GUIDANCE ON PRODUCED WATER TREATMENT RESEARCH, DEVELOPMENT, AND DEMONSTRATION TESTING AND EVALUATION

NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM
NEW MEXICO STATE UNIVERSITY

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PREFACE

This guidance document was prepared by the New Mexico Produced Water Research Consortium (Consortium) to support of the New Mexico Environment Department by providing a framework to be used by the Consortium to conduct project planning, testing, and evaluation efforts of pilot or field-scale produced water treatment technologies for fit-for-purpose applications outside the oil and gas sector. The guidance is based on other pilot-testing and evaluation programs conducted by organizations such as the Environmental Protection Agency, the Department of Energy, and federal agencies comprising the Federal Remediation Technologies Roundtable to assess the operational cost and performance of water and waste treatment technologies and their ability to meet state and federal standards for public and environmental protection and health and safety.

The framework provides step-by-step guidance to technology developers on how the Consortium will:

- identify technologies for early-level research and development and laboratory and bench-scale testing and performance analysis; and
- for more mature technologies, establish pilot-scale demonstration testing and analysis efforts that would include;
    - project planning and approval requirements,
    - demonstration testing and monitoring requirements,
    - collection of technology operational cost and performance data, and
    - evaluation of human environmental risk and toxicology to verify the safety of the effectiveness of the treatment technology application.

Federal environmental technology evaluation programs that have utilized detailed pilot-scale, field demonstration testing and cost and performance evaluation approaches, have been able to successfully facilitate the understanding of the operational performance of innovative technologies in large-scale, real-world applications, and help improve technology acceptance and commercialization. The efforts and approach provided in this document utilizes approaches used successfully for bench and pilot-testing and cost and performance evaluation by several federal agencies including the Departments of Energy and Defense, and the Environmental Protection Agency.

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ACRONYMS

bbl	Barrels (42 gallons)
DOE	Department of Energy
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
FRTR	Federal Remediation Technology Roundtable
GAB	Government Advisory Board
ITRD	Innovative Technology Treatment Demonstration
NMED	New Mexico Environment Department
NMPWRC	New Mexico Produced Water Research Consortium
O&M	Operation and Maintenance
QA/QC	Quality Assurance and Quality Control
SOP	Standard Operating Procedure
TSC	Technical Steering Committee
USGS	United States Geological Survey

CHAPTER 1. INTRODUCTION and BACKGROUND

Introduction. Oil and gas production also produces large volumes of water, with the ratio of water produced to oil produced commonly varying from 4 - 10 barrels of produced water for each barrel (42 gallons per barrel) of oil, which varies by formation and basin across the U.S. But as shown in Figure 1, oil and gas production occurs in many regions of the U.S., with as many as 21 billion bbls of produced water generated each year. Around 80% of the produced water generated occurs in the Western part of the country (Dahm, 2014), including large volumes in the Permian Basin in west Texas and southeast New Mexico.

The volume of produced water has increased significantly over the past two decades with the introduction and more common use of non-conventional oil and gas drilling, exploration, and production operations supported by the increased use of horizontal drilling and hydraulic fracturing.

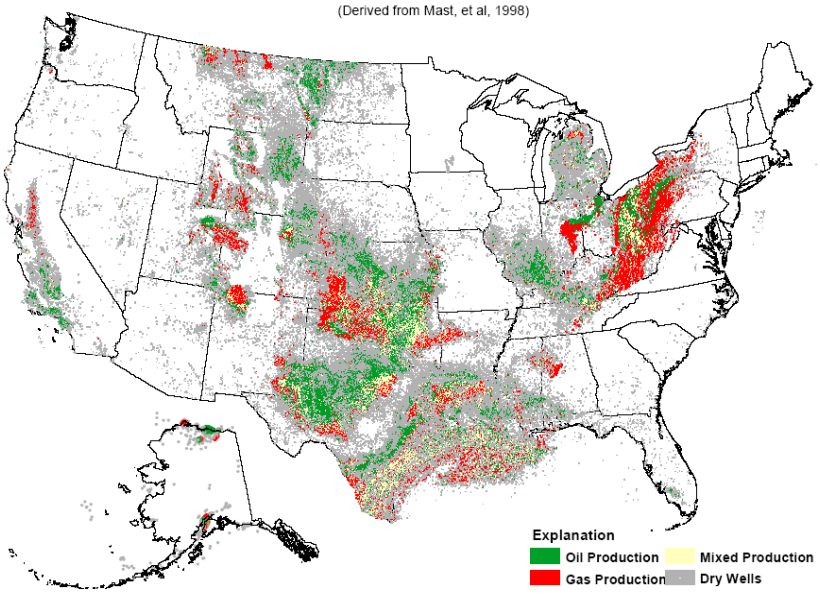

Figure 1. U.S. Oil and Gas and Produced Water Production Areas (USGS, 2006).

As shown in Figure 2, the deeper underground waters produced in oil and natural gas extraction areas are almost all brackish, with much of the produced water in the U.S. being even saltier than seawater. As shown in Figure 3, produced water also often contains high levels of other dissolved minerals such as naturally occurring radioactive materials (NORM), trace heavy metals and rare earth compounds, as well as trace levels of organics and petroleum hydrocarbons. Some of these minerals impact produced water treatment or pretreatment needs in various applications.

For example, boron levels above 2 ppm are not recommended for use in agricultural applications. High levels of NORM and total organic carbon (TOC) are not recommended for surface water applications outside oil and gas. Therefore, because of the often high mineral and organic levels in produced water, for it to be used to supplement fresh water supplies or support many industrial applications, at least some level of treatment – including pre-treatment, desalination, distillation,

and post-treatment of the produced water is often required. (Watson et al., 2003). Therefore, to make use of the large volumes of produced water available, the cost and performance evaluation of a wide range of treatment technologies and approaches is needed to assure the treated produced water is protective of human and environmental health and safety.

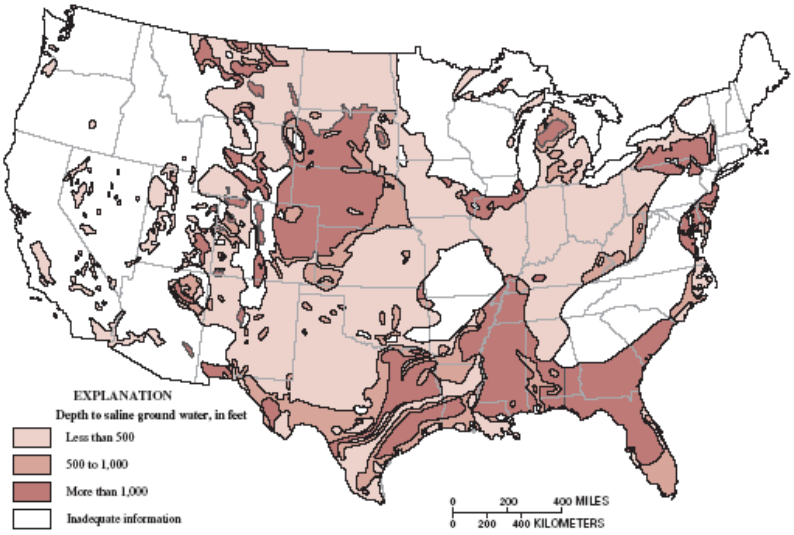

Figure 2. Brackish Ground Water Resources of the U.S. (USGS, 2003).

