

# Hydrogen-Based Gas Permeable Membrane Pilot Study System Operation Manual Nevada Environmental Response Trust Site Henderson, Nevada

## PREPARED FOR

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### **Nevada Environmental Response Trust**

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**July 29, 2020**

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## LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
AHA	Activity Hazard Analysis
AP	Ammonium Perchlorate
APT	APT Water, LLC
AWF	Athens Road Well Field
cfh	cubic feet per hour
cfm	cubic feet per minute
CO <sub>2</sub>	carbon dioxide
COPC	Contaminants of Potential Concern
Cr <sup>+3</sup>	trivalent chromium
Cr <sup>+6</sup>	hexavalent chromium
DI	deionized
DO	dissolved oxygen
EQ	equalization
FBR	Fluidized Bed Reactor
gph	gallon per hour
gpm	gallon per minute
GWETS	groundwater extraction and treatment system
GWTP	Groundwater Treatment Plant
H <sub>2</sub>	hydrogen gas
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HDPE	high density polyethylene
HMI	Human Machine Interface
hp	horsepower
HSM	Health and Safety Manual
IDLH	Immediately Dangerous to Life or Health
IOM	Installation, Operations and Maintenance
IWF	Interceptor Well Field
L/hr	liters per hour
Manual	System Operation Manual
MBfR	membrane biofilm reactor
MoC	Management of Change
N <sub>2</sub>	Nitrogen

Acronyms/Abbreviations	Definition
NDEP	Nevada Division of Environmental Protection
NERT or Trust	Nevada Environmental Response Trust
O&M	operations and maintenance
ORP	Oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
P&IDs	piping and instrumentation diagrams
PFD	process flow diagram
Pilot Treatment System	Hydrogen-Based Gas Permeable Membrane Technology Pilot Treatment System
PLC	programable logic controller
psig	pounds per square inch gauge
PVC	polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RO/DI	reverse osmosis/deionized
Site	Nevada Environmental Response Trust site, Clark County, Nevada
SOP	Standard Operating Procedure
SWF	Seep Well Field
SWP	safe work practices
TDS	total dissolved solids
TSS	total suspended solids
Tetra Tech	Tetra Tech, Inc.
µg/L	micrograms per liter
VFD	variable frequency drive
Work Plan	Hydrogen-Based Gas Permeable Membrane Technology Pilot Test Work Plan

## CERTIFICATION

### NERT Hydrogen Based Gas Permeable Membrane Treatability Study System Operation Manual

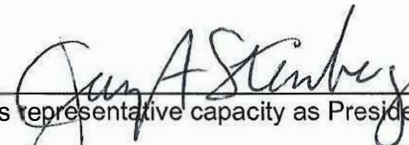
**Nevada Environmental Response Trust Site  
(Former Tronox LLC Site)  
Henderson, Nevada**

#### Nevada Environmental Response Trust (NERT) Representative Certification

I certify that this document and all attachments submitted to the Division were prepared at the request of, or under the direction or supervision of NERT. Based on my own involvement and/or my inquiry of the person or persons who manage the systems(s) or those directly responsible for gathering the information or preparing the document, or the immediate supervisor of such person(s), the information submitted and provided herein is, to the best of my knowledge and belief, true, accurate, and complete in all material respects.

Office of the Nevada Environmental Response Trust

Le Petomane XXVII, not individually, but solely in its representative capacity as the Nevada Environmental Response Trust Trustee

**Signature:**  **Not Individually, but Solely as President of the Trustee**, not individually, but solely in his representative capacity as President of the Nevada Environmental Response Trust Trustee

**Name:** Jay A. Steinberg, not individually, but solely in his representative capacity as President of the Nevada Environmental Response Trust Trustee

**Title:** Solely as President and not individually

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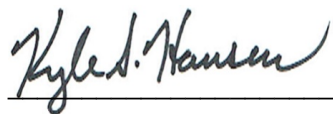
**Date:** 7/29/2020

## CERTIFICATION

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I hereby certify that I am responsible for the services described in this document and for the preparation of this document. The services described in this document have been prepared in a manner consistent with the current standards of the profession, and to the best of my knowledge, comply with all applicable federal, state, and local statutes, regulations, and ordinances. I hereby certify that all laboratory analytical data was generated by a laboratory certified by the NDEP for each constituent and media presented herein.

**Description of Services Provided:** Prepared NERT Hydrogen Based Gas Permeable Membrane Treatability Study System Operation Manual.



**Kyle Hansen, CEM**  
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Tetra Tech, Inc.

July 29, 2020

Date

Nevada CEM Certificate Number: 2167  
Nevada CEM Expiration Date: September 18, 2020

## 1.0 INTRODUCTION

At the direction of the Nevada Environmental Response Trust (NERT or Trust), Tetra Tech, Inc. (Tetra Tech) has prepared this System Operation Manual (Manual) for the Hydrogen-Based Gas Permeable Membrane Technology Pilot Treatment System (Pilot Treatment System) that will be utilized at the NERT site (Site) consistent with the Nevada Division of Environmental Protection (NDEP)-approved *Hydrogen-Based Gas Permeable Membrane Technology Pilot Test Work Plan (Pilot Work Plan)* (Tetra Tech, 2019). This Manual covers the operation of the Pilot Treatment System, which will operate on a temporary basis to collect data during the pilot study. Operations will cease at the end of the pilot study after which the Pilot Treatment System and all ancillary equipment will be removed from Site. As this Manual is for a new, temporary system being operated for testing purpose, variations to this Manual may be required to meet project objectives. Relevant changes to this Manual will be discussed in the monthly progress report submitted to NDEP.

### 1.1 PURPOSE

The purpose of this Manual is to provide general procedures for operations and maintenance of the Pilot Treatment System in order to collect data to achieve the pilot study objectives as outlined in the Work Plan. These general procedures for operations and maintenance will be updated, as deemed necessary by the system operator, to ensure proper system operation and to meet the overall pilot test objectives.

The Manual presents the following:

- Pilot Treatment System Description (Section 2.0)
- Safety (Section 3.0)
- Operations (startup, normal operations, normal shutdown and emergency shutdown; Section 4.0)

The Manual includes updates to the Nevada Division of Environmental Protection (NDEP)-approved *Hydrogen-Based Gas Permeable Membrane Technology Pilot Test Work Plan* (Tetra Tech, 2019) that resulted during detailed design, construction, and implementation planning of the pilot study.

Since the submittal of the Work Plan, there have been modifications to the Pilot Treatment System construction and proposed operations that do not impact the project objectives. The modifications are as follows:

- A new pilot unit was constructed versus modifying an existing pilot unit. A post-reactor tank was added to the pilot unit for potential future projects and will be used on this project to further reduce any residual perchlorate, chlorate or nitrate leaving the last module tank, if needed
- The temporary secondary containment system for the treatment container, post-treatment container, influent water tanks and final solids tank was constructed with 30-mil polyvinyl chloride versus a 60-mil liner.
- The sampling and analytical plan in the Workplan has been updated as part of the system design. The main change is that an on-site laboratory will not be utilized. The sampling and analytical plan is discussed in Section 4.5.3 below.
- The influent water collection plan was updated based on discussions with ETI, the proposed flow rates for each test scenario and to minimize potential for spills. The influent water collection plan is discussed in Section 4.2 below.



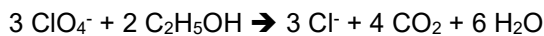
## 2.0 PILOT TREATMENT SYSTEM DESCRIPTION

### 2.1 GENERAL TECHNOLOGY DESCRIPTION

The *Hydrogen-Based Gas Permeable Membrane Technology Pilot Test Work Plan* (Work Plan), prepared by Tetra Tech (Tetra Tech 2019) and approved by NDEP on March 27, 2019, provides a detailed description of the technology that is the basis of the Pilot Treatment System referenced in this Manual. A simplified description of the technology is included in this section.

APT Water, LLC (APT) has developed a treatment system using patented hydrogen-based gas permeable membrane technology for the reduction of nitrate, perchlorate, chlorate and other oxidized compounds via a proprietary hollow-fiber membrane biofilm reactor (MBfR). This technology is being pilot tested to determine if it can remove perchlorate at high concentrations and if there are any advantages of this technology over the existing Fluidized Bed Reactor (FBR) process currently treating perchlorate-laden groundwater extracted from the Site. This technology is also being tested to determine whether hexavalent chromium (Cr<sup>+6</sup>) can be reduced to trivalent chromium (Cr<sup>+3</sup>) during the biological reduction of perchlorate under anoxic conditions. The water insoluble Cr<sup>+3</sup> can then be flocculated using polymer and removed from the treated water in the clarification system. Potential advantages may include lower excess biological solids generation, and lower cost for hydrogen as an electron donor compared to ethanol currently use by the FBR.

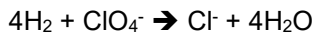
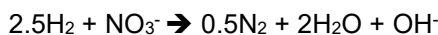
The current FBR biologically reduces perchlorate to chloride ions and nitrate to nitrogen gas, by heterotrophic bacteria (using ethanol as the electron donors) or autotrophic bacteria (using inorganic electronic donors). The reaction mechanisms for the reduction processes in this system can be described approximately as follows:



Based on theoretical stoichiometric equations, the following are required for reduction of perchlorate and nitrate, using ethanol as the electron donor for the heterotrophic bacteria present in the FBR:

- 0.31 grams of ethanol are needed to reduce one gram of perchlorate to chloride ion, and
- 1.4 grams of ethanol are needed to reduce one gram of nitrate-nitrogen to nitrogen gas.

Unlike the FBR, the MBfR grows autotrophic microorganisms that use hydrogen gas (H<sub>2</sub>) as their electron donor to reduce nitrate, perchlorate, and a range of other oxidized contaminants. The equations for reduction of NO<sub>3</sub><sup>-</sup> and ClO<sub>4</sub><sup>-</sup> with H<sub>2</sub> are:

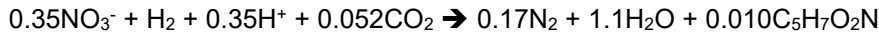
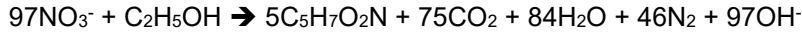


Based on theoretical stoichiometric equations, the following are required for reduction of perchlorate and nitrate, using H<sub>2</sub> as the electron donor for the MBfR's autotrophic bacteria:

- 0.08 grams of H<sub>2</sub> are needed to reduce one gram of perchlorate to chloride ion, and
- 0.36 grams of H<sub>2</sub> are needed to reduce one gram of nitrate nitrogen to nitrogen gas.

The equations show that a lower quantity of H<sub>2</sub> than ethanol would theoretically be required for perchlorate and nitrate reduction, suggesting the potential for both lower chemical use and cost with this technology.

Another potential advantage of using hydrogen as electron donor versus ethanol is that the amount of excess biomass generated in a hydrogen system could be much smaller than that generated in an ethanol system, such as the NERT FBR. The following equations show the biomass synthesis in each system for denitrification (the mechanisms for perchlorate reduction are believed to be similar).



The above equations indicate that for every gram of nitrate nitrogen that is reduced using ethanol as the electron donor approximately 0.42 grams of biomass is generated; however, when hydrogen is used as the electron donor only 0.23 grams of biomass is generated for one gram of nitrate nitrogen being reduced. Therefore, a system using hydrogen as electron donor would theoretically generate 50% less waste biomass than a system using ethanol.

Hydrogen gas can be generated at the site in real time and fed directly to the reactors, thereby eliminating the need to store pressurized hydrogen in bulk quantities.

In the MBfR, pressurized H<sub>2</sub> diffuses through the walls of a polypropylene hollow fiber membrane. The dense polypropylene membrane allows the pressurized gas to diffuse through the membrane without forming bubbles. After it goes through the membrane, the H<sub>2</sub> comes in contact with the perchlorate or nitrate to be reduced. Biofilm containing autotrophic bacteria that use the H<sub>2</sub> accumulates on the outside of the membrane fibers. The hollow fibers are woven into fabric sheets to provide the large surface area required for commercial applications, and the fabric sheets along with a flow spacer are incorporated into spiral-wound modules similar in construction to commercial reverse osmosis modules.

Biological processes operated under anoxic conditions (i.e. the absence of molecular oxygen) have been shown to reduce hexavalent chromium to trivalent chromium. The resulting trivalent chromium can then be precipitated as solids and removed from the water stream in a clarification step. The Pilot Treatment System will, as a secondary objective, evaluate the viability of hexavalent chromium removal via this process in conjunction with perchlorate removal.

APT has demonstrated the effectiveness of its membrane technology in removing perchlorate and nitrate, but not hexavalent chromium, in pilot and full-scale applications ranging from 3 to 150 gallons per minute (gpm). Although these are likely lower flow rates than would be anticipated for full-scale applications at the NERT site, biological treatment systems are scalable such that higher flow rate treatments reactors may be designed based on the data that will be collected during this pilot study.

## 2.2 GENERAL DESCRIPTION OF PILOT UNIT AND PILOT TREATMENT SYSTEM

A new pilot unit has been designed and constructed by APT for use during the pilot study. This section provides a general discussion of the Pilot Treatment System. A more detailed description of the major equipment is provided in Section 4.1.

The pilot unit consists of two 20-foot long shipping/storage containers. The first container is called the treatment container and the second container is called the post-treatment container.

The treatment container houses the following unit operations:

- Three (3) module tanks (i.e. reactors), with each tank comprised of two modules containing APT's patented hollow-fiber membranes and a recirculation pump to ensure the tank contents are completely mixed;
- A 12" (diameter) X 84" (high) cylindrical post-reactor tank
- A hydrogen generator, including gas monitor and shut-down alarms;
- Two carbon dioxide (CO<sub>2</sub>) cylinders (staged outside the container) and an associated delivery system;
- A phosphate (nutrient) storage and delivery system;
- An in-line nitrate sampling and analysis system;

- A nitrogen generation, storage, and sparge system;
- Programmable logic controller (PLC) based process controls;
- Data logging;
- A remote monitoring and control system; and,
- Safety alarms and system shutdown controls.

The post-treatment container houses of the following unit operations:

- A surge tank that receives mixed liquor (treated water and biological solids) leaving the biological reactors;
- A coagulant addition system to reduce hexavalent chromium to trivalent chromium if necessary;
- A polymer addition system to flocculate biological solids and also precipitate the trivalent chromium solids;
- A lamella clarifier to remove the excess biological solids and precipitated chromium from the treated water;
- A holding tank to store filtrate leaving the clarifier;
- A cartridge filter to remove residual solids from treated water;
- An initial solids holding tank to store settled solids leaving the clarifier.

Select Pilot Treatment System operations will be controlled by the PLC in the treatment container.

Exterior to both the treatment container and post-treatment container, additional components of the Pilot Treatment System include influent tanks, the final solids holding tank, discharge piping to the GW-11 Pond, and ancillary pumps and piping. The Pilot Treatment System will be installed at the location shown on **Figure 1**. The pilot unit, the influent tanks and the solids holding tank will be located in a common secondary containment system constructed of 30-mil polyvinyl chloride (PVC) liner.

The Pilot Treatment System unit operations are further discussed in Section 4. **Figure 2A** and **Figure 2B** present the process flow diagram (PFD) for the Pilot Treatment System. **Figure 3** and **Figure 4** show the layout of the treatment and post-treatment container, respectively. The piping and instrumentation diagrams (P&IDs) for the Pilot Treatment System are included in **Appendix A**.

The anticipated flow rate through the Pilot Treatment System is expected to range from 1 to 3 gpm, depending on the influent concentrations of nitrate, chlorate, and perchlorate. Since this is a pilot program, the flow rate will be adjusted relative to the influent concentration of these contaminants to keep loading and treatment rates constant so that the desired removal efficiency can be achieved and performance can be adequately evaluated.

## 2.3 PILOT TEST OBJECTIVES

The objectives of the pilot demonstration program are to:

1. Demonstrate the ability of the APT MBfR technology to reduce perchlorate at high concentrations (i.e. levels equal to groundwater currently extracted from the NERT Interceptor Well Field) to less than 18 micrograms per liter ( $\mu\text{g/L}$ ), the current perchlorate discharge limit for the FBR system, and evaluate its ability to achieve even lower concentrations;
2. Demonstrate that using hydrogen gas as the electron donor instead of ethanol generates less excess biomass;
3. Demonstrate stable and sustainable treatment system operation and performance, including evaluation of the safety and effectiveness of the on-site hydrogen generator;

If the above prove successful, Tetra Tech will work with NERT to define a set of assumptions for a hypothetical scaled up system to then:

1. Demonstrate that the cost of hydrogen as electron donor is less than the cost of ethanol;
2. Develop strategies for scaling up the pilot system reactors under field conditions at NERT;
3. Evaluate the staffing and operations and maintenance (O&M) needs for a full-scale system; and,
4. Develop the following key design and operating information for sizing and costing a full-scale treatment system:
  - Collect and analyze data on H<sub>2</sub> and CO<sub>2</sub> consumption rates;
  - Determine the degree of perchlorate reduction in different reactors of the pilot unit;
  - Establish individual reactor performance (flux) which would be used to design a large-scale treatment system;
  - Establish the sparge frequency necessary to maintain stable pressure drop control and the potential for decreased treatment efficiency in the event of frequent sparging;
  - Quantify the rate of biomass generation and establish the filtration requirements for biomass removal and,
  - Quantify the budgetary capital and operational costs for the APT system for use in the Feasibility Study.

