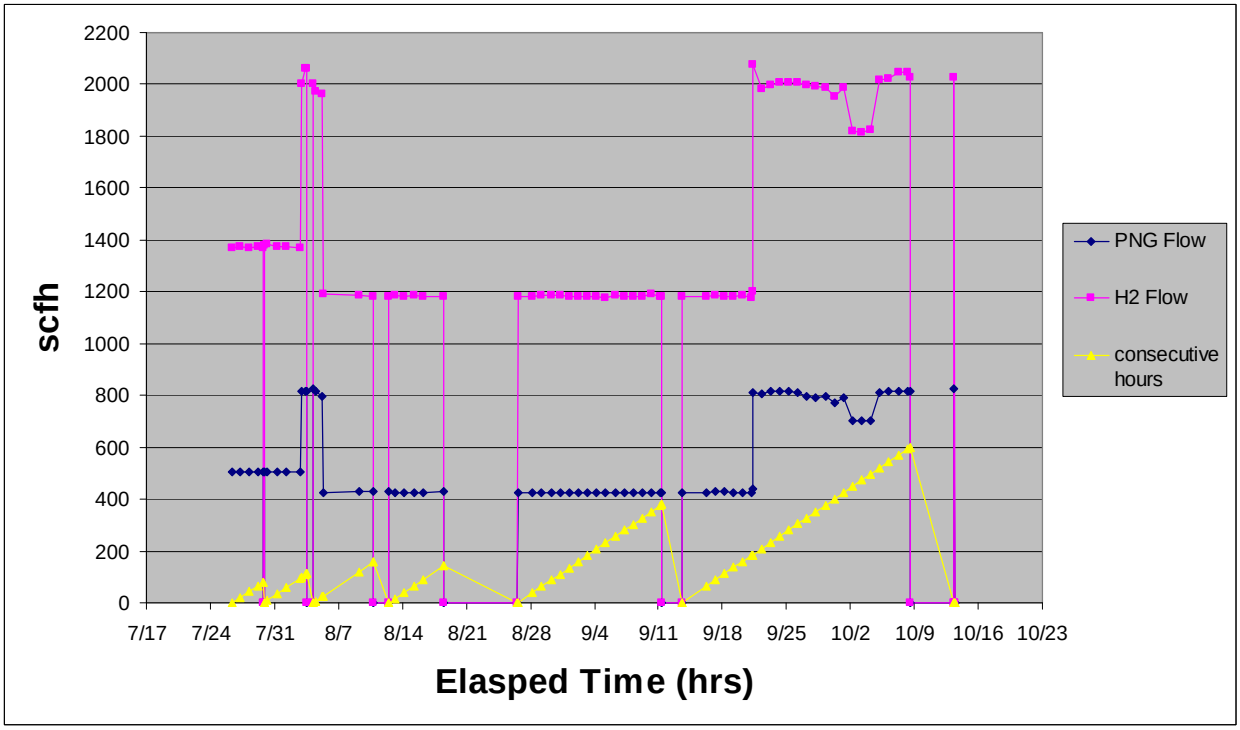



2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Temp (F)
5/9
5/16
5/23
5/30
6/6
6/13
6/20
6/27
7/4
7/11
7/18
7/25
8/1
8/8
8/15
8/22
8/29
9/5
9/12
9/19
9/26
10/3
10/10
10/17
10/24
Elasped Time (hrs)
Catalyst outlet °F
Catalyst outlet °F


1000
950
900
850
800
750
700
650
600
550
500
Temp (F)
5/9
5/16
5/23
5/30
6/6
6/13
6/20
6/27
7/4
7/11
7/18
7/25
8/1
8/8
8/15
8/22
8/29
9/5
9/12
9/19
9/26
10/3
10/10
10/17
10/24
Elasped Time (hrs)
Shfit inlet °F
Shift outlet °F


% on-stream (cumulative hours/Elapsed time)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
%
5/9
5/16
5/23
5/30
6/6
6/13
6/20
6/27
7/4
7/11
7/18
7/25
8/1
8/8
8/15
8/22
8/29
9/5
9/12
9/19
9/26
10/3
10/10
10/17
10/24
Elasped Time (hrs)
% on-stream (cumulative hours/Elapsed time)


