Energy & Environmental Research Center (EERC)

DEVELOPING AND VALIDATING PRESSURE MANAGEMENT AND PLUM CONTROL STRATEGIES IN THE WILLISTON BASIN THROUGH A BRINE EXTRACTION AND STORAGE TEST (BEST)

2019 Annual Project Review Meeting for Crosscutting, Rare-Earth Elements, Gasification Systems, and Transformative Power Generation

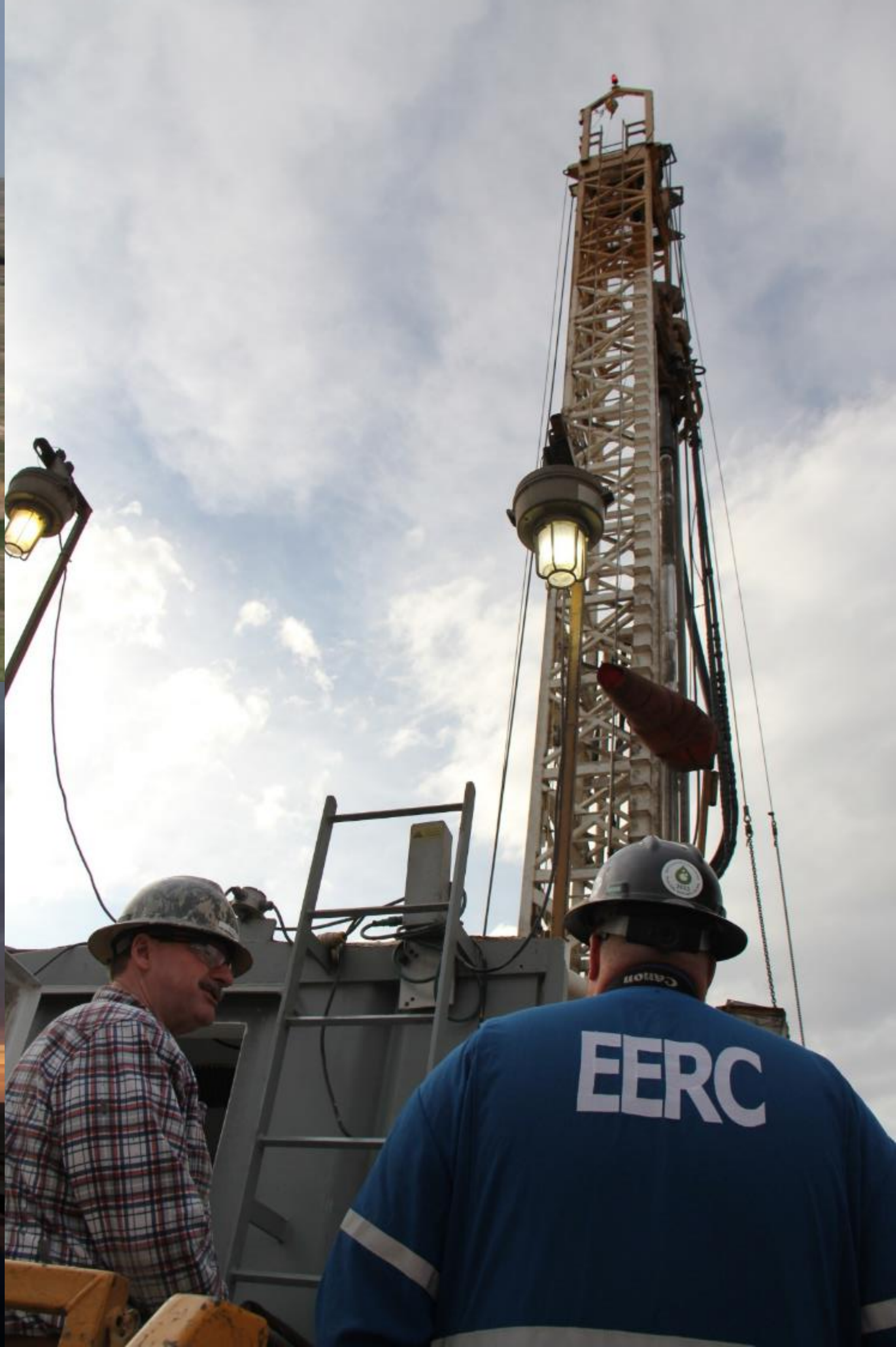
Pittsburgh, Pennsylvania

April 10, 2019

John A. Hamling

Assistant Director, Integrated Projects

NORTH DAKOTA
BRINE TREATMENT USER FACILITY



EERC

UND UNIVERSITY OF NORTH DAKOTA

PROJECT OVERVIEW – GOALS AND OBJECTIVES

- Confirm efficacy of active reservoir management (ARM)
  - Brine extraction as a means of managing formation pressure and the injected fluid plume
  - Predicting and monitoring plume movement
  - Validating pressure and brine plume model predictions

- Implement and operate a test bed facility for the evaluation of selected brine treatment technologies applicable to ARM for carbon capture, utilization, and storage (CCUS)

- Three development stages
  1. Site preparation and construction (active)
  2. Site operations including ARM and extracted brine treatment technology testing and demonstration
  3. Project closeout/decommissioning and data processing and reporting

STATUS

Phase I – Complete

- Regional characterization
- Site screening and feasibility study
- Site selection
- Geologic modeling
- Reservoir simulation resulting in ARM schema
- Site infrastructure design and field implementation plan

Phase II – Under Way

- ARM site preparation
  - Permitting
  - Well drilling
  - Surface infrastructure installation
  - Site characterization/model updates
- Brine treatment test bed site preparation
  - Permitting
  - Test bed facility installation
  - Seek treatment technologies
- ARM operation
  - Execute FIP (injection/extraction)
  - Conduct monitoring, verification, and accounting (MVA)
  - Model updates/history matching
- Test bed treatment operations
  - Facility shakedown/training
  - Treatment technology selection
  - Conduct testing/evaluation of selected technologies
- ARM site closeout
  - ARM site decommissioning
  - ARM test results/data reporting
- Brine treatment test bed closeout
  - Decommissioning
  - Test bed results/data reporting

GEOLOGIC CO_2 STORAGE

COMMERCIAL CONSIDERATIONS

- Buoyant fluid
- Large volumes = large footprint
- Regulatory compliance, liability, cost
- Conformance and utilization efficiency
- Access to pore space
  - Leasing, unitization/amalgamation, trespass
- Assuring permanence and credits

Because of a host of technical, social, regulatory, environmental, and economic factors, brine disposal tends to be more accessible and generally quicker, easier, and less costly to implement compared to dedicated CO_2 storage.

Brine extraction can enable dedicated CO_2 storage and improve the geologic CO_2 storage potential of a site.

PARTNERS

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

EERC

Nuverra Environmental Solutions

CMG

Schlumberger Carbon Services

MAJOR CONTRACTORS

AE2S CONSTRUCTION

AE2S INDUSTRIAL

HAM'S WELL SERVICE WESTHOPE, ND

This material is based upon work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Award No. DE-FE0026160.

TWO COMPLEMENTARY COMPONENTS

<u>ARM Test</u>
- Reduce stress on sealing formation
- Geosteer injected fluids
- Divert pressure from leakage pathways
- Reduce area of review (AOR)
- Improve injectivity, capacity, and storage efficiency
- Validate monitoring techniques, and forecast model capabilities

<u>Brine Treatment Test Bed</u>
- Alternate source of water
- Reduced disposal volumes
- Salable products for beneficial use