In addition to the objectives listed above, the test will also evaluate if a potential secondary benefit of technology is that the hexavalent chromium can be effectively reduced to trivalent chromium in the reactors and if the trivalent chromium can be effectively removed from the water using flocculation and clarification downstream of the reactors.

## 2.4 PILOT TESTING SCENARIOS

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Contaminants of Potential Concern (COPC) in groundwater at the site include perchlorate, chlorate, and hexavalent chromium. As described in the Work Plan, the pilot study will test water with a range of contaminant concentrations to evaluate the applicability of the technology under various conditions and collect design and operational data for use in a potential, future full-scale design. The following three (3) testing scenarios will be evaluated:

1. Test Scenario #1: Existing FBR Influent: This scenario will test water representative of the groundwater stream currently entering the existing FBR treatment system. Water for the pilot test for this scenario will be obtained from one of the FBR equalization (EQ) tanks, which receive water from the Athens Road Well Field (AWF), the Interceptor Well Field (IWF) via the groundwater treatment plant (GWTP) after chromium removal, and the portion of the Seep Well Field (SWF) that is not currently treated by an ion exchange system. Data will be used to compare estimated pilot unit operational performance and quantify chemical consumption relative to the FBRs.
2. Test Scenario #2: Blend of AWF and IWF after Chromium Removal: This scenario is based on a potential future site condition where the SWF is replaced by an in-situ treatment approach along the Las Vegas Wash or ion exchange and the SWF no longer provides water to the groundwater extraction and treatment system (GWETS). Water to be tested under this scenario will be a blend from the AWF and the IWF after chromium pre-treatment via the GWTP in the same proportion they are currently generated. Test Scenario #2 excludes the water from the SWF, which typically has high flow and generally lower

concentrations than the other well fields, thus Test Scenario #2 is expected to have higher perchlorate and chromium concentrations relative to Test Scenario #1.

3. Test Scenario #3: Blend of AWF and IWF without Chromium Removal: This test scenario is intended to evaluate the hydrogen-based gas permeable membrane treatment system's ability to effectively treat water for perchlorate and chromium removal simultaneously without pretreating the water to remove chromium first. Hexavalent chromium is expected to be reduced to insoluble trivalent chromium in the reactors, and the trivalent chromium should subsequently be removed in the downstream clarification step. Test water would be identical to Test Scenario #2, except the water from the GWTP would not be pre-treated for chromium removal, thus chromium concentrations are expected to be much higher than both Test Scenarios #1 and #2.

Other Test Scenarios: Data generated from testing the above scenarios will be evaluated and may identify other relevant scenarios for testing. This could include using water from any well field (AWF or IWF) or from other sources at the Site. The option to add other test scenarios will be discussed with the Trust and NDEP as the testing program progresses.

Additionally, if the Pilot Treatment System is not functioning as intended and not demonstrating reduction of perchlorate to acceptable levels, the pilot test may be stopped prior to completing all test scenarios.

The COPC concentrations tested in the Pilot Treatment System will vary depending on the GWETS operations and fluctuations in groundwater concentrations over the duration of the pilot study. The feed water for each scenario will be analyzed to determine perchlorate, chlorate, nitrate, total chromium, and hexavalent chromium concentrations, as well as other parameters such as total dissolved solids (TDS) and total suspended solids (TSS) to assist with the operation of the Pilot Treatment System.

Pilot study operations for each test scenario are anticipated to require up to three months to complete for a total of up to nine months of operation.

## 3.0 SAFETY

Tetra Tech has developed a *Health and Safety Plan* (Tetra Tech, 2020), which specifies the minimum required work practices and procedures for Tetra Tech and its subcontractor personnel engaged in the planned Site-wide activities. The HASP addresses items specified under OSHA Title 29 of the CFR, Part 1910.120(b), Hazardous Waste Operations and Emergency Response (HAZWOPER) and applicable Nevada Occupational Safety and Health Administration (OSHA) requirements. The HASP is supported by the Tetra Tech Health and Safety Manual (HSM) and safe work practices (SWPs), which were developed to comply with the OSHA HAZWOPER standard and applicable sections of 29 CFR Part 1910 (General Industry Standards) and Part 1926 (Construction Standards). The HASP also incorporates elements of the Tetra Tech Nevada Workplace Safety Program, (DCN 2-13), which complies with the requirements of the Nevada Revised Statute 618.383 and the Nevada Administrative Code Sections 618.540 and 618.542.

The site-wide HASP is being revised to address additional health and safety measures for the Pilot Treatment System operations and maintenance. Activities including health and safety hazard identification, specialized training including hazard communication and compressed gas safety, site chemical inventory and Safety Data Sheets, operator training, personal protective equipment, hazard mitigation measures including real-time gas (including oxygen and flammable/toxics), sensors and alarms, dilution ventilation, exhaust systems, and electrical equipment ratings.

Contractors and all lower tier subcontractors working at the NERT site are required to develop a site-specific health and safety plan (HASP) and/or Job Safety Analysis that addresses all applicable federal, state, municipal, local, and NERT requirements associated with their activities. The contractor HASP/JSA must be submitted to Tetra Tech for review prior to mobilization. A copy of the HASP/JSA shall be maintained at the Site where employees will have access to a hard copy. The contractor HASP shall also be provided to Contractor employees for review, understanding and compliance.

The following sections describe specific hazards and mitigation practices specific to the Pilot Treatment System and the activities associated with the pilot study.

## 3.1 HAZARDS

### 3.1.1 Hydrogen Gas

Hydrogen gas is flammable. In the treatment container, hydrogen gas will be generated in small quantities (4 to 10 standard cubic feet per hour [scfh]) and supplied to the modules as an electron donor supporting biological treatment. Hydrogen gas will be generated only when it is needed and will be used immediately. The hydrogen generator ( a Nel S Series S40, see information sheet in **Appendix B**) will match the hydrogen generation rate to the use rate by automatically maintaining a >200 pounds per square inch gauge (psig) hydrogen pressure at its ¼" tubing product discharge fitting.

Hydrogen gas is lighter than air. The hydrogen is applied to the water at the modules inside the module tanks which are open to the atmosphere and extend above the roofline through a 11-ft by 3.5-ft opening in the top of the treatment container so that any excess hydrogen applied is safely vented outdoors. Additionally, an evaporative cooler fan provides sufficient ventilation of approximately 3,000-5,000 cubic feet per minute (cfm) from one end of the treatment container to dilute and force out any potential hydrogen leaks within the treatment container up and out the roof opening around the module tanks at the other end of the container as shown on **Figure 3**. Hydrogen concentrations inside the treatment container at the ceiling and above each open-top module tank will be closely monitored via four hydrogen sensors and interlock with the control system for immediate shutdown if excess hydrogen is detected (i.e., if the % of lower explosive limit [LEL] measurement is above 25%). In addition, the hydrogen generator, as received from the manufacturer, contains an internal hydrogen gas leak sensor which will

shut down the generator if the sensor detects vapor concentrations above 50% of the LEL. Consistent with manufacturer specifications, this sensor will be checked and calibrated at least every three months for the hydrogen generator to continue to operate.

The minimum ventilation rate to dilute 110% of the maximum hydrogen generation rate of 40-standard cubic feet per hour (scfh) to below 25% of the LEL (calibrated to hydrogen gas) in the treatment container is 73 cfm. This minimum required air flow will be verified with a flow instrument that is interlocked to the control system and will prevent operation of the hydrogen generator in the case of low ventilation flow.

Hydrogen is only used in the treatment container; therefore, no hydrogen monitoring is necessary in the post-treatment container.

### 3.1.2 Oxygen-Depleted Environment

Nitrogen and other non-oxygen gases will be stored inside or near the treatment container. Specifically, the hydrogen generator, the nitrogen generator, and receiver tank will be inside the treatment container. The bulk CO<sub>2</sub> tank will be stored outside the treatment container but will supply CO<sub>2</sub> gas via ¼" diameter tubing to inside the treatment container. While highly unlikely based on the active ventilation monitoring in the treatment container as described in the previous section, leakage of these gasses could displace the ambient oxygen in the treatment container which could result in an oxygen-deficient environment (defined as less than 19.5% oxygen) and potential asphyxiation hazard.

To mitigate this potential hazard, the oxygen level within the treatment container will be continuously monitored by an oxygen sensor located near the nitrogen receiver tank and CO<sub>2</sub> flow controller. The oxygen sensor will be linked to a red light on the outside of the container and an audible alarm located inside the container that will notify the operators, send an email notification, and shutdown in the event of a low oxygen environment within the treatment container (i.e. less than 19.5% oxygen.) Additionally, during inspections, the access doors on the treatment container will be opened to ventilate the space while operators work inside.

Nitrogen and other non-oxygen gases are only used in the treatment container; therefore, no oxygen monitoring is necessary in the post-treatment container.

### 3.1.3 Compressed Gases

Hydrogen, carbon dioxide, nitrogen and mixtures of carbon dioxide/ hydrogen are stored in or near the treatment container at elevated pressures (5- psig). Uncontrolled release of compressed gases to atmospheric pressure is potentially dangerous. Care must be taken to avoid release of compressed gases. Proper precautions will be followed when depressurizing or disconnecting process lines prior to maintenance. The carbon dioxide and nitrogen cylinders will be secured outdoors to the side of the Treatment Container. No compressed gases are used at the post-treatment container.

## 3.2 MANAGEMENT OF CHANGE

Proposed changes to operations, procedures, equipment, and materials may require the use of the Management of Change (MoC) process. This is a systematic review by technical, engineering, safety and other subject matter experts for potential impacts to safety, quality, and reliability. Some changes (i.e., minor changes in daily work tasks; weather; site conditions, etc.) may be handled by the Activity Hazard Analysis (AHA) or HASP review process and other forms of hazard evaluation and risk assessment, as authorized by Tetra Tech's NERT Program Health and Safety Director. Proposed changes that may pose a risk of serious injury or fatality, Immediately Dangerous to Life or Health (IDLH) conditions, and catastrophic outcomes such as fire or explosion, major environmental release, significant property damage, etc. must be managed through MoC.



As this Manual is for a new, temporary system being operated for testing purpose, variations to this Manual may be required to meet project objectives. Relevant changes to this Manual will be discussed in the monthly progress report submitted to NDEP.

### 3.3 EMERGENCY

An emergency shutdown of the Pilot Treatment System can be initiated by pushing the red emergency (E-Stop) button located on the front of the PLC/Control Enclosure in the treatment container. Pushing the E-Stop button will result in the following:

- The influent feed pump, all module tank recirculation pumps, and gas feeding equipment in the treatment container, the chemical dosing pumps stop immediately and the treated water pump will stop after 10 minutes to allow continued forwarding of gravity-flowing inventory. The evaporative cooler fan (ventilation) will remain on.
- An alarm email notification will be sent to the Tetra Tech operator, an APT representative, ETI and the Trust.

The following will need to be stopped manually:

- Initial solids handling pump (P-580) if ON.
- Mixers: surge tank mixer (A-450), treated water tank mixer (A-550), polymer tanks mixers (A-480A/B), solids holding tank mixer (A-580), and solids handling pump (P-581) if ON.
- Influent feed tanks recirculation pumps (P-001 and P-002).

### 3.4 CONTACT INFORMATION

Emergency contacts for this project are included in **Table 1**. Calls to agencies should be coordinated through the Project Manager except in the event of urgent matters requiring emergency response such as life threatening injury or fire.

**Table 1** Emergency Contacts

Emergency Responder	Telephone Number
<b>Local Emergency Responders and Services</b>	
<b>EMERGENCY</b>	<b>911</b>
<b>City of Henderson Police Department</b> (Non-emergency)	(702) 267-5000
<b>Fire Department</b> (Non-emergency)	Henderson: (702) 267-2222 Clark County: (702) 455-7311
<b>Yuri Graves</b> Emergency Management City of Henderson	(702) 267-2272
<b>Henderson Public Utilities</b> (Emergency Notification Numbers)	NV Energy Electric: (702) 402-2900 Natural Gas: (877) 860-6020 Water: (702) 267-5900



Emergency Responder	Telephone Number
<b>St. Rose Dominican Hospital</b> Henderson, NV	(702) 564-2622
<b>Site and Project Contacts</b>	
<b>Katie Hendrickson</b> Tetra Tech Project Manager	(720) 648-9868
<b>Kyle Hansen</b> Tetra Tech Site Manager	(801) 949-6663
<b>Steve Clough</b> Remediation Director Nevada Environmental Response Trust	(702) 686-9611
<b>Wendy Prescott</b> ETI Plant Manager	(702) 371-9307
<b>David Friese</b> APT Technology Director	(925) 708-0480
<b>Nathan Atoigue</b> APT Field Service Technician	(925) 470-7896
<b>State and National Resources</b>	
<b>Poison Control Center</b>	(800) 222-1222
<b>CORE Occupational Medicine Time Zero Injury Management</b> (for non-life-threatening incidents, available 24/7)	(855) 683-9006

## 4.0 OPERATIONS

A PFD for the Pilot Treatment System is included on **Figures 2a and 2b**. The P&ID drawings for the Pilot Treatment System are included in **Appendix A**. The Pilot Treatment System and operations are described in more detail in the below sections.

The Pilot Treatment System will treat water collected from various locations as described in Section 2.4 above. Treated water will be conveyed to the GW-11 Pond. The system is expected to treat water continuously at a flow rate from 1 to 3 gpm, 24 hours per day and seven (7) days per week during each testing scenario. The Pilot Treatment System will be monitored remotely in addition to inspected by the on-site operator every weekday.

### 4.1 MAJOR EQUIPMENT

The Pilot Treatment System consists of the following:

- Two (2) influent 20,000-gallon feed tanks, each with a dedicated 50-gpm centrifugal recirculation pump;
- Two (2) containers installed with the following major equipment:
  - The treatment container houses the following unit operations:
    - One (1) 3-gpm centrifugal influent feed pump;
    - Biological treatment system (MBfR) containing:
      - Three (3) 500-gallon module tanks in series, with each module tank containing two modules with APT's patented hollow fiber membranes and an 80-gpm dedicated centrifugal recirculation pump;
      - One (1) 12" (diameter) by 96" (high) post-reactor tank;
      - One (1) 40-cfh H<sub>2</sub> generator, with an upstream 10-liter per hour (L/hr) reverse osmosis/deionized (RO/DI) system for feed water supply;
      - One (1) phosphate feed system, with one (1) 15-gallon and one (1) 0.1-gallon per hour (gph) feed pump;
      - One (1) 0.8 cfm CO<sub>2</sub> feed system using CO<sub>2</sub> cylinders;
      - One (1) 63 cfm nitrogen generator and one (1) nitrogen 200-gal receiving tank;
      - One (1) evaporative cooler;
      - One (1) PLC with the E-Stop button; and,
      - Flowmeters, control valves, control panels, cellular modem for internet-based monitoring and control, other instruments for nitrate, pH and oxidation reduction potential (ORP) measurements, and accessories required for operation of the Pilot Treatment System.
  - The post-treatment container consists of the following unit operations:
    - One (1) 200-gallon surge tank and 1/3-horsepower (hp) mixer;
    - One (1) 0.4 gph coagulant storage and feed system with one (1) 30-gallon tank and one (1) 0.4 gph peristaltic metering pump;
    - One (1) polymer dilution and feed system with two (2) 40-gallon make-down tanks with 1/4-hp mixers and one (1) 1 gph peristaltic metering pump;
    - One (1) 5 gpm lamellar clarifier with 4.4-gal flash tank and 1/4-hp mixer;
    - One (1) 55-gallon treated water holding tank to collect clarified effluent with 1/4-hp mixer;
    - One (1) 5 gpm treated water pump;
    - One (1) cartridge filter with 7 gpm hydraulic capacity;
    - One (1) 1 gpm solids handling pump;
    - One (1) 200-gallon initial solids holding tank with 1/3-hp mixer;
    - One (1) 10 gpm final solids handling pump;
    - One (1) air conditioner;

- Flowmeters, control valves, control panels, other instruments, and accessories required for operation of the Pilot Treatment System;
- One (1) 5 cfm air compressor.
- One (1) 3,000-gallon final solids holding tank.
- Two-inch high-density polyethylene (HDPE) or PVC discharge piping to GW-11 Pond.