Steam Flow (lbs/hr)
lbs / hr
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
5/9
5/16
5/23
5/30
6/6
6/13
6/20
6/27
7/4
7/11
7/18
7/25
8/1
8/8
8/15
8/22
8/29
9/5
9/12
9/19
9/26
10/3
10/10
10/17
10/24
Elasped Time (hrs)
Steam Flow (lbs/hr)


2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
scfh
7/17
7/24
7/31
8/7
8/14
8/21
8/28
9/4
9/11
9/18
9/25
10/2
10/9
10/16
10/23
Elasped Time (hrs)
PNG Flow
H2 Flow
consecutive hours

Appendix E
Operational Data

Las Vegas H2 Generator Performance Test Summary

Product			Design Case	Harvest Shop - Performance Test Case	Harvest Shop - Performance Test Case	Site - Performance Test Case	Site - Performance Test Case	Site - Performance Test Case	Site - Performance Test Case	Site - Performance Test Case	Site - Performance Test Case	Potential max rate case
				810 scfh Process NG 2002 04 20	405 scfh Process NG 2002 04 22	405 scfh Process NG 2002 08 17	775 scfh Process NG 2002 08 18	650 scfh Process NG 2003 12 15	775 scfh Process NG 2003 12 17	775 scfh Process NG 2003 12 17	405 scfh Process NG 2003 12 18	775 scfh Process NG
H2	scfh	FI-111	2731	1994	1178	1184	1938	1714	1996	1782	1025	1964
	kg/hr		6.6	4.8	2.8	2.9	4.7	4.1	4.8	4.3	2.5	4.7
	Nm3/hr		73.1	53.4	31.5	31.7	51.9	45.9	53.4	47.7	27.5	52.6
	lbmole/hr		7.19	5.25	3.10	3.12	5.10	4.51	5.26	4.69	2.70	5.17
Natural Gas												
Feed	HHV btu/hr		943,618	808,412	406,397	415,797	786,129	654,386	779,758	782,307	404,863	788,695
	lbmol/hr	FI-102	2.37	2.10	1.05	1.05	2.00	1.66	1.98	1.98	1.03	2.01
Fuel	HHV btu/hr		172,087	166,782	140,504	129,567	75,103	361,698	414,703	40,674	74,384	81,411
	lbmol/hr	calc.	0.43	0.43	0.36	0.33	0.19	0.92	1.05	0.10	0.19	0.21
MW	lb/lbmole		17.1	16.9	16.9	17.1	17.0	17.0	17.0	17.0	17.0	17.0
HHV	btu/scf		1049	1015	1015	1043	1034	1038	1038	1038	1038	1034
LHV	btu/scf		946	914	914	940	932	936	936	936	936	932
Efficiency												
Gross Efficiency	HHV btu/scf		408	489	464	461	444	593	598	462	467	443
	LHV btu/scf		368	441	419	415	401	535	540	416	422	399
Thermal Efficiency	HHV basis		79%	66%	70%	70%	73%	55%	54%	70%	69%	73%
	LHV basis		74%	62%	65%	66%	68%	51%	51%	66%	65%	69%
Reformer												
Steam-to-Carbon			3.50	4.85	5.94	5.53	3.91	4.36	4.16	4.41	4.94	4.03
Process Duty	btu/hr		290,252	257,393	149,870	145,340	242,142	216,698	251,197	252,066	138,002	246,497
Reforming Temp	deg F	TI-101A/B	1298	1231	1394	1316	1224	1366	1297	1262	1399	1250
Reforming Pres	psia	estimate	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
Approach Temp	deg F	calc.	-50	-48	-55	-37	-12	-30	-22	-19	-12	-30
CH4 Slip	mole % dry	by GC	1.09%	1.37%	0.06%	0.19%	1.35%	0.17%	0.48%	0.64%	0.06%	1.14%
Shift Reactor												
Inlet Temp	deg F	TI-104	600	644	653	623	636	627	626	625	606	650
Outlet Temp	deg F	TI-105	711	691	719	678	699	697	683	669	671	715
Approach Temp	deg F	calc.	50	245	122	229	187	251	297	333	293	180
WGSV	hr-1		3064	3069	1842	1799	2706	2440	2815	2917	1630	2769
CO in syngas	mole % dry	by GC	3.15%	4.07%	2.30%	3.19%	4.25%	4.88%	5.54%	5.44%	4.45%	4.27%
PSA												
Recovery	%		80.1%	70.0%	75.5%	75.5%	70.0%	70.8%	70.8%	63.4%	67.8%	70.0%
Purge Gas	lbmole/hr	FI-110	4.38	4.49	2.13	2.16	4.36	3.67	4.32	4.87	2.40	4.39
MW	lb/lbmole		24.29	20.23	22.75	22.49	20.17	20.41	20.23	18.20	19.57	20.18
HHV	btu/scf		188	222	173	182	223	204	213	228	205	213
Furnace												
Duty (HHV)	btu/hr		469,882	463,290	273,664	271,518	406,318	361,982	415,053	440,249	252,557	428,198
Radiant Efficiency (HHV)	btu/hr		62%	56%	55%	54%	60%	60%	61%	57%	55%	58%
Purge Gas Duty	%		63%	64%	49%	52%	82%	0%	0%	91%	71%	81%
Nat. Gas Duty	%		37%	36%	51%	48%	18%	100%	100%	9%	29%	19%
Tailgas Burned	%			78%	95%	95%	90%	0%	0%	95%	95%	95%
Tailgas Vent valve position	%			n/a	n/a	1.8	n/a	n/a	n/a	5.5	3.1	n/a
Fuel NG valve position	%			n/a	n/a	38.0	30.2	54.3	56.8	29.7	33.7	30.2
Combustion Air	lb/hr	calc.	485	498	340	355	360	460	498	460	323	404