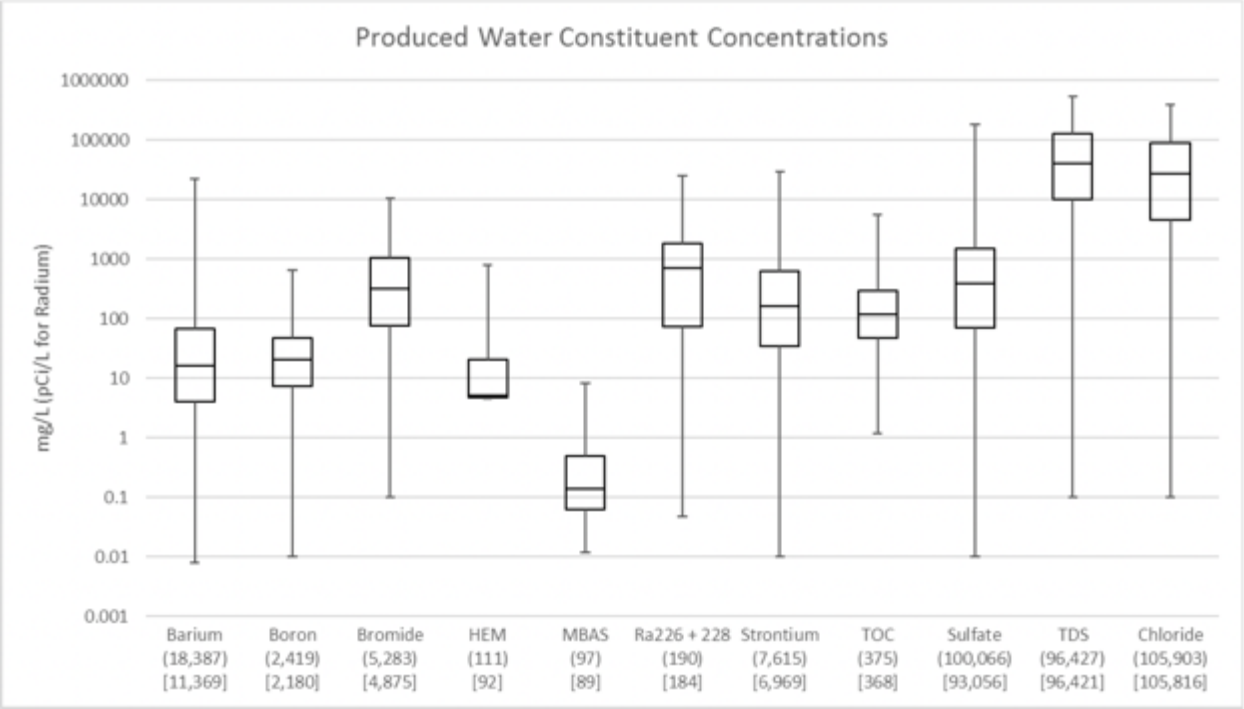

Figure 3. Example of Common Produced Water Constituents and Concentrations (USGS).

Consortium Research and Development Focus. The New Mexico Produced Water Research Consortium (Consortium) was established to improve the science and technology associated with the treatment and use of produced water for uses outside the oil and gas sector and to make sure the use of treated produced water is protective of human health and the environment. In the role of supporting research to identify and develop new and innovative produced water treatment and reuse technologies, the Consortium has established an integrated technology research, development, and demonstration program as highlighted in Figure 4. This is a common approach that often leads to accelerated acceptance and commercialization of new technologies.

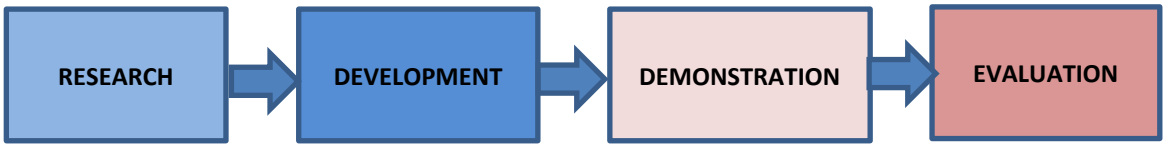

Figure 4. Consortium Technology Research and Development Phases.

Common sequential efforts include:

- Basic and applied research in modeling and analysis of a range of new technologies, materials, and processes,
- Bench-scale and laboratory-scale prototype technology development and assessment,
- Larger-scale pilot-system innovative technology demonstration and testing, and
- Large-scale innovative technology operational testing to collect cost and performance data on system-level operations to verify the effectiveness of new and emerging technologies and their applicability.

The intent of the Consortium research approach is to assess and place technologies in the right research and development category, and assure that the appropriate information and treatment data is collected to enable a technology to advance to the next phase.

Consortium Technology and Research Areas of Interest. The focus of the research, development and demonstration efforts by the Consortium include:

- Processes and technologies that help reduce or eliminate the use of fresh water in oil and gas operations,
- Processes and technologies that cost-effectively create new water supplies that can be safely used to supplement existing fresh water resources,
- Processes and technologies that cost-effectively reduce produced water disposal issues and challenges,
- Processes and technologies that can cost-effectively and safely create new chemical and mineral recovery opportunities, and
- Processes, technologies, and approaches that cost-effectively support the safe use of treated produced water for municipal or industrial applications, which could support improved energy, industrial, and economic development opportunities in New Mexico.

The processes and technologies could include new or innovative pre-treatment, treatment, post-treatment, or disposal technologies, or associated innovative monitoring systems.

This will provide the Consortium and New Mexico with a broad produced water treatment research and development portfolio of innovative technologies and processes focused on reducing fresh water use in the oil and gas sector and creating economic opportunities for the use of treated produced water in New Mexico.

Consortium Technology Review. Following any request for proposals (RFP) by the Consortium for produced water treatment technology ideas or concepts, or for self-funded testing of technologies, the Consortium will conduct an initial assessment of each technology to assess current technical maturity, available cost and performance data in cooperation with the New Mexico Environment Department, academia, and state and regional stakeholders. This will include a comprehensive assessment of potential public, environmental, health, and safety risks for fit-for-purpose applications and expected operational cost and performance benefits. Depending on the review, the technology or process will be ranked for placement into either a research, bench-scale, or large-scale pilot demonstration category.

Consortium Research, Testing, and Evaluation Selection. A description of the basic and applied research, modeling, and analysis data needed by the Consortium to review and initiate planning efforts for bench and large-scale pilot demonstrations are presented in Chapter 2. If that information is not yet available for a given technology, then the Consortium will work with the technology vendor to establish additional research and development testing and evaluation needed to get that technology ready for pilot-scale testing and evaluation.