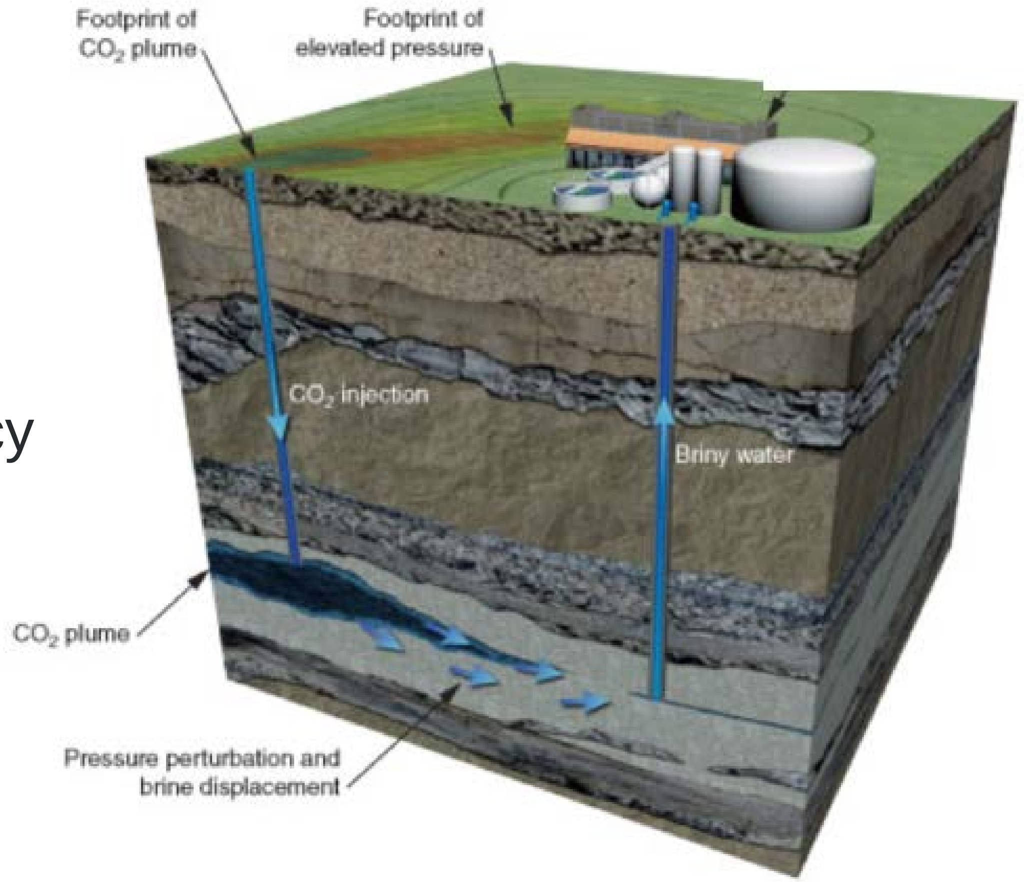
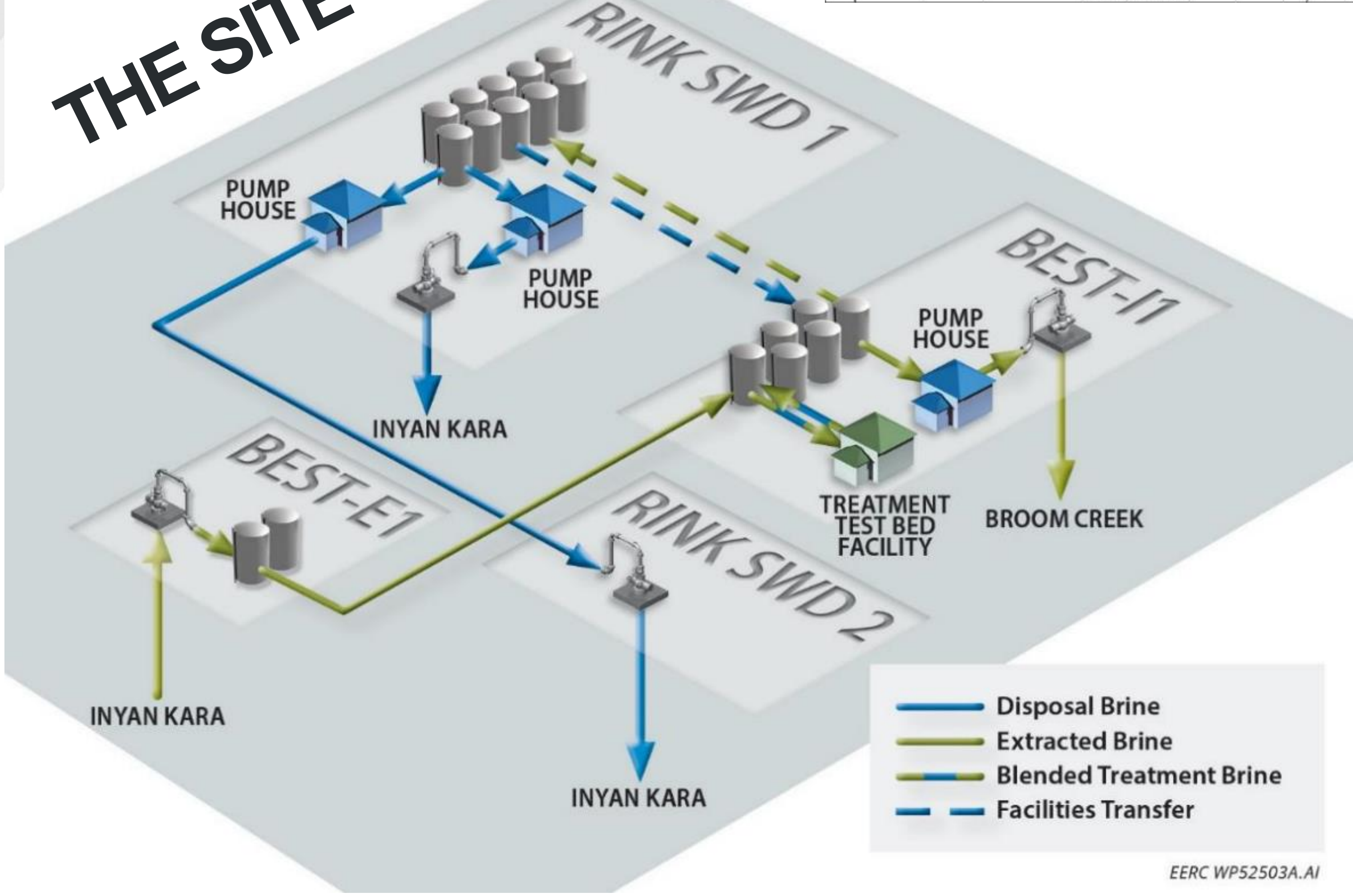
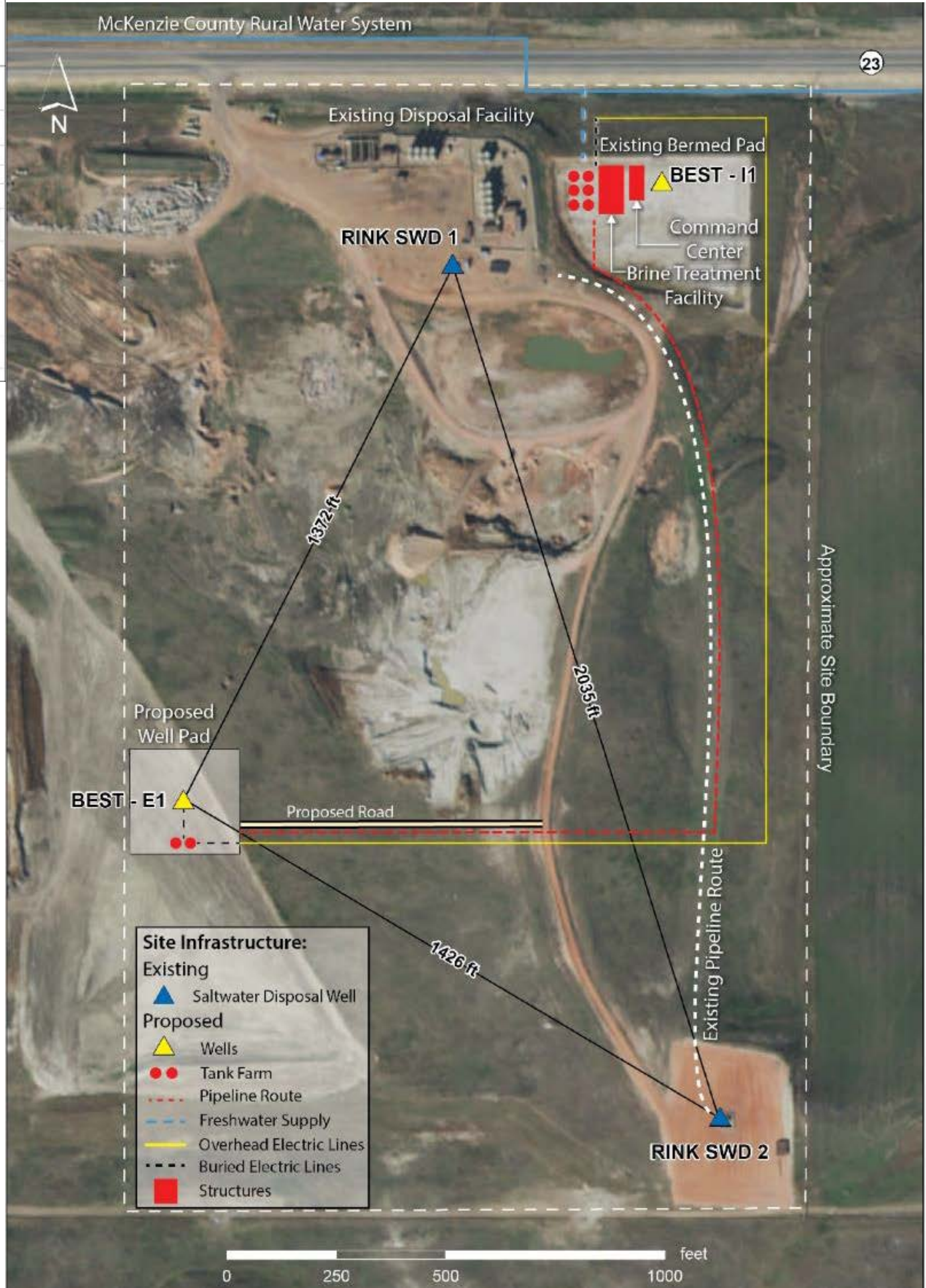


Illustration modified from Lawrence Livermore National Laboratory https://str.llnl.gov/Dec10/aines.html

THE SITE


Saskatchewan
Manitoba
CANADA
UNITED STATES
Williston
Minot
BEST Site
North Dakota
Grand Forks
Minnesota
Montana
Bismarck
Dickinson
Fargo
South Dakota
0 40 80 miles
0 50 100 kilometers


RINK SWD 1
PUMP HOUSE
PUMP HOUSE
INYAN KARA
BEST-I1
PUMP HOUSE
TREATMENT TEST BED FACILITY
BROOM CREEK
BEST-E1
RINK SWD 2
INYAN KARA
INYAN KARA
Disposal Brine
Extracted Brine
Blended Treatment Brine
Facilities Transfer
EERC WP52503A.AI


McKenzie County Rural Water System
23
N
Existing Disposal Facility
Existing Bermed Pad
BEST - I1
Command Center
Brine Treatment Facility
RINK SWD 1
1372 ft
2035 ft
Proposed Well Pad
BEST - E1
Proposed Road
1426 ft
Approximate Site Boundary
Existing Pipeline Route
RINK SWD 2
Site Infrastructure:
Existing
Saltwater Disposal Well
Proposed
Wells
Tank Farm
Pipeline Route
Freshwater Supply
Overhead Electric Lines
Buried Electric Lines
Structures
feet
0 250 500 1000

REGIONAL CHALLENGES

EXTRACTED WATER TREATMENT

Technological

- Very high salinity brines (100,000 to >350,000 mg/L TDS).
- Potential for TENORM (technologically enhanced naturally occurring radioactive material) in treated concentrate streams.