Excess Air	%	calc.	64%	71%	95%	106%	47%	78%	68%	80%	111%	57%
Burner Surface Temp	deg F	TI-102A/B		1875	1738	1727	1857	1710	1816	1879	1746	1857
Tubewall Temp	deg F	TI-103A/B		1458	1494	1405	1397	1529	1530	1535	1515	1397
Steam System												
Steam Production	lb/hr	FI-101A	157	186	114	109	146	136	154	164	95	151
Steam Drum Pressure	psia	Heise Gauge	26.7	32.1	25.1062236	24.2144444	27.3775	25.05	25.6666667	25.9	24.175	27.4
Mixed Feed Preheater - E1												
Mixed Feed Flow	lbmole/hr	calc.	11.11	11.89	7.40	7.12	10.10	9.19	10.53	11.08	6.30	10.38
Mixed Feed to E1	lbmole/hr	estimate	11.09	8.38	5.22	5.02	7.12	6.48	7.42	7.81	4.44	7.32
Mixed Feed Bypass	%	estimate	0%	29%	29%	29%	30%	29%	30%	29%	30%	30%
Mixed Feed Inlet Temp	deg F	TI-107	217	220	222	222	218	220	219	220	221	219
Mixed Feed Outlet Temp	deg F	TI-111	684	801	857	829	804	815	808	800	833	781
Process Gas Flow	lbmole/hr		15.85	15.87	9.53	9.30	13.99	12.62	14.56	15.09	8.43	14.32
Process Gas Inlet Temp	deg F	TI-112	1000	1000	1055	1007	994	996	989	984	991	994
Process Gas Outlet Temp	deg F	TI-104	600	644	653	623	636	627	626	625	606	650
Heating Duty	btu/hr		-51,479	-46,919	-32,095	-29,743	-41,290	-38,155	-43,273	-44,604	-26,722	-40,581
Cooling Duty	btu/hr		49,420	45,042	30,811	28,554	39,638	36,629	41,542	42,820	25,653	38,958
Heat Leak	btu/hr		-2,059	-1,877	-1,284	-1,190	-1,652	-1,526	-1,731	-1,784	-1,069	-1,623
Heat Leak	%		4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
LMTD	deg F		348	297	299	275	289	279	279	280	255	309
UA	btu/hr-F		148	158	107	108	143	137	155	159	105	131
Design UA	btu/hr-F			148	98	97	134	123	138	142	89	136
Actual vs. Design	%			107%	109%	112%	107%	111%	112%	112%	117%	96%
Boiler Process Gas Coil - B2												
BFW Flow	lbmole/hr		2.65	2.85	1.92	1.67	2.53	2.27	2.54	2.57	1.48	2.40
BFW Inlet Temp	deg F	TI-117	165	219	208	196	190	167	182	200	185	120
Steam Temp	deg F	calc.	244	254	240	238	245	240	242	242	238	245
Process Gas Flow	lbmole/hr		15.85	15.87	9.53	9.30	13.99	12.62	14.56	15.09	8.43	14.32
Process Gas Inlet Temp	deg F	TI-105	711	691	719	678	699	697	683	669	671	715
Process Gas Outlet Temp	deg F	TI-118	300	287	267	267	279	269	273	277	263	300
Heating Duty	btu/hr		-51,757	-51,361	-34,764	-30,668	-46,718	-42,829	-47,196	-46,917	-27,377	-47,376
Cooling Duty	btu/hr		49,169	50,334	34,068	30,055	45,783	41,972	46,252	45,979	26,829	46,429
Heat Leak	btu/hr		-2,588	-1,027	-695	-613	-934	-857	-944	-938	-548	-948
Heat Leak	%		5%	2%	2%	2%	2%	2%	2%	2%	2%	2%
LMTD	deg F		267	198	200	203	225	237	222	205	208	302
UA	btu/hr-F		194	259	173	151	208	181	212	229	132	157
Design UA	btu/hr-F			194	129	126	175	161	181	186	117	178
Actual vs. Design	%			134%	135%	120%	119%	112%	117%	123%	113%	88%
Boiler Flue Gas Coil - B2												
BFW Flow	lbmole/hr		6.09	7.45	4.42	4.40	5.57	5.26	6.01	6.52	3.79	5.97
BFW Inlet Temp	deg F	TI-117	165	219	208	196	190	167	182	200	185	120
Steam Temp	deg F	calc.	244	254	240	238	245	240	242	242	238	245
Flue Gas Flow	lbmole/hr		20.41	20.20	13.65	14.13	15.45	16.88	18.33	19.14	12.94	17.14
Flue Gas Inlet Temp	deg F	TI-115	1000	1155	1028	1008	1130	1035	1077	1080	963	1130
Flue Gas Outlet Temp	deg F	TI-116	275	328	284	281	313	270	287	301	268	280
Heating Duty	btu/hr		-118,822	-134,058	-80,071	-80,626	-102,919	-99,175	-111,924	-119,162	-70,249	-117,978
Cooling Duty	btu/hr		112,881	131,377	78,470	79,014	100,860	97,191	109,685	116,778	68,844	115,619
Heat Leak	btu/hr		-5,941	-2,681	-1,601	-1,613	-2,058	-1,983	-2,238	-2,383	-1,405	-2,360
Heat Leak	%		5%	2%	2%	2%	2%	2%	2%	2%	2%	2%
LMTD	deg F		335	374	304	311	386	338	353	348	296	424
UA	btu/hr-F		355	358	263	259	267	294	317	342	237	278
Design UA	btu/hr-F			352	257	264	284	305	325	337	246	308
Actual vs. Design	%			102%	102%	98%	94%	96%	97%	102%	96%	90%