Chapter 3 provides information on bench-scale testing approaches to bring the maturity of a new or innovative technology up to a level for pilot-scale or field-scale if that data is not yet available. This would include testing of technologies with real produced water under typical field operations and considerations of up to a few barrels of produced water per day or per hour depending on the system design. This allows for assessment of the technology performance and cost and enable the vendor to identify operational or technology issues that could be improved or modified before pursuing more costly field-scale operational testing.

Chapter 4 provides a discussion of successful pilot-demonstration approaches used for environmental remediation and innovative treatment and restoration technology assessment, and cost and performance verification. These are federal programs that conduct large field demonstrations of innovative technologies needed to provide the type of information the Consortium and NMED need to address the health and safety and cost and performance challenges of produced water treatment and reuse. Chapter provides a step-by step process for 1) developing treatment and application pilot-demonstration projects, 2) planning and conducting demonstration projects, 3) evaluating operational cost and performance information, and 4) developing associated cost and performance evaluation reports.

Chapters 5, 6, and 7 discuss in detail the information that will be needed by the Consortium to approve each step of the pilot-demonstration process from pre-planning, planning, demonstration and operation, through cost and performance evaluation and verification, and reporting of results.

CHAPTER 2. RESEARCH and DEMONSTRATION REVIEW

As noted in Chapter 1, the Consortium will help support projects and research needed to fill current science and technology gaps associated with the cost-effective treatment and safe use of produced water for fit-for-purpose applications outside the oil and gas sector. This will be supported by, 1) evaluating and conducting basic or advanced research and development efforts on new technologies and innovations, and 2) supporting technology vendors in conducting pilot demonstrations of more mature technologies and assessing field-scale cost, performance, and public health and safety impacts. This Chapter addresses the Consortium approach for evaluating technology research and development, as well as pre-planning efforts needed for pilot and field-scale demonstrations.

While the Consortium is interested in testing innovative technologies that can be implemented economically at large-scale, it is understood that preliminary laboratory and bench-scale research and development data are needed to show general system efficacy and viability. Therefore, basic and applied research and bench-scale data often is needed before large and more sophisticated bench of field-scale testing is conducted, as noted in Figure 5 below. For example, all the major environmental treatment technology demonstration programs discussed in Chapter 3, require initial laboratory and bench-scale test data before a large field-scale pilot demonstration or field application of a technology is considered..

Therefore, if a produced water technology is going to be approved for use outside the oil and gas sector in New Mexico, and likely other states, it will be important that basic and applied research, testing, and data collection be available or be collected on the appropriate analytical constituent data and cost and performance data needed to support the use of a technology in a field application. This data can either be generated by the Consortium or could be created through other academic, industrial, federal laboratory, or commercial efforts.

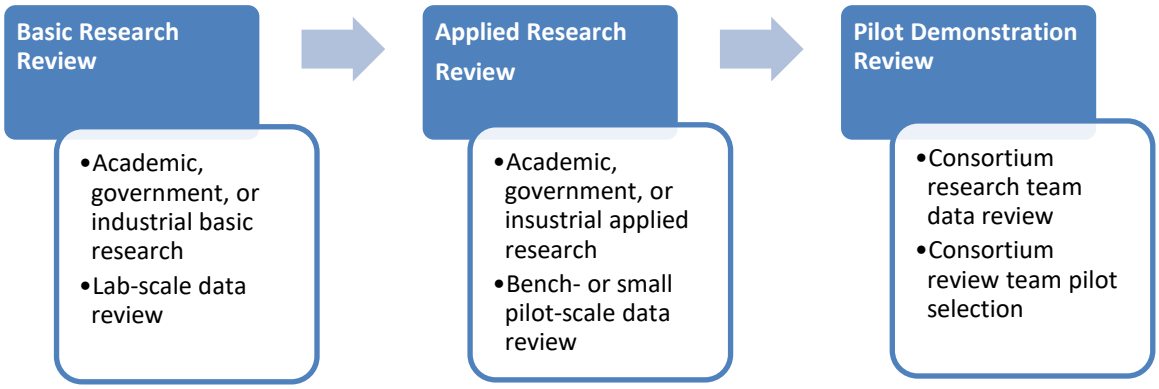

Figure 5. Consortium Research and Pilot-Demonstration Review Process.

Basic and Applied Research Review. To accomplish this, the Consortium has established a process to evaluate and validate laboratory and bench-scale treatment studies. As part of this approach the Consortium:

- Has established a clearing house for innovative treatment technologies, processes, or approaches to be submitted by technology developers, owners, vendors, or users for

consideration and review. This provides the Consortium an "expression of interest" and makes sure that appropriate technologies and research is continually tracked,

- Will release Request for Proposals (RFPs) or open solicitations as appropriate, to identify produced water treatment research and demonstration ideas or concepts, including technologies that have provided an "expression of interest" for testing submitted by technology developers, owners, vendors, or technology users.
- Utilize Consortium members and selected independent reviewers to evaluate proposals for technology maturity, if current data support moving to a field-scale or pilot-scale demonstrations, cost and schedule, proposed application, and proposed approach, and
- Identify and rank technologies for Consortium research support and technologies ready for Consortium support for bench of pilot-demonstration pre-planning and planning.

A Consortium Technology Clearinghouse is coordinated by the Consortium Fellows. A technology vendor, owner, or user can be placed on the list by contacting the Consortium Fellows and providing preliminary background information on the technology. The Consortium Fellows will work with the Consortium and NMED to coordinate a broad technical review committee of Consortium and other technical reviewers from academia, research labs, government agencies, and related fields to review all proposals. Reviewers will be required to sign a Conflict of Interest (COI) form and a Non-Disclosure Agreement (NDA). The established technical review team will review and rank technologies into bench-scale demonstrations that need further research and technical data, or rank technologies ready for pilot demonstration.

Bench-scale Demonstration Review and Approval. Bench-scale demonstrations are less extensive with a reduced level of monitoring and testing to help evaluate the viability of a given process or innovation. The testing needs to represent general produced water and associated operational environments, but at a smaller throughput, treating a few barrels to tens of barrels of produced water per day. Therefore it is important to adequately address the planning activities identified in Chapter 3 to collect the appropriate cost and performance data to support system modifications and the ability to move to a pilot-scale technology testing and evaluation project.

Pilot Demonstration Review and Approval. Pilot demonstrations are often extensive and expensive efforts, especially with the level of monitoring and testing needed to provide cost and performance data and to make sure public and environmental health and safety requirements are met. Therefore it is imperative that responders to the RFPs address some of the planning activities identified in Chapter 4, including a preliminary demonstration plan, operational team, testing and analysis plan, and good cost and performance data. These will be important factors in enabling pilot demonstration projects to be approved and allowed to move forward. Additional ranking criteria will include expected treatment project costs, schedule, applicability, ease of replication, and environmental and public health impact. The results of the review will be provided to the Government Advisory Board for final review and approval of Consortium support for either additional research or for pilot demonstrations.