Logistical

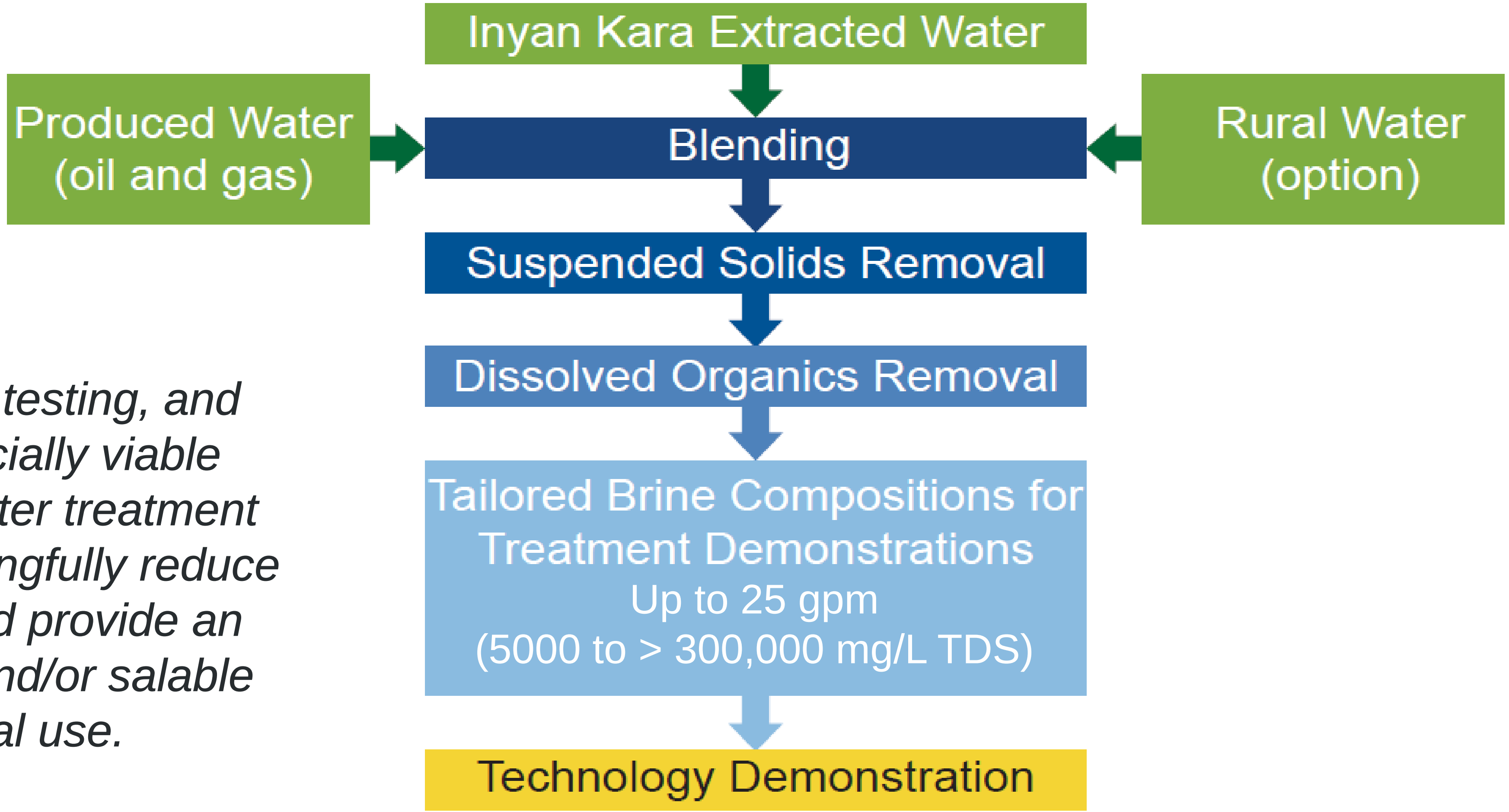
- Environmental conditions.
  - e.g., **Winter!**
- Temporary storage.

Economic

- Geologic injection is cost-efficient and convenient.
- Fresh water is inexpensive and abundant.
- Limited current demand for brine treatment.

User facility can replicate extracted waters that are representative of locations/sources throughout United States.

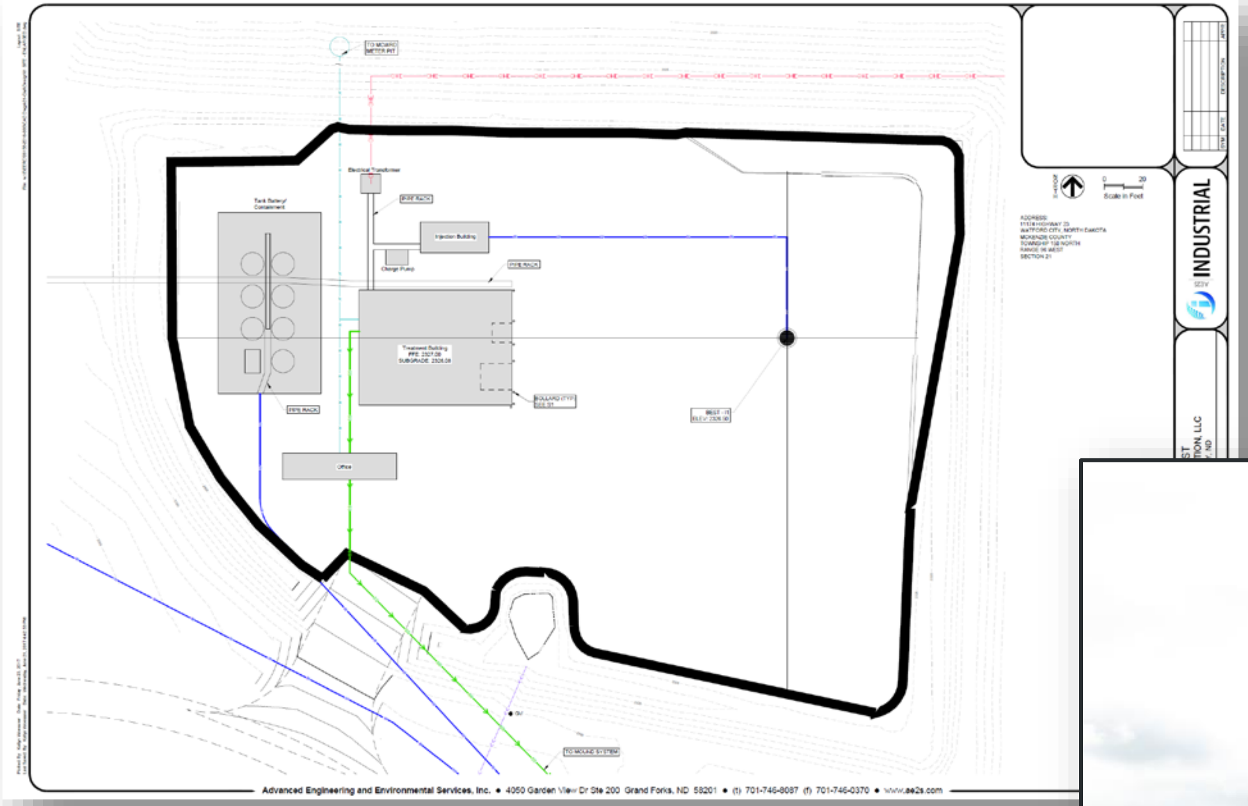
BRINE TREATMENT TEST BED



Enable development, pilot testing, and advancement of commercially viable extracted and produced water treatment technologies that can meaningfully reduce brine disposal volumes and provide an alternate source of water and/or salable products for beneficial use.

- Permanently installed environmental enclosure
- Concrete floor integrated with ARM and SWD infrastructure
- Pilot treatment rates up to 25 gpm (bench to pilot)
- Pretreatment
- Technology demonstration bay

WATER TREATMENT DEMONSTRATION FACILITY AND COMMAND CENTER



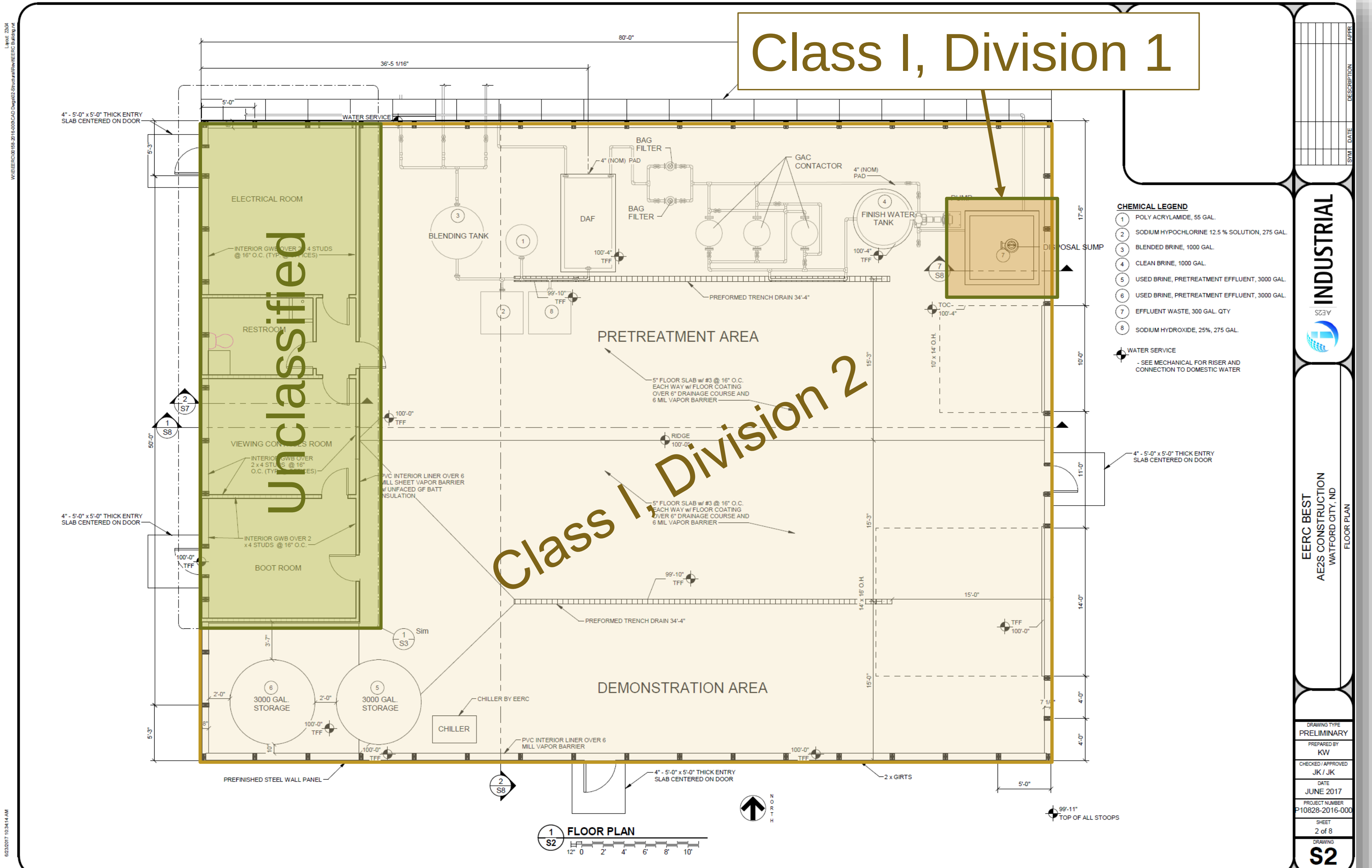
60 ft x 80 ft (18-ft walls)