BFW Preheater - E2

BFW Flow	lbmole/hr		8.74	10.30	6.34	6.07	8.10	7.53	8.55	9.09	5.27	8.37
BFW Inlet Temp	deg F	estimate	73	67	69	72	69	52	52	62	52	69
BFW Outlet Temp	deg F	TI-117	165	219	208	196	190	167	182	200	185	120
Flue Gas Flow	lbmole/hr		20.41	20.20	13.65	14.13	15.45	16.88	18.33	19.14	12.94	17.14
Flue Gas Inlet Temp	deg F	TI-116	275	328	284	281	313	270	287	301	268	280
Flue Gas Outlet Temp	deg F	handheld	180	138	125	150	160	140	136	140	135	220
Heating Duty	btu/hr		-14,637	-28,581	-16,159	-13,749	-17,881	-15,843	-20,261	-23,041	-12,748	-7,778
Cooling Duty	btu/hr		14,418	28,152	15,917	13,543	17,613	15,605	19,957	22,696	12,557	7,661
Heat Leak	btu/hr		-220	- 429	- 242	- 206	- 268	- 238	- 304	- 346	- 191	- 117
Heat Leak	%		2%	1%	2%	2%	1%	1%	2%	1%	2%	2%
LMTD	deg F		108	88	65	82	106	95	94	89	83	155
UA	btu/hr-F		135	324	248	168	169	167	215	259	154	50
Design UA	btu/hr-F			134	98	101	108	116	124	129	94	118
Actual vs. Design	%			241%	253%	167%	156%	143%	173%	201%	164%	43%

standard conditions:

deg F	60
psia	14.696
scf/lbmole	379.7

Appendix F

General Performance Observations
&
Equipment Operational Problems and Resolution

General Performance Observations:

Performance Test Data and Simulation

The hydrogen generator was designed to produce hydrogen product to document hydrogen's competitiveness as a fuel compared to gasoline.

