Hydrogen-Based Gas Permeable Membrane Technology
Pilot Test Work Plan
Nevada Environmental Response Trust Site
Henderson, Nevada

PREPARED FOR

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LIST OF ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
APT	APT Water, LLC
AWF	Athens Road Well Field
COPC	contaminants of potential concern
DO	dissolved oxygen
ETI	Envirogen Technologies, Inc.
FBR	fluidized bed reactor
FS	Feasibility Study
gpm	gallon per minute
GWETS	groundwater extraction and treatment system
GWTP	groundwater treatment plant
IWF	Interceptor Well Field
MBfR	hollow-fiber membrane biofilm reactor
mg/L	milligrams per liter
NDEP	Nevada Division of Environmental Protection
NERT or Trust	Nevada Environmental Response Trust
ORP	oxidation reduction potential
PLC	programmable logic controller
ppb	part per billion
ppm	part per million
QA/QC	quality assurance/quality control
SLMW	stabilized Lake Mead water
SWF	Seep Well Field
TDS	total dissolved solids
Tetra Tech	Tetra Tech, Inc.
TSS	total suspended solids
U.S. EPA	United States Environmental Protection Agency

CERTIFICATION

Hydrogen-based Gas Permeable Membrane Technology Pilot Test Work Plan

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

not individually, but solely as Pres.

Signature: ______________, 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

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

Date: 2/15/19

CERTIFICATION

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 Hydrogen-based Gas Permeable Membrane Technology Pilot Test Work Plan.

Kyle S. Hansen

February 15, 2019

Kyle Hansen, CEM
Field Operations Manager/Geologist
Tetra Tech, Inc.

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 Hydrogen-based Gas Permeable Membrane Technology Pilot Test Work Plan to outline a pilot testing program for treatment of perchlorate present in groundwater at the NERT site. The Trust is in the process of evaluating potentially applicable groundwater treatment technologies and remedial alternatives to include as part of the Feasibility Study (FS). Rather than default to an approach that assumes that ex-situ groundwater remedial alternatives will rely solely on the Fluidized Bed Reactor (FBR) or Ion Exchange (IX) treatment technologies currently utilized by the Trust, the Trust is interested in evaluating other technologies that may be used in lieu of or in conjunction with the FBRs and/or IX, or as standalone treatment options for specific discrete areas of the plume.

Specific objectives for the study are described in Section 3.1, but the overarching goal of the pilot study is to determine if perchlorate present in extracted groundwater may be effectively treated for a lower cost per pound than conventional methods with recently developed hydrogen-based gas membrane technology. The pilot test has been designed to evaluate key design parameters to allow estimation of treatment costs for larger scale systems. It is anticipated that no additional testing beyond this pilot test will be required to evaluate this technology in the FS due to the scalable nature of biological treatment technology.

1.1 WORK PLAN ORGANIZATION

This Work Plan is organized as follows:

- **Technology Description (Section 2):** Provides an overview of the hydrogen-based gas permeable membrane technology, and a description of the pilot treatment unit operations.
- **Pilot Test Objectives and Testing Scenarios (Section 3)**: Presents the pilot test objectives and describes three contaminant of potential concern (COPC) concentration scenarios to be tested at the site.
- **Pilot Test Overview (Section 4)**: Provides a detailed overview of key steps required to design and implement the pilot test including design and implementation of pilot test unit modifications; site preparation including design and implementation of site improvements and infrastructure; pilot system installation, start-up, operations, and monitoring; and reporting.
- **Schedule (Section 5):** Provides an estimated schedule to complete project design and implementation, system operation and testing, and reporting.

2.0 TECHNOLOGY DESCRIPTION AND PILOT UNIT OVERVIEW

2.1 TECHNOLOGY DESCRIPTION

This Work Plan describes a process for pilot testing hydrogen-based gas permeable membrane technology developed by APT Water, LLC (APT). APT is a privately-held technology development company that offers treatment systems utilizing oxidation or reduction processes for treatment of contaminated water. APT has developed a patented process for the reduction of nitrate, perchlorate, chlorate and other oxidized compounds using a proprietary hollow-fiber membrane biofilm reactor (MBfR), which may have advantages over the currently used FBR process as described below.

Current FBR Process

Perchlorate and nitrate can be reduced biologically to chloride ion and nitrogen gas, respectively using heterotrophic or autotrophic bacteria. Heterotrophic bacteria use organic compounds such as methanol, ethanol, or acetic acid as electron donors while autotrophic bacteria use inorganic compounds such as hydrogen as electron donors. The FBR treatment system currently operating at the NERT facility use heterotrophic bacteria with ethanol as an electron donor for biological reduction of nitrate to nitrogen gas and chlorate and perchlorate to chloride ions. The reaction mechanisms for the reduction processes in this system can be described approximately as follows:

$$7\,NO_3^- + 3\,C_2H_5OH \rightarrow 3.5\,N_2 + 6\,CO_2 + 6\,H_2O + 6\,OH^-$$

$$3\,ClO_4^- + 2\,C_2H_5OH \rightarrow 3\,Cl^- + 4\,CO_2 + 6\,H_2O$$

The above equations indicate that theoretically 1.4 grams of ethanol is needed to reduce one gram of nitrate nitrogen to nitrogen gas and 0.31 grams of ethanol is needed to reduce one gram of perchlorate to chloride ion.

MBfR Process

In the APT's MBfR, autotrophic microorganisms use hydrogen gas (H_2) as their electron donor to reduce nitrate, perchlorate, and a range of other oxidized contaminants. The equations for reduction of NO_3^- and ClO_4^- with H_2 are:

$$2.5H_2 + NO_3^- \rightarrow 0.5N_2 + 2H_2O + OH^-$$

$$4H_2 + ClO_4^- \rightarrow Cl^- + 4H_2O$$

The above equations indicate that theoretically only 0.36 grams of hydrogen is needed to reduce one gram of nitrate nitrogen to nitrogen gas and only 0.08 grams of hydrogen is needed to reduce one gram of perchlorate to chloride ion. Therefore, the quantity of hydrogen needed to reduce perchlorate and nitrate is significantly less than ethanol.