Two overhead doors

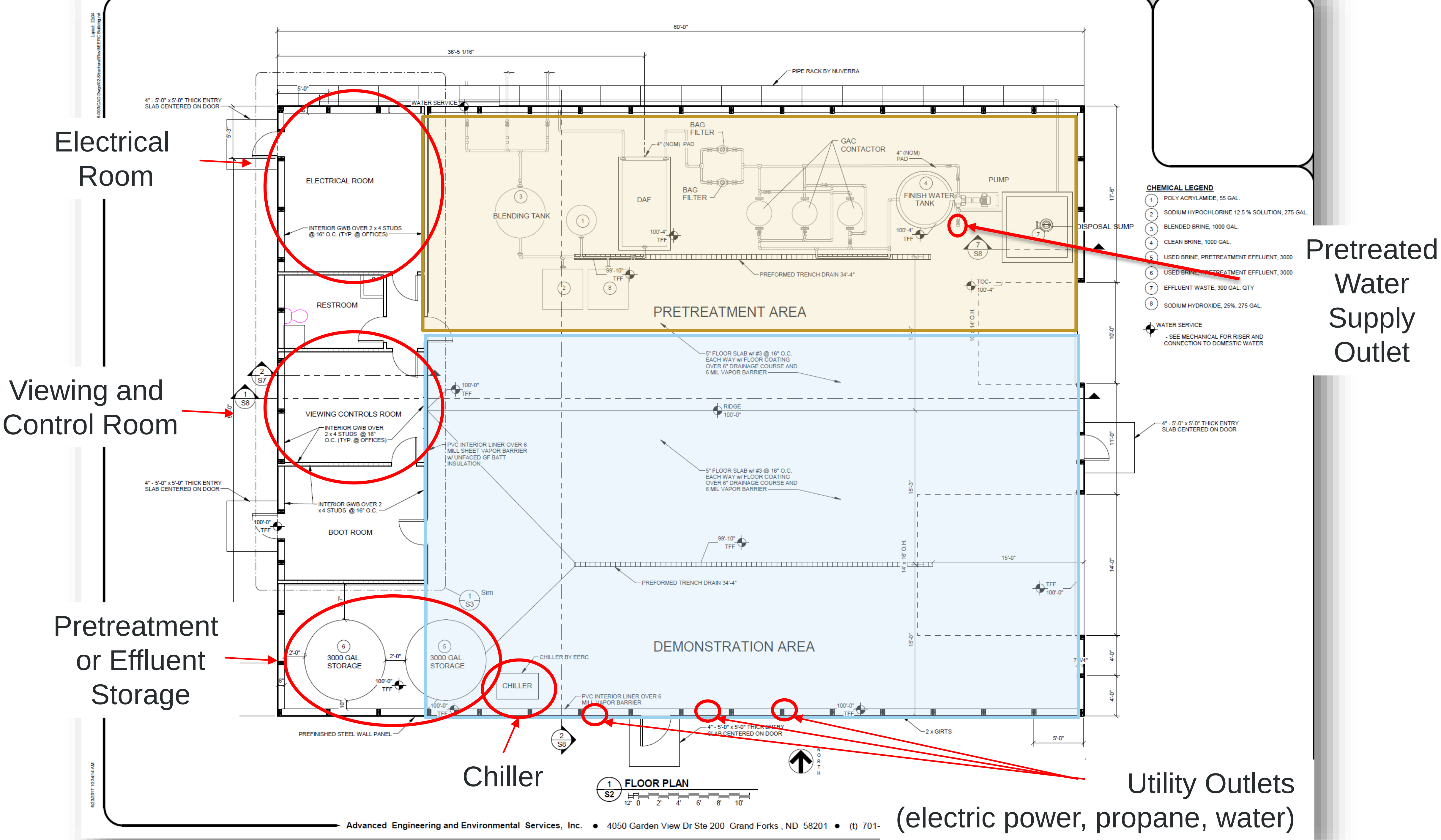
Heated environmental enclosure

Air handling/exchange

53-ft demonstration bay



Class I, Division 1
Unclassified
Class I, Division 2
80'-0"
36'-5 1/16"
5'-0"
4" - 5'-0" x 5'-0" THICK ENTRY SLAB CENTERED ON DOOR
WATER SERVICE
ELECTRICAL ROOM
RESTROOM
VIEWING CONTROLS ROOM
BOOT ROOM
BAG FILTER
4" (NOM) PAD
GAC CONTACTOR
DAF
BLENDING TANK
FINISH WATER TANK
DISPOSAL SUMP
PUMP
PREFORMED TRENCH DRAIN 34'-4"
PRETREATMENT AREA
DEMONSTRATION AREA
5" FLOOR SLAB w/ #3 @ 16" O.C. EACH WAY w/ FLOOR COATING OVER 6" DRAINAGE COURSE AND 6 MIL VAPOR BARRIER
PVC INTERIOR LINER OVER 6 MILL SHEET VAPOR BARRIER w/ UNFACED GF BATT INSULATION
PVC INTERIOR LINER OVER 6 MILL VAPOR BARRIER
RIDGE 100'-0"
3000 GAL. STORAGE
3000 GAL. STORAGE
CHILLER BY EERC
CHILLER
PREFINISHED STEEL WALL PANEL
2 x GIRTS
99'-11" TOP OF ALL STOOPS
CHEMICAL LEGEND
1 POLY ACRYLAMIDE, 55 GAL.
2 SODIUM HYPOCHLORINE 12.5 % SOLUTION, 275 GAL.
3 BLENDED BRINE, 1000 GAL.
4 CLEAN BRINE, 1000 GAL.
5 USED BRINE, PRETREATMENT EFFLUENT, 3000 GAL.
6 USED BRINE, PRETREATMENT EFFLUENT, 3000 GAL.
7 EFFLUENT WASTE, 300 GAL. QTY
8 SODIUM HYDROXIDE, 25%, 275 GAL.
WATER SERVICE
- SEE MECHANICAL FOR RISER AND CONNECTION TO DOMESTIC WATER
FLOOR PLAN
INDUSTRIAL
EERC BEST
AE2S CONSTRUCTION
WATFORD CITY, ND
FLOOR PLAN
DRAWING TYPE PRELIMINARY
PREPARED BY KW
CHECKED / APPROVED JK / JK
DATE JUNE 2017
PROJECT NUMBER P10828-2016-000
SHEET 2 of 8
DRAWING S2



Electrical Room
Viewing and Control Room
Pretreatment or Effluent Storage
Chiller
Utility Outlets (electric power, propane, water)
Pretreated Water Supply Outlet
ELECTRICAL ROOM
RESTROOM
VIEWING CONTROLS ROOM
BOOT ROOM
PRETREATMENT AREA
DEMONSTRATION AREA
BLENDING TANK
DAF
BAG FILTER
GAC CONTACTOR
FINISH WATER TANK
PUMP
DISPOSAL SUMP
3000 GAL. STORAGE
CHILLER
CHILLER BY EERC
PIPE RACK BY NUVERRA
WATER SERVICE
PREFORMED TRENCH DRAIN 34'-4"
PREFINISHED STEEL WALL PANEL
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6 USED BRINE, PRETREATMENT EFFLUENT, 3000
7 EFFLUENT WASTE, 300 GAL. QTY
8 SODIUM HYDROXIDE, 25%, 275 GAL.
1 FLOOR PLAN S2
Advanced Engineering and Environmental Services, Inc. • 4050 Garden View Dr Ste 200 Grand Forks , ND 58201 • (t) 701-

Temporary Water Storage Tanks for Demonstration Supply/Reinjection

SWD Facility Supplies High-TDS Blend Water to Treatment Facility

BEST-E1 Provides Medium-TDS Blend Water to Treatment Facility

Water Blending and Pretreatment

Water blending leverages:

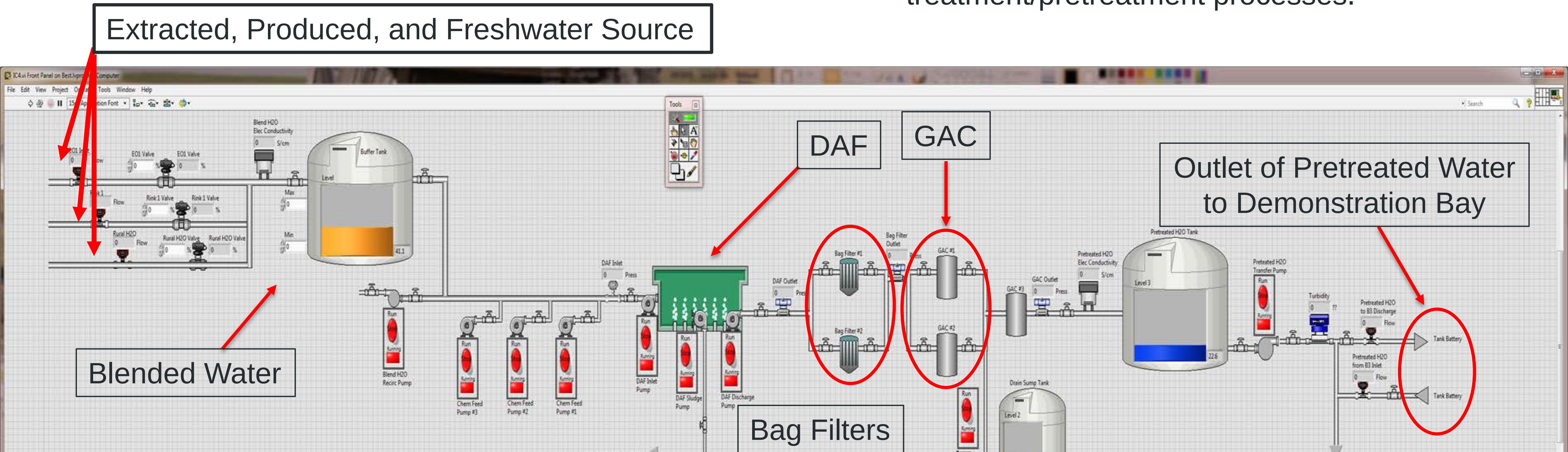
- Produced water (~300,000 mg/L TDS)
- Extracted formation water (~100,000 mg/L TDS)
- Fresh water

Available on-site to generate tailored brine compositions

BLENDING AND PRETREATMENT

Blending of water to target TDS level of 180,000 mg/L or tailored blends ranging between <5000 mg/L TDS to >300,000 mg/L TDS to suit capabilities and/or limitations of selected technologies.

- Suspended solids removal (dissolved air flotation [DAF]).
- Filter bags.
- Dissolved organics removal (granular activated carbon [GAC]).
- Facility can be adapted for use with alternate fluid compositions and treatment/pretreatment processes.



Water Blending and Pretreatment

Finished Water Supply for Demonstrations

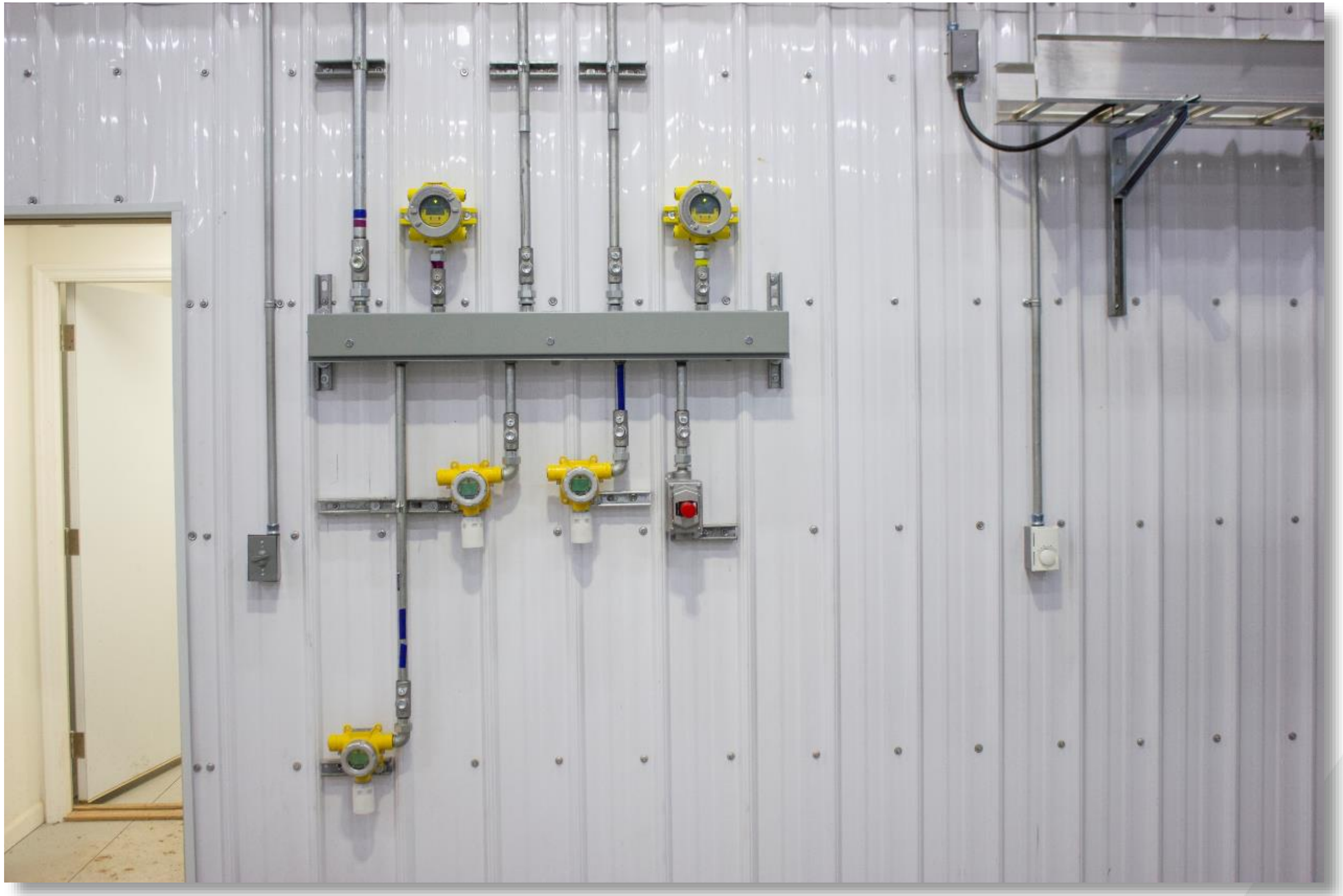
Demonstration Bay and Effluent Storage

- Sized to accommodate up to a semitractor trailer (53-ft-long)-sized demonstration
- 300 kW electric power
- Propane (5000-gal tank)
- Noncontact cooling water (30 gpm)

Demonstration Bay

Hazardous Environment Detection and Alarm

- Shunts power to demonstration area in event of hazardous atmosphere.
- Allows nonrated technology to be operated in test bay.
- Hazard assessment of each technology still required.



ELECTRICAL ROOM WITH SCADA SYSTEM JUNCTION BOX

SCADA System Operations Control Room

- Influent and effluent flow rates and composition
- Chemical usage
- Energy & thermal use/load
- HSE and operability systems (e.g., pretreatment systems, hazardous environmental monitoring…)
- Remote real-time secure access

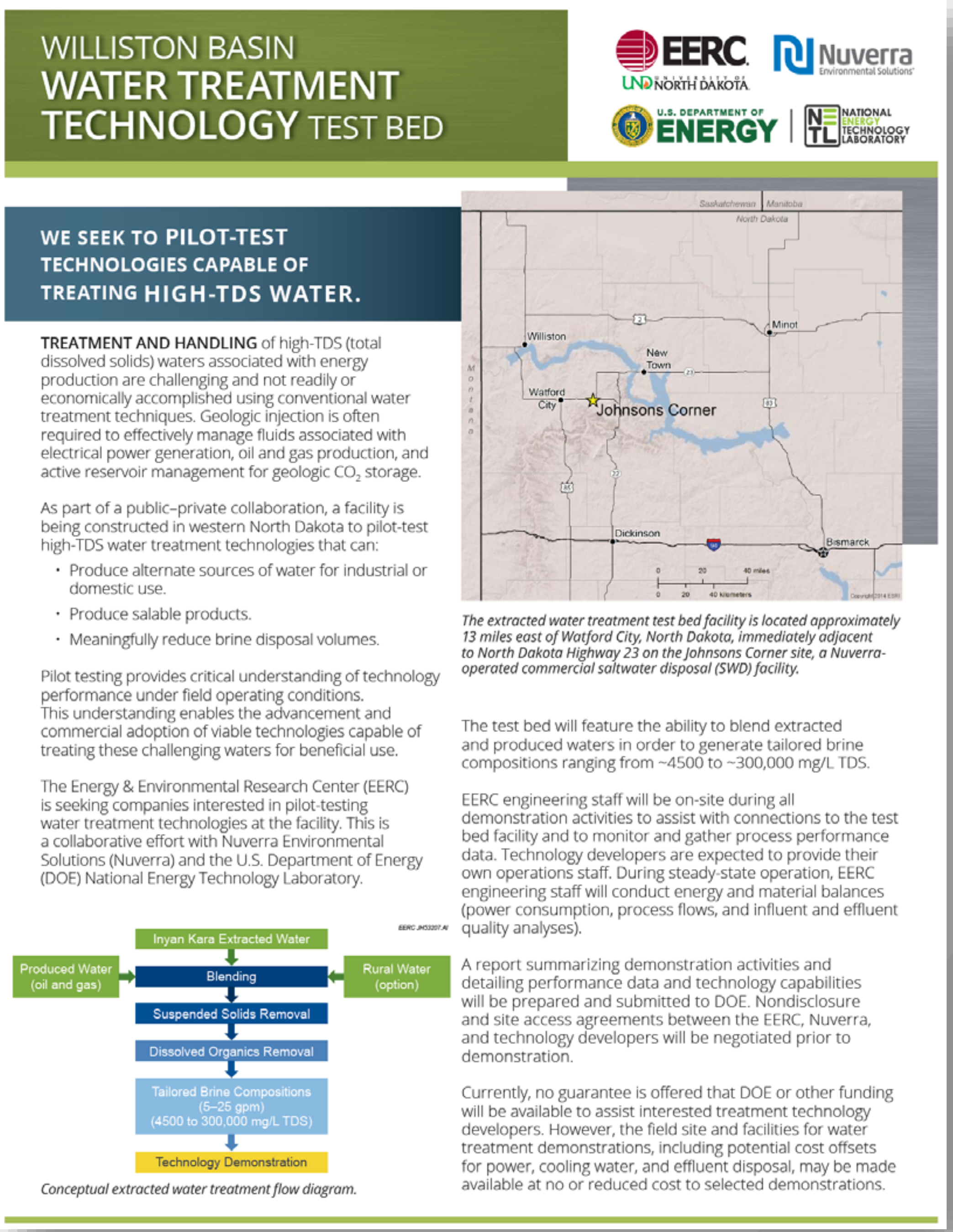
NEXT STEPS

SEEKING BRINE TREATMENT TECHNOLOGIES FOR DEMONSTRATION

- NETL, EPRI, and the EERC cooperatively define water treatment goals and solicit technologies for pilot testing:
  - Fact sheet, questionnaire, and selection criteria.
  - Several responses, engagement ongoing, actively seeking technology demonstrations.
- The North Dakota and Florida facilities offer unique opportunities to demonstrate water treatment technologies.
- The EERC test bed will be operational by June 2019.