## 4.2 INFLUENT WATER COLLECTION

Water trucks will collect the water needed for the three testing scenarios at different locations and transfer the water to the two influent tanks in secondary containment. The water collection procedures for each scenario are described in the sections below.

Water flow to the Pilot Treatment System will be controlled based on the influent concentrations of chlorate and perchlorate (see Section 4.4.3 for analytical details) and is expected to range from 1 to 3 gpm. As the concentration of these contaminants increases, the flow through the pilot unit may be adjusted to maintain the target mass loadings of these contaminants.

Two (2) influent feed tanks (T-001 and T-002) are provided to hold raw water. Each tank will have a dedicated recirculation pump (P-001 and P-002 for T-001 and T-002, respectively) to provide continuous mixing in the tank. The recirculation pumps will only operate when the water level in the feed tanks is above a minimum level (2 feet) to protect the pumps.

The influent feed tanks will be used to collect and blend the water to the ratios required for each testing scenario. Water will be added and mixed in the first influent feed tank until it is determined to have reached its target fill volume based on visual inspection. Once the first influent feed tank is full, water from this tank will be mixed and fed to the Pilot Treatment System. The second influent feed tank will then be used for water blending and storage for the next batch. The influent water collection process may be adjusted, as deemed necessary by the operator, to ensure the appropriate blend of water for each testing scenario. The influent water volumes and concentrations will be included in the monthly progress reports to NDEP.

### 4.2.1 Scenario #1

Water for Test Scenario #1 will be obtained from the FBR EQ Tank 101A that currently supplies water to the FBR system. A 5,000-gallon water truck will connect to the bottom of Tank 101A to collect water from this location. Assuming a flow rate of 2 gpm through the Pilot Treatment System, approximately 20,000 gallons of water will be transported a week.

### 4.2.2 Scenario #2

Water for Test Scenario #2 will be a blend of water from the AWF and water from the IWF after chromium pre-treatment in the same proportion they are currently produced by the extraction well fields. Based on the average representative flows from these well fields, the blend will consist of approximately 10% from IWF and 90% from AWF. Assuming a flow rate of 1 gpm through the Pilot Treatment System for this scenario due to the higher perchlorate concentrations than Scenario #1, approximately 2,000 gallons of IWF water following chromium pretreatment and approximately 18,000 gallons of AWF water will be transported and blended every two weeks.

IWF water following chromium pre-treatment will be collected in the FBR EQ area. A 2 gpm pump will transfer the water to a 500-gallon storage tank that will be positioned in the FBR EQ secondary containment. The pump operation will be controlled using high and low float switches. The low-level float switch will start the pump and transfer water to the 500-gallon tank from a connection point on an existing 2-inch line that currently transfers treated water from IWF wells to FBR EQ Tank 101A. When the 500-gallon tank is full, the high-level float switch will shut off the transfer pump. A high, high-level float switch will also be installed for redundancy. As needed, the water truck will collect the water from the 500-gallon tank for transport to the Pilot Treatment System.

Water from the AWF will be collected using a 20 gpm pump and a 5,000-gallon holding tank. The pump will transfer the water from the Lift Station 3 wet well to the 5,000-gallon holding tank. The pump will be controlled by float switches and the 5,000-gallon water truck will collect approximately 4,500-gallon load of water from the 5,000-gallon tank for transport to the Pilot Treatment System.

To achieve a generally consistent blend of feed water for this scenario, samples from the influent tank will be collected and analyzed for perchlorate after the third load of water from both the IWF and AWF (approximately 15,000 gallons). The water volume from AWF and IWF for the fourth load (to fill the 20,000-gallon influent tank) may be adjusted based on these results.

### 4.2.3 Scenario #3

Water for Test Scenario #3 will be a blend of water from the AWF and untreated water from the IWF (i.e., prior to the chromium pre-treatment) in the same proportion they are currently produced by the extraction well fields (approximately 10% from IWF and 90% from AWF). Similar to Scenario #2, it is assumed the Pilot Treatment System flow rate of 1 gpm and approximately 2,000 gallons of untreated IWF water and approximately 18,000 gallons of AWF water will be transported and blended every two weeks.

The untreated IWF water will be collected from the Ground Water Influent Tank located in the containment area of the GWTP. A 2 gpm pump will be used to transfer untreated IWF water from the Groundwater Influent Tank to a 500-gallon holding tank. The pump will be operated using floats as discussed in Scenario #2. The water truck will collect the water from the 500-gallon tank for transport to the Pilot Treatment System.

The AWF water will be collected in the same way as discussed for Test Scenario #2. Also similar to Scenario #2, samples from the influent tank will be collected and analyzed for perchlorate after the third load (approximately 15,000 gallons) to determine the water volume from AWF and IWF for the final and fourth load in order to maintain a consistent blend over the entire scenario.

## 4.3 PILOT TREATMENT SYSTEM OPERATION

The pilot unit consists of a treatment container and a post-treatment container. The operations associated with each container are described below. As discussed earlier, the Pilot Treatment System operations described below may be adjusted as deemed necessary to ensure proper system operations and to meet the overall objectives of the pilot test.

### 4.3.1 Treatment Container

One variable-speed influent feed pump (P-010 with variable frequency drive [VFD]) will pump water from one of the influent tanks to the treatment container at a flowrate of 1 to 3 gpm. The influent feed pump will pump water from the influent feed tank until the tank level is visually determined to have reached a low level, then the valving will be manually configured by the operator so that the influent feed pump will draw water from the second influent feed tank until that tank is observed to reach a low level, and the process will be repeated.

When water enters the treatment container, phosphoric acid will be added to the water via the phosphate feed system. The phosphate feed system consists of one (1) phosphate storage tank (T-011) in which phosphoric acid is diluted with water from the RO / DI System (X-025) and one (1) phosphate feed pump (P-011) to add the phosphate solution into the influent flow. Flow through the system will be measured by a flowmeter (FIT-015) on the influent feed line, with the desired flow rate manually input into the PLC.

Under normal operations, water will be pumped to the first module tank (T-100), where oxygen is removed, and the majority of nitrate is reduced to nitrogen gas, which may bubble to the surface and be emitted to the atmosphere at the top of the module tank which is above the top of the container. Nitrate entering the first module tank will be measured using an in-line process analyzer (AIT-160). Water out of the first module tank will overflow

into the second module tank (T-200), where chlorate and perchlorate are reduced to chloride ion. Effluent out of the second module tank will then overflow into the third module tank (T-300), and then to the post-reactor tank (T-400), where chlorate and perchlorate are further reduced to achieve desired discharge levels. Reduction of hexavalent chromium to trivalent chromium is expected in the module tanks under anoxic conditions.

In order to balance the biomass generation in both quantity and biological community, the pilot unit can be operated using the third module tank (T-300) as the lead module tank. Water would then flow to the second module tank (T-200), then to the lag module tank (T-100), then post-reactor tank (T-400.) The operator must open manual ball valves BV-016 or BV-017 to set the feed direction to the desired lead module tank (T-100 or T-300) and the transfer valves between the lead module tank to the middle module tank by opening ball valves BV-103 or BV-303 and for the lag module tank to the post-reactor tank via ball valves BV-102 or BV-302. The operator must tell the PLC which module tank (T-100 or T-300) is the lead module tank with the other then being the lag module tank by default. T-200 is always in the middle position.

The three (3) module tanks include independent flow-controlled recirculation pumps (P-100, P-200, and P-300 for T-100, T-200, and T-300, respectively) to continuously and completely mix the contents inside each module tank. The water recirculation rate of the module tanks T-100, T-200 and T-300 are set by providing a flow setpoint of approximately 40 gpm per each module (80 gpm for each module tank). The PLC will modulate each pump's motor speed using VFD-100, VFD-200 and VFD-300, respectively, to achieve the desired flow.

Hydrogen gas will be introduced into each module within the module tanks via the hydrogen generator (X-030), which generates gas using DI water from the upstream RO/DI (X-025) system. The H<sub>2</sub> gas to each module tank will be controlled by the PLC, and the H<sub>2</sub> gas entering the hollow fibers in each module will be continuously metered. H<sub>2</sub> gas introduced into the hollow fibers will diffuse radially outward and into the biofilm that develops on the hollow-fiber's exterior surface. The biofilm will consume the hydrogen as the electron donor using dissolved perchlorate, chlorate, and nitrate as its source of oxygen (respiration). For each module tank, in-line process analyzers will continuously monitor the pH, ORP and the nitrate concentrations, and perchlorate concentrations will be determined from laboratory analysis (see Section 4.4.3). The nitrate concentration at each recirculation pump discharge (P-100, P-200 and P-300), as measured by analyzer AIT-160 when the appropriate sample valve is open, is controlled by manipulating the hydrogen flow rate to the modules. Initial targets are to achieve 80% nitrate reduction in the lead module tank, 20% in the middle module tank, and a fixed hydrogen flow will be delivered to the lag module tank. The lag module tank hydrogen flow will be based on perchlorate sample results. The H<sub>2</sub> gas flow set point will be adjusted manually based on the in-line nitrate analysis and the reported perchlorate concentrations. H<sub>2</sub> gas will be adjusted automatically by maintaining a forward pressure (via FPR-030) on the supply from the hydrogen generator system.

The reduction of contaminants using H<sub>2</sub> gas may increase the pH of the water. In-line process analyzers on the recirculation lines to each module tank will continuously monitor pH (AIT-170, AIT-270, and AIT-370 for module tanks T-100, T-200, and T-300, respectively). A CO<sub>2</sub> cylinder with pressure regulator (FPR-020) will feed CO<sub>2</sub> gas into each module tank to lower the pH as required based on an operator-adjustable set point. Carbon dioxide is fed to each module tank via two pathways. One pathway for approximately two-thirds of the total demand is by blending carbon dioxide with the supplied hydrogen using a fixed CO<sub>2</sub>:H<sub>2</sub> ratio that is adjusted based on nitrate concentrations. The remaining one third of the total demand is added to the recirculation water to control the pH to a desired setpoint.

The rate of biofilm growth will be monitored during the pilot test. Biofilm growth on the outside of the hollow fibers will increase the pressure drop across the modules. Pressure transmitters (PT-100 through PT-300 for R-101/102 through R-301/302, respectively) will monitor pressure drop in each module. A nitrogen sparging system consisting of an air compressor (C-040), nitrogen generator (X-040) and receiver tank (T-040) will periodically sparge nitrogen gas into the modules to create a mixed-phase flow through the modules to scour excess biological growth and decrease the system pressure drop to initial conditions. Nitrogen gas is used to prevent the addition of oxygen from degrading anoxic conditions during the module sparge. The frequency of sparging is

expected to be approximately 20-60 seconds of air every 12 – 24 hours. The sloughed biological solids will be collected and measured in the post-treatment container.

Temperature and oxidation-reduction potential (ORP) will be monitored in each module tank (AIT-171, AIT-271, and AIT-371 for module tank T-100, T-200, and T-300, respectively).

An operations summary presenting relevant data of the process within the treatment container will be provided through the Trust's monthly reporting.

### 4.3.2 Post-Treatment Container

Treated water from the treatment container will flow to the post-treatment container. Mixed liquor (treated water and biological solids) leaving the MBfR post-reactor will discharge into the surge tank (T-450) in the post-treatment container, which will be continuously mixed by a manually operated fixed-speed mixer (A-450).

The presence of hexavalent chromium in the water exiting the MBfR will be analyzed via a sample port (SP-450). It is expected that hexavalent chromium will be reduced in the reactors under anoxic conditions. The presence of hexavalent chromium in the treated water leaving the biological reactors will indicate that the hexavalent chromium is not being reduced in the biological reactors, and therefore chemical reduction is necessary. To chemically reduce hexavalent chromium, an iron- or aluminum-based coagulant will be added to the surge tank to reduce any residual hexavalent chromium to insoluble trivalent chromium, similar to the process currently used in the GWTP. The coagulant feed system consists of one (1) coagulant storage tank (T-410) and one (1) coagulant feed pump (P-410). Coagulant dosage will be manually controlled based on hexavalent concentrations, and coagulant dilution may be required before adding to the surge tank if required dosages are low.

Treated water from the surge tank will then overflow to a lamella clarifier (T-500). A flash-mix zone located at the head of the lamella clarifier is fitted with a PLC-controlled variable-speed mixer (A-500 with VFD). This mixer speed can be adjusted by the operator. Polymer will be added to the flash-mix zone to flocculate both the biological solids from the MBfR and the precipitated trivalent chromium solids. The polymer feed system consists of two (2) polymer dilution tanks (T-480A and T-480B), each with a manually controlled fixed-speed mixer (A-480A and A-480B for T-480A and T-480B, respectively), and one (1) polymer feed pump (P-480). This will provide continuous polymer feed, with one tank feeding the lamella clarifier and the other tank used to prepare the polymer solution. Polymer will be diluted in batches manually by the operator using Stabilized Lake Mead Water, and dosed based on flow entering the lamella clarifier. Supernatant leaving the lamella clarifier will be collected in the treated water holding tank (T-550).

The treated water holding tank will be continuously mixed via a manually operated fixed-speed mixer (A-550) and contains a level indicator (LIT-550) for level control. When the level in the treated water holding tank reaches an operator-adjustable high-level, the variable-speed treated water pump (P-550 with VFD) will send treated water through the cartridge filter (F-550) to remove residual solids for discharge into the GW-11 Pond. The treated water pump will stop at an operator-adjustable low level to protect the pump. A flowmeter on the effluent line (FIT-550) leaving the cartridge filter will measure the flows discharged into GW-11.

The cartridge filter will be monitored using one of the following methods:

1. The cartridge filter has an upstream pressure indicator to monitor the pressure upstream of the cartridge filter. When the pressure exceeds an operator-adjustable set-point, an email will notify the operator for a cartridge replacement. The initial set-point will be 8 psig but may be adjusted based on filter performance.
2. The treated water pump (P-550) will automatically adjust speed to maintain flow on the effluent flowmeter (FIT-550) at the same flow being fed the MBfR tanks (FIT-015). When the treated water feed pump no longer can maintain same flow as the influent flow, an alarm will notify the operator to check the cartridge filter for a cartridge replacement.



A sample port downstream of the cartridge filter (SP-551) allows the ability to analyze the removal efficiencies of the Pilot Treatment System for chlorate, perchlorate, and hexavalent chromium.

The settled solids in the sludge holding compartment of the lamella clarifier will be pumped via the initial solids handling pump (P-580) to the initial solids holding tank (T-580). This tank is equipped with a manually operated fixed-speed mixer (A-580) to keep solids in suspension and a level indicator (LIT-580) for level control. When the level in the initial solids holding tank rises above an operator-adjustable high-level set-point, an alarm will notify the operator to transfer the solids to the final solids holding tank (T-581) via the manually operated final solids handling pump (P-581). Flowmeter (FIT-580) with totalizer and sample port (SP-581) are located on the discharge line of the initial solids holding tank. Solids samples will be collected to analyze for TSS concentrations. This information will be used to quantify the total solids generated by the biological treatment system during pilot testing. A truck will collect solids from the final solids holding tank (T-581) and transport it for off-site to an approved waste disposal facility when the tank is full. Based on solids yield of 20%, approximately one pound of excess biological solids is expected to be generated from the system per day, requiring periodic truck haul-off.

An operations summary presenting relevant data of the process within the post-treatment container will be provided through the Trust's monthly reporting.

## 4.4 SYSTEM START-UP AND SHUTDOWN

This section describes the anticipated general system start-up and shutdown procedures associated with typical operations. As discussed earlier, the procedures may be updated following system start-up and shakedown or as otherwise deemed necessary to ensure proper system operation and to meet the overall pilot test objectives.

### 4.4.1 System Start-up

An overview of the normal start-up procedure (i.e., following initial system start-up and shakedown) is described below.