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).

$$97NO_3^- + C_2H_5OH \rightarrow 5C_5H_7O_2N + 75CO_2 + 84H_2O + 46N_2 + 97OH^-$$

$$0.35NO_3^- + H_2 + 0.35H^+ + 0.052CO_2 \rightarrow 0.17N_2 + 1.1H_2O + 0.010C_5H_7O_2N$$

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.

Until recently, the use of hydrogen gas as an electron donor for microbial reductions was impractical, but today, hydrogen generators and gas control with membrane technology has advanced such that hydrogen gas delivery is not the hurdle it was previously. Hydrogen can be generated in real time and fed directly to the bioreactor eliminating the need to store bulk quantities of hydrogen gas. In the MBfR, pressurized hydrogen gas (H_2) diffuses through the walls of a polypropylene hollow fiber. The dense polypropylene membrane allows the pressurized gas to diffuse through the membrane without forming bubbles. Because the H_2 electron donor meets the contaminant electron acceptor as soon as it diffuses out of the wall, biofilm naturally grows on the outside wall of the membrane fibers as shown in Figure 1. The H_2 passing through the membrane is used to reduce the oxidized contaminant, which could provide better process stability compared to FBR systems that use sand or activated carbon as media for biomass growth when appropriately scaled.

To create the high surface area required for commercial applications, the APT technology bundles hollow fibers together, potted with a sealant at the ends which are later cut or trimmed to expose the tube ends. The potted bundles are incorporated into reactors that allow separation of the gas and liquid phases.

In addition to reducing perchlorate and chlorate, a potential secondary benefit of the MBfR technology is that it may also reduce hexavalent chromium (Cr^{+6}) to trivalent chromium (Cr^{+3}). Following chemical reduction in the bioreactor, the trivalent chromium could be precipitated and removed from the water stream. Evaluating the treatment efficiency of hexavalent chromium will be a secondary objective of the pilot test.

APT has demonstrated the effectiveness of this technology for perchlorate, nitrate, and chromium removal in several applications including:

- A pilot unit was used in Rancho Cordova, CA to treat 3 gallons per minute (gpm) water containing 14 parts per million (ppm) perchlorate. The perchlorate was reduced to less than 4 parts per billion (ppb);
- A pilot unit was used in Rialto, CA to treat 14 gpm water contaminated with nitrate and perchlorate; the initial concentration of perchlorate was 200 ppb, which was then reduced to less than 10 ppb;
- A pilot unit was tested in Burbank, CA to treat 3 gpm water contaminated with chromium and nitrate;
- A commercial unit was designed and used in Rancho Cucamonga, CA to treat 130 gpm water containing nitrate. This unit was the first commercial unit for APT that received regulatory approval for treating drinking water in CA; and
- A 150 gpm commercial unit was designed and began operation in La Crescenta, CA to treat water containing 8 ppm nitrate. The system began operating in the third quarter 2018.

Although all of the above listed applications have lower flow rates than those anticipated for a full-scale application at the NERT site, biological treatment systems are scalable such that larger treatment reactors may be designed to achieve the desired flow rate.

2.2 DESCRIPTION AND GENERAL OPERATION OF THE PILOT UNIT

An existing APT pilot unit will be modified for use at the NERT Site. The main unit operations of the existing pilot treatment system consist of:

1. Three reactors which contain the patented APT hollow fiber membranes;
2. Three recirculation pumps;
3. CO_2 delivery system;
4. Hydrogen monitoring and shutdown alarms;
5. Programable logic controller (PLC) based process control;

6. Data logging;
7. Remote monitoring and control; and
8. Safety alarms and shutdown.

A picture of the current, unmodified skid-mounted pilot treatment system is presented in Figure 2.

The existing pilot unit will require modifications prior to mobilizing to the NERT Site. Planned modifications to the existing pilot system will consist of adding the following components:

- A clarifier and coagulation/flocculation system to separate the excess biological solids from the treated water;
- A filtration system for residual final solids removal;
- A chemical addition system to precipitate and flocculate the trivalent chromium so it can be removed in the clarifier;
- An air supply system for sparging;
- A modified PLC reconfigured to be suitable for this application; and,
- A small hydrogen gas generation system in lieu of the hydrogen gas cylinders used in the existing pilot system.

Pilot unit modifications are further discussed in Section 4.1.

Figure 3 presents a preliminary process flow diagram for the upgraded pilot unit. The pilot unit consists of three reactors. The first reactor is used to remove oxygen and reduce nitrate to nitrogen gas. Nitrate must be reduced before chlorate or perchlorate are reduced. In the second reactor, perchlorate and chlorate are reduced to chloride. The third reactor provides additional treatment to further reduce compound concentrations to achieve discharge requirements. As the concentration of contaminants in the feed water increases, the flow through the pilot unit is reduced to maintain the optimum reaction rate in the system. It is anticipated that the flow rate of the pilot unit would range from 1 to 3 gpm depending on the nitrate, chlorate, and perchlorate influent concentrations. As the concentration of these contaminants in water changes, the flow rate through the pilot unit will be adjusted to achieve the desired removal efficiency.

Although the pilot system flow range is much smaller than the current GWETS flows, biological treatment systems are easily scalable from low flow rates to high flow rates. The pilot unit available from APT is suitable for testing at this flowrate for the perchlorate, chlorate, and nitrate concentrations expected and very suitable to provide the necessary data for full-scale design while balancing the treatability study cost. A full-scale system would be operated in this same configuration but with larger reactors to achieve the desired flow rate.

Raw feed water from various locations at the facility will be transferred to a set of feed storage tanks depending on the testing scenario (see Section 3.2). Water from the feed storage tanks is pumped to the first reactor. The overflow water from each reactor flows to the next reactor. Each reactor includes an independent flow-controlled recirculation system. A PLC is used to operate the system continuously. Water flow through the system is controlled by a flow control valve on the inlet water line. The desired flow rate is a manual input to the PLC.