Possible Technology Provider Workshop

Spring/Summer 2019



WILLISTON BASIN
WATER TREATMENT TECHNOLOGY TEST BED

WE SEEK TO PILOT-TEST TECHNOLOGIES CAPABLE OF TREATING HIGH-TDS WATER.

TREATMENT AND HANDLING of high-TDS (total dissolved solids) waters associated with energy production are challenging and not readily or economically accomplished using conventional water treatment techniques. Geologic injection is often required to effectively manage fluids associated with electrical power generation, oil and gas production, and active reservoir management for geologic CO_2 storage.

As part of a public–private collaboration, a facility is being constructed in western North Dakota to pilot-test high-TDS water treatment technologies that can:

- Produce alternate sources of water for industrial or domestic use.
- Produce salable products.
- Meaningfully reduce brine disposal volumes.

Pilot testing provides critical understanding of technology performance under field operating conditions. This understanding enables the advancement and commercial adoption of viable technologies capable of treating these challenging waters for beneficial use.

The Energy & Environmental Research Center (EERC) is seeking companies interested in pilot-testing water treatment technologies at the facility. This is a collaborative effort with Nuverra Environmental Solutions (Nuverra) and the U.S. Department of Energy (DOE) National Energy Technology Laboratory.

Conceptual extracted water treatment flow diagram.

The extracted water treatment test bed facility is located approximately 13 miles east of Watford City, North Dakota, immediately adjacent to North Dakota Highway 23 on the Johnsons Corner site, a Nuverra-operated commercial saltwater disposal (SWD) facility.

The test bed will feature the ability to blend extracted and produced waters in order to generate tailored brine compositions ranging from ~4500 to ~300,000 mg/L TDS.

EERC engineering staff will be on-site during all demonstration activities to assist with connections to the test bed facility and to monitor and gather process performance data. Technology developers are expected to provide their own operations staff. During steady-state operation, EERC engineering staff will conduct energy and material balances (power consumption, process flows, and influent and effluent quality analyses).

A report summarizing demonstration activities and detailing performance data and technology capabilities will be prepared and submitted to DOE. Nondisclosure and site access agreements between the EERC, Nuverra, and technology developers will be negotiated prior to demonstration.

Currently, no guarantee is offered that DOE or other funding will be available to assist interested treatment technology developers. However, the field site and facilities for water treatment demonstrations, including potential cost offsets for power, cooling water, and effluent disposal, may be made available at no or reduced cost to selected demonstrations.

TECHNOLOGY DEMONSTRATION

OPERATIONS

- Technology selection.
- Negotiate site access agreement and contacting for selected technology.
- Hazard and operability assessment of selected technology.
- Scheduled demonstration (consideration for site operability and technology provider needs).
  - Operations will be preferentially scheduled to coincide with appropriate periods of Inyan Kara water extraction and/or other efficient operating windows whenever possible.
- Prepare test bed and staffing schedule, receive consumables.
- Shakedown pretreatment equipment prior to demonstration.
- Selected technologies connected to the test bed facility – electric, propane, cooling water, instrumentation (EERC assistance to ensure operability and HSE requirements are satisfied).
  - Technology providers to provide operations staff, with assistance by EERC staff.
    - ♦ Technology providers operate their technology under EERC supervision.
    - ♦ EERC operate test bed facility to accommodate technology demonstration needs.
- During steady-state operation, EERC staff will conduct energy and material balances (power consumption, process flows, influent and effluent quality analyses).
- Extended operating periods (30 to 60 days) with consideration for operational and maintenance requirements.
- Effluent and treated water will be blended and reinjected where possible; waste streams unable to be reinjected will be disposed of at an authorized facility.

2019

- Test bed operational June 2019.
- Seeking technology providers for testing at North Dakota BEST site.
- First technology selection and scheduled by fall 2019.

2020

- Seeking technology providers for testing at EERC's BEST site.
- Preferred operations in spring, summer, or fall.
- Operational until September 2021.

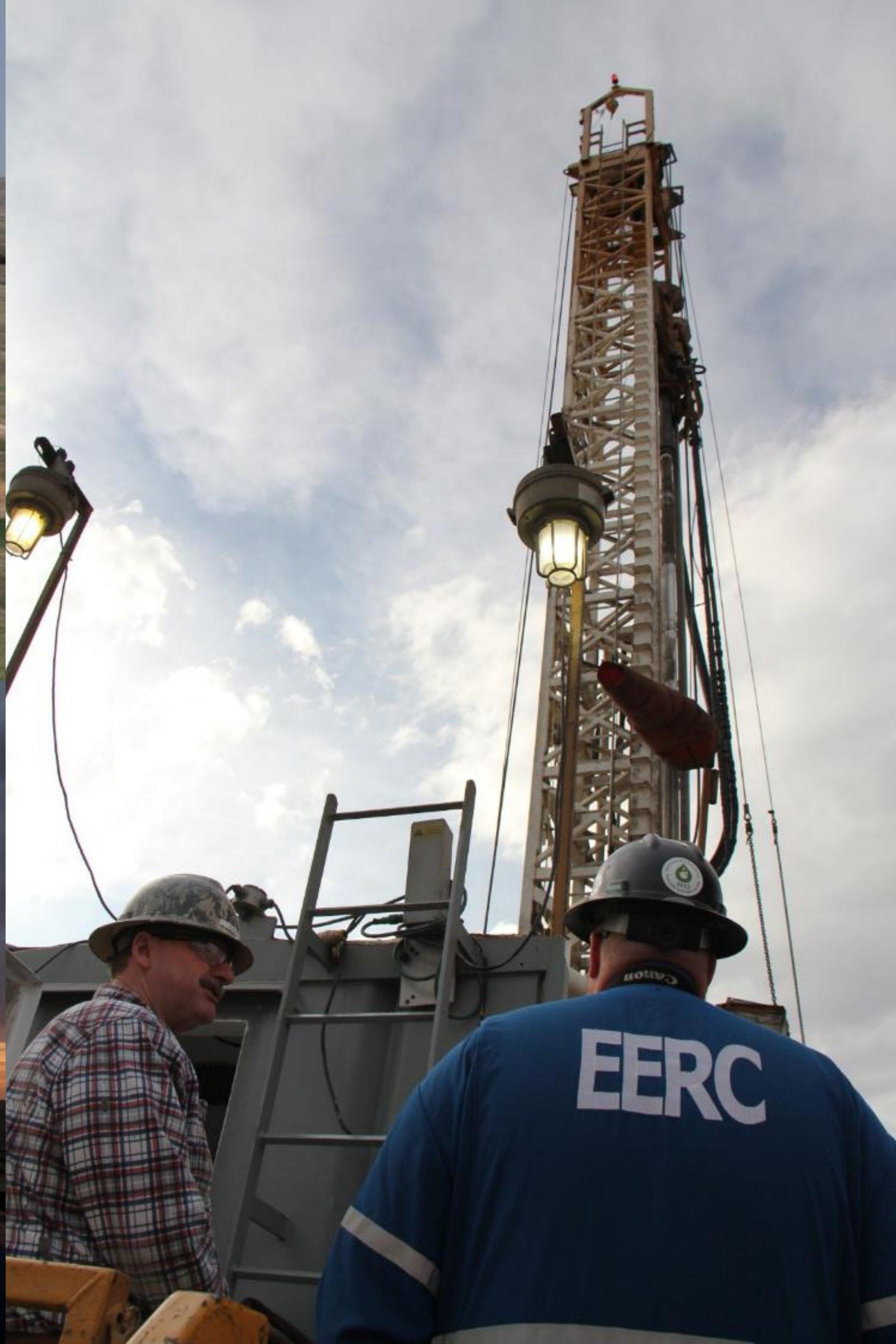
2021

- Decommissioning of test bed anticipated September 2021.

North Dakota Brine Treatment User Facility Operating Time Frame

Top-ranked technologies may benefit from cost offsets.

ACCOMPLISHMENTS



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NORTH DAKOTA BRINE TREATMENT USER FACILITY

OPPORTUNITIES FOR LEVERAGING INVESTMENT

- Technology providers indicate limited resources and incentives for technology development for CCUS-related brine treatment demonstration.

- Facility can be readily adapted for use with alternate fluid compositions or treatment processes.
  - Alternate water sources trucked and offloaded at site.
  - Pretreatment and conditioning can be modified to replicate broader influent specifications.
  - Blending of alternate fluid chemistries for demonstration of water or chemical treatment processes.
  - Enabling technologies (e.g., power/thermal supply, pretreatment/conditioning…).
  - On-site SWD and waste handling.

