Phase II Field Demonstration at Plant Smith Generating Station: Assessment of Opportunities for Optimal Reservoir Pressure Control, Plume Management and Produced Water Strategies

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Presentation Outline

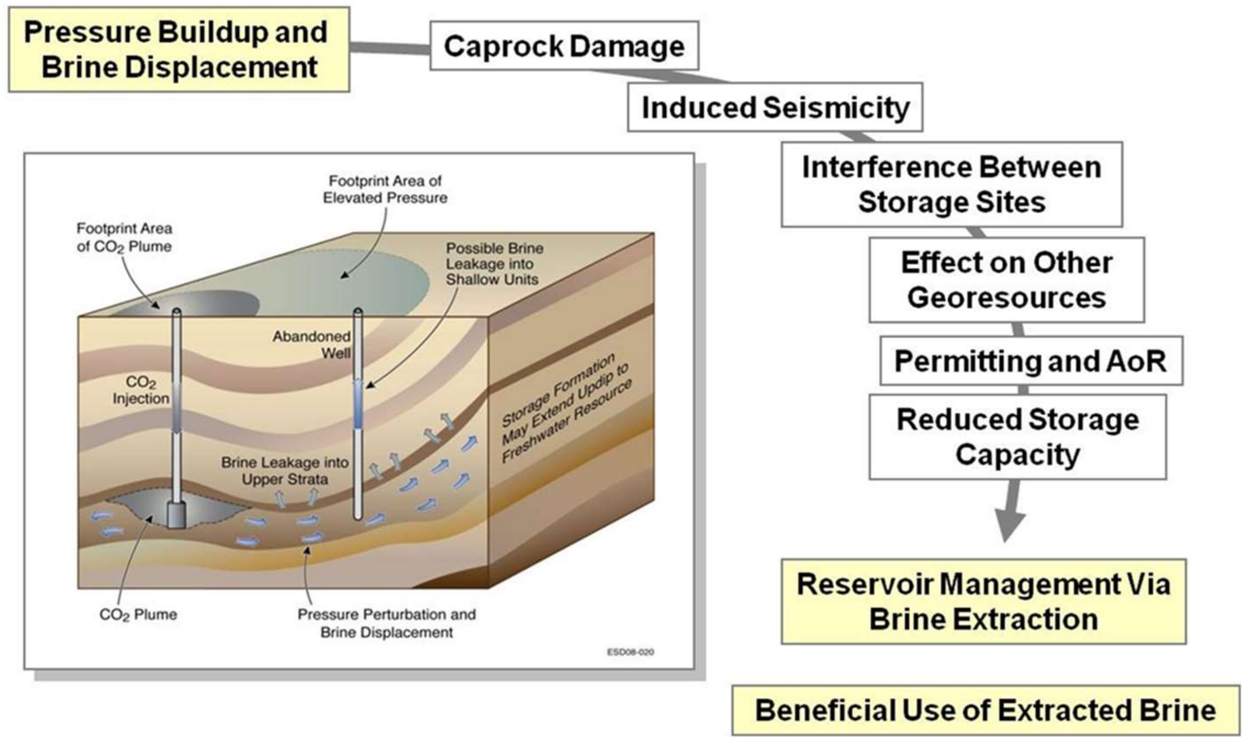
- Project Goals and Objectives
- Project Location
- Technical Objectives
- Scope
  - Experimental Design
  - Infrastructure Design
  - Permitting
  - Water Treatment User Facility
- Accomplishments to Date
- Project Summary

Photographs of existing Gulf Power wellfield. Photos clockwise from upper left: Eocene Injection well EIW-4; graveled access road; pump station under construction; cleared and permitted drilling pad location for future well