A hydrogen generator will be used to produce hydrogen for the treatment process. Hydrogen is continuously metered into the hollow fibers in each reactor. The hydrogen diffuses radially outward through the hollow fibers and into the biofilm that develops on the hollow-fiber's exterior surface. The biofilm consumes the hydrogen as food using oxygen, dissolved perchlorate, chlorate, and nitrate as its source of oxygen (respiration). The hydrogen flow to each reactor is controlled by the PLC. An on-line process analyzer continuously monitors the nitrate concentrations and the hydrogen flow set point is adjusted manually based on the online nitrate analysis and the perchlorate concentrations reported from the on-site analytical laboratory (see Section 4.4). Hydrogen production is adjusted automatically by maintaining a back pressure on the hydrogen supply produced by the hydrogen generator system. Hydrogen is flammable but lighter than air and can be handled very safely by pairing the rate of generation with the rate of use in the bioreactor and providing venting and monitoring of the areas where hydrogen is generated and used. As indicated earlier generating hydrogen at the site will be very safe since hydrogen will only be generated when it is needed and used immediately. Any excess would be emitted to the atmosphere without being trapped in the system; thus mitigating any measurable explosion potential.

As the hydrogen and contaminants in solution are consumed, the pH of the water may increase. A continuous, on-line process analyzer will monitor pH, and carbon dioxide is added to control the pH around a set point.

Biofilm growth is normal in any biological treatment system. One expected advantage of the MBfR is a lower rate of biofilm growth compared to the FBR. The rate of biofilm growth will be monitored during the pilot test. Specifically, as the biofilm grows, the pressure drop across the reactors will increase. Compressed air will be periodically sparged into the reactor to create a mixed phase flow through the reactor with the intent of removing the excess bio-growth and restoring the system to its initial pressure drop conditions. The sloughed biofilm will be collected, measured and evaluated as part of this study.

Mixed liquor (treated water and biological solids) leaving the third reactor will be discharged into a surge tank. A potential secondary benefit of the MBfR process is that hexavalent chromium is expected to be reduced to trivalent chromium in the three reactors. Samples of the water leaving the reactors will be analyzed to determine the amount of hexavalent chromium reduction occurring in the reactors. If the data indicate that hexavalent chromium still exists in the discharge stream from the reactors, a coagulant, consisting of salts of iron or aluminum, will be added to the mixed liquor in the surge tank to reduce any remaining water soluble hexavalent chromium that is present in the treated water to insoluble trivalent chromium, similar to the process that is currently used in the Groundwater Treatment Plant (GWTP). A polymer will then be added to the mixed liquor leaving the surge tank to flocculate the solids and help separate any biological solids and precipitated chromium from the treated water in an inclined plate clarifier. Clarified water leaving the clarifier will be pumped through a cartridge filter and discharged into an effluent water storage tank. Biological sludge from the bottom of the clarifier will be pumped into a biomass/solids accumulation tank.

Treated water from the effluent storage tank is expected to contain very low concentrations of perchlorate, chlorate, and nitrate, therefore, it will be periodically discharged to the GW-11 Pond for subsequent treatment in the FBR plant. Plans to direct the treated water to the GW-11 pond have been discussed with Envirogen Technologies Incorporated (ETI), the Groundwater Extraction and Treatment System (GWETS) operator, and they have no concerns with processing this water through the FBRs, nor do they have any concerns regarding GWETS compliance with its NDPES permit as a result of processing this treated water. It is estimated that the system will generate less than 4 pounds of excess biological solids per day. The small amount of solids from the solids storage tank will be periodically disposed off-site.

3.0 PILOT TEST OBJECTIVES AND TESTING SCENARIOS

3.1 PILOT TEST OBJECTIVES

The objectives of the pilot demonstration program are:

1. Demonstrate the ability of the APT MBfR technology to reduce various influent concentrations of perchlorate to less than 18 ppb, the current perchlorate discharge limit for the FBR system, and evaluate its ability to achieve even lower concentrations;
2. Demonstrate that the hydrogen system generates less excess biomass compared to a system using ethanol as the electron donor;
3. Demonstrate that the cost of hydrogen as electron donor is less than the cost of ethanol;
4. Develop strategies for scaling up the pilot system reactors under field conditions at NERT;
5. Demonstrate stable and sustainable treatment system operation and performance, including evaluation of the effectiveness of the on-site hydrogen generator;
6. Evaluate the staffing and O&M needs for the full-scale system; and,
7. Develop the following key design and operating information for sizing and costing a full-scale treatment system:
   - Collect data on H_2 and CO_2 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 FS.

In addition to the objectives listed above, the test will also evaluate if a potential secondary benefit of the APT System is that the hexavalent chromium (Cr^{6+}) can be effectively reduced to trivalent chromium (Cr^{+3}) in the reactors and if the trivalent chromium can be effectively removed from water using flocculation and clarification downstream of the reactors.

As indicated in Section 1.0, this system is not necessarily being evaluated as a replacement to the existing FBR system but rather to gather data that can be used to evaluate in the FS if this technology could be used as a cost-effective treatment technology at the NERT site in lieu of or in tandem with other technologies such as FBRs, IX, or other in-situ technologies as appropriate.

3.2 PILOT TESTING SCENARIOS

COPCs in groundwater at the NERT site include perchlorate, chlorate, and hexavalent chromium. In addition, the groundwater contains high concentration of total dissolved solids (TDS) that must be considered in biological treatment approaches. The pilot program will test water with a range of contaminant concentrations to evaluate the applicability of the technology under various on-site and off-site conditions and maximize the relevant data collected from the pilot project for use in the FS. The following three testing scenarios will be evaluated.