The heat and material balance was simulated using Aspen by setting the measured temperatures, pressures, syngas compositions, process natural gas flow, tailgas flow, and hydrogen product flow, and a best estimate of the amount of tailgas burned and steam produced. The air flow for combustion, the reformer and shift reactor approach temperatures, and exchanger heat leaks were adjusted to close the heat and material balance. Finally, all 8 simulations were compared to the original heat and material balance from HET to determine consistency.

Maximum Production vs. Design

At the shop performance test, Dave Warren of Harvest Energy Technology (HET) commented that the reformer did not make design production because the reformer is heat transfer limited.

The attainable catalyst outlet temperature limits the amount of natural gas that can be processed by the reformer. The reformer tubes are "regenerative tubes", heated both by radiant heat from a central burner and by heat from the catalyst outlet gas flowing through a center tube. The fuel to the burner is adjusted to maintain a burner surface temperature. The burner surface temperature is set based on plant rates to give sufficient heat to achieve acceptable methane conversion in the reformer. Secondary air is added to the furnace to cool the tube walls below the shutdown limit. The amount of secondary air varies the steam production since it changes the fluegas flow to the boiler.

The highest rates that could be achieved at the HET shop test were 810 scfh process natural gas feed vs. a design of 900 scfh. The catalyst outlet temperature was at 1230 deg F for this case. The highest rates that could be achieved at the Las Vegas site were 775 scfh process natural gas fee. This was limited by the amount of combustion air the primary air fan could provide. The 2100 foot elevation and 115 deg F Summer temperatures limited the fan throughput vs. the shop test conditions.

Efficiency vs. Design

The plant efficiency expressed as either Thermal Efficiency (btu of H2 product per btu of feed gas) or as gross efficiency (btu of feed gas per scf of H2 product) was lower than the design case. This is attributed to three main factors – Shift reactor design, PSA recovery, and high steam production.

First, the shift reactor approach temperature is lower than design. This is mostly due to the high space velocity (WGSV) through the reactor. Based on communications with Sud Chemie, the design wet gas SV for the reactor at 650 deg F inlet temperature should be on the order 1700 hr-1. The shift reactor design is WGSV =3000 hr-1, and the plant has operated between 3000 hr-1 at high rates and 1600 hr-1 at turndown rates. The high

WGSV results in worse shift reactor approach temperatures and higher than design syngas CO content. This leads to both loss of this conversion to hydrogen and to lower PSA recovery.

Second, the PSA recovery is lower than that assumed in the design heat and material balance. At high rates, the PSA recovery has been observed around 70% vs. a design of 80%.

Third, to cool the tubewall, the secondary air is higher than design resulting in high steam production. All steam produced is mixed with process natural gas resulting in a high steam to carbon ratio. This results in more duty to heat the syngas to reforming temperatures. This also leads to higher shift reactor space velocities, which converts less of the CO to H2.

Demand / Hours of Production

The hydrogen generator was designed to supply hydrogen fuel to a fleet of hydrogen powered and hydrogen/NG blend vehicles, to be operated by the City of Las Vegas. The fleet of vehicles has never materialized. There is a H2/NG blend pick-up truck and a H2/NG blend bus each operated a minimum number of hours per month. Maintenance issues on these vehicles have prevented them from continuous operation.

In addition to the vehicles, a 50 kw PEM fuel cell manufactured and operated by Plug Power is to base-load the hydrogen demand, producing electricity with the hydrogen produced at turndown rates when vehicles are not fueling. This fuel cell has had very few operating hours, and many of the hours it did run, it consumed vaporized liquid hydrogen to verify operation on fuel lower than the guaranteed 10 ppm CO produced from the H2 generator.

Due to the low demand, nearly all of the operating hours were R&D hours to understand operation, controls, and reliability issues. The plant has operated between 2500 and 3000 hours between August 2002 and February 2004.

Reliability / Operating Issues

During the first 2500 hours of operation, there have been many outages due to instrumentation and equipment problems. Most notably are issues with

- the reformer burner failed,
- the reformer catalyst degradation, and
- syngas compressor vibrations causing failure of piping and nozzle welds on vessels associated with the syngas compressor.

The following are short descriptions of the operating issues. They are not in-depth analysis of each topic.