Project Overview—Goals and Objectives

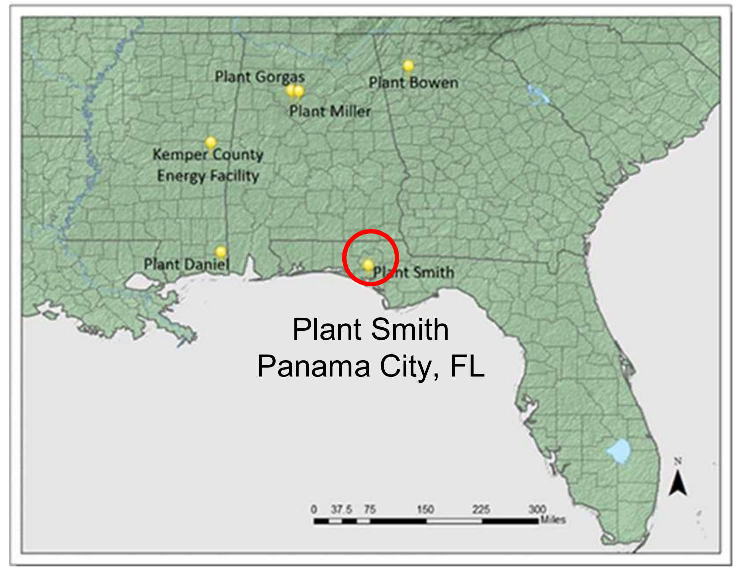
- Objective : Develop cost effective pressure control, plume management and produced water strategies for: 1) Managing subsurface pressure; 2) Validating treatment technologies for high salinity brines

Pressure management practices are needed to avoid these risks. Brine extraction is a possible remedy for reducing or mitigating risk



Phase I Site Screening and Down Selection Resulted in Selection of Plant Smith

- Evaluated existing geologic, geophysical and hydrologic data in the vicinity of each site, including
  - Well records, logs, core data, regional structural and stratigraphic studies and subsurface production/injection data
- Examined existing surface infrastructure at each plant
- Gaged plant commitment to hosting the BEST project
- Selected Plant Smith

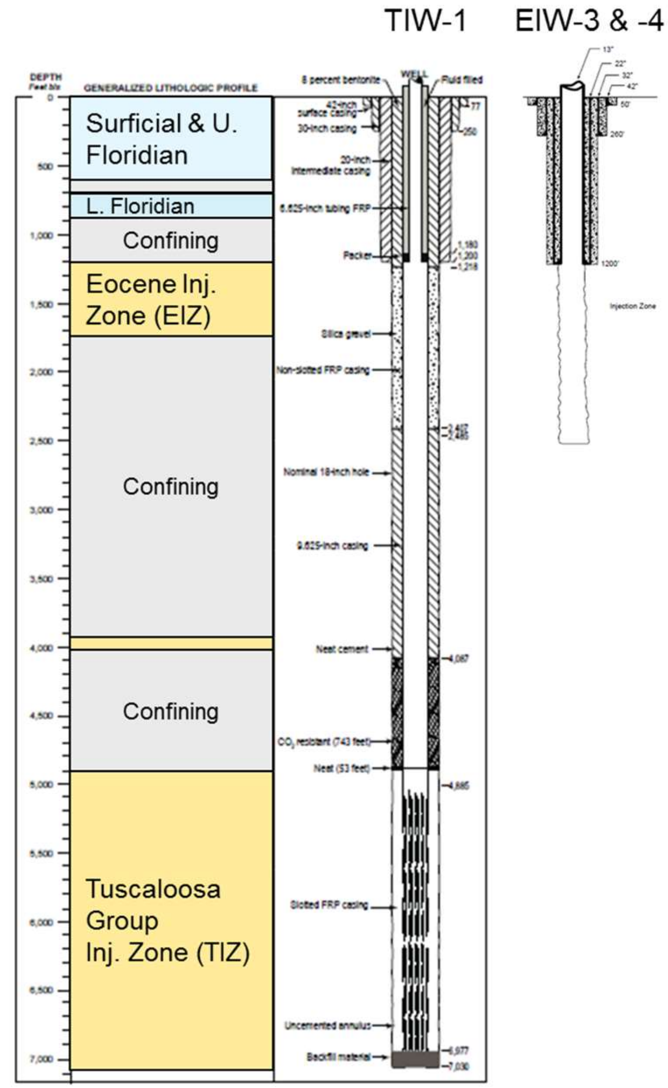


Plant Bowen, Euharlee GA
Plant Daniel, Escatawpa MS
Plant Gorgas, near Parrish AL
Plant Miller, near West Jefferson AL
Kemper Co Energy Facility, MS