- Complete the start-up checklist (**Appendix C**).
- Manually start influent feed tanks recirculation pumps (P-001 and P-002)
- Initiate the start-up procedure from the HMI (Human Machine Interface) on the system PLC by pressing the "Start" buttons on the Feed, Reactor Modules, Coagulation, Treated Water, and Solids Handling Systems.
  - Influent feed pump starts (P-010)
  - Hydrogen generator (X-030) starts
  - Phosphate feed pump starts (P-011)
- Once the three (3) module tanks (T-100, T-200, T-300) and one (1) post-reactor tank (T-400) fill to a pre-set level:
  - Module tank recirculation pumps (P-100, P-200, and P-300) start
  - Hydrogen feed starts
  - Carbon dioxide feed starts
- Once nitrate  $\leq 8.0$  mg-N/L is achieved in the tank modules, the system is advanced to "Normal Run" and feed flow via the influent feed pump (P-010) continues into the module tanks.
- During "Normal Run," water is allowed to flow from the biological reactors to the surge tank (T-450). Coagulant feed pump (P-410) will be started automatically and will dose coagulant into the surge tank based on an operator-adjustable dose set-point.
- Water then overflows from the surge tank into the lamella clarifier (T-500). Polymer feed pump (P-480) will be started automatically and will add polymer into the lamella clarifier based on an operator-adjustable set-point.
- Supernatant from the lamella clarifier overflows into the treated water tank (T-550). When the level in the treated water tank (LIT-550) reaches an operator-adjustable high-level setpoint:

- Treated water pump (P-550) starts
  - Water flows through the cartridge filter (F-550) and discharges into the GW-11 Pond
- Treated water pump will stop once the treated water tank level drops below an operator-adjustable low-level setpoint.
- Once the solids level in the solids settling compartment of the clarifier reach a high level, the operator manually starts the solids handling pump (P-580) and pumps the settled solids to the solids holding tank.
- Solids enter the initial solids holding tank (T-580). When the solids level in the initial solids holding tank reach a high level (LIT-580), the operator will use the final solids handling pump (P-581) and pump the solids to the final solids holding tank (T-581).

## 4.4.2 System Shut down

The following describes the normal (non-emergency) shut down process.

- Initiate the shut-down procedure from the HMI on the PLC by pressing the “Stop” button for each process.
- This will initiate the following response:
  - Influent feed pump stops (P-010)
  - Recirculation pumps in the module tanks stop (P-100, P-200, and P-300)
  - Hydrogen feed stops
  - Carbon dioxide feed stops
  - All nitrogen sparge valves to each module tank and post-reactor tank close (SV-100, SV-200, SV-300, and SV-400)
  - Coagulant feed pump stops (P-410)
  - Polymer feed pump stops (P-480)
  - Treated water pump stops (P-550)
- Manually stop initial solids handling pump (P-580) if ON.
- Manually stop mixers: surge tank mixer (A-450), treated water tank mixer (A-550), polymer tanks mixers (A-480A/B), solids holding tank mixer (A-580), and solids handling pump (P-581) if ON.
- Manually stop influent feed tanks recirculation pumps (P-001 and P-002).

Should the system need to be shut down due to an emergency, hit the red emergency (E-Stop) button on the front of the Hydrogen Generator and the PLC Control Cabinet.

## 4.5 DATA COLLECTION AND MANAGEMENT

The pilot study will consist of two phases for each test scenario: a start-up phase and an operational phase. The start-up phase will consist of sludge acclimation and the initial operation of the system to confirm operation of process equipment and establish the preliminary operating parameters. After the system is confirmed to be operating as intended and has reached steady-state operation, the operational phase will begin. Steady state condition is defined as when the perchlorate, chlorate, and nitrate concentrations in the treated water reach a constant level and the variation in the contaminant effluent concentration is generally within 10 to 20% or +/- 5 µg/L, whichever is greater. During each phase on-site inspections, field monitoring, and sampling will be required to support the operations and these procedures will be updated as needed to ensure proper system operation and to meet the overall pilot test objectives. A summary of relevant draft results will be provided through the Trust’s monthly reporting.

### 4.5.1 Daily Inspections

Daily inspections of the equipment in the treatment container and the post-treatment container include the following:



- Check water level in influent feed tanks to ensure adequate quantity of influent water exists in the tank for proper operation.
- Check levels in phosphate tank and mix up new batches as necessary.
- Inspect online analytical analyzers, sensors and transmitters including nitrate analyzers, pH sensors, ORP sensors, level sensors, and temperature transmitters to ensure that values are consistent with previously measured values.
- Inspect the hydrogen generator for any warning or alarm conditions.
- Check RO/DI conductivity reading to ensure ultrapure water generation.
- Inspect air compressor for dew point and any warning or alarm conditions.
- Check all other valves and fittings for possible leakage.
- Check polymer tank to ensure adequate polymer solution in the tank for proper operation.
- Check coagulant holding tank to ensure adequate coagulant exists in the tank for proper operation.
- Check sludge level in clarifier to ensure solids levels is not too high to cause TSS overflow from clarifier.
- Check cartridge filter pressure and change cartridge if necessary.
- Check solids level in initial solids holding tank and pump to final solids holding tank as necessary.
- Inspect discharge pipe to GW-11 for any leaks.

### 4.5.2 Field Monitoring

Field parameter data will be collected during both the start-up phase and the operational phase. The following data will be monitored using built-in analyzers on the pilot system: nitrate, pH, ORP, and temperature. Field measured data will be utilized for pilot unit system operations and adjustments. Additionally, turbidity on the water leaving the lamella clarifier (sample port SP-500) will be measured using a hand-held probe to provide data on residual solids in the treated water.

### 4.5.3 Sampling and Analytical Program

A sampling and analytical program will be implemented to gather data to operate the Pilot Treatment System and evaluate the Pilot Treatment System's performance.

Analytical testing will include operational samples intended to monitor and adjust the Pilot Treatment System operational parameters and performance assessment samples intended to measure the technology performance relative to the objectives identified in Section 2.3. Operational samples will be collected during both the start-up phase and an operational phase while performance assessment samples will only be collected during the operational phase of each test scenario.

Both operational and performance samples will be analyzed at off-site laboratories. The operational samples will be analyzed on a quick turn-around time for immediate use and will not be validated. The performance samples will be collected and analyzed under normal turn-around times and will be validated in accordance with the Quality Assurance Project Plan, Revision 4 (QAPP, Ramboll, 2019) and assessed in the final report.

Samples will be collected from several locations on the Pilot Treatment System:

- Influent samples will be collected from the sample port on the line entering the module tanks (sample port SP-015).
- Reactor samples will be collected from sample ports installed after each module tanks (SP-100, SP-200, and SP-300 for the first, second, and third module tank, respectively) and the post-reactor tank (SP-400) to measure parameter concentrations following treatment in each tank.
- Treated water samples will be collected from a sample port on the discharge line of the treated water holding tank (SP-550) before the cartridge filter for Scenario #3.
- Effluent samples to GW-11 Pond will be collected from a sample port on the discharge line of the cartridge filter (SP-551).

In addition, operational samples will be collected from the influent feed tanks to confirm the required and consistent water make-up for each test scenario as discussed in Section 4.2 and a TSS sample collected from the initial solids holding tank every time the tank is full and transferred to the final solids holding tank as discussed in Section 4.2.4.2.

The sampling and analytical program for the operational phase of each scenario is summarized in **Table 2** and **Table 3**. Refer to P&ID in **Attachment A** for sample port locations.

**Table 2** Pilot Test Operational Samples

Frequency	Every Weekday	Twice a Week
Parameter	Perchlorate	Chromium: Total and Hexavalent <sup>1</sup>
Sample Location		
Influent to Reactor Modules (SP-015)	1	1
Module Tank 1 Effluent (SP-100)	1	-
Module Tank 2 Effluent (SP-200)	1	-
Module Tank Effluent (SP-300)	1	1
Post-Reactor Tank Effluent (SP-400)	1	1
Treated Water Holding Tank Effluent (SP-550)	-	1
Cartridge Filter Effluent (SP-551)	1	1

Notes:

Operational Sample analysis will be performed at Silver State or Pace Analytical under rush turn-around time (1 day for perchlorate and 3 days for chromium). Laboratory results will be in Level 1 reports. These results will not be validated or added to the NERT database. The Operational Sample program will be adjusted if needed to ensure proper system operation and to meet overall pilot test objectives. Operational samples for perchlorate for all scenarios and chromium for Scenario #3 will also be collected from the influent tanks as needed to ensure consistent make-up of the influent to the system. In addition to perchlorate and chromium, up to 25 samples will be collected after the post- reactor column and analyzed for ortho-phosphate for operational support.

<sup>1</sup> The chromium analysis will only be performed during Scenario #3. The hexavalent chromium will be analyzed by spectrometer method SM 3500.

**Table 3** Pilot Test Performance Assessment Samples

Frequency	Weekly						Twice a Week
Parameter	Perchlorate	Chlorate	Nitrate	Hexavalent Chromium <sup>1</sup>	Total Chromium <sup>1</sup>	TDS	TSS
Sample Location							
Influent to Module Tanks (SP-015)	1	1	1	1	1	1	1

Frequency	Weekly						Twice a Week
	Perchlorate	Chlorate	Nitrate	Hexavalent Chromium <sup>1</sup>	Total Chromium <sup>1</sup>	TDS	TSS
Sample Location							
Module Tank 1 Effluent (SP-100)	1	1	1	-	-	-	1
Module Tank 2 Effluent (SP-200)	1	1	1	-	-	-	1
Module Tank 3 Effluent (SP-300)	1	1	1	1	1	-	1
Post-Reactor Tank Effluent (SP-400)	1	1	1	1	1	-	1
Treated Water Holding Tank Effluent (SP-550)	-	-	-	1	1	-	1
Cartridge Filter Effluent (SP-551)	1	1	1	1	1	1	1

**Notes:**

Pilot Test Assessment Sample analysis will be performed at Test America or Pace Analytical under standard turn-around time. Laboratory results will be in Level 3 reports. These results will be validated and added to the NERT database. Additionally, a TSS sample will be collected and analyzed each time the 200-gallon solids holding tank is full.

<sup>1</sup> The chromium analyses will only be performed during Scenario #3.

### 4.5.4 Data Validation

Only with respect to the Pilot Test Assessment Sample Analysis, the laboratory analytical data from the performance assessment samples will be verified and validated in accordance with procedures described in the QAPP, “Data Validation Guidance” (NDEP, 2018), and the references contained therein. The samples will be validated to Stage 2A. The review process uses professional judgment and guidance from the National Functional Guidelines to determine the final qualifiers, which will be added to the database and presented in the final report. Quality assurance/quality control (QA/QC) samples including equipment blanks, field blanks, field duplicates, and matrix spike/matrix spike duplicates will be collected at appropriate frequencies to support the data evaluation.

### 4.6 ALARMS AND INTERLOCKS

The Pilot Treatment System is constructed with multiple alarms and interlocks as discussed below.

- Hydrogen leak sensor inside the hydrogen generator (X-030) will turn OFF the hydrogen generator as part of its independent control system.
- Any hydrogen sensor above the module tanks (AIT-136/236/336) or in the treatment container (AIT-030) at >25% LEL will be linked in an audible alarm and initiate system shutdown.
- High level switches in module tanks (LSH-100, LSH-200, LSH-300), post reactor column (LSH-400) and treated water holding tank (LIT-550) will turn OFF influent feed pump (P-010) and initiate system shutdown.

- Low flow on the ventilation fan (FIT-900) inside the treatment container will initiate system shutdown and send an email notification.
- Low oxygen sensor (AIT-050) inside the treatment container will be linked to a visual and an audible alarm and will initiate shutdown if oxygen levels reach 19.5%.
- Phosphate feed pump P-011 will not turn ON if influent feed pump P-010 is OFF.
- Coagulant feed pump P-410 will not turn ON if influent feed pump P-010 is OFF.
- Polymer feed pump P-480 will not turn ON if influent feed pump P-010 is OFF.

The control system will send an email for all warning notifications and shutdown alarms.

## 4.7 MAINTENANCE

A summary of maintenance activities and schedules are provided below. Maintenance will be conducted to keep system operational and to identify potential issues quickly so they can be resolved in a timely manner. **Table 4** below shows preventative measures for the Pilot Treatment System. Relevant maintenance activities will be provided through the Trust’s monthly reporting.

**Table 4** Maintenance Measures

Frequency	Process	Description
Every Weekday	General	Check that all operating equipment and instruments are working properly. Inform the process engineer of any non-working equipment and instruments.
	Treatment and Post-Treatment Containers	Visually inspect all tanks, pumps, pipes and valves for leaks or signs of damage. Fill out inspection and operational logs.
	Containment Area	Visually inspect secondary containment liner system.
Every week	General	Clean pH, ORP and nitrate sensor surfaces.
		Check and change cartridge filters as needed.
		Test oxygen sensor.
		Check and change carbon dioxide cylinders, polymer and coagulant if needed.
		Check mixers for any necessary cleaning and/or lubrication.
		Check mechanical seals on the pumps.
Check pump motor bearings for any necessary lubrication.		

Frequency	Process	Description
Minimum of every 3 months	Hydrogen Generation	Calibrate hydrogen sensors.
Minimum of every 3 months	Oxygen Level	Check and calibrate oxygen sensor.

## 4.8 TROUBLESHOOTING

There are several performance issues that may arise in the Pilot Treatment System. **Table 5** lists some common issues and provides corrective actions for each.

**Table 5** Troubleshooting Measures

Symptom	Cause	Corrective Action
1. High perchlorate concentration in effluent	1. Higher influent flow	1. Check influent flow. 2. Adjust speed of the influent feed pump as required to provide the desired mass loading.
	2. Insufficient hydrogen gas flow	1. Check to make sure hydrogen flow is adequate. Check to make sure hydrogen generator is operating. Troubleshoot generator as required. 2. Adjust hydrogen flow via the PLC to provide the desired feed rate to each reactor as necessary to meet treatment objectives.
	3. High nitrate concentrations.	1. Check nitrate concentration in the treated water. See below for additional corrective measures.
2. High nitrate concentration in effluent	1. Higher influent flow	1. Check influent flow. 2. Adjust speed of the influent feed pump as required to provide the desired design influent flow.
	2. Insufficient hydrogen generation	1. Check to make sure hydrogen flow is adequate. Check to make sure hydrogen generator is operating. Troubleshoot generator as needed. 2. Adjust hydrogen generator via the PLC to provide the desired feed rate to each reactor as necessary to meet treatment objectives.
3. High chromium concentration in effluent	1. Cr <sup>+6</sup> not reducing to Cr <sup>+3</sup>	1. Check Cr <sup>+6</sup> concentration in treated water to check if MBfR is reducing Cr <sup>+6</sup> to Cr <sup>+3</sup> . If not add coagulant.
	2. Insufficient coagulation	1. Check coagulant feed system: Ensure that coagulant is added at the desired concentration. Run process calculations to confirm desired feed rate, and check that feed pump speed provides desired feed rate. Troubleshoot feed pump as required per the IOM. May have to conduct jar tests to determine optimum coagulant type and concentration. 2. If needed, adjust coagulant feed system: Adjust concentration of coagulant as required and/or adjust feed pump speed to provide the desired feed rate.
	3. Insufficient effluent filtration	1. Visually check the cartridge filters. 2. Replace cartridges if determined that excess solids are present. 3. Check TSS concentration in the effluent stream.

Symptom	Cause	Corrective Action
4. High pressure drop across cartridge filters	1. Cartridge is plugged with solids	<ol style="list-style-type: none"> <li>1. Visually check the cartridge filters.</li> <li>2. Replace cartridges if determined that excess solids are present.</li> </ol>
	2. Faulty upstream and downstream pressure sensors	<ol style="list-style-type: none"> <li>1. Troubleshoot pressure sensors as required by the IOM; calibrate sensor and/or replace parts as necessary.</li> </ol>

## 5.0 REFERENCES

Ramboll. (2019). *Quality Assurance Project Plan, Revision 4, Nevada Environmental Response Trust Site Henderson, Nevada*. December 30.

Tetra Tech. (2019). *Hydrogen-Based Gas Permeable Membrane Technology Pilot Test Work Plan, Nevada Environmental Response Trust Site Henderson, Nevada (Work Plan)*. February 15.

Tetra Tech. (2020). *Health and Safety Plan for Site-Wide Investigation, Remedial and Construction Operations, Nevada Environmental Response Trust Site Henderson, Nevada (HASP)*. February 10.