1. Test Scenario #1: Existing FBR Influent: This scenario will test water representative of the existing FBR groundwater influent stream. Historical data indicate that the perchlorate concentration in the water used for this test would contain approximately 72 mg/L perchlorate and 0.08 mg/L chromium. Water for the pilot test will be obtained from the FBR equalization tank, which currently receives water from the Athens Road Well Field (AWF), the Interceptor Well Field (IWF) via the GWTP, and the portion of the Seep Well Field (SWF) that is not treated by the ion exchange system. This test will use a representative blend of water from the three well fields but will exclude the high concentration water from the AP-5 solids washing tanks; the AP-5 wash water enters the FBRs at a separate location and does not get routed to the FBR equalization tank. 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 and the SWF no longer provides water to the GWETS. Water representative of a blend from the AWF and the IWF after chromium pre-treatment via the GWTP will be tested. The concentration of perchlorate and chromium in the water used for this test scenario is estimated to be approximately, 135 mg/L, and 0.17 mg/L, respectively. 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 concentration 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 potential secondary benefit of the APT system's ability to effectively treat groundwater for perchlorate and chromium removal simultaneously without pretreating the water to remove chromium first. The concentrations of perchlorate and chromium in the water used in this test scenario is estimated to be 135 mg/L, and 0.9 mg/L, respectively. Hexavalent chromium will be reduced to trivalent chromium in the reactors, and water insoluble chromium will subsequently be removed from the groundwater in the clarification step. The treatment influent water would be identical to Test Scenario #2, except the water from the GWTP (a combination of the IWF and AP Area Extraction Wells) is not pretreated for chromium removal, and the chromium concentrations are expected to be much higher than either Test Scenario #1 or #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 NERT site. The option to add other test scenarios will be discussed with the Trust and NDEP as the tests progress.

Data from the August 2018 GWETS operational metrics was used to estimate perchlorate and chromium characteristics for water to be tested in the three scenarios (***Table 1***). Understanding the chlorate and nitrate concentrations present in the water is also critical; however, chlorate and nitrate data is not currently available for all the test scenario water sources. Based on the data available, chlorate concentrations are expected to be higher than the estimated perchlorate concentrations presented in ***Table 1***. As noted previously, chromium removal is a potential secondary benefit, but not a primary objective of the pilot test. Samples will be collected and analyzed to determine whether hexavalent chromium is reduced to trivalent chromium in the reactors. If the reduction is complete, then adding a polymer/flocculent to the clarifier would remove the precipitated trivalent chromium. If reduction does not occur or is not complete, a coagulant will be added to the water leaving the reactors to chemically reduce hexavalent chromium to trivalent chromium before the clarifier.

Table 1 Estimated Water Characteristics for Test Scenarios

Test Scenario	Perchlorate (mg/L)	Total Chromium (mg/L)
Test Scenario #1	72	0.08
Test Scenario #2	135	0.17
Test Scenario #3	135	0.9

Table 1 is intended to illustrate the potential COPC test concentrations and differences between the concentrations tested in each scenario. The actual COPC concentrations tested in the pilot system may vary depending on the GWETs operations and fluctuations in groundwater concentrations over the duration of the pilot study. During the design phase, samples from each of the test scenario feed water sources, described in Section 3.2.1, will be sampled and analyzed to ensure the feed water characteristics are adequately understood for the system design and operations. The feed water will be analyzed to determine perchlorate, chlorate, nitrate, total chromium, and hexavalent chromium concentrations, as well as other parameters such as TDS and total suspended solids (TSS) that will assist with characterization of the feed water and planning design and operation of the pilot study.

3.2.1 Obtaining Water for Testing

Water trucks have been selected as the most cost-effective means to transfer water from various sources to the feed storage tank at the pilot system to support each test scenario. Based on a site walk-through and discussions with ETI, the GWETS operator, water required to support the three test scenarios is readily accessible and the design and installation of piping, valves, or access ports will not be required.

Test Scenario #1 will use water obtained from the equalization tanks that currently supply groundwater to the FBR system. A flexible hose will be connected to an existing connection at the bottom of the equalization tank and water will be transferred from the equalization tank to the water truck.

Water for Test Scenario #2 will be a blend of water from the AWF and IWF wells fields after IWF water has been pretreated for chromium removal via the GWTP. Based on the average flows from these well fields, the blend will consist of approximately 11% IWF and 89% AWF water. To achieve the correct blend of water, samples of the blend will be collected and analyzed for perchlorate to ensure that the feed water to the pilot unit has consistent characteristics. Water from the AWF well field will be collected from the sump at the well field. A sump pump connected to a flexible hose will be used to pump water from the AWF sump to the water transfer truck or a vacuum pump installed on the water truck will be used to pull water from the AWF sump to the water transfer truck. The IWF portion of water for Test Scenario #2 will be obtained from a connection at the discharge of the effluent pumps from the GWTP.

Water for Test Scenario #3 will be similar to the water used for Test Scenario #2 except that the IWF fraction will be collected from the IWF feed water storage in the GWTP equalization tank before treatment for removal of chromium. There are two options for collecting untreated IWF water for blending with AWF water for Test Scenario #3. The first option is to insert a flexible hose into the equalization tank via the opening at the top and vacuum water from the tank using a vacuum pump from the water transfer truck. The second option is to pump raw IWF water from a connection at the bottom of the equalization tank to the water transfer truck.

4.0 PILOT TEST OVERVIEW

Implementation of the Pilot Study will include the following key steps:

- Design and implement modifications to the existing pilot unit;
- Design and implement on-site components;
- Installation and start-up of the pilot unit;
- Operation and testing of the pilot unit under each test scenario;
- System decommissioning; and,
- Reporting.

4.1 PILOT UNIT MODIFICATIONS

The existing pilot unit will require some modifications prior to shipping the unit to the site for installation. The existing pilot system consists of only the three reactors and associated controls. The system does not have a clarifier for solids and liquid separation. Tetra Tech will work with APT to specify a clarification system such that the excess biological solids can be separated from treated water and the sludge yield can be measured. The system will also be upgraded to add feed equipment for the coagulants and flocculants. Due to the short-term nature of this pilot test, rental components will be used when possible if deemed to be cost effective.

Specific modifications will include:

- Additional sampling ports to allow comprehensive sampling at different treatment stages;
- Solids handling and separation capabilities consisting of a mixed liquor surge tank, a clarifier where treated water is separated from biological solids, and a solids/biomass storage tank;
- A coagulation/flocculation system to improve excess biological solids and chromium removal consisting of metering pumps to deliver coagulant to the water leaving the reactor and a polymer make up system with metering pumps to deliver diluted polymer solution to the clarifier; and,
- A cartridge filter to remove residual solids contained in the treated water leaving the inclined plate clarifier.