CHAPTER 3. LABORATORY AND BENCH-SCALE TESTING

The Consortium laboratory and bench-scale testing program is designed to enable the testing and evaluation of new or innovative technologies under testing scenarios that represent general field quality produced water and associated operational environments at smaller scales. These would include bench-scale systems designed to treat a few barrels to tens of barrels per day of produced water. These systems would commonly be tested at national or regional test sites under better controlled test conditions and with less stringent performance expectations. This provides the new technologies with a chance to assess their suitability in treating produced water under general field conditions and helps vendors assess general operational performance, and identify modifications and changes needed to improve pilot-scale and field-scale application success.

The Consortium has coordinated with New Mexico State University and the Brackish Ground Water National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico to support laboratory and bench-scale testing. These facilities provide opportunities to use actual produced water or treated produced water under controlled conditions to maintain strict environmental control of both raw and treated produced water. For example, BGNDRF has established a produced water pilot testing area with secondary containment where raw and treated produced water can be safely stored. Figure 7 shows the outside and inside test areas at BGNDRF available for produced water bench-scale and even pilot testing.

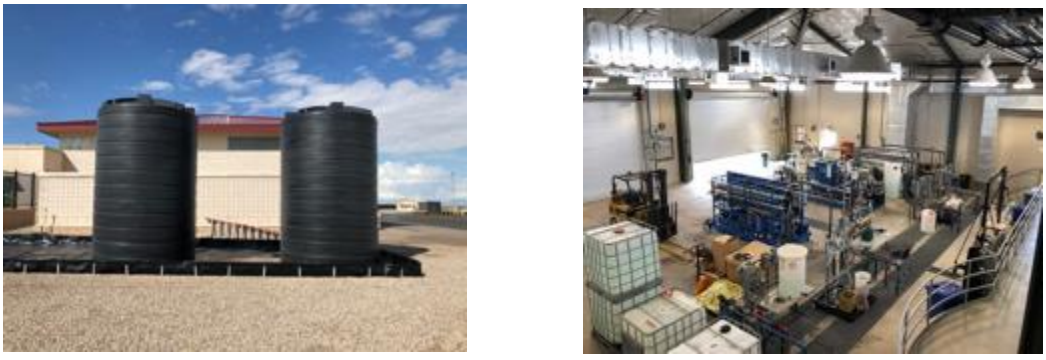

Figure 6. BGNDRF outdoor and indoor bench-scale produced water testing areas.

Consortium Bench-scale Testing Process: The Consortium has prepared this guidance manual to provide technology developers and technology implementers with a process to support collecting cost and performance data using vendor developed bench-scale testing plans.

The **Bench-Scale Testing Document** should include a general discussion of the following items.

- Executive Summary
  - A short paragraph or paragraphs of the general purpose and benefits of the proposed technology process and use application (pre-treatment, treatment, post-treatment). Expected system performance and potential benefits of existing technologies in terms of improved cost, performance, or safety. Expected testing duration, produced water testing rate, and expected dates for testing.
- Site Identification
  - Provide a short discussion of the identified site.

- Schedule
  - Provide a brief description of expected operations and duration. Include mobilization, operations, and demobilization.
- Treatment System Design Overview
  - Provide a brief description of general technology approach, process flow, and needed energy, chemicals.
- Test Plan
  - Short discussion of treatment rates and any potential wastes. A general water, chemical, and energy summary should be included.

    Currently all treated produced water streams need to be recombined and disposed at a salt water disposal well.

  - Include a statement of the relationships to be tested, what characteristics or conditions will be tested or varied to meet the general schedule.
- Data Collection and Sampling Plan
  - Provide a short summary of the type of data to be collected (elements, values, sampling frequency, sampling locations, approach etc.) needed for effective evaluation of operational performance. Include any confirmatory sampling to be done. Include Key Performance Goals expected and measured such as $/bbl, $/acre, bbl/day, chemical use (e.g., gram or lbs/bbl), energy consumption (kWh/bbl, MMBTU/bbl), etc.
- Safety Considerations and Operations
  - Provide a discussion of the expected operating procedures and emergency and safety monitoring and control. Also provide information on your emergency response plans (including spill prevention and secondary containment needs, as needed).
- Coordination between Operations and Site Managers and Consortium Evaluation Team
  - Provide information on coordination of work schedule and Consortium review
- Summary of Existing Operational Data
  - Summarize information on existing laboratory and demonstration scale data. This will be used to screen projects and technologies, so past and recent data collection should be included for review.

The independent technical review team will work with the vendor to finalize the bench-scale testing and planning review and coordinate feedback, updating, and approval. Once approved, a bench-scale project can be initiated, with project progress reviewed by the Consortium identified Project Evaluation Team weekly or biweekly during operations.

Each Bench-scale project will be asked to prepare a **Summary Project Description** as identified in Appendix A (also see **Background Information Form** pages 24 - 26), that provides summary information and scheduling of the project. It shall be used to Summarize Demonstration Testing in NMED Treatment Permit Discussions. The completed Form shall be submitted to the Consortium Executive Director and to the New Mexico Environment Department, as described on https://www.env.nm.gov/new-mexico-produced-water/guidelines-and-forms/ and will also be added to NMED's web site to keep the public and Consortium members informed of project progress and highlights.

CHAPTER 4. PILOT DEMONSTRATION PROCESS

The Consortium Pilot Demonstration and technology verification process approach is based on a series of national environmental technology remediation and verification programs established in the late 1990's and early 2000's to move innovative treatment technologies into routine use and accelerate full-scale applications of emerging new technologies. These include four major national environmental field-scale technology evaluation programs including:

- EPA's Superfund Innovative Technology Evaluation (SITE) Program - established to work with state and federal regulatory agencies and technology providers to identify the cost and performance of innovative soil and water treatment and remediation technologies in large-scale applications, designed to collect operational performance and cost data at full-scale to help reduce both regulatory and operational risks, accelerate acceptance, and promote their use (EPA, 2003).

- The Federal Remediation Technology Roundtable (FRTR) a consortium established in 1995 to coordinate federal agency use and collection of data to establish standardized technology cost and performance comparisons. Their efforts were published in an often used report for federal environmental remediation projects, "Guide to Documenting and Managing Cost and Performance Information for Remediation Projects", EPA 542-B-98-007, October 1998 (EPA, 1998).

- DOE's Innovative Treatment Remediation Demonstration (ITRD) Program - established in 1994 to work with state and federal regulators, DOE and EPA laboratories, the EPA Site Program, to utilize the FRTR approach with innovative technology providers, utilizing DOE sites to collect independent third-party evaluations of operational cost and performance data of large-scale demonstrations of innovative treatment and remediation technologies (DOE, 1998). It had a similar focus of reducing regulatory and operational risks and accelerating acceptance and use of innovative waste treatment and environmental remediation technologies.

- EPA's Environmental Technology Verification (ETV) Program - established to utilize independent third parties, such as national laboratories and technical associations, to conduct full-scale, field operations and evaluate and verify the operational cost and performance of environmental monitoring, site characterization, and hazardous waste treatment technologies. With successful completion, the EPA provides a performance certification for the conditions tested, helping to accelerate the acceptance and use of the tested technologies (EPA, 1996).