## Figures



GW-11

Pilot Treatment System Location



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NEVADA ENVIRONMENTAL RESPONSE TRUST

HYDROGEN-BASED GAS PERMEABLE MEMBRANE PILOT STUDY  
HENDERSON, NEVADA

**PILOT TREATMENT SYSTEM LOCATION**

Project No.: 117-7502018-M26

Date: MARCH 25, 2020

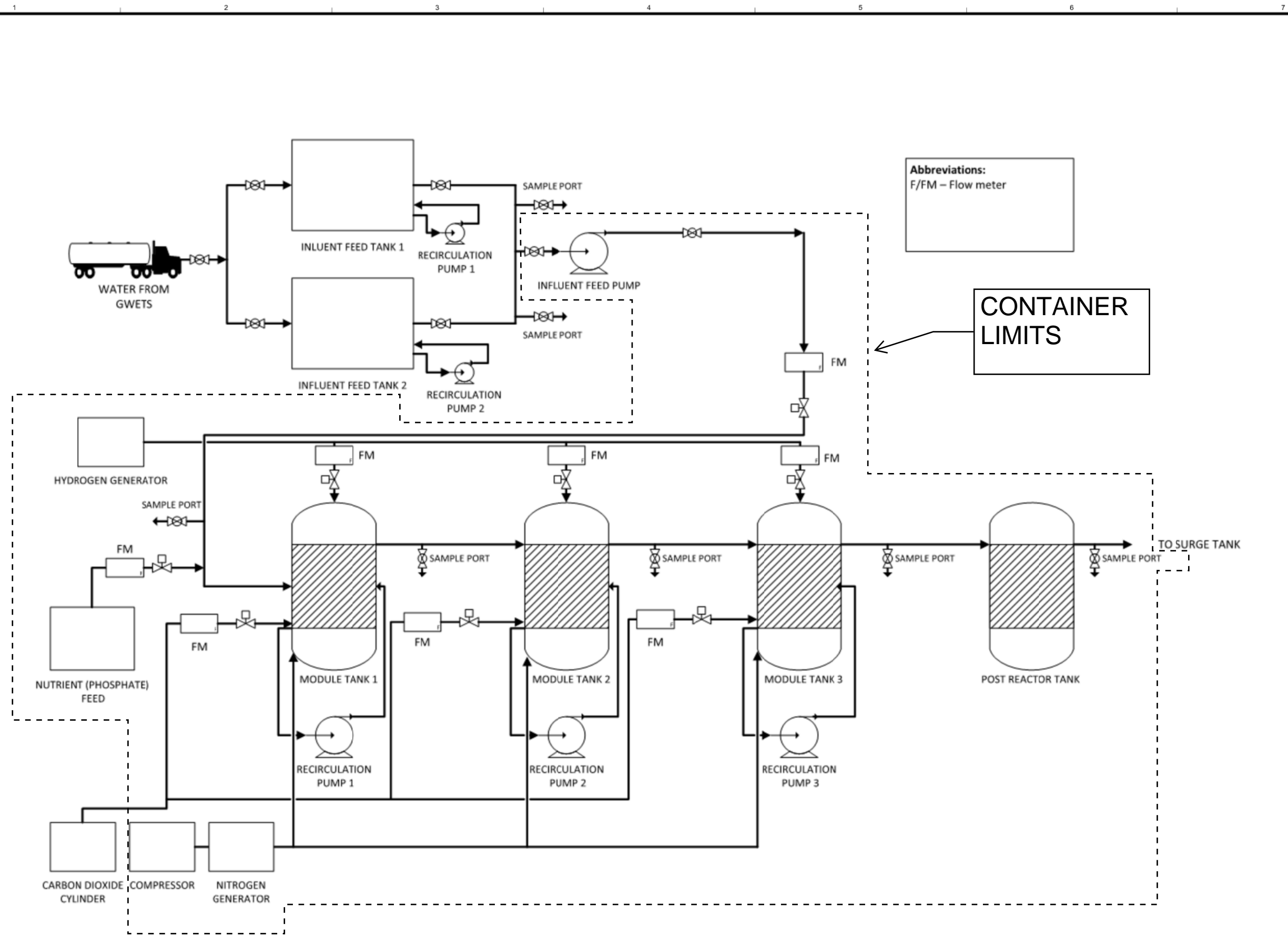
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Figure No.

**1**

Imagery Source: Esri World Map, May 2017.

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MARK	DATE	DESCRIPTION

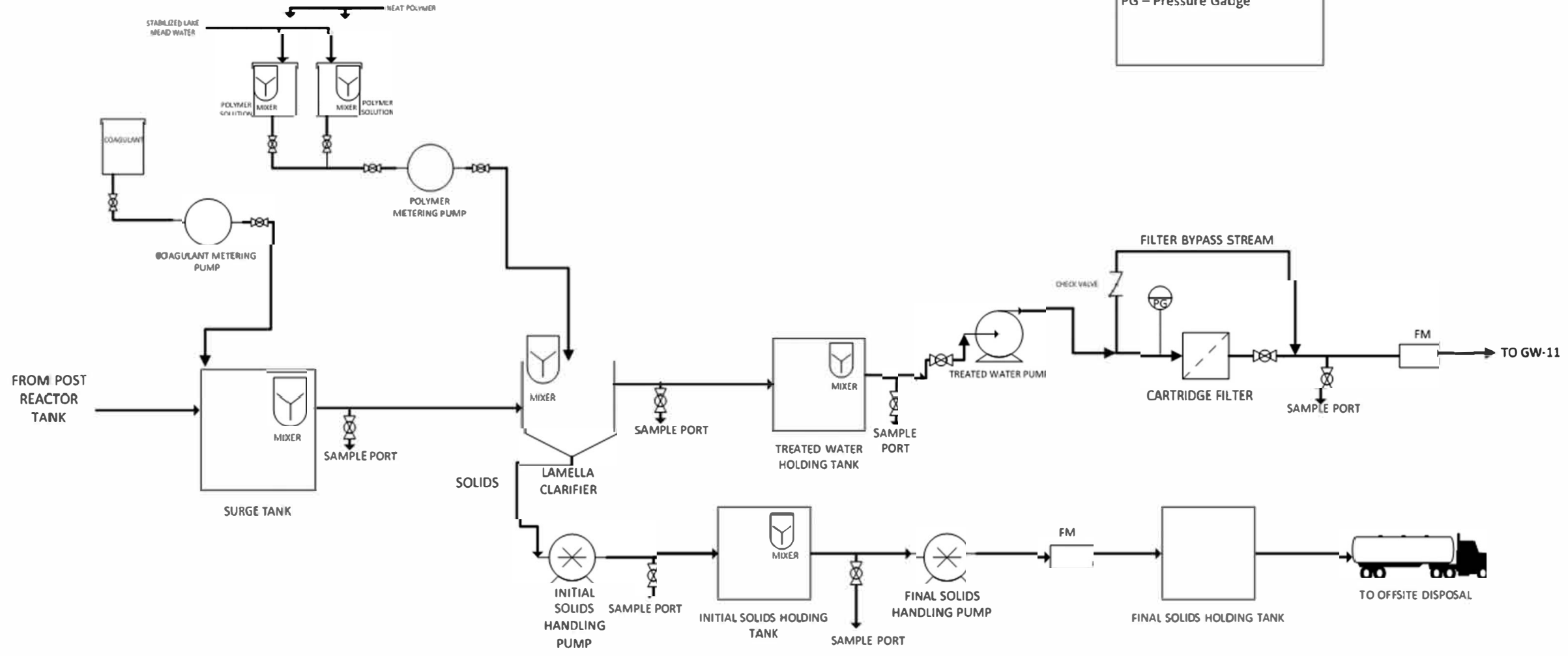
NEVADA ENVIRONMENTAL RESPONSE TRUST  
HENDERSON, NEVADA  
HYDROGEN-BASED GAS PERMEABLE  
MEMBRANE PILOT STUDY  
SYSTEM OPERATION MANUAL  
**PROCESS FLOW DIAGRAM**  
1 OF 2

Project No.: 117-7502020-M26  
Designed By: APTwater  
Drawn By: B. CHHUN  
Checked By: K. HENDRICKSON

**Fig. 2A**

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**Abbreviations:**  
 F/FM – Flow meter  
 PG – Pressure Gauge

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CHECKED	
DATE	

NEVADA ENVIRONMENTAL RESPONSE TRUST  
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 HYDROGEN-BASED GAS PERMEABLE  
 MEMBRANE PILOT STUDY  
 SYSTEM OPERATION MANUAL  
**PROCESS FLOW DIAGRAM**  
 2 OF 2

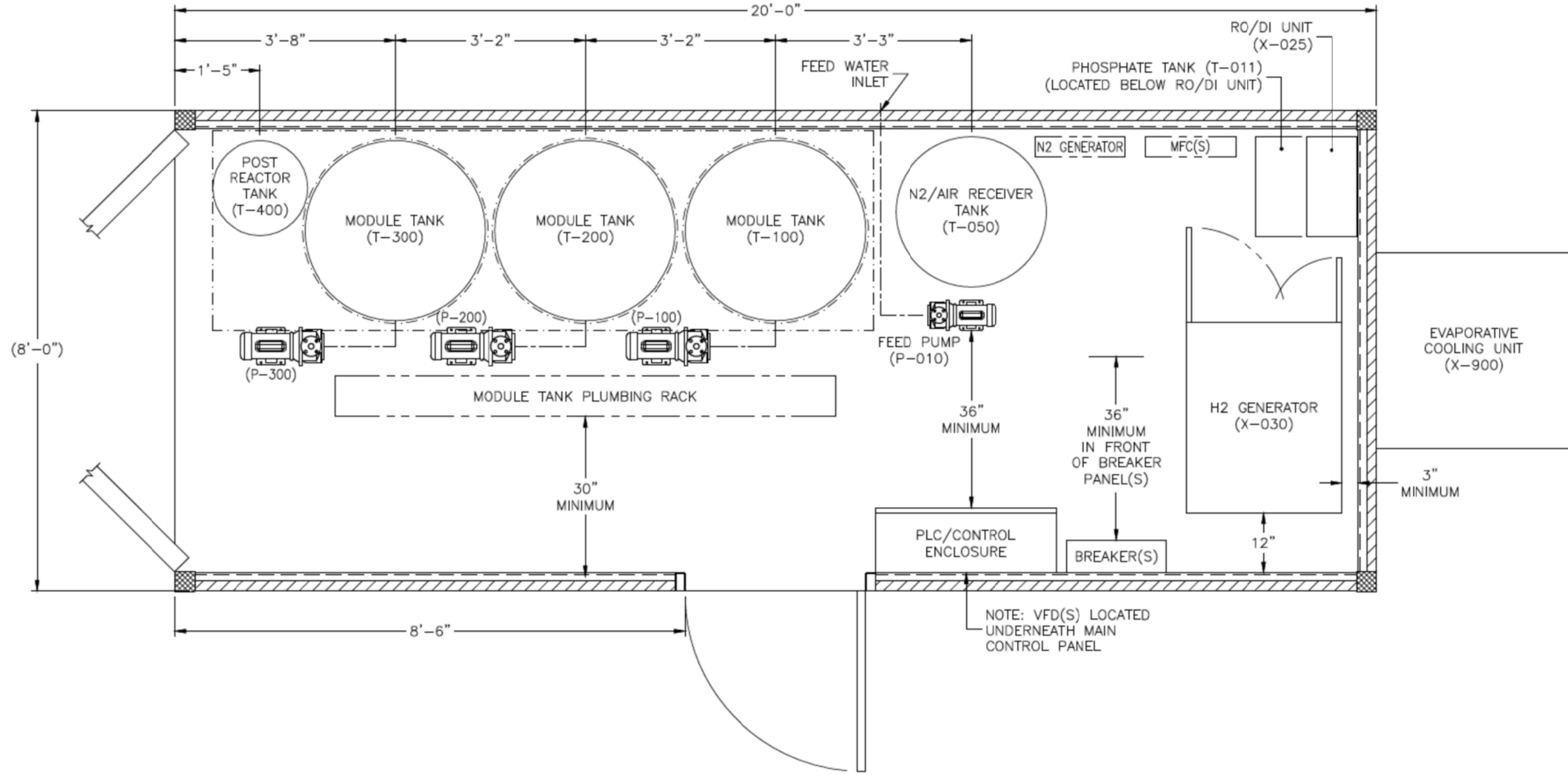
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**Fig. 2B**

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**ABBREVIATION LIST:**  
 A/C = AIR CONDITIONER  
 MFC = MASS FLOW CONTROLLER  
 N2 = NITROGEN  
 H2 = HYDROGEN  
 PLC = PROGRAMMABLE LOGIC CONTROLLER  
 P = PUMP  
 RO/DI = REVERSE OSMOSIS/DE-IONIZED WATER  
 T = TANK  
 VFD = VARIABLE FREQUENCY DRIVE  
 X = GENERATOR



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 HENDERSON, NEVADA  
 HYDROGEN-BASED GAS PERMEABLE  
 MEMBRANE PILOT STUDY  
 SYSTEM OPERATION MANUAL  
**TREATMENT CONTAINER  
 LAYOUT**

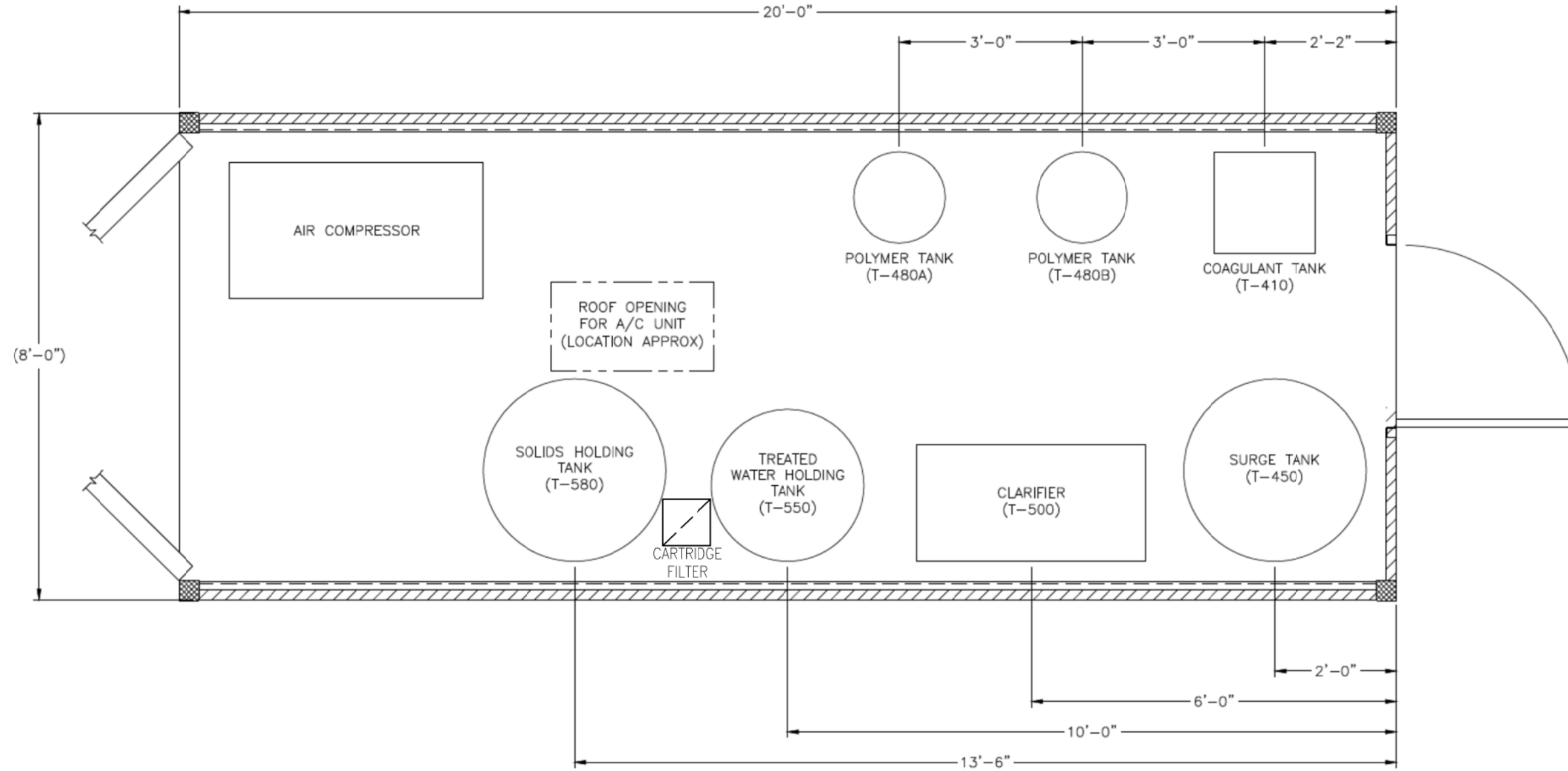
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**Fig. 3**

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**ABBREVIATION LIST:**  
 N2 = NITROGEN  
 H2 = HYDROGEN  
 PLC = PROGRAMMABLE LOGIC CONTROLLER  
 P = PUMP  
 RO/DI = REVERSE OSMOSIS/DE-IONIZED WATER  
 T = TANK  
 VFD = VARIABLE FREQUENCY DRIVE  
 X = GENERATOR