The modified APT pilot unit will consist of two separate skids. The first skid will consist of the existing reactors and instrumentation. The second skid will consist of a surge tank where, if necessary, coagulant can be added to the mixed liquor, the clarifier, the cartridge filter, and a small hydrogen generation system. As noted previously, a small hydrogen generator is safer than bulk hydrogen storage in gas cylinders, given the expected low hydrogen consumption rates. Power use by the hydrogen generator during the pilot test is expected to be similar to a small refrigerator. All modifications to the APT pilot unit will be completed at APT's facilities. Upon completion, the two skids of the modified pilot unit will be shipped to the NERT Site.

During the project design phase, the final pilot unit modifications may be adjusted. A system operations manual will be prepared as part of the final pilot unit upgrades. The operations manual will be adjusted and finalized as necessary during the pilot unit installation and start-up process.

4.2 SITE PREPARATION

4.2.1 Pilot Unit Location

The following factors have been considered in identifying the best location for the pilot system:

- The pilot system should be close to the source of water for the three test scenarios.

- The pilot system should be located close to the GW-11 Pond to minimize logistics associated with discharge of the treated water to GW-11.
- The location must be reasonably flat to minimize site grading and preparation required to install the two skids from the pilot system.
- Power must be available close by to minimize costs of extending power to the system.

Based on a site reconnaissance and evaluation of these factors, the pilot unit will be located south of the GW-11 Pond, east of the AP-5 storage tanks, west of the FBR system, and north of the existing road (Figure 4). This area is reasonably flat, close to GW-11, and power is available just south of the location from the panel that provides power to the AP-5 storage tank area. The APT system will be located and configured to ensure there is adequate space for the GWETS operator to access the western end of the FBRs for maintenance if necessary. The power supply will be reviewed and finalized during the design phase to confirm there is adequate available power for the AP-5 tank mixers and planned solids dewatering operations, and for the additional relatively small requirements of the APT pilot unit.

4.2.2 Site Improvements/Infrastructure

Site preparation activities will include design and implementation of required infrastructure and site improvements necessary for the safe installation and operation of the pilot study equipment. The pilot testing program will require design and installation of:

- Site grading, if necessary, to create an appropriate area for the pilot testing system;
- Secondary containment for the pilot unit and associated temporary supply and accumulation tanks;
- Electrical power to operate the pilot unit;
- Temporary tanks (i.e. frac tanks) for feed water storage and treated water accumulation;
- Solids storage areas; and,
- If necessary, access for consumable delivery and storage (e.g. coagulant, polymer).

As noted above, the area selected for the pilot testing unit is relatively flat and site grading may not be required. If site grading is determined to be necessary during system design, site grading plans will be prepared as necessary to support permit applications. The need for structural improvements (i.e. compacted aggregate base and slabs) will also be evaluated as necessary to support the pilot testing unit and ancillary temporary tanks.

A temporary secondary containment system for the pilot unit, temporary feed water tanks, treated water accumulation tank, and solids accumulation tank will be designed and installed. The secondary containment berm will be constructed on-site and likely will consist of a concrete F-rail system (e.g. precast concrete highway barriers) with a 60-mil liner with padding.

Raw feed water from various GWETS source locations (dependent on the scenario) will be transferred via tanker truck to a set of feed storage tanks in lieu of connecting the pilot system to the GWETS source waters via piping. Two temporary tanks will be used as feed water storage tanks. The raw water supply system will be designed such that water can be supplied from either tank when necessary. Therefore, when one tank is being used to feed the pilot unit the other tank can be filled for the next batch of operation. This approach will ensure continuous operation for the pilot unit. Perchlorate concentrations in the feed tanks will be monitored to ensure that the feed water characteristics are consistent to within 10% of the desired characteristics for each test scenario.

The feed water storage tank approach allows maximum flexibility in providing various mixes of feed water concentrations for testing. In addition, if desired, the feed water concentration can be modified during the testing, or additional scenarios can be developed and tested.

Likewise, the treated water will be accumulated in an effluent storage tank. The treated water will be either transported to the GW-11 Pond via tanker truck or discharged to GW-11 using a small pump and temporary piping. Both options will be evaluated in the design phase.

Solids from the clarifier will be pumped into a small holding tank and periodically transported off-site for disposal. The pilot system will generate very small quantities of solids and it is not anticipated that solids dewatering operations will be needed for the tests.

4.2.3 Pilot Unit Installation and Start-up

When the pilot unit modifications are complete and the appropriate site infrastructure is in place, the two pilot unit skids will be shipped to the NERT site and installed.

System start-up will include testing all piping and connections (water, air, CO_2, and H_2 lines) to ensure there are no leaks, testing all electrical connections, testing pumps to ensure proper operation, and testing the PLC to ensure all systems are operating appropriately. Water for Test Scenario #1 will then be added to system to begin establishing biological growth and acclimation. Biomass from the existing FBR unit will be used as seed sludge for the system to expedite the startup process.

During startup, frequent samples of raw and treated water will be collected and analyzed to confirm feed water concentrations and system performance. Based on the frequency of the samples and the need for very fast analysis to provide information for operational adjustments, the system operator will rely on field measurements and the in-house laboratory for much of the data required for routine operations (see Section 4.4). Any analysis provided by the off-site certified laboratory will be requested with the fastest possible turnaround to support project needs during system start-up.

Final installation and start-up are anticipated to require up to a month to ensure all systems are operable, all controls are in place, and to train a part-time operator for basic trouble-shooting and daily sampling tasks. Technical staff from APT will be available as necessary at the site to assist with pilot system installation and start-up. When all systems are tested and confirmed operational and the system operations have stabilized, pilot study operations and completion of the three test scenarios will commence.

4.3 PILOT STUDY OPERATIONS

The pilot study operations will include the following activities:

- Daily inspections to monitor for leaks or operational issues
- Periodic sampling (see Section 4.4)
- Refilling the feed water storage tanks.
- Emptying the treated water and solids accumulation tanks.