Consortium Pilot Demonstration Process: Borrowing from these successful innovative, large-scale, treatment technology testing and evaluation programs, the Consortium has established a similar technology review, selection, planning, demonstration, and verification process for pilot demonstrations of produced water treatment and application technologies. As suggested in these related initiatives, the Consortium has prepared this guidance manual to provide technology developers and technology implementers with a step-by-step process that includes data required in each step to prepare produced water pilot demonstration project, demonstration, and

technology cost and performance verification plans. The identified demonstration and verification process provide technology developers and demonstration coordinators with a clearly defined technology testing, sampling, and verification pathway - from planning, to pilot testing and demonstration, data collection and analysis, risk evaluation, and finally technology cost and performance evaluation and verification. The process was established to assure technical and environmental issues are addressed in order to help facilitate regulatory approval.

The pilot demonstration review and operation process is shown in Figure 6, and identifies for pilot demonstration developers the information needed for each of the three phases of a pilot project, specifically:

- Development, review, and approval of a demonstration plans highlighting operations and testing, data collection and monitoring, and performance assessment.
- Demonstration of technology operational performance via introduction of variables, documentation of system performance, conduct of sampling and analysis, and
- Evaluation of technology performance and effectiveness, along with process operations and cost assessment, and other overall considerations, as appropriate.

General elements of these three phases of pilot demonstrations are highlighted below, with indications of the level of detail and background information needed to move forward.

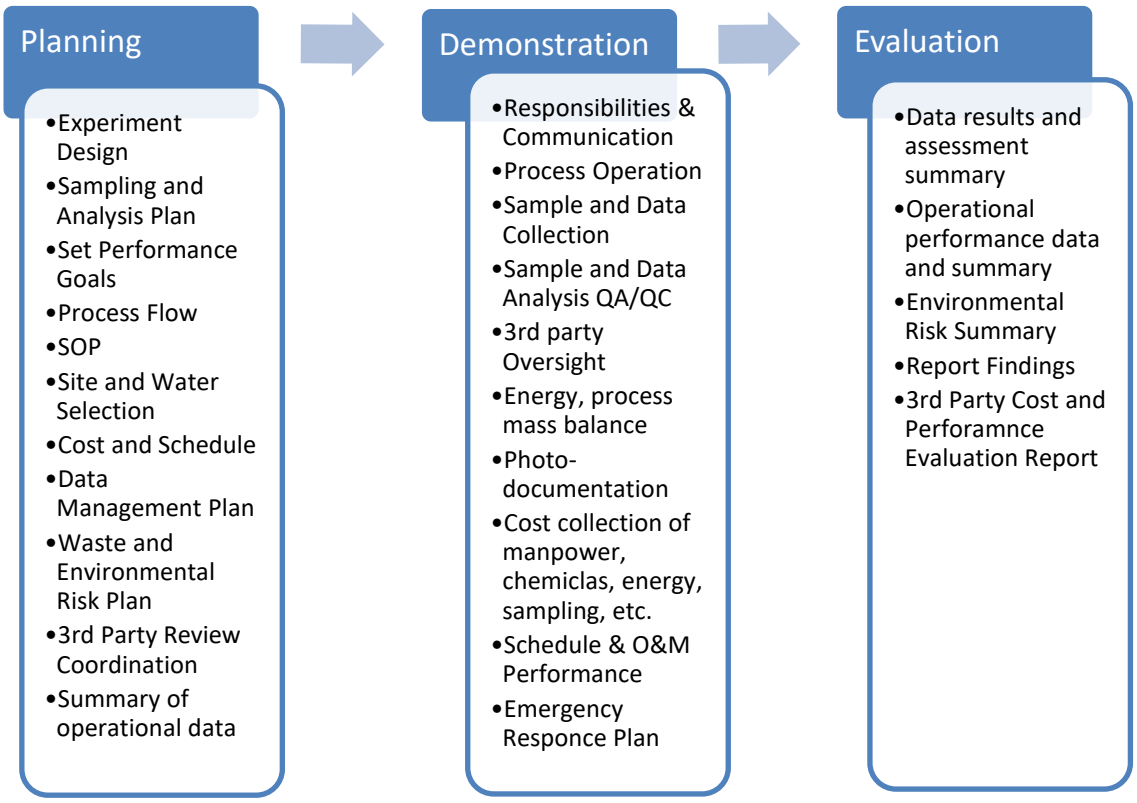

Figure 7. Pilot-demonstration Process and Requirements.

Each of the following Chapters provides more detail on each of the pilot-demonstration steps and associated processes to move from creating laboratory and bench-scale testing and demonstration data that is at an appropriate scale to suggest a potential accelerated testing and evaluation pathway all the way to a successful pilot-scale demonstration. This is extremely important since large-scale demonstrations can be expensive, and therefore opportunities for large demonstrations are limited and they must be designed and coordinated carefully and efficiently to maximize pilot-scale testing and demonstration opportunities and maximize associated national impacts. The Consortium will support the pilot demonstration by providing 3rd party review of the project planning, demonstration planning and operations, and provide a performance validation report to facilitate regulatory review and approval.

The detailed guidance provided in the following Chapters is to assure that appropriate research and development data are collected, that pilot operations are appropriately designed, that data quality assurance approaches are utilized, and that the health, safety, regulatory, and environmental risks and concerns related to the pilot demonstrations are appropriately and adequately addressed prior to project implementation and pilot testing. Finally, the process assures that the cost and performance data collected will be valuable and appropriate, and will be able to be utilized to provide verification of technology performance and cost. The process also assures that the information collected delivers enough information to provide a commercially viable pathway for use and acceptance of the technology and the ability to utilize it across different basins, regions, and states.

CHAPTER 5. PILOT DEMONSTRATION PLANNING

The purpose of the Pilot Demonstration Planning Phase efforts are to provide a structured project planning and operation plan including what variables in the demonstration effort may be held constant, varied, and established/tested/analyzed/recorded. It is designed to help encourage demonstration proponents to establish a technically rigorous demonstration plan and approach that effectively addresses existing science and technology gaps and will provide high quality data and information to rapidly validate innovative produced water treatment technologies/approaches and bring these to commercial readiness.

Pilot Planning Document. As noted in Figure 6, a brief **Pilot Planning Document** must be submitted as part of the project proposal including general experimental design and purpose, technology operation and discussion, proposed site selection, presentation of existing experimental data, cost and schedule expectations, preliminary sampling and analysis plans, SOPs, health and safety, and environmental and public health and risk information and mitigation plans. All the planning elements should be briefly but thoroughly addressed in an approximately 2-page overview and 10-20-page **Pilot Planning Document** that will be shared with reviewers from the Consortium review and evaluation team. Additional appendices and supporting information can be included as necessary.

The **Pilot Planning Document** should provide the independent technical review team with enough information and data to assure them that the pilot project presented has been well thought out, addresses existing science and technology gaps and potential confounding aspects, can be conducted safely and in a way that is protective of public and environmental health and safety. Additionally some consideration of replicability and use across the region should be mentioned.