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 SYSTEM OPERATION MANUAL  
**POST TREATMENT  
 CONTAINER LAYOUT**

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**Fig. 4**

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# **Appendix A**

## **Pilot Treatment System Process and Instrumentation Diagrams**

### VALVES/PUMPS/EQUIPMENT

	2-WAY BALL VALVE		2-WAY ACTUATED BALL VALVE (PNEUMATIC)
	2-WAY BALL VALVE (CONTROL)		2-WAY ACTUATED BALL VALVE (ELECTRIC)
	3-WAY BALL VALVE		2-WAY ACTUATED BALL VALVE (MOTORIZED)
	3-WAY BALL VALVE (CONTROL)		3-WAY ACTUATED BALL VALVE (PNEUMATIC)
	2-WAY GATE VALVE		3-WAY ACTUATED BALL VALVE (ELECTRIC)
	NEEDLE VALVE		3-WAY ACTUATED BALL VALVE (MOTORIZED)
	CHECK VALVE		BUTTERFLY VALVE (PNEUMATIC)
	BUTTERFLY VALVE		FORWARD PRESSURE REGULATOR
	PRESSURE RELIEF VALVE		BACK PRESSURE REGULATOR
	ROTAMETER		ROTAMETER W/FLOW CONTROL
	GAS FILTER		BASKET STRAINER
	Y-STRAINER		CARTRIDGE FILTER
	CHEMICAL MIXER		STATIC MIXER
	EDUCTOR		FAN
	CENTRIFUGAL PUMP		HEAT EXCHANGER
	BLOWER		COOLING UNIT
	METERING PUMP		MASS FLOW CONTROLLER
	PERISTALTIC PUMP		VENT VALVE
	INLINE PUMP		
	GAS STORAGE TANK		
	LIQUID STORAGE TANK		
	LIQUID STORAGE TANK W/SECONDARY CONTAINMENT		
	CALIBRATION CYLINDER		

### PROCESS/INSTRUMENTATION

	ANALOG INPUT
	ANALOG OUTPUT
	DIGITAL INPUT
	DIGITAL OUTPUT
	ETHERNET
	INTERLOCK
	INSTRUMENT (LOCAL MOUNT)
	INSTRUMENT (PANEL MOUNT)
	INSTRUMENT W/TRANSMITTER
	INSTRUMENT W/REMOTE TRANSMITTER

### PIPE SYMBOLS

	CONCENTRIC REDUCER
	ECCENTRIC REDUCER
	CAP/PLUG
	FLEX COUPLING/JOINT
	FLANGE/DISCONNECT POINT
	TIE POINT
	DIRECTIONAL FLOW ARROW

### ABBREVIATIONS

AE	ANALOG ELEMENT	LP	LOAD PANEL
AI	ANALOG INDICATOR, ANALOG INPUT	LS	LIQUID LEVEL SWITCH
AIT	ANALOG INDICATOR W/TRANSMITTER	LSH	LIQUID LEVEL SWITCH (HIGH)
AO	ANALOG OUTPUT	LSL	LIQUID LEVEL SWITCH (LOW)
AT	ANALOG TRANSMITTER	LT	LEVEL TRANSMITTER
B	BLOWER	MCP	MAIN CONTROL PANEL
BPR	BACK PRESSURE REGULATOR	MX	MIXER
BV	BALL VALVE, BUTTERFLY VALVE	N2	NITROGEN
C	COMPRESSOR	P	PUMP
CDA	CLEAN DRY AIR	PCV	PRESSURE CONTROL VALVE
CI	CAST IRON	PE	POLYETHYLENE
CL	CALIBRATION COLUMN	PI	PRESSURE INDICATOR
CO2	CARBON DIOXIDE	PIV	ISOLATION VALVE, PRESSURE INDICATOR
CV	CHECK VALVE	PT	PRESSURE TRANSMITTER
DI	DIGITAL INPUT	PTV	ISOLATION VALVE, PRESSURE TRANSMITTER
DO	DIGITAL OUTPUT	PWR	POWER
DP	DRIVE PANEL	S	GAS LIQUID SEPARATOR
DPT	DIFFERENTIAL PRESSURE TRANSMITTER	SP	SAMPLE VALVE, SAMPLE POINT
DS	DISCONNECT SWITCH	SSTL	STAINLESS STEEL
DV	DRAIN VALVE	STL	STEEL
E	EDUCTOR	STR	STRAINER
ETH	ETHERNET	SV	SOLENOID VALVE
F	FILTER, FAN	T	TANK, TRANSFORMER
FCIT	FLOW CONTROLLER	TI	TEMPERATURE INDICATOR
FCV	FLOW CONTROL VALVE	TP	TIE POINT
FE	FLOW ELEMENT	TS	TEMPERATURE SWITCH
FI	FLOW INDICATOR	TSH	TEMPERATURE SWITCH (HIGH)
FIT	FLOW INDICATOR W/TRANSMITTER	TSL	TEMPERATURE SWITCH (LOW)
FIV	FLOW INDICATOR W/CONTROL VALVE	UTV	UTILITY VALVE
FPR	FORWARD PRESSURE REGULATOR	VFD	VARIABLE FREQUENCY DRIVE
FS	FLOW SWITCH	VV	VENT VALVE
FSH	FLOW SWITCH (HIGH)	X	GENERATOR
FSL	FLOW SWITCH (LOW)	XV	ACTUATED VALVE
H2	HYDROGEN		
HS	HAND SWITCH		
HTX	HEAT EXCHANGER		

NOTE:  
CONTACT PROJECT ENGINEER FOR ABBREVIATIONS  
NOT LISTED HERE.

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4	GENERAL CHANGES	07/20/20	LT
3	GENERAL CHANGES	01/14/20	LT
2	UPDATED PER INTERNAL REVIEW	11/12/19	LT
1	ISSUED FOR CUSTOMER REVIEW	10/18/19	LT
REV	DESCRIPTION	DATE	NAME

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		CLIENT: <b>TETRA TECH</b>	
PROJECT: <b>03585</b>		LOCATION: <b>HENDERSON, NV</b>	
TITLE: <b>P&amp;ID LEGEND</b>			
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CHECKED			SCALE: N/A FILE:0358530P000-R4 SHEET 1 OF 1
APPROVED			
INVENTORY ID:	N/A		
NEXT ASSEMBLY:	N/A		

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DO NOT SCALE DRAWING

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A

TIE POINT SCHEDULE				
TP #	Process	Size	Connection Type	Material
TP-1	Influent Water	1"	150# Flange	SCH 80 PVC
TP-2	Treated Water	1"	150# Flange	SCH 80 PVC
TP-3	Phosphoric Acid	N/A	Manual fill	N/A

SYSTEM TAG DESIGNATORS
000 - GENERAL EQUIPMENT
010 - FEED SYSTEM
050 - AIR DELIVERY SYSTEM
100/200 - MODULE SYSTEM
110/210 - MODULE DRAIN SYSTEM
115/215 - H2/CO2 BLEND SYSTEM
120/220 - CO2 SYSTEM
130/230 - H2 SYSTEM
800 - EFFLUENT SYSTEM

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REV	DESCRIPTION	DATE	NAME
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3	GENERAL CHANGES	01/14/20	LT
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		CLIENT: TETRA TECH	
		PROJECT: 03585	LOCATION: HENDERSON, NV
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**PROPRIETARY**

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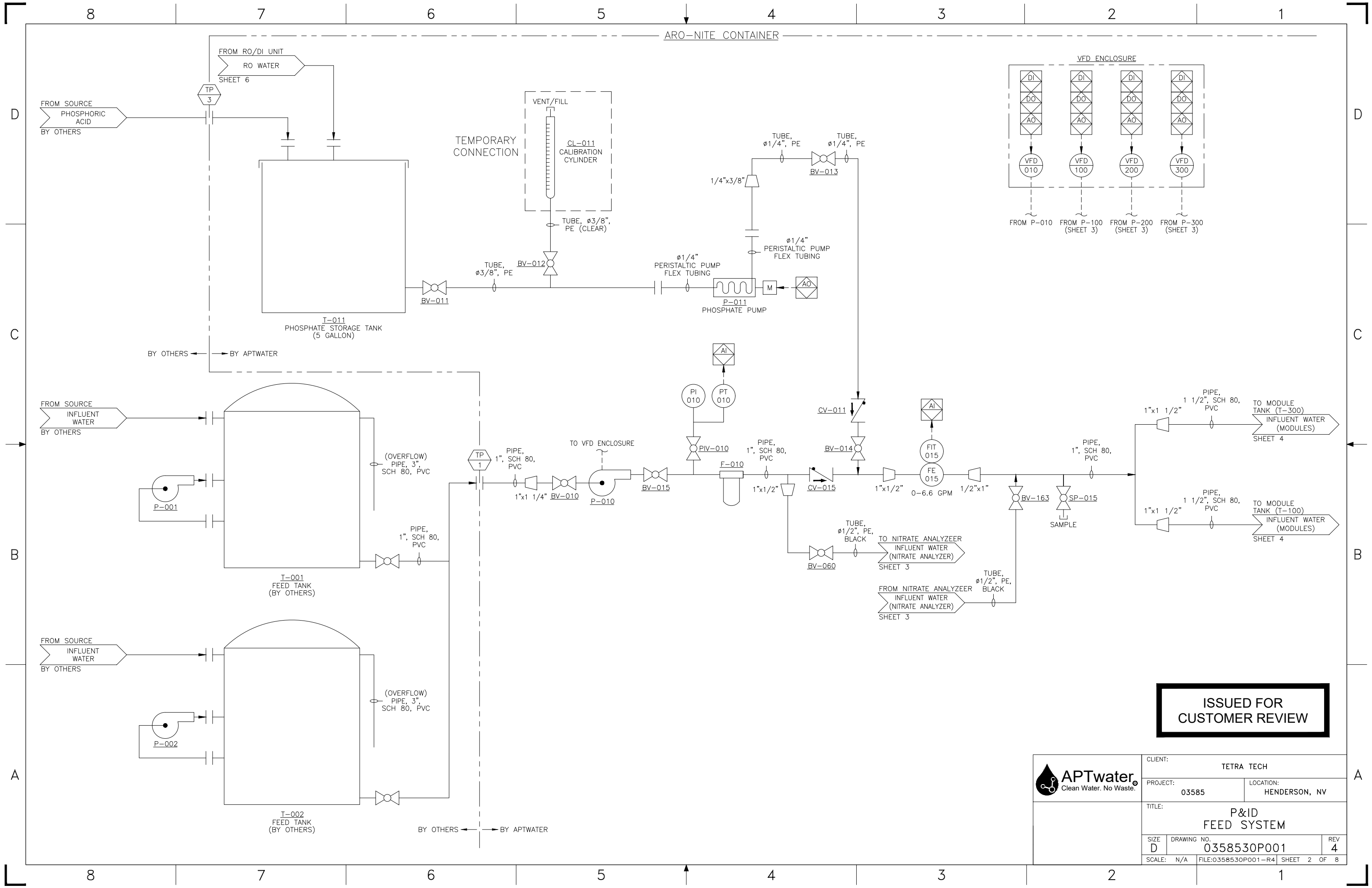
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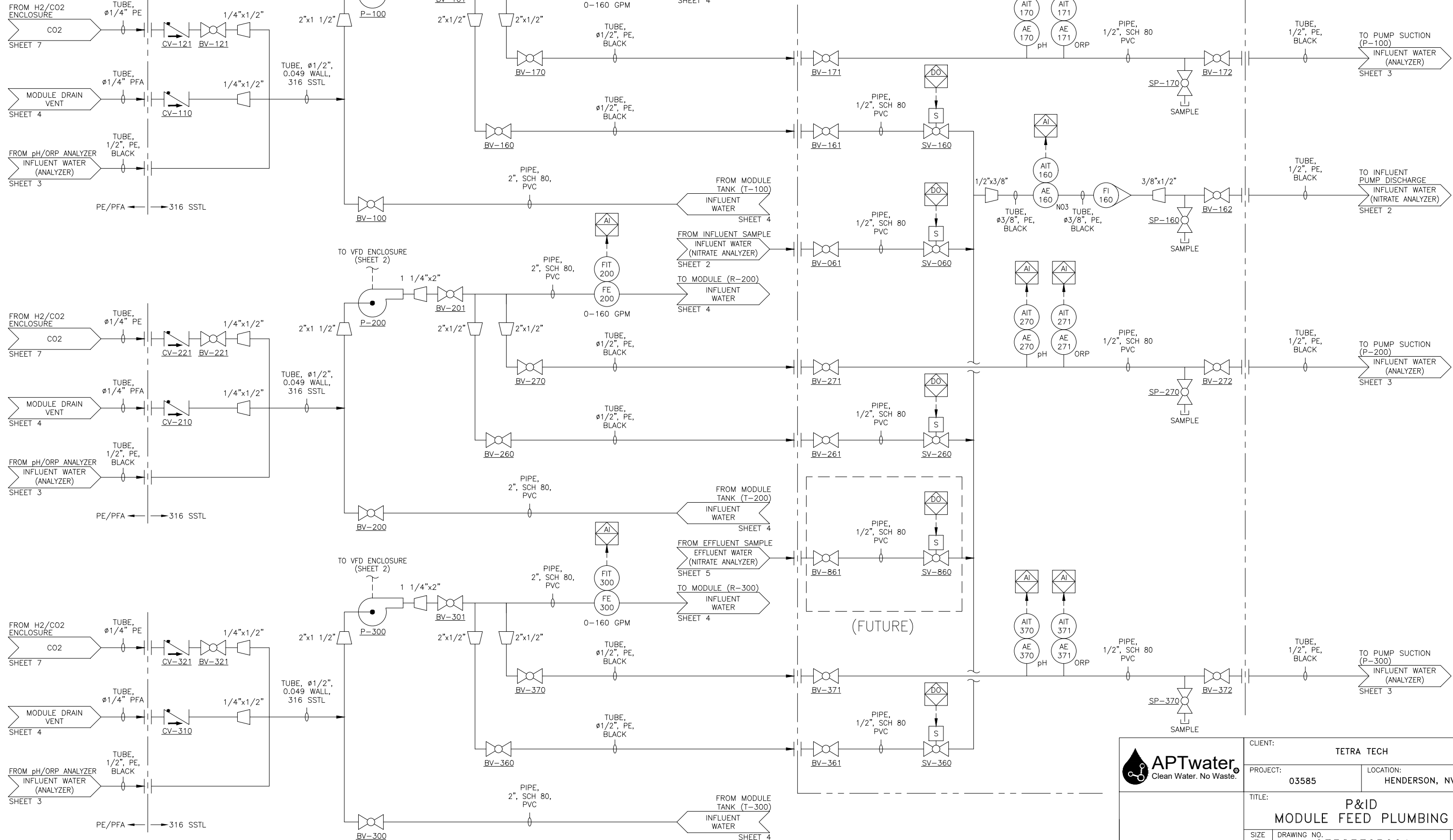