The pilot treatment system will be designed to operate with daily two hour operator oversight for system inspection, sampling, and adjustment. However higher levels of operator involvement will be required at the beginning of each test scenario. In addition, the feed tanks will have to be filled and the treated water and solids accumulation tanks periodically emptied. Based on an assumed flow rate of 3 gpm, and the use of 20,000-gallon frac tanks for the feed water tank, each feed water tank will require refilling approximately every four days. Similarly, the treated water accumulation tank will be emptied approximately every four days. During the design phase, the use of additional tanks to reduce the frequency of refilling and emptying operations will be evaluated.

Pilot study operations for each test scenario are anticipated to require approximately three months to complete, a total of nine months of operation. Biomass from the existing FBR system will be used to acclimate bacteria to the pilot unit. Two to four weeks is allocated for the system to reach steady state under each test scenario. Steady state is achieved when the concentrations of contaminants in the treated water stabilize and do not fluctuate by more than 10%. Once steady state is achieved samples will be collected and analyzed for key parameters for four weeks. During the last four weeks, effect of various parameter on the stability of the system may be evaluated. For example, the effect of sudden changes in the feed water characteristics on system performance can be evaluated. The last four weeks may also be used to recover the system from shock loadings or mechanical breakdowns. The duration of any test scenario may be shortened if data indicates that the objectives have been successfully met. The transition process between test scenarios may include implementing additional operational or minor equipment modifications to take advantage of lessons learned during the previous test scenario operations. The transition period may also include acclimating the biological mass to the new test scenario concentrations. This would be accomplished by gradually changing the feed water mix to ramp up to appropriate concentrations for the next test scenario.

4.4 SAMPLING AND ANALYTICAL PROGRAM

A sampling and analytical program will be implemented to gather data to evaluate the pilot system's performance. The analytical program will consist of a combination of on-site laboratory and off-site third party certified analytical laboratory testing. Analytical testing will include operational samples intended to monitor and adjust the pilot unit system operations, and performance samples intended to measure the systems performance relative to the objectives established in Section 3.1.

- The system operator will rely on field measurements and analytical data provided by the on-site laboratory for the data required for system operations and adjustments as this data can be available rapidly.
- Data used to evaluate the overall performance of the hydrogen-based gas permeable membrane technology pilot testing relative to the project objectives will be submitted to a certified analytical laboratory.

The following subsections outline the basic analytical program. A detailed sampling and analysis program will be developed as part of the system design.

4.4.1 On-Site Laboratory

An on-site laboratory was established for the Southern Nevada Water Authority (SNWA) Weir Dewatering Treatment Plant project and is currently set-up to analyze water samples for perchlorate and nitrate. The laboratory was operated for approximately nine months during operation of the treatment plant. Quality assurance samples were routinely collected and analyzed by Test America, a third-party laboratory which confirmed the accuracy of the on-site laboratory analyses. This in-house analytical testing has been demonstrated to be accurate, cost effective, and is best suited to provide the quick analytical results and real-time feedback required to adjust operational parameters for test scenarios as necessary, particularly during the start-up and transitional phases when fast turnaround data is required for system operational checks and adjustments. The on-site laboratory will also be used to confirm perchlorate concentrations in the feed water storage tanks each time replacement water is added to the tanks.

Samples will be collected and analyzed at the in-house lab daily during project start-up and transition between test scenarios until it is confirmed that the system is running properly, at which time the sampling program will transition to the operational phase. Additional analysis beyond the current capabilities of the on-site lab (i.e. chlorate, nitrite, total suspended solids) will be performed by an outside certified laboratory on a rush-turnaround basis. During the final system design, expansion of the on-site laboratory's capabilities to include other operational parameters will be evaluated.

The on-site laboratory is not certified, and data from the on-site laboratory will not be validated. Confirmation samples will periodically be submitted to a certified outside laboratory to confirm the accuracy of the on-site laboratory analytical results. Water treated during the pilot test will be routed to the GW-11 pond for subsequent treatment in the GWETS FBR system. GWETS operations include a separate and independent analytical testing program to demonstrate compliance with the GWETS National Pollutant Discharge Elimination System permit.

4.4.2 Off-site Certified Laboratory

Samples used to evaluate the objectives outlined in Section 3.1 will be collected during the system operations phase and analyzed at a certified analytical laboratory. The preliminary sampling and analytical program is summarized in ***Table 2*** for the operation period. The sampling and analytical plan will be finalized during the project design phase.

Samples will be collected from several locations of the pilot unit:

- Influent samples will be collected from the water feed tanks or, depending on final design and pilot study modifications, from a sample port installed between the feed tanks and reactor 1.
- Reactor samples will be collected from sample ports installed after each reactor to measure parameter concentrations following treatment in each reactor.
- The effluent samples will be collected from a sample port at the discharge line of the cartridge filter.

During the operational period, samples will continue to be analyzed in the on-site laboratory to provide data necessary for operational adjustments.

Table 2 Operational Period Sampling and Analysis Program

Parameter	Sample Location and Analysis/Week				
	Influent	Reactor 1	Reactor 2	Reactor 3	Effluent
Certified Analytical Lab Analysis					
Perchlorate	1	1	1	1	1
Chlorate	1	1	1	1	1
Nitrate	1	1	1	1	1
Hexavalent Chromium	1	NR	NR	1	1
Total Chromium	1	NR	NR	1	1
TSS	1	1	1	3[A]	3
TDS	1	NR	NR	NR	1

Notes: NR – No sample required.
A. These TSS samples will be collected at the surge tank, not the reactor 3 sample port.

4.4.3 Field Measurements

Data for some parameters will be collected with portable field instruments, or instrumentation built into the pilot unit. Field measurement data may include nitrate, turbidity, pH, dissolved oxygen (DO), oxidation reduction potential (ORP), and temperature. Field measurement data will be utilized for pilot unit system operations and adjustments. The potential use of field test kits for obtaining quick system operations monitoring data will be evaluated during preparation of the final sampling and analysis plan.