Plant Smith Overview

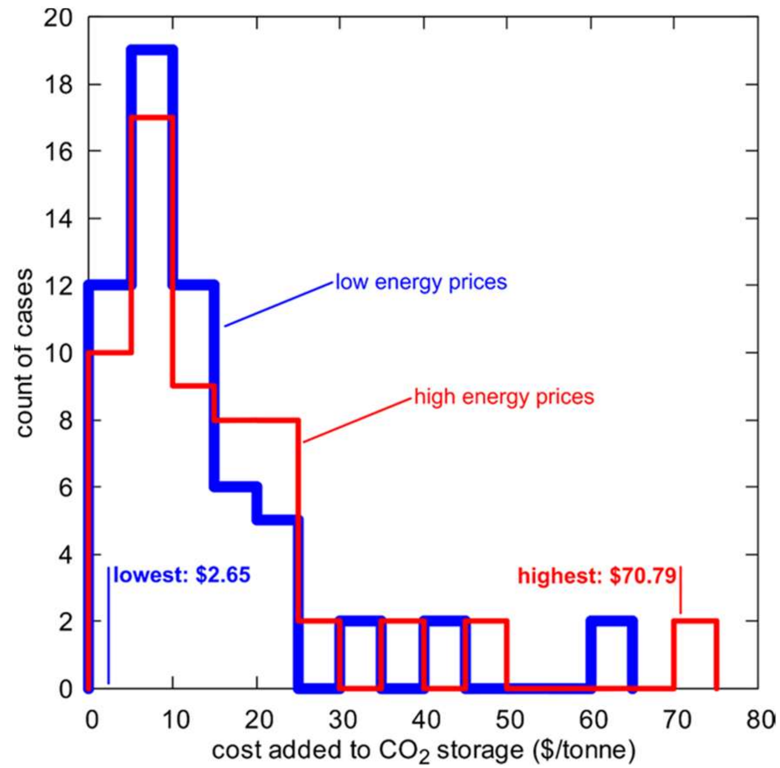
- Multiple confining units
- Thick, permeable saline aquifers
  - Eocene Series (870-2,360)
  - Tuscaloosa Group (4,920-7,050 ft)
  - Represent significant CO_2 storage targets in the southeast US
- Large Gulf Power Co. waste water injection project under construction (infrastructure)
- Water injection pressures will be managed as a proxy for CO_2 injection (~500k-1M gal/day)

No CO_2 injection will take place



During Phase I EPRI Conducted a Life-Cycle Analysis of Extracting and Treating Brine, Transmitting Treated Water

- Used Plant Smith waters as the basis for the analysis
- Performed techno-economic assessment of a hypothetical CCS water extraction project
  - Extraction
  - Transportation
  - Pre- and primary-treatment assuming zero liquid discharge
  - Residual waste disposal
- Computed power required over 30 years of operation
- Calculated CapEx/OpEx costs for entire system

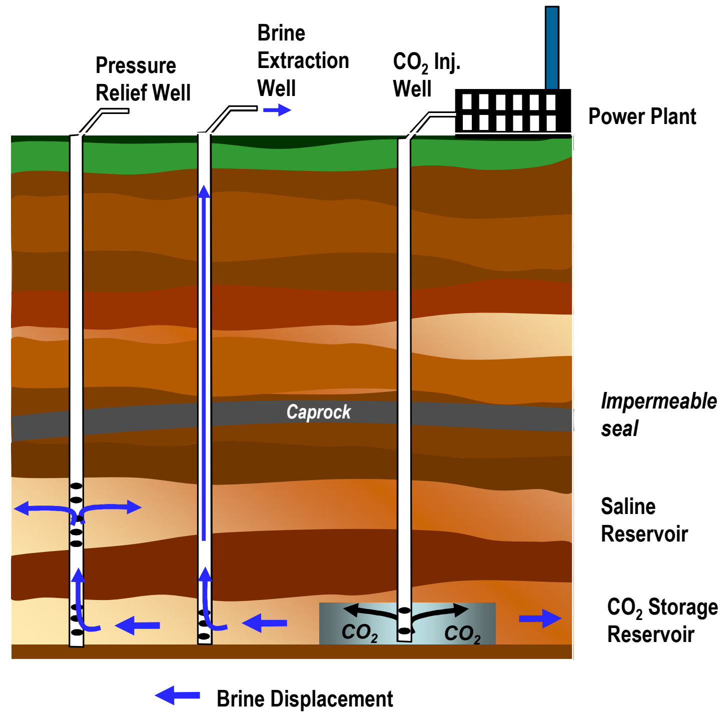


Added cost of water treatment can be significant

Phase II Field Demonstration Experimental Design—Passive and Active Pressure Management