ISSUED FOR  
CUSTOMER REVIEW

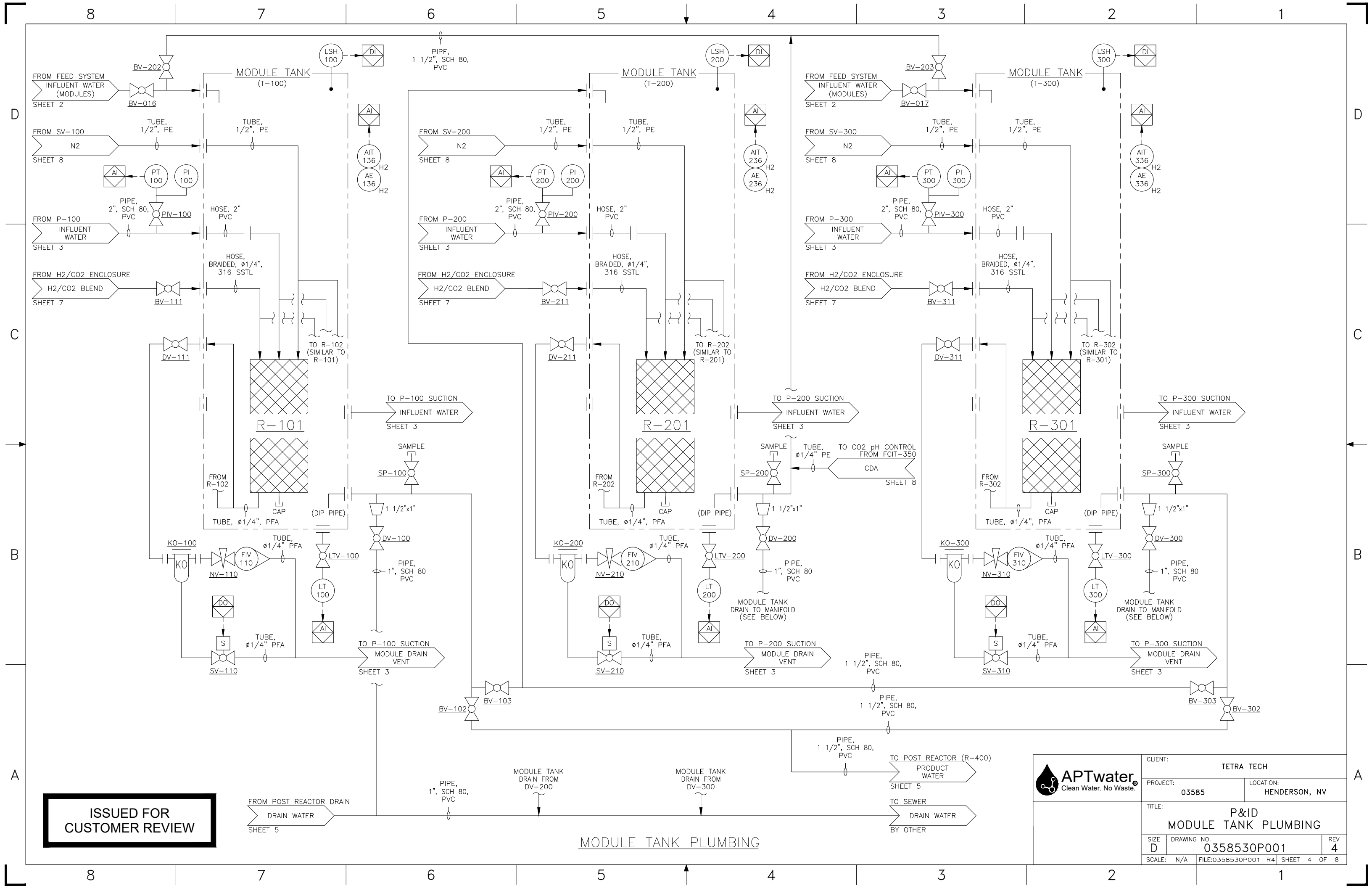


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SCALE: N/A	REV: 4
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**ISSUED FOR  
CUSTOMER REVIEW**



		CLIENT: TETRA TECH	
		PROJECT: 03585	LOCATION: HENDERSON, NV
TITLE: P&ID MODULE FEED PLUMBING			
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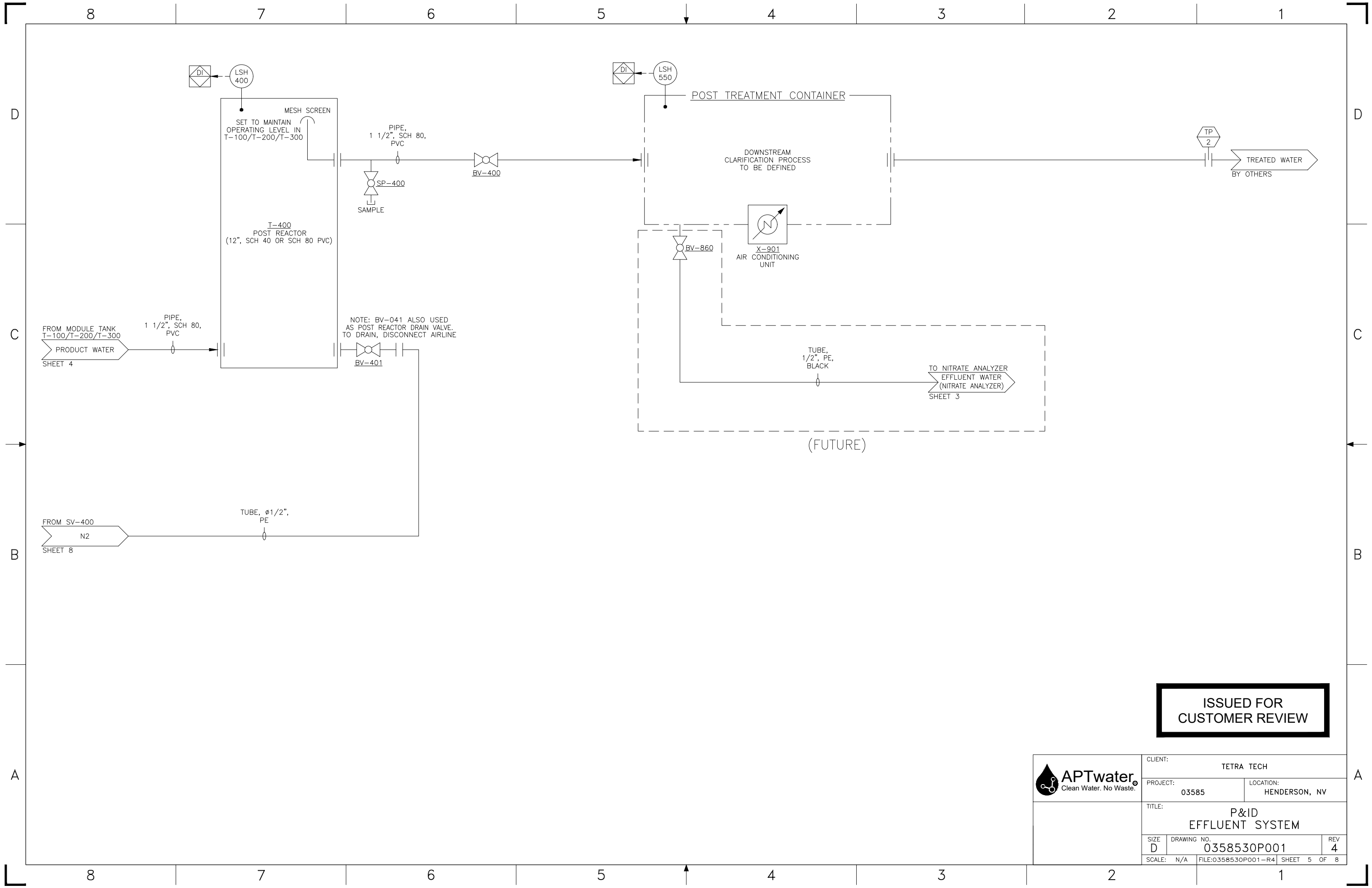


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MODULE TANK PLUMBING



CLIENT: TETRA TECH	
PROJECT: 03585	LOCATION: HENDERSON, NV
TITLE: P&ID MODULE TANK PLUMBING	
SIZE: D	DRAWING NO. 0358530P001
SCALE: N/A	REV 4
FILE: 0358530P001-R4 SHEET 4 OF 8	



FROM MODULE TANK  
T-100/T-200/T-300  
PRODUCT WATER  
SHEET 4

LSH 400  
MESH SCREEN  
SET TO MAINTAIN  
OPERATING LEVEL IN  
T-100/T-200/T-300  
T=400  
POST REACTOR  
(12", SCH 40 OR SCH 80 PVC)

PIPE,  
1 1/2", SCH 80,  
PVC  
SP-400  
SAMPLE

NOTE: BV-041 ALSO USED  
AS POST REACTOR DRAIN VALVE.  
TO DRAIN, DISCONNECT AIRLINE

FROM SV-400  
N2  
SHEET 8  
TUBE,  $\phi$ 1/2",  
PE

LSH 550

POST TREATMENT CONTAINER

DOWNSTREAM  
CLARIFICATION PROCESS  
TO BE DEFINED

X-901  
AIR CONDITIONING  
UNIT

BV-860

TUBE,  
1/2", PE,  
BLACK

TO NITRATE ANALYZER  
EFFLUENT WATER  
(NITRATE ANALYZER)  
SHEET 3

TP  
2

TREATED WATER  
BY OTHERS

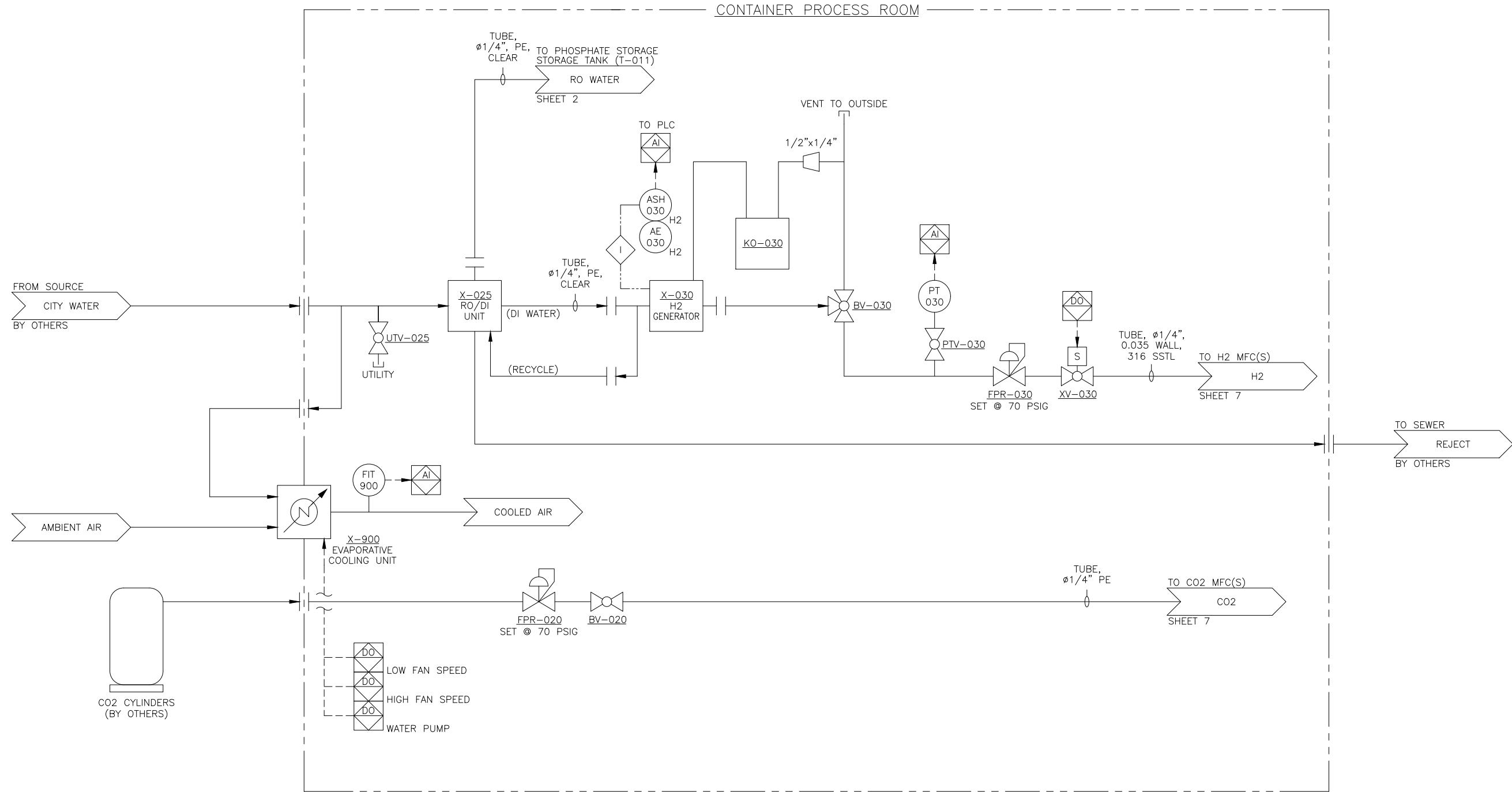
(FUTURE)

**ISSUED FOR  
CUSTOMER REVIEW**



CLIENT: TETRA TECH	
PROJECT: 03585	LOCATION: HENDERSON, NV
TITLE: P&ID EFFLUENT SYSTEM	
SIZE D	DRAWING NO. 0358530P001
SCALE: N/A	REV 4
FILE:0358530P001-R4 SHEET 5 OF 8	