4.4.4 Data Validation

Analytical data received from the certified off-site laboratory that are intended to be used to evaluate the project objectives outlined in Section 3.1 will be reviewed for quality and usability and will be validated at Level 2B in accordance with Nevada Division of Environmental Protection's Data Verification and Validation Requirements for groundwater. 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.

Analytical data from the on-site laboratory and the certified off-site laboratory that are intended for use during system start-up and transitional phase, and for managing the day-to-day performance of the treatment system will not be validated.

4.5 PILOT UNIT DECOMMISSIONING

Upon completion of all pilot study operations and testing, the unit will be decommissioned. The unit will be flushed with stabilized Lake Mead water (SLMW), disconnected from all power and water supplies, loaded, and shipped back to APT. All water conveyance lines and electrical lines will be removed. Temporary tanks will be cleaned and returned to the equipment suppliers. Any semi-permanent at-grade improvements (e.g. concrete pads) will be left in place unless they pose a safety risk or an impediment to the completion of other site activities.

4.6 REPORTING

Monthly updates will be prepared for the duration of the project and provided to the Trust and the Nevada Division of Environmental Protection (NDEP). A summary of the test results will be provided after completion of each test scenario. At the conclusion of the pilot study operations, a final Hydrogen-based Gas Permeable Membrane Technology Pilot Study Report will be prepared. This report will include:

- Description of the final system design and operation;
- Summary of all pilot-study field activities including instrumentation measurement records;
- Summary of on-site laboratory results;
- Summary of off-site laboratory results including a data validation summary report;
- Evaluation of the pilot unit’s performance relative to the project objectives, which include evaluation of the budgetary construction and operating costs for a typical MBfR treatment system.

5.0 SCHEDULE

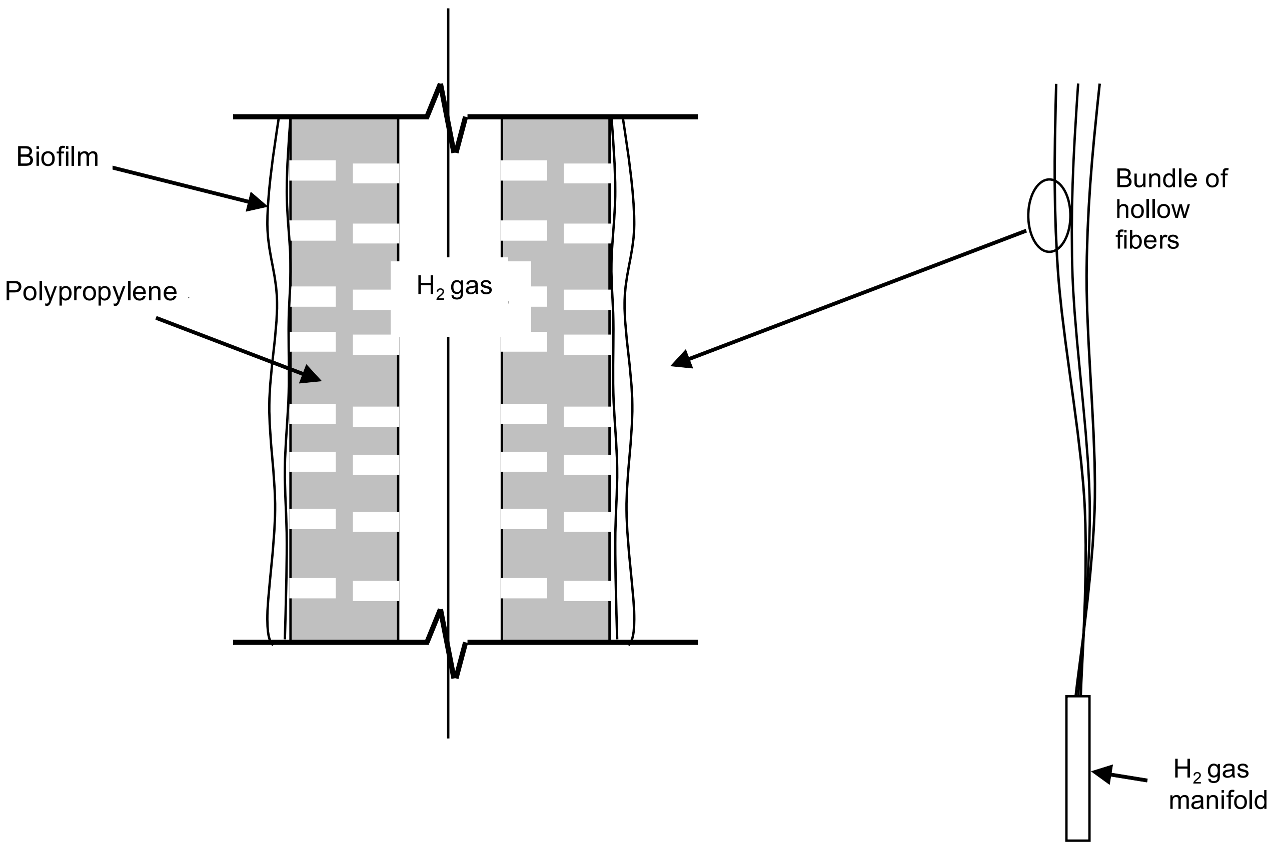
Table 3 provides an estimated schedule for completion of the pilot study design, construction, operations and reporting.