The **Pilot Planning Document** should include a general discussion of the following major items.

- Experimental Design
    - A short paragraph or paragraphs of the general purpose and benefits of the proposed technology pilot test and/or use application. Experimental design should include a succinct statement of the relationships to be tested, what characteristics or conditions will be tested or varied, by how much and within what range (and why); the means of establishing baseline and experimental parameters, the data to be collected and analyzed and what the analyses will contribute to the assessment.
    - General applicability of the approach and safeguards to protect the environment during the testing and evaluation should be included. The discussions should address how the pilot demonstration will help address current science and technical gaps in produced water use and applications.

- Site Selection
    - Provide a short discussion of the identified site with an overall site plan and discussion of location benefits, and efforts to minimize public and environmental impact. Include information on mobilization & demobilization planning/schedule,

site energy requirements and availability, availability of other utilities (e.g., sewer connections), waste management plans, produced (?) water availability, etc.

- Sampling and Analysis Plan
    - Provide a short summary of the type of sampling and analysis (analytes, sampling frequency, sampling locations, approach etc.) needed for effective evaluation of operational performance (consistent with the experimental design), laboratories used for sample analysis, verification sampling, data quality assurance approach, and experimental methods.

- Identify Performance Goals
    - Discuss expected cost and performance goals of the technology or project. Data should be normalized in terms of $/bbl, $/1000 gal, $/acre, bbl/day, gal/day, chemical use (e.g., gram or lbs/kgal), energy consumption (kWh/kgal), etc., as well as seasonal variability challenges. Identify how ranges in cost of treatment or use goals would change based on changes in produced water volume or quality.

- Process Flow
    - Provide a general process flow sheet of mass, energy, chemicals, and wastes treated, generated, or consumed. A general water, chemical, and energy summary should be provided.

- SOP
    - Provide a discussion of the expected operating procedures, process control and monitoring, and emergency and safety monitoring and override sensors and controls. Also provide information on your emergency response plans (including spill prevention and secondary containment needs, if any).

- Cost and Schedule
    - Provide a brief description of expected pilot operations, an explanation of duration, and expected operational costs, and funding available or needed. Include mobilization, demobilization, construction, infrastructure, chemicals, consumable, labor and manpower, energy, etc.

- Data Management Plan
    - Provide a brief discussion or table of all demonstration data collection, data management, and data delivery expected to the TSC team for review and evaluation.

- Residual and Environmental Risk Plan
    - Provide an overview of waste generation and disposal (outside normal operations, in the case of piloting at an established operating facility), associated costs, and impacts to public and potential environmental risks. Include cost of analysis and disposal as well as any regulatory notification or permitting required

    - Provide an overview of hazardous air pollutants generation, treatment, and disposal, associated costs, and full-scale costs and impacts to public and potential environmental risks.

- 3rd Party Review Coordination
    - Provide information on coordinating independent 3rd party technical and regulatory review, how you would work with them, data to be provided, and operation stoppage criteria.

- Summary of Operational Data
    - Summarize information on existing laboratory and demonstration scale data, other pilot-scale operations conducted, etc. This will be used to screen projects and technologies, so past and recent data collection should be included for review.

The independent technical review team will work with the GAB to finalize the demonstration planning review and coordinate feedback, request for changes, and/or approval.

It is expected that the **Pilot Planning Document** will be updated by addressing comments from the TSC review committee and used to create a more detailed Pilot Demonstration Test Plan, as discussed in Chapter 6.

CHAPTER 6. PILOT DEMONSTRATION TEST PLAN

The purpose of the Pilot Demonstration Test Plan is to describe the procedures that will be used to conduct the pilot operations and verify system performance and overall project cost and benefits. The test plan should incorporate the QA/QC elements needed to provide data of appropriate quality sufficient to reach a defensible position regarding the technology and system cost and performance. The focus on the data collection is to provide data of sufficient quality to enable industry to make a judgement about the application of the technology or system under similar conditions to those encountered in the pilot demonstration, and provide enough information to understand the potential for other fit-for-purpose applications.

Pilot Demonstration Test Plan. As noted in Figure 6, the **Pilot Demonstration Test Plan** must include detailed information on several elements including; Process Operation, Sample and Data Collection, Sample and Data Analysis QA/QC, 3rd party analysis and review, process energy and mass balance, photo-documentation, operational cost data collection utilizing approaches suggested by the Federal Remediation Technologies Roundtable and approved by the technical review team, on implementation – including operations and maintenance costs for personnel, chemicals, energy, sampling, etc., expected operational schedule, waste generation and management, treated water quality monitoring and analysis, assessment of public health and environment impact and risk relative to NMED and Consortium water treatment guidelines, and operational reliability of the system.

All these elements need to be adequately addressed in an approximately 20-30 page **Pilot Demonstration Test Plan** that will be shared with reviewers from the Consortium review and evaluation team. The **Pilot Demonstration Test Plan** can utilize the **Pilot Planning Document** as a basis and provide the review team with additional detail on the operations and conduct of the pilot demonstration. Enough information and data is needed to assure the reviewers, including NMED, that the pilot demonstration will operate smoothly, can be conducted safely in a way that is protective of public and environmental health and safety, has an emergency response and operation plan, and the sampling plan and sample QA/QC plan is sound. Information on the operational data, down time, energy, etc., must be collected to provide adequate information on O&M challenges, costs, etc., of the technology.

Pilot Demonstration Test Plan Elements. The **Pilot Demonstration Test Plan** should include at a minimum discussion of the following items.

- Process Operation
    - Detailed process flow sheet with sampling locations, process control, start-up schedule and approach, operational schedule, expected operational throughput and flowrate, etc.

- Sample and Data Collection
    - Detail on sample collection locations, expected data output format, typical operational data sheets/s collected including operational performance, reason for the sampling, number of sampling events, archiving of data.

- Sample and Data Analysis QA/QC
    - Approved QA/QC plan, third party analysis, etc.

- 3rd party analysis and review
    - How 3rd party will review data, onsite access, summary reports to reviewers, etc.

- Energy, process mass balance
    - How these elements will be recorded, how often, sample data collection sheets

- Photo-documentation
    - Expected photo/video information, access to photos/videos, photo documentation of operations, schedule of photo documentation

- Cost of manpower, chemicals, energy, sampling, etc.
    - Data to be collected, data display format, example tables for cost analysis, templates, to be used such as FRTR, or ITRD basis

- Schedule & O/M Performance
    - Collection of daily schedules of intended vs actual operations
    - Listing of downtimes and reasons for variances

- Emergency Response Plan
    - Emergency shutdown plan, emergency services, personnel training, site safety requirements, safety officer, etc.

Once this plan has preliminary approval from the independent technical review team, the pilot demonstration and construction will be provided to the GAB for approval. Pilot demonstration operations can be initiated once the plan receives final approval from the technical review team and the GAB.