NORTH DAKOTA BRINE TREATMENT USER FACILITY

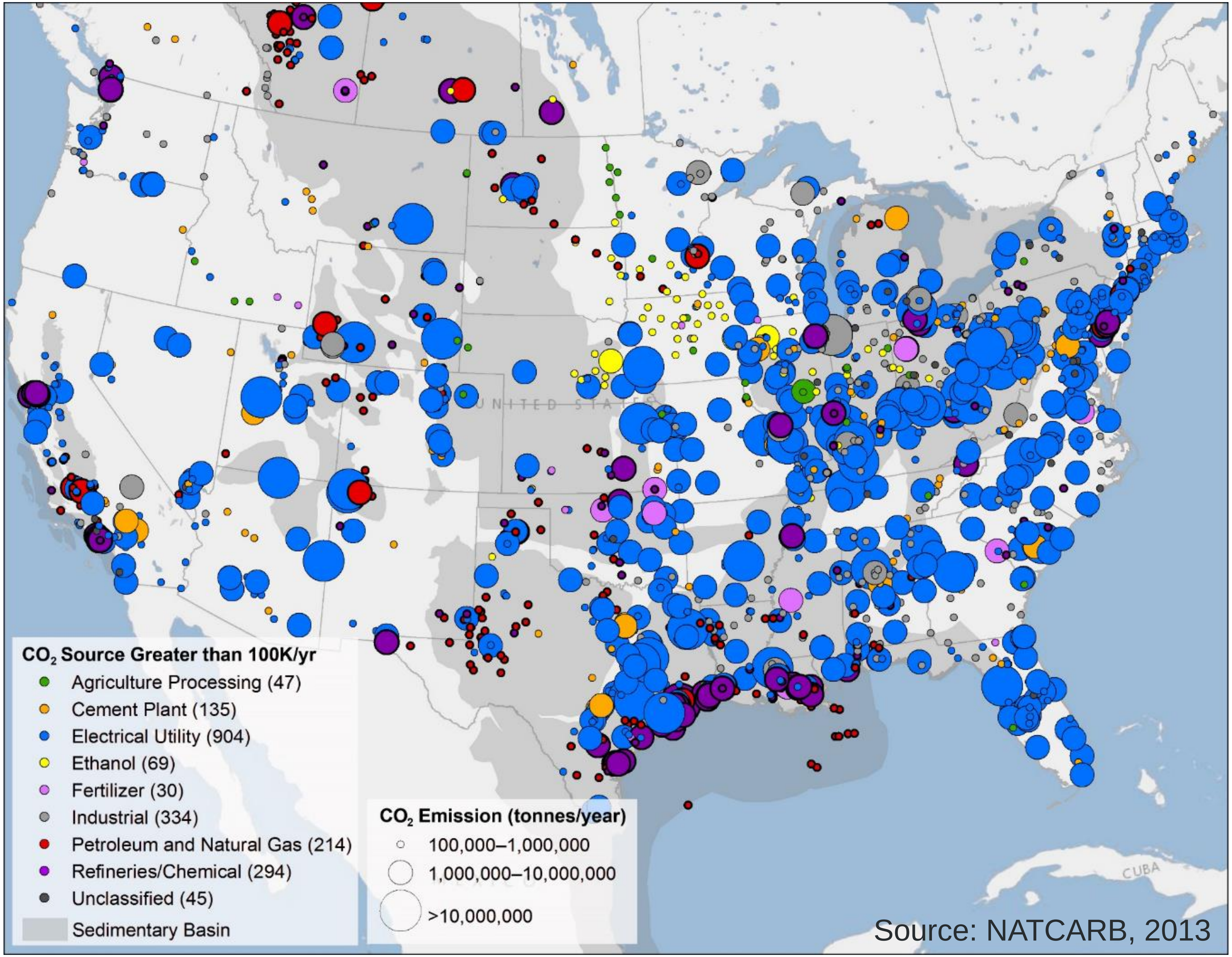
OPPORTUNITIES FOR LEVERAGING INVESTMENT

Adaptable Facility
for Technology Demonstration

- Oil and gas fluid conditioning (e.g., emulsion breaking, corrosion, scale inhibitors, fluid compatibility testing, etc.) and produced water treatment.
- High-value material extraction and/or mineral resource recovery.
- Electric power generation wastewater treatment.
- Industrial and municipal waste and water treatment.
- Agricultural water treatment.
- Geologic filtering, conditioning and homogenization as a means of water pretreatment.
- Synergistic opportunities with other federal, state, or industry groups.
- Benchmarking the economic and technical limits of water treatment technologies (e.g., mechanical vapor recompression [MVR]).

CO_2 Point Sources with Emissions Greater Than 100,000 metric tons/year

Many industrial point sources of anthropogenic CO_2 are located in proximity to sedimentary basins that are geologic CO_2 storage candidates.



Source: NATCARB, 2013

Brine extraction can enable dedicated CO_2 storage and improve the geologic CO_2 storage potential of a site.

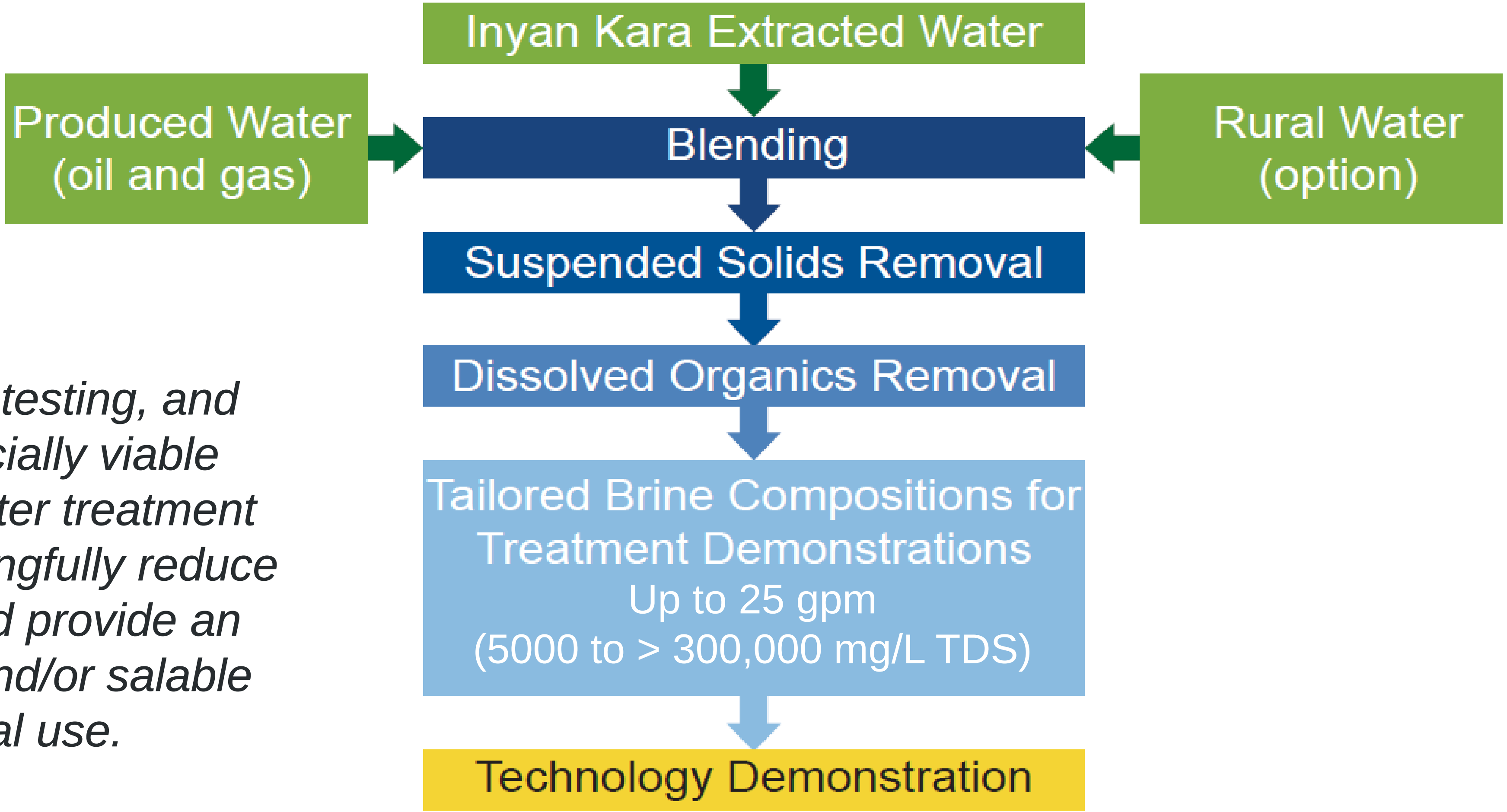
Because of a host of technical, social, regulatory, environmental, and economic factors, brine disposal tends to be more accessible and generally quicker, easier, and less costly to implement compared to dedicated CO_2 storage.

Brine treatment:

Provides alternate sources of water.
Reduces disposal volumes.
Creates salable products for beneficial use.

BRINE TREATMENT TEST BED

Enable development, pilot testing, and advancement of commercially viable extracted and produced water treatment technologies that can meaningfully reduce brine disposal volumes and provide an alternate source of water and/or salable products for beneficial use.