Table 3 Pilot Testing Schedule

Task	Description	Schedule[1]
Detailed Design	• Finalize selection of existing pilot unit modifications • Complete mechanical, electrical and structural designs for the pilot plant and site improvements • Evaluate expansion of on-site lab capabilities • Finalize water and solids management strategies • Finalize sampling and analytical program • Finalize data management plan • Identify applicable permits, if any, and initiate permit applications	Mar- May 2019
Construction	***Pilot Unit*** • Complete pilot modifications ***Site Improvements*** • Obtain permits if necessary • Grading and structural improvements, if necessary • Bring power to treatment system • Install secondary containment • Install temporary tanks and piping	May- Jul 2019
Install and Startup	• Finalize operational manual • Ship pilot unit to site and complete final installation and connections • Train part-time operator • Start-up and troubleshoot system	Jul- Aug 2019
Operation	• Daily inspections • Refill water supply tanks • Empty treated water and solids accumulation tanks • Implement sampling and analysis plan • Complete three test scenarios.	Test #1: • Aug – Oct 2019 Test #2: • Nov 2019 – Jan 2020 Test #3: • Feb – Apr 2020
Decommissioning	• Disassemble pilot unit and remove from site • Clean and remove all temporary tanks • Decommission electrical and mechanical components	May 2020
Reporting	• Complete reporting	May – Aug 2020

Notes: [1]The dates indicated on Table 3 are based on Work Plan and budget approval and notice to proceed by 2/28/19.

Figures



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NEVADA ENVIRONMENTAL RESPONSE TRUST

HYDROGEN-BASED GAS PERMEABLE MEMBRANE PILOT STUDY
HENDERSON, NEVADA

APT HOLLOW-FIBER MEMBRANE BIOFILM REACTOR
HOLLOW-FIBER CONFIGURATION

Project No.: 117-7502018-M26
Date: OCTOBER 16, 2018
Designed By: AAM

Figure No.
1

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NEVADA ENVIRONMENTAL RESPONSE TRUST

HYDROGEN-BASED GAS PERMEABLE MEMBRANE PILOT STUDY
HENDERSON, NEVADA

EXISTING PILOT TREATMENT SYSTEM

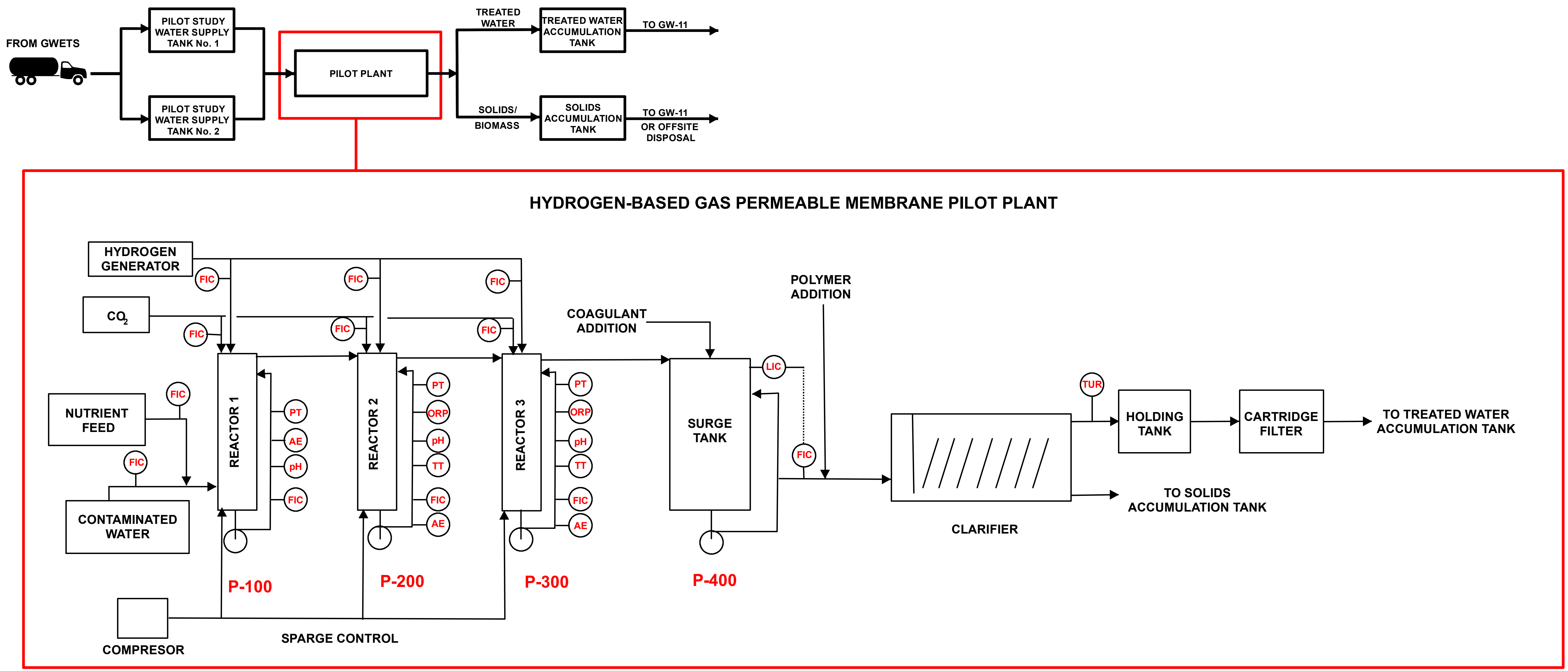
Project No.: 117-7502018-M26

Date: OCTOBER 16, 2018

Designed By: AAM

Figure No.

2



Notes:
1. Process flow will be finalized during design.
2. Preliminary figure does not show all instrumentation.
3. AE = Nitrate
FIC = Flow
LIC = Level Control
ORP = Oxidation Reduction Potential
PT = Pressure
TT = Temperature
TUR = Turbidity

C:\USERS\AMY.WOODS\DESKTOP\FIGURE 3.MXD

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NEVADA ENVIRONMENTAL RESPONSE TRUST

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HENDERSON, NEVADA

PRELIMINARY CONCEPTUAL PILOT PLANT PROCESS FLOW

Project No.: 117-7502018-M26
Date: OCTOBER 16, 2018
Designed By: AAM
Figure No.
3

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Note:
The location and area for the APT Pilot Plant are approximate and not representative of the area required for the Pilot Plant.

Imagery Source: Esri World Map, May 2017.

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NEVADA ENVIRONMENTAL RESPONSE TRUST

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HENDERSON, NEVADA

PLANNED PILOT PLANT LOCATION

Project No.: 117-7502018-M26
Date: OCTOBER 16, 2018
Designed By: AAM
Figure No.
4