Each Pilot-scale project will be asked to prepare a **Summary Project Description** as identified in Appendix A (also see **Background Information Form** pages 24 - 26), that provides summary information and scheduling of the project. It shall be used to Summarize Demonstration Testing in NMED Treatment Permit Discussions. The completed Form shall be submitted to the Consortium Executive Director and to the New Mexico Environment Department, as described on https://www.env.nm.gov/new-mexico-produced-water/guidelines-and-forms/ and will also be added to NMED's web site to keep the public and Consortium members informed of project progress and highlights.

CHAPTER 7. DEMONSTRATION COST and PERFORMANCE EVALUATION

The Consortium's pilot demonstration efforts are designed to be an operational testing and evaluation program to assist New Mexico environmental and natural resources agencies in identifying and evaluating innovative technologies and systems that can support the treatment and use of produced water from oil and gas operations outside the oil and gas sector for fit-for-purpose uses. This is a recent national strategy and therefore there is currently limited large-scale cost and performance information available for many innovative emerging technologies and potential application in New Mexico and the western US.

Therefore, the Consortium's efforts are focused on working with the demonstration project to reduce many of the classic barriers to the acceptance and use of new technologies and approaches by involving government, industry, academia, and regulatory agencies in the operation, assessment, evaluation, and verification of innovative treatment technology operational cost and performance data.

Cost and Performance Evaluation. By design, the information required and approved in both the **Pilot Planning Document** and the **Pilot Demonstration Test Plan** require all the testing operational testing information needed to accurately prepare a **Cost and Performance Evaluation Report** of the system operation and performance of the identified treatment technology for the use and application identified. This allows the Consortium independent technical review team to work with the technology provider during a demonstration project to assess the collected data and provide an unbiased assessment of the pilot technology performance and costs.

This provides the technology provider and regulatory agencies with a fact-based assessment of the technology performance relative to technical and engineering goals and objectives and public and environmental health and safety impacts. This approach has been used successfully in the EPA Environmental Technology Verification Program and other federal programs to enable vendors to use the evaluation report and an association verification letter in getting regulatory approval and acceptance for use in other large-scale commercial projects.

The **Cost and Performance Evaluation Report** will be prepared by the Consortium identified technical independent 3rd party review team. The report will be a short summary technical report of 20-40 pages, with a supporting **Technology Testing Data Report** from the demonstration testing. The **Cost and Performance Evaluation Report** will include the following sections:

- Foreword
- Summary

- Site Information
    - Identifying Information and Location map
    - Site Background
    - Site History
    - Produced Water, Treatment, and Demonstration Application Characteristics
    - Project, Site, and Technology Contacts

- Technology Description
    - Fundamental Science and Expected Benefits
    - Technology Advantages
    - Technology Limitations
    - Summary of Results of Basic and Advanced Research testing results
    - Pilot System Description – pictures, schematics, cross-sections, videos, modeling, analysis
    - Treatment and pilot system schematic and operation
    - Key pilot design criteria
    - Operating parameters

- Treatment System or Application Performance
    - Demonstration Objectives and Approach
    - Performance Evaluation Criteria
    - Identified Performance Goals and Objectives
    - Performance Summary – data tables, charts, figures,
        - Show for each performance evaluation criteria and goals and objectives
        - Provide summary table of performance

- Treatment System or Application Cost
    - Cost breakdown structure per the FRTR
    - Demonstration normalized costs
    - Full-scale normalized costs – estimated

- Regulatory/Institutional Issues
    - Risk monitoring results
    - Risk analysis results
    - Identified challenges and remediation issues

- Observations and Lessons Learned
    - Performance observations and lessons learned
    - Cost Observations and Lessons Learned
    - Summary

- Consortium Validation and/or Verification Letters
    - Consortium Letter
    - Regulatory agency letters

These reports are designed so that they can be read in a few hours and provide interested industry, regulatory, and commercial user groups with the high-level summary information needed to quickly understand the benefits, liabilities, and opportunities of the treatment technology for produced water treatment and reuse and potential applications. The supporting **Technology Testing Data Report** will include all the technical data generated and prepared as identified in the **Pilot Demonstration Test Plan.**

Appendix A - Summary Project Description

1. **Project Name:**
   Company:
   Point of Contact:
   Project Description: A paragraph or two on the goals and objectives of the project
   Project Location: Short description of the test location and associated site operator
   Project type: Identify if a bench, pilot, pre, post, or primary treatment effort
   Target test dates: Projected month or months and year
   Expected project duration: weeks of testing expected
   Type of produced water expected to be treated: Desired TDS level or range

2. **Treatment system description:** (A paragraph or two of discussion of treatment process)
   Process type: Short discussion of process **(**thermal, membrane, other) and benefits
   System size and footprint: General system size
   Current Technology Readiness Level (TRL): Short note on current TRL level
   Process flow diagram: Information on streams and flow types and rates
   Picture of system: Picture of test unit

3. **Technology performance evaluation:** (a paragraph describing performance goals)
   Produced water treatment target: bbls/day
   Expected freshwater recovery rate: bbls/year
   Daily operational target: hrs/day
   System operational availability target: % operational daily and weekly
   Potential application: wholesale water, ag/rangeland, industrial, water augmentation use
   Treated produced water recovery target: % of raw water feed
   Treated produced water quality target: TDS, organics, inorganics, etc.
   Treatment energy use target: kWh or MMBTU/bbl
   Chemicals/consumable use: type, volume or weight per bbl of treated water, safety issues
   Operational manpower: Estimated manhours per day onsite or if autonomous operations

4. **Process monitoring and sampling goals:**
   Types and Locations: Where in process, how many locations, lab or in-line analysis
   Times/day or times/week: When and how often
   Constituents sampled: Number and typed of primary constituents to be monitored

Both Bench-scale and Pilot Projects shall refer to the following Produced Water treatment Pilot Project Background Information Form which may be used to Summarize Demonstration Testing For Use in NMED Treatment Permit Discussions. The completed Form shall be submitted to the Consortium Executive Director and to the New Mexico Environment Department, as described on https://www.env.nm.gov/new-mexico-produced-water/guidelines-and-forms/ and will also be added to NMED's web site to keep the public and Consortium members informed of project progress and highlights.

Produced Water Treatment Pilot Project Background Information For Use in NMED Treatment Permit Discussions

1. **Applicant Summary Information:**

Company: (Name and Address)

Points of Contact	Company	Email	Phone

Company Description and Produced Water Treatment Experience:
(Need short paragraph of company experience)

Application Date:
Pilot Date:
Type and scale of Project: (Bench-scale/Pilot-scale)
Project Funding: (Consortium funded, private funded, shared funding, etc.)

Project Collaborators: (if any)

Group/Company	Role	Contact Info

2. **Project Site Location and Description:**

- **Basin**:
- **Location**: (Nearest landmark highway, site location, etc.)
  Coordinates: (Lat/Long)
- **General Directions**: (Need general directions to site from nearest highway and mile marker)
- **Site Description**: (Site designation, name, etc. and type of site i.e. SWD site?)
- **Land Status**: (Private, OCD, BLM, other)
- **Arial view of site**: (Need picture)
- **Produced Water Source and Quality**: (produced water source and general quality in ppm TDS)

3. Executive Summary:

(One or two paragraphs)

4. Proposed Reuse Application of Treated Water: (following statement required)

For the purposes of this test, there will be no discharge of the produced water. The distillate will be collected in a holding tank for sampling before being blended back with the concentrated brine for reinjection into the SWD.