Burner Failure

During operation in May 2003, the plant tripped due to failure of the burner. The plant was operating at normal operating conditions with tailgas to the burner. Analysis of the

operating data showed that this was a quick failure and the reformer temperatures never went above normal operating values.

It was contemplated that potentially the primary air fan had a failure causing a back-flash in the burner. A replacement fan was inexpensive and available so the primary air fan was replaced.

The burner was replaced and the plant was restarted. This restart was difficult to control since the replacement fan speed was adjusted differently than the originally installed fan. There is not any air flow measurement, so it was difficult to return the plant to normal operating temperatures. All controls are setup for fixed output to fan outputs and burner setpoint without feedback adjustment.

In July 2003 a primary air flow meter was installed and the plant was restarted.

Reformer Catalyst Degradation

During the July 2003 restart, it was discovered that the plant production had dramatically decreased. For 650 scfh H2 produced, less than 1200 scfh H2 was produced vs. around 1800 scfh H2 during operation at these rates earlier in the year. After investigating the syngas compressor for potential leaks and the PSA for potential leaks from syngas or product H2 to the tailgas header, a GC was sent to site and the syngas feed to the PSA was found to contain >12% methane vs. a design of 1.5%.

The methane slip could have been caused by either a leak from feed gas to the syngas stream, maldistribution in the reformer feed header, or from catalyst inactivity. Possible leaks in either the reformer tubes or in the E-1 feed preheat exchanger were ruled out. The reformer catalyst was removed and sent to Sud Chemie for analysis. Possible poisons to the catalyst are sulfur breakthrough from the desulfurizers, or chlorine breakthrough from the feedwater treatment. Additionally, low steam to carbon ratio could cause carbon deposition on the catalyst blocking active sites on the catalyst.

Sud Chemie found no indication of deactivating poisons or carbon on the catalyst. An activity test showed that the catalyst at the inlet of the reformer tubes was of normal activity, but the catalyst from the outlet was nearly completely inactive. The catalyst apparently had suffered nickel sintering caused by exposure to high temperatures.

It is contemplated that temperature cycling due to discrete boiler level control. The control logic has been changed to provide continuous actuation of the feedwater pump speed to maintain boiler level.

Additional instrumentation have been added including temperature measurements along the length of the reformer tubes, temperature measurements along the length of the furnace, and steam flow measurement.

The catalyst has been replaced and the plant will be restarted in the Spring of 2004 for a 2000 hour test period to determine if the boiler level logic change has fixed the catalyst degredation issue.

Syngas Compressor Vibrations

Since the initial startup, there have been at least 3 failures of piping or nozzle welds associated with vibrations of the syngas compressor. The compressor is attached to the iso-container via shock absorbing feet that allow some movement of the compressor during operation. The transition between the compressor and the fixed piping into and out of the compressor is accomplished with flex hoses. There have been failures of both vessel nozzles and flex hoses.

Note that the piping failures around the syngas compressor have resulted in syngas leaks into the iso-container. The leaks were not bad enough to trip the enclosure combustible gas monitor. They were detected by observation of the product recovery decreasing. An alarm has been defined in the PLC which calls the Sacramento plant operators if a low product recovery is detected.

Controls Performance

The control strategy delivered from HET is a simple linear model scaling key controls based on rates as defined by the setpoint of the process natural gas flow. The signals output are:

- primary and secondary air fan output
- burner surface temperature setpoint

Air Products added PSA speed logic to also adjust the PSA with plant rates.

Instrumentation Shortcomings

Primary and secondary air fan was controlled too simplistically. The as-delivered logic directly sent output to the fans based on the desired plant rates. This approach fails to account for air flow variations with ambient conditions. The result was day-to-night as well as seasonal variations in air flow for a given plant rate. The plant saw daily swings in steam production which caused compositions to swing. The fan speeds have been adjusted based on ambient temperature indication. A primary air flow measurement has also been installed, but feedback flow control has not yet been programmed.

There was no steam flow measurement. During the analysis of the catalyst mal-performance, we could not tell for certain that there was sufficient steam flow. A steam flow measurement has been installed. It will be used for information only, not feedback for controls.

The enclosure fire detector was installed with the Fire Relay and the Fault Relay in series. Therefore, any plant trip caused by the fire detector could not be determined to be a fault vs. a detected fire. This has been modified to bring separate signals, tripping on a detected fire and alarming only on a fire detector fault indication.