- Passive pressure relief in conjunction with active pumping can reduce pressure buildup, pumping costs and extraction volume
- Existing "pressure relief well" and "new" extraction well will be used to validate passive and active pressure management strategies

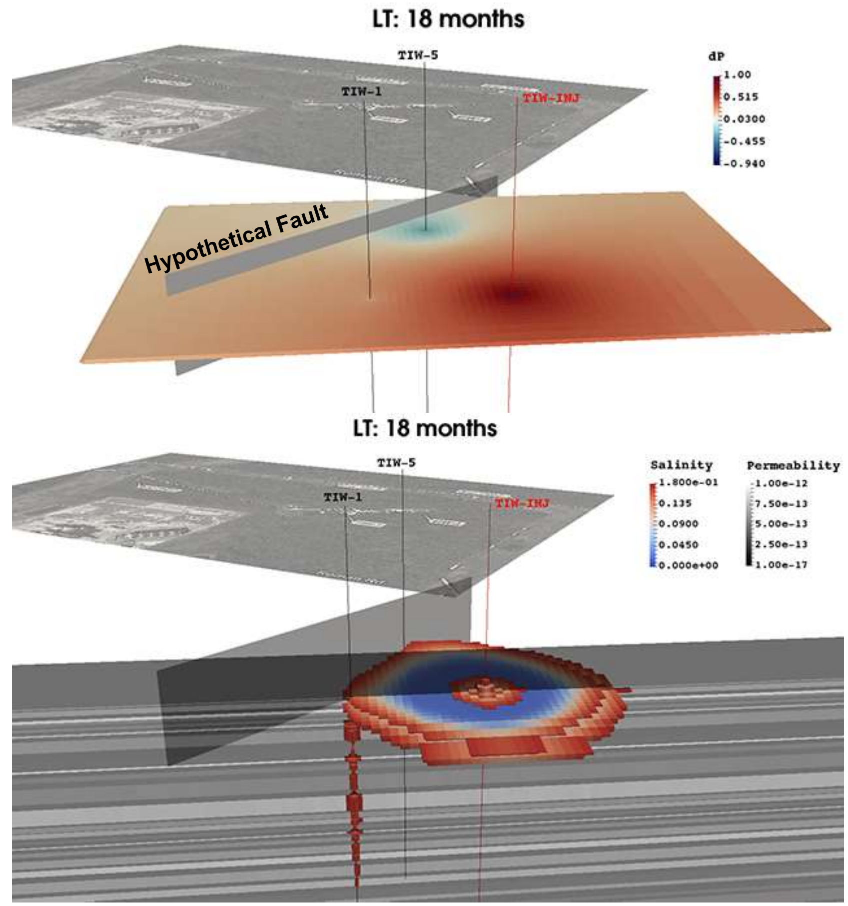
Pressure relief well has the potential to reduce extraction volume by 40%



Hypothetical CO_2 storage project showing "active" extraction and "passive" pressure relief well

Goals of Subsurface Pressure Management Via Passive + Active Brine Extraction at Plant Smith

- Scenario—Minimize risks for injection-induced seismic events and leakage along hypothetical faults by controlling
  - Pressure buildup
  - Plume migration
- Limit the size of the Area of Review
- Limit the volume extracted
- Develop and test effectiveness of adaptive optimization methods and tools to manage overall reservoir system response