5. Similar or related permits/notification needed with other agencies, or nearby properties:

(What is the nearby property, is it owned by the same company, or another operator. They should be contacted and know of the project.)

6. Pilot-System Process and Design:

(Two to three paragraphs of your treatment process and what you will do. Discuss general throughput and expected performance, etc. Include a simple treatment process flow sheet.)

7. Project Goals and Objectives: (Summary of objectives and KPI's similar to below)

The pilot project is expected to operate for up 'x' weeks, treating up to 'y' bbls/day of produced water of a water quality compatible with reuse for 'z' (i.e. agricultural irrigation). It is expected the concentrate and distillate will have the following beginning and final qualities.

Parameter	Feed Water	Brine	Clean Distillate
TDS, mg/L	a	b	c
pH	e	f	g
Water Volume	h bbls/day	i bbls/day	j bbls/day
Ammonia, mg/L	x	y	z

Additionally, …… (i.e. Solids and ammonia recovery will be evaluated for economic reuse of those recovered minerals). The following Key Performance Indicators (KPI's) will be evaluated to assess system and process cost effectiveness and overall performance:

Operational throughput - x bbls/hr
Operational efficiency - x average hrs/day
Downtime - x average hrs/wk
Meet water quality target - x % of time
Max. water quality variation - x average % above target level
Energy use/cost per bbl treated - x kwh/bbl, x btu/bbl, and $x/bbl
Treatment vs pre and post treatment costs of operation - y in %
Distillate and concentrate recovery - average bbls/bbls treated
Mineral recovery - x tons per day per bbls treated
(Additional KPI's as required)

The data collected will be utilized to help develop of design of larger-scale treatment systems to support enhanced operations efficiencies and reduce full-scale treatment costs.

8. Summary of Risk and Toxicology Sampling, Testing, and Analysis: (Following Statement Required)

The KPI's noted above will be measured daily on-site with simple field testing systems and monitors.

Risk and Toxicology testing and analysis of thee treated produced water will be coordinated and managed through the NMPWRC. Samples will be taken and tested using the Consortium's sampling protocol, and their Risk and Toxicology testing protocol. Bechtel will coordinate with the NMPWRC so they can to collect and prepare Risk and Toxicology analysis samples to ensure proper care, custody, and control. The Consortium will collect up to two set of samples once routine operations have been established to provide information on process efficacy and reliability relative to potential future treated water safety.

9. Equipment Vendor and Associated Suppliers: (Identify as appropriate)

Equipment or Vendor Name/Description	Role

10. Expected Produced Water Users: (Required Statement)

The effluent for the pilot operations will be recombined and placed in an SWD and residuals disposed as noted below.

11. Disposal and Decommissioning: (Required information)

Equipment: None - Reuse for testing at other sites
Material: Secondary containment and expendables for the treatment system will be…….
Water: All water will be disposed by ….. i.e. SWD injection
Soil: Any contaminated soil will be disposed at the following permitted ……

12. Expected Operational Testing, Reporting, and Proposed Review Schedule

Pilot mobilization, set up, and shakedown: x-y 2023
Pilot Operations: x-y 2023
Draft Report: z 2023

Company POC **Date**

Appendix B - Treated Water Monitoring Requirements

Consortium TIER 1 Analytes	Pretreatment Technology Testing	Treatment Technology Testing
Temperature, ^{0}C	x	x
Dissolved Oxygen (DO)	x	x
pH	x	x
Electrical Conductivity	x	x
Oxidation Reduction Potential (ORP)	x	
Turbidity	x	x
Total suspended solids	x	
Total Dissolved solids	x	x
Chlorides	x	
Hardness (total or dissolved)	x	
Iron (total, Fe / Fe2+ / Fe3+)	x	x
Nitrogen, Ammonia	x	x
Sulfide/Hydrogen Sulfide	x	
Specific gravity	x	
Total organic carbon (TOC)	x	x
Dissolved organic carbon (DOC)	x	
Chemical oxygen demand (COD)	x	
Selected Tier 2 analytes as determined by technology (TRL) and application as noted below		x

Metals/Elements
Metals/Elements - speciated
Anions
Radionuclides
Organics - VOCs and TPH
Organics - SVOCs - General, TPH, explosives, agent breakdown products, pesticides/herbicides, PCBs, PAHs, organic acids, dioxins

Appendix C - Monitoring of Key Technology Performance Indicators

Pre-treatment Technology - Key Performance Indicators to be Measured

Vendor	Units
Treatment Unit Description :	
Technology Readiness Level	
Unit design treatment rate	gal/min or bbl/hr
Treatment system footprint	length/width/height in ft
Initial Water Quality:	
TDS	mg/L
TSS/Turbidity	NTU
Iron	mg/L
Organics	ppm
Treated Water Quality:	
TDS	mg/L
TSS/Turbidity	NTU
Iron	mg/L
Organics	ppm
ORP	
Waste Water Quality:	
TDS	mg/L
TSS	NTU
Iron	mg/L
Organics	ppm
Energy Input	Per/bbl
System Throughput:	bbl/day
Operations	hrs/day
Max throughput	bbl/hr
Avg. throughput	bbl/hr
Best 7-day throughput	bbl/hr
Avg. treated water volume	%
Avg. waste water volume	%
Clean In Place (CIP) Process:	
Avg. cleaning frequency	Per bbl treated
Avg. cleaning duration	minutes
Chemicals and volumes	Per CIP
Other consumables:	
Chemicals, materials, etc.	Volumes or weight per bbl
Mobilization/demob time	Cost and days for each
Unit treatment costs of energy, manpower, consumables, etc.	$/bbl

Treatment Technology - Key Performance Indicators to be Measured

Vendor	Units
Treatment Unit Description :	
Technology readiness level	
Unit design treatment rate	gal/min or bbl/hr
Treatment system footprint	length/width/height in ft
General Raw Produced Water Quality	TDS
Energy Required:	Electric / Heat (grade - Temperature in / out) / Gas btu/bbl - mcf/bbl
Pre-Treatment	Type required
Treatment System Throughput:	
Operations	hrs/day
Duration	days
Max throughput	bbl/hr
Total Downtime during duration	hrs
Avg. throughput per day	bbl/hr/day
Permeate/distillate recovery	bbl/hr
Waste recovery	bbl/hr
Avg. treated water recovery	%
Avg. waste generated	%
Permeate Quality	
TDS	ppm
Other constituents volumes	Applicable units
Avg. Waste generated	bbl/day
Waste Type	classification
Consumables	gal or lbs/bbl
Chemicals	gal or lbs/bbl
Post Treatment Needed	Type and volume
Mobilization/demob	Cost and duration in days
Unit treatment costs of energy, manpower, consumables, etc.	$/bbl

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