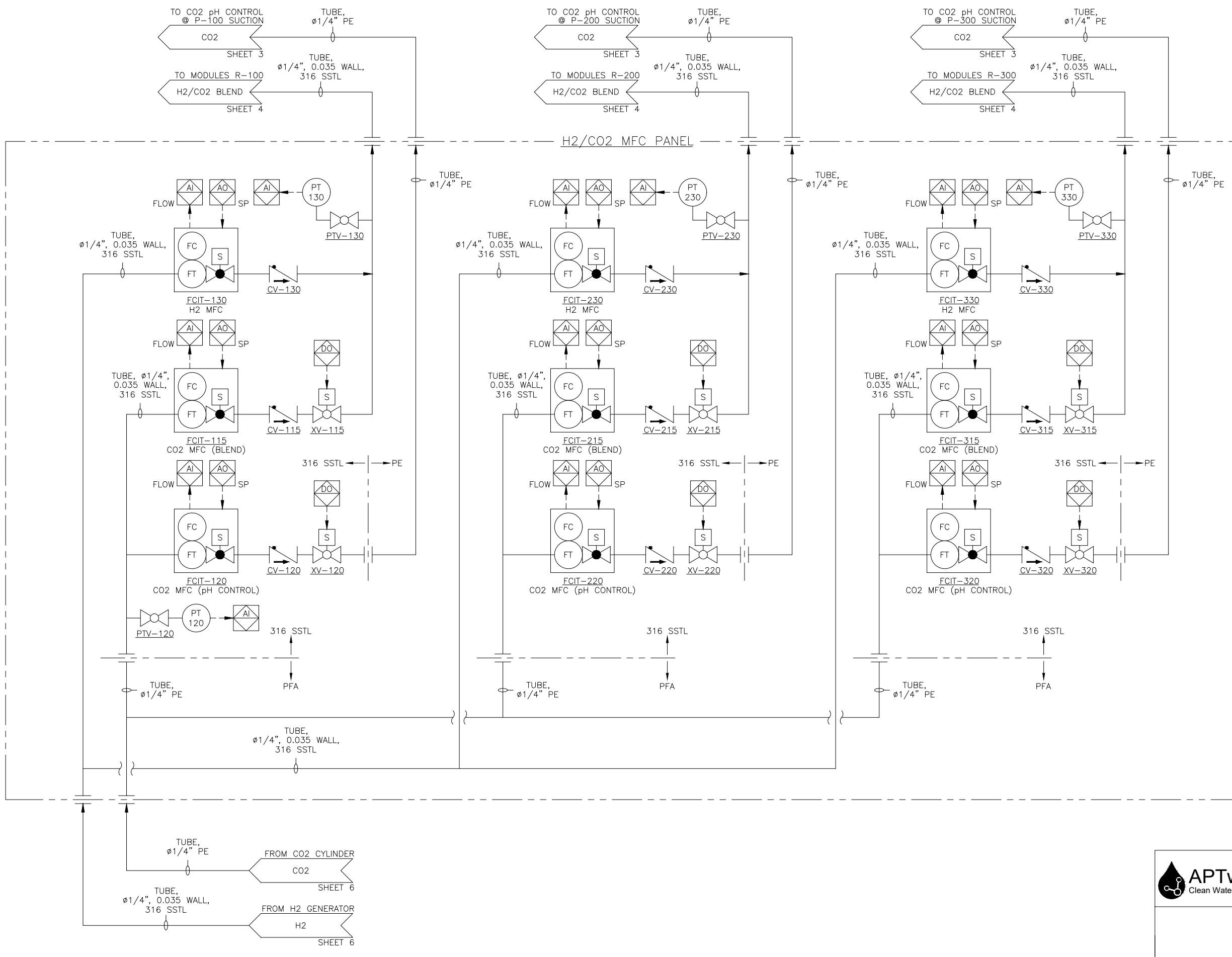
CONTAINER PROCESS ROOM



ISSUED FOR  
CUSTOMER REVIEW



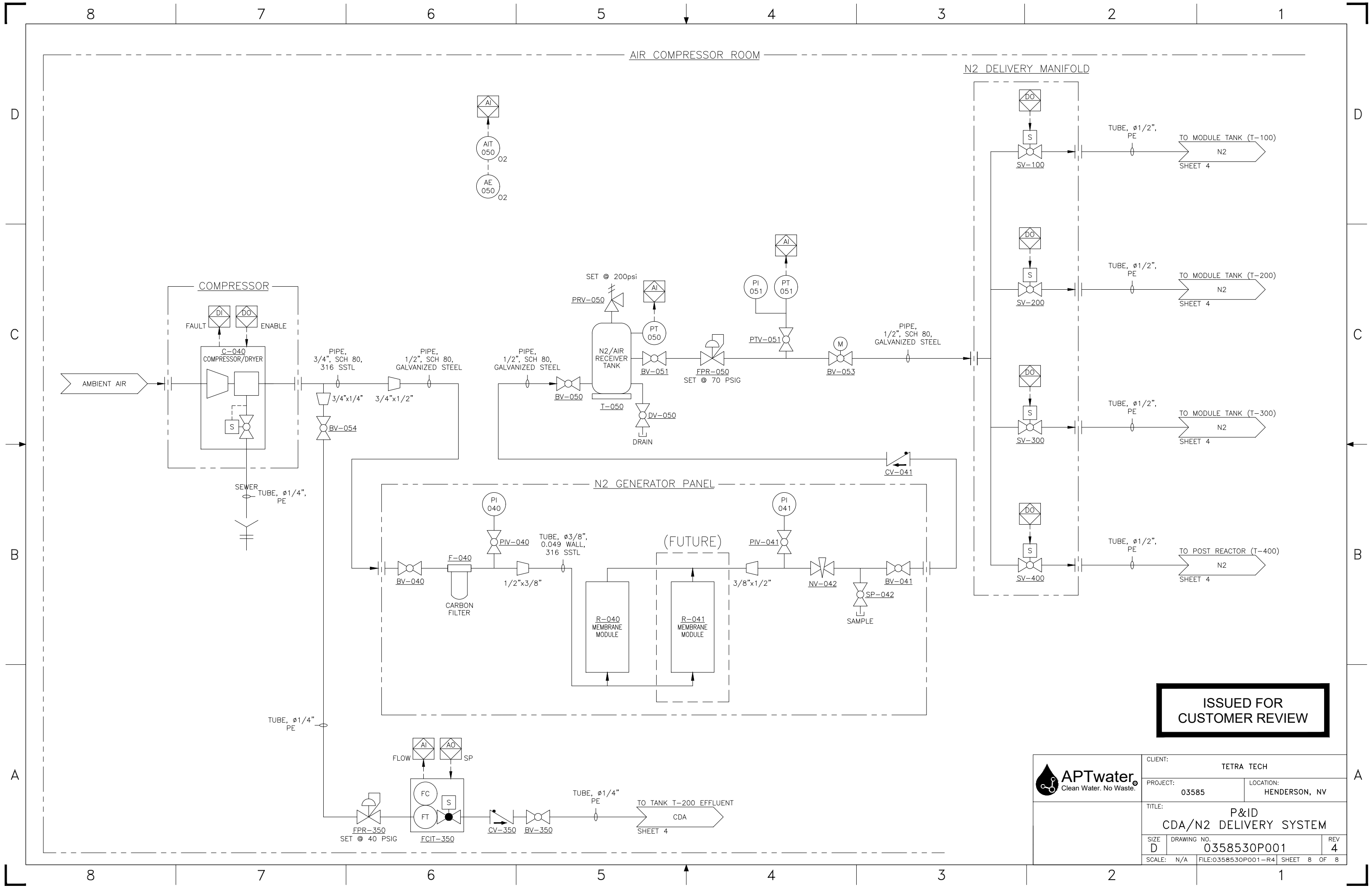
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PROJECT: 03585	LOCATION: HENDERSON, NV
TITLE: P&ID H2/CO2 SUPPLY	
SIZE D	DRAWING NO. 0358530P001
SCALE: N/A	REV 4
FILE: 0358530P001-R4	SHEET 6 OF 8



ISSUED FOR  
CUSTOMER REVIEW



CLIENT: TETRA TECH	
PROJECT: 03585	LOCATION: HENDERSON, NV
TITLE: P&ID H2/CO2 DELIVERY	
SIZE: D	DRAWING NO. 0358530P001
SCALE: N/A	REV: 4
FILE: 0358530P001-R4   SHEET 7 OF 8	

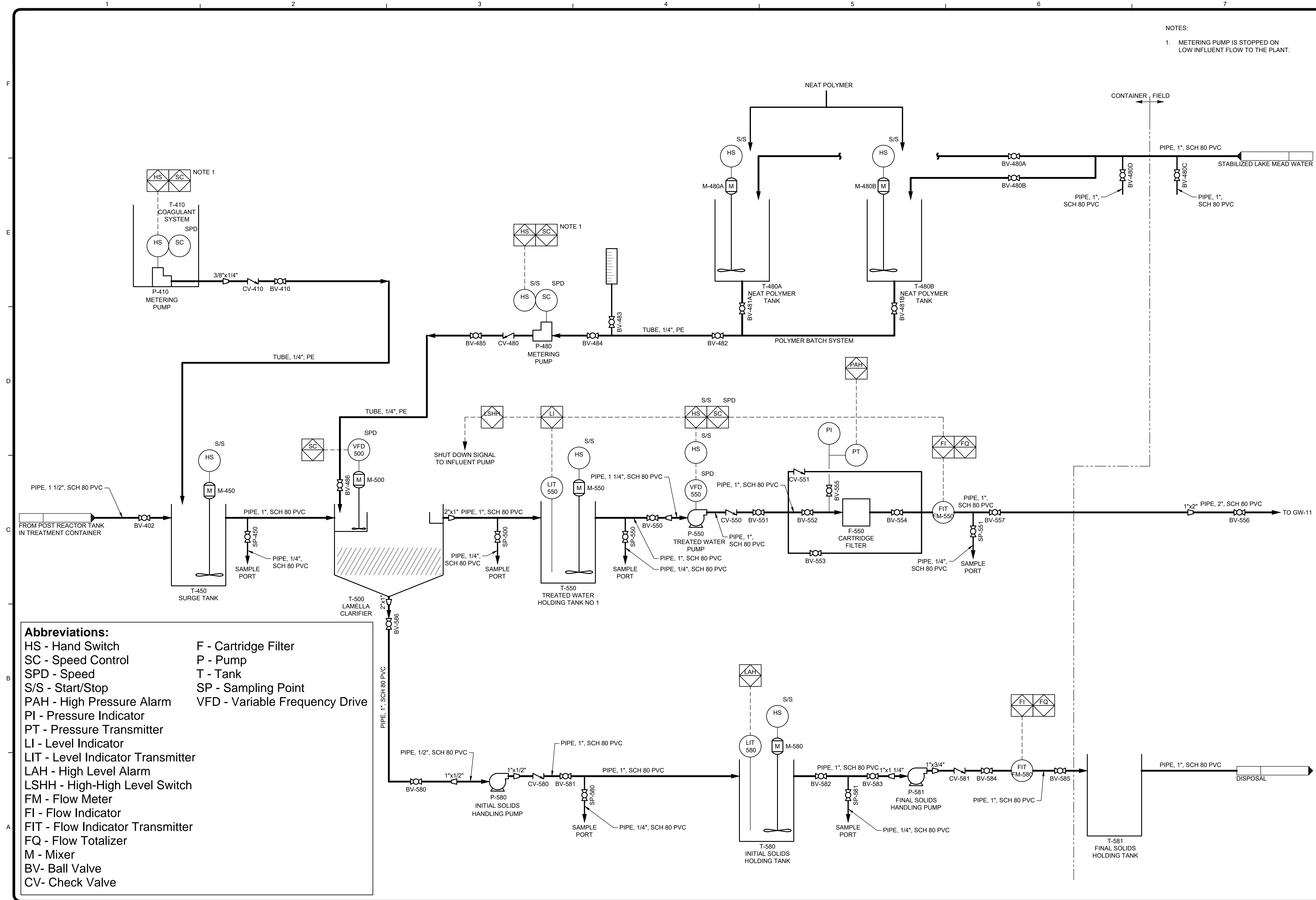


ISSUED FOR  
CUSTOMER REVIEW



CLIENT: TETRA TECH	
PROJECT: 03585	LOCATION: HENDERSON, NV
TITLE: P&ID CDA/N2 DELIVERY SYSTEM	
SIZE D	DRAWING NO. 0358530P001
SCALE: N/A	REV 4
FILE: 0358530P001-R4 SHEET 8 OF 8	

3/13/2020 10:05:53 AM - O:\PROJECTS\ATLANTA\NER01299-2002\CAD\SHEETFILES\I-101 NERT PNID\_1.DWG - KUCHIBHOTLA, RAM



NOTES:  
1. METERING PUMP IS STOPPED ON LOW INFLUENT FLOW TO THE PLANT.

**Abbreviations:**

- HS - Hand Switch
- SC - Speed Control
- SPD - Speed
- S/S - Start/Stop
- PAH - High Pressure Alarm
- PI - Pressure Indicator
- PT - Pressure Transmitter
- LI - Level Indicator
- LIT - Level Indicator Transmitter
- LAH - High Level Alarm
- LSHH - High-High Level Switch
- FM - Flow Meter
- FI - Flow Indicator
- FIT - Flow Indicator Transmitter
- FQ - Flow Totalizer
- M - Mixer
- BV - Ball Valve
- CV - Check Valve
- F - Cartridge Filter
- P - Pump
- T - Tank
- SP - Sampling Point
- VFD - Variable Frequency Drive



1899 POWERS FERRY ROAD SE, SUITE 400  
ALANTA, GA 30339  
PH: 770.850.0949 FAX: 770.850.0950

MARK	DATE	DESCRIPTION	BY

NERP PILOT PLANT  
**POST TREATMENT SYSTEM P&ID**

PROJ:	200-01299-2002
DESN:	RAK
DRWN:	RWP
CHKD:	RAK

I-101



# **Appendix B**

## **Hydrogen Generator Information**



**PROTON® PEM**

## S Series

### Hydrogen Generation Systems



MODEL	S10	S20	S40
Description	On-site hydrogen generator in an integrated, automated, site-ready enclosure Load following operation automatically adjusts output to match demand Full differential Pressure, H <sub>2</sub> over O <sub>2</sub>		
Electrolyte	Proton Exchange Membrane (PEM) – Caustic-Free		
<b>HYDROGEN PRODUCTION</b>			
Nominal Production Rate Nm <sup>3</sup> /h @ 0°C, 1 bar SCF/h @ 70°F, 1 atm SLPM @ 70°F, 1 atm kg/24 h	0.27 Nm <sup>3</sup> /h 10 SCF/h 4.8 SLPM 0.58 kg/24 h	0.53 Nm <sup>3</sup> /h 20 SCF/h 9.4 SLPM 1.14 kg/24 h	1.05 Nm <sup>3</sup> /h 40 SCF/h 18.8 SLPM 2.27 kg/24 h
Delivery Pressure – Nominal	13.8 barg (200 psig)		
Power Consumption by System per Volume of H <sub>2</sub> Gas Produced <sup>1</sup>	6.1 kWh/Nm <sup>3</sup> (16.3 kWh/100 ft <sup>3</sup> )		
Purity (Concentration of Impurities)	99.9995% [H <sub>2</sub> O < 5 ppm, -65°C (-85°F) Dew Point, N <sub>2</sub> < 2 ppm, O <sub>2</sub> < 1 ppm, all other undetectable]		
Turndown Range	0-100% net product delivery (automatic)		
Upgradeability	N/A		
<b>DI WATER REQUIREMENT</b>			
Consumption Rate at Maximum Production	0.26 L/h (0.08 gal/h)	0.47 L/h (0.13 gal/h)	0.94 L/h (0.25 gal/h)
Temperature	5-35°C (41-95°F)		
Pressure	1.5-4 barg (21.8-58 psig)		
Input Water Quality	Required: ASTM Type II Deionized Water, < 1µS/cm (> 1 MΩ-cm) Preferred: ASTM Type I Deionized Water, < 0.1 µS/cm (> 10 MΩ-cm)		
<b>HEAT LOAD AND COOLANT REQUIREMENT</b>			
Coolant	Air-cooled; ambient air		
Maximum Heat Load	1.1 kW (3,754 BTU/h)	2.2 kW (7,507 BTU/h)	4.3 kW (14,673 BTU/h)
<b>ELECTRICAL SPECIFICATIONS</b>			
Maximum Power Required within Expected System Life	3 kVA	4.5 kVA	8.5 kVA
Electrical Requirements	208-240 VAC, single phase, 50 or 60 Hz		

Model	S10	S20	S40
<b>INTERFACE CONNECTIONS – CONSULT INSTALLATION MANUAL FOR DETAILS</b>			
H <sub>2</sub> Product Port	1/4" CPI™ compression tube fitting, SS		
H <sub>2</sub> /H <sub>2</sub> O Vent Port	1/2" CPI™ compression tube fitting, SS		
O <sub>2</sub> Vent Port	3/8" FNPT		
DI Water Port	1/4" tube push-to-lock, polypropylene		
Drain Port	1/4" tube push-to-lock polypropylene		
Electrical	Connect to on-board circuit breaker		
Communications	Ethernet, 24 VDC dry contacts		
<b>CONTROL SYSTEMS</b>			
Standard Features	<ul style="list-style-type: none"> <li>Fully automated, push button start/stop</li> <li>Automatic fault detection and system depressurization</li> </ul>		<ul style="list-style-type: none"> <li>E-stop</li> <li>Remote start/stop</li> <li>On-board H<sub>2</sub> leak detection</li> <li>Remote communications</li> </ul>
Remote Shutdown	Hardwire input to safety PLC		
<b>PHYSICAL CHARACTERISTICS</b>			
Dimensions W x D x H	Product Est. Shipping	79 cm x 97 cm x 112 cm (31" x 38" x 44") 97 cm x 114 cm x 137 cm (38" x 45" x 54")	
Weight	Product Est. Shipping	209 kg (460 lbs) 289 kg (635 lbs)	
IP Rating	IP 22		
<b>ENVIRONMENTAL CONSIDERATIONS – DO NOT FREEZE</b>			
Standard Siting Location	Indoor, level ± 1°, 0-90% RH non-condensing, non-hazardous/non-classified environment		
Storage/Transport Temperature	5-60°C (41-140°F)		
Ambient Temperature Range	5-40°C (41-104°F); Optional: 5-50°C (41-122°F)	5-40°C (41-104°F)	
Altitude Range – Sea Level	1,520 m (5,000 ft)		
Ventilation	Proper ventilation must be provided from a non-hazardous area, at a rate in accordance with IEC60079-10, Zone 2 NE		
<b>SAFETY AND REGULATORY CONFORMITY</b>			
Maximum On-board H <sub>2</sub> Inventory at Full Production	0.016 Nm <sup>3</sup> 0.56 SCF 0.001 kg		
Cabinet Ventilation with Environment	NFPA 69 and EN 1127-1, Clause 6.2 Vent fan draws fresh air up to 28 Nm <sup>3</sup> /min (1,000 ft <sup>3</sup> /min)		
Noise dB(A) at 1 Meter	< 70		
Conformity	cTUVus (UL and CSA equivalent), CE (PED, Mach. Dir., EMC), ISO 22734-1		



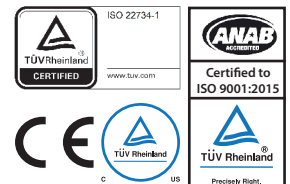
Specifications are subject to change. Please contact Nel Hydrogen for solutions to best fit your needs.

<sup>1</sup> Dependent on configuration and operating conditions.

www.nelhydrogen.com | +1.203.949.8697 | info@nelhydrogen.com

MADE IN USA

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PD-0600-0061 Rev F

# **Appendix C**

## **Start Up Checklist**

### Start Up Check List

	Bubble check all compressed gas lines with Snoop (or water with 1% dish soap added) that have been disturbed.
	Turn power on to the hydrogen generator (rotary switch on the back of the unit). Check hydrogen generator for any warnings or alarms on its HMI display. Verify hydrogen generator is in "Remote" setting per the key under the top cabinet door.
	Confirm that the LEL sensors have been calibrated within the last 90 days. The hydrogen generator will give a warning 14 days before the 90 day expiration and will not run after the 90 day expiration.
	Check Carbon Dioxide (CO <sub>2</sub> ) Pressure, needs to be >30 psi from the CO <sub>2</sub> Cylinder.
	Check Polymer Level in tank, needs to be ≥25% Full, if polymer is being used. Switch tanks or mix polymer batch if necessary.
	Check Phosphate Level, needs to be ≥5 gal. If < 5 gal. add additional phosphoric acid and dilution water to refill T-011 per recipe.
	Check Coagulant Levels which need to be ≥5 gal., if coagulant is being used. If < 5 gallon add additional coagulant and dilution water per recipe.
	Verify all drain valve in the entire system are closed.
	Verify all isolation valve are in their normal operating position.
	Verify all circuit breakers are in their normal operating position (ON)
	Check Supply Baker tanks for sufficient level, about 70 inches of water, in tank to be used.