SEEKING

Brine Treatment Technologies for Demonstration

DISCLAIMER

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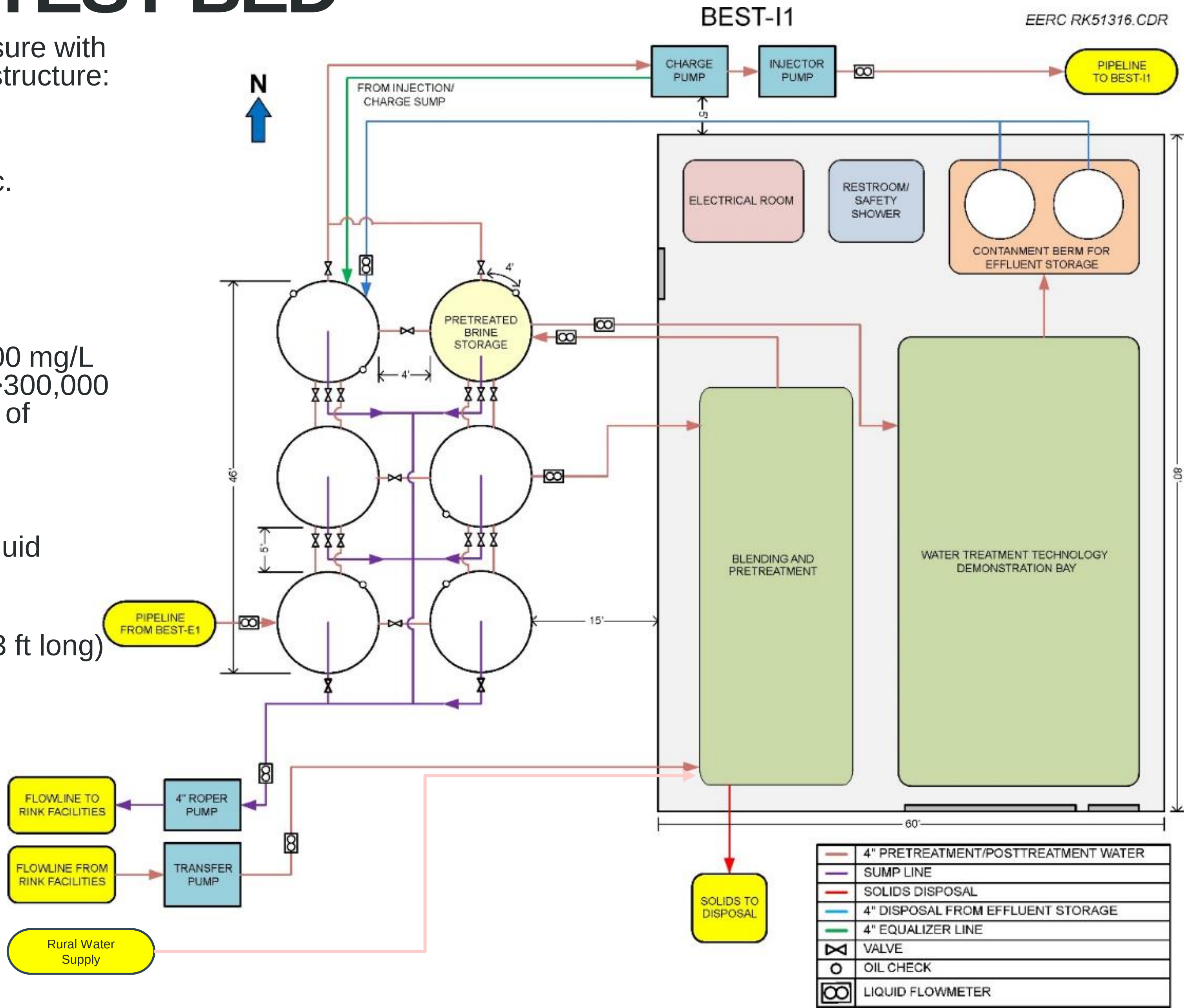
THANK YOU

Critical Challenges. Practical Solutions.

BRINE TREATMENT TEST BED

- Permanently installed heated environmental enclosure with concrete floor integrated with ARM and SWD infrastructure:
  - 30–60⁺-day extended-duration tests.
  - 24/7/365 operations-capable.
  - Monitoring of energy, flow, chemical usage, etc.
  - Waste management and SWD on-site.
  - Workspace, control room, restroom.
- Pilot treatment rates up to 25 gpm.
- Pretreatment:
  - Blending of water to target TDS level of 180,000 mg/L or tailored blends ranging between <5000 to >300,000 mg/L TDS to suit capabilities and/or limitations of selected technologies.
  - Suspended solids removal (DAF).
  - Dissolved organics removal (GAC).
  - Facility can be adapted for use with alternate fluid compositions and treatment processes.
- Technology demonstration bay:
  - Accommodates standard semitractor trailer (53 ft long) inside the building.
  - 300 kW electric power.
  - Propane (5000-gal tank).
  - Noncontact cooling water (30 gpm).



EMERGING BRINE TREATMENT TECHNOLOGIES

- Treatment technologies for high-salinity brines continue to evolve, but few have been tested at commercial scale.
- Most technologies fall into four main categories or a combination of categories:
  - Evaporation/distillation
  - Evaporation/crystallization
  - Membrane treatment
  - Freezing-based treatment

TREATMENT TECHNOLOGY

SELECTION PROTOCOL

- Screening criteria:
  - Ability to produce a beneficial use effluent or product at reasonable operating costs based on target influent water quality.
  - Enable successful operation of other technologies (i.e., pretreatment).
  - Provide a relatively high yield of treated water or product.
  - Significantly reduce the volume of fluids requiring subsequent disposal.
  - Not produce hazardous by-products.

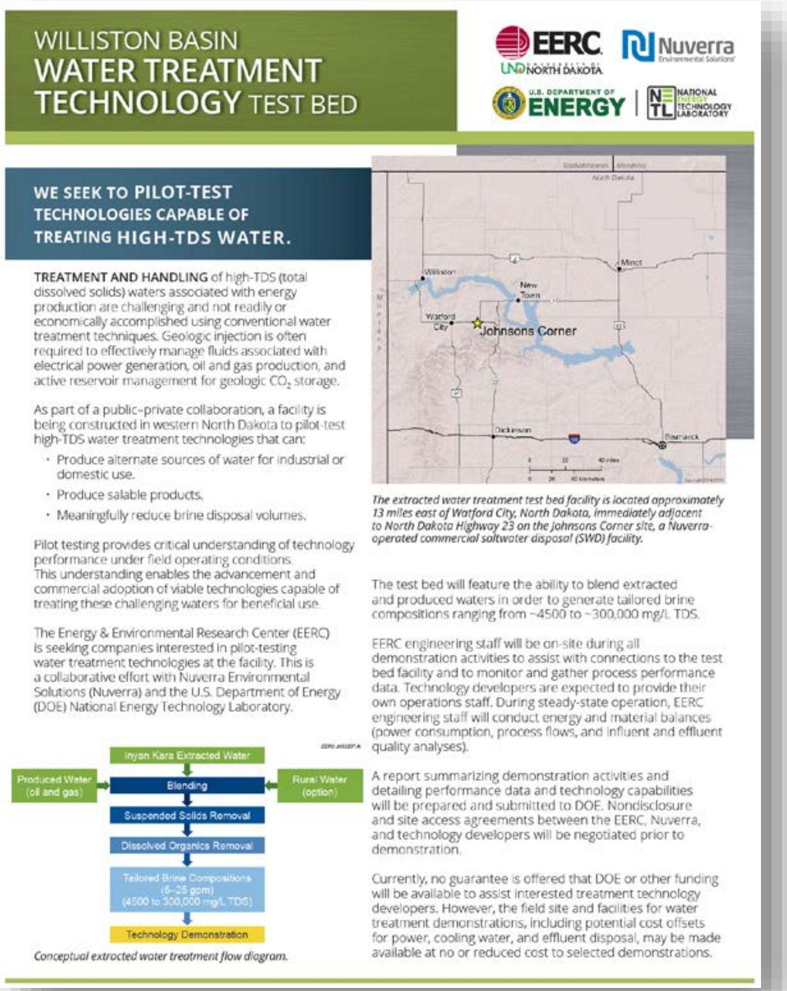
- Ranking factors:
  - Treatment costs (40%).
  - Readiness level (30%).
  - Safety considerations (20%).
  - Waste generation (10%).

NEXT STEPS

- M13 – Water Treatment Test Bed Fully Operational (anticipated by June 1, 2019)
- M7 – First Treatment Technology Selected (anticipated before August 31, 2019)
- D4 – Preliminary Schedule of Technologies (anticipated before August 31, 2019)
- M15 – First Treatment Technology Evaluated (anticipated before December 31, 2019)

TECHNOLOGY PROVIDERS ENGAGED

- The EERC and EPRI collaborated with NETL to develop list of potential technology providers, a treatment technology screening questionnaire, project fact sheets, and a technology demonstration screening and selection process.
  - The EERC and EPRI are collaborating on engagement with potential brine treatment technology providers .
  - Technology providers were contacted and provided with the project fact sheets and questionnaire between April and June 2018.
- Several responses.
- Engagement is ongoing.



WILLISTON BASIN
WATER TREATMENT
TECHNOLOGY TEST BED

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<u>Technology Providers Contacted by EERC</u>

- ABR Process Development
- AE_2S, Inc.
- Caloris Thermal Process Technology
- Encon Evaporators
- Illinois State Geological Survey
  - University of Illinois at Urbana-Champaign
- Los Alamos National Laboratory
- Mantra Energy Alternatives
- MGX Minerals
- NETL
- Nuverra Environmental Solutions, Inc.
- Oasys Water
- Ohio University
  - Russ College of Engineering and Technology
- RTI International
- RWL Water
- GE Global Research
- Slipstream ZLD
- University of Pittsburgh
  - Department of Civil and Environmental Engineering

DIRECT PROJECT CHALLENGES

- **Geologic**
  - Completion of additional Amsden interval (BEST-I1) to meet FIP injection target.
- **Change in market conditions**
  - Project planned during a regional market depression (February 2016), work performed during a regional market peak (spring and fall 2018).
    - Availibity of services (i.e., increased wait time, reduction in efficiency).
    - Cost escalation of tangibles and services.
- **Operational**
  - Muddy conditions required additional site preparation.
  - Spring load restrictions requiring overweight permits (drilling).
  - Efficiency (e.g., unplanned wiper trips and cleanouts, reduced penetration rate due to smaller mud motors, etc.).
  - Availability of services/service efficiency (e.g., ESP procurement, third-party equipment failures, wait time for third-party services, etc.).
  - Shorter days reduced efficiency during well completion (daylight operation).
- **Extended site preparation**
  - Longer-than-anticipated time line for securing permits, site access agreements, and contracting of third-party services (e.g., drilling contractor).
  - Multiple plan revisions and re-compete of tangibles and services.