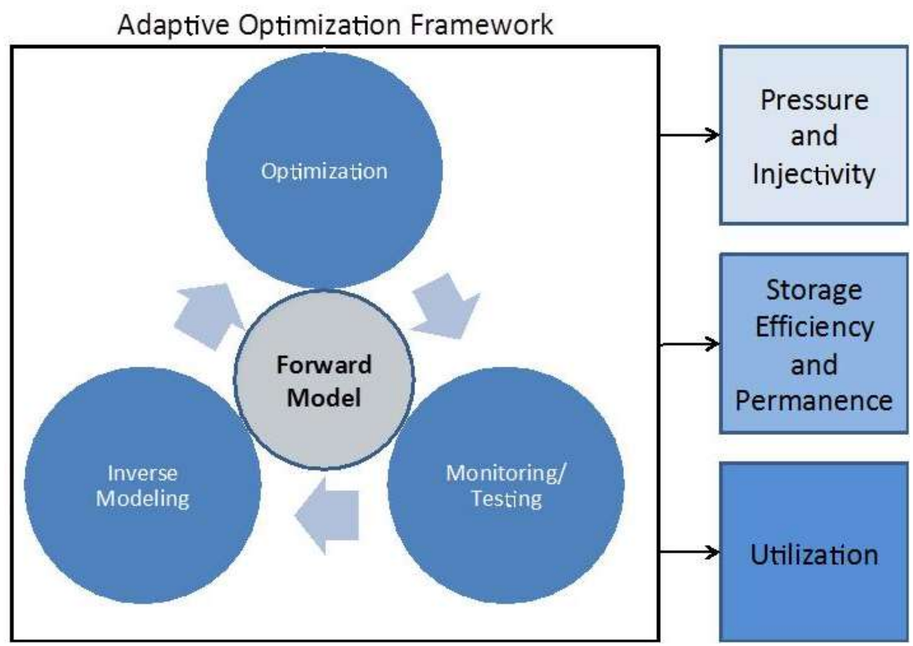


Adaptive Pressure Management will Ensure Proper Control of Pressure and Plume Migration

- The adaptive management workflow integrates modeling + optimization + monitoring + inversion
- The adaptive workflow for optimized management of CO_2 storage projects utilizes the advanced automated optimization algorithms and suitable process models

Why is adaptive management needed?

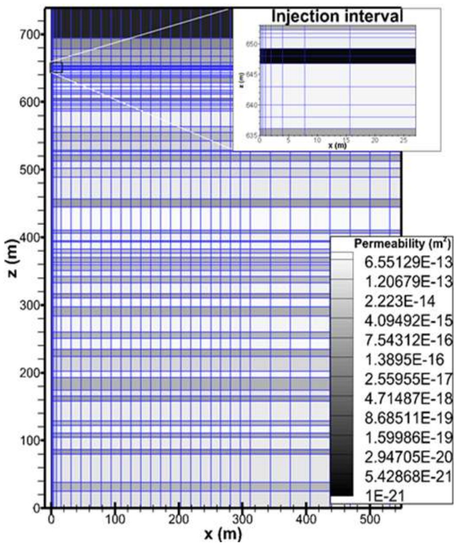
- Incomplete knowledge of subsurface properties exist, especially during the planning stages of CO_2 projects
- During operations, the subsurface system behavior needs to be monitored continuously, and the models need to be frequently updated



Base Case Injection and Pressure Management Scenario

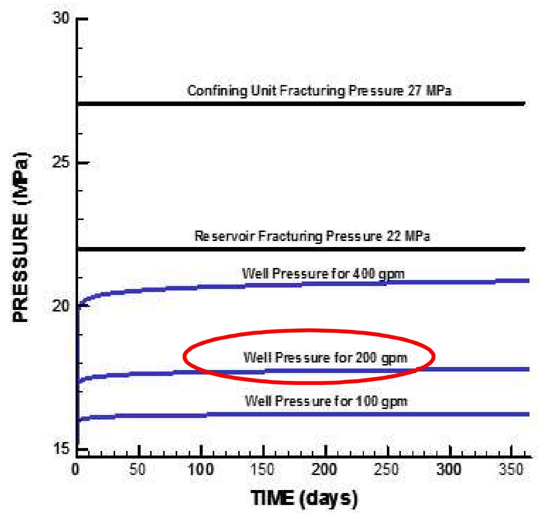
- Involves an 18-month injection of ~1,090 m^3/d (200 gal/min) of water disposal
- Injection into relatively thin and confined layers ensures generation of easily detectable differential pressures
- Strong contrast between low salinity injected fluid (~1,200 mg/L) and the Tuscaloosa brine (about 166,000 mg/L on average) enables geophysical plume monitoring

Selected two geological layers located close to the top of the LT domain for injection and extraction in our base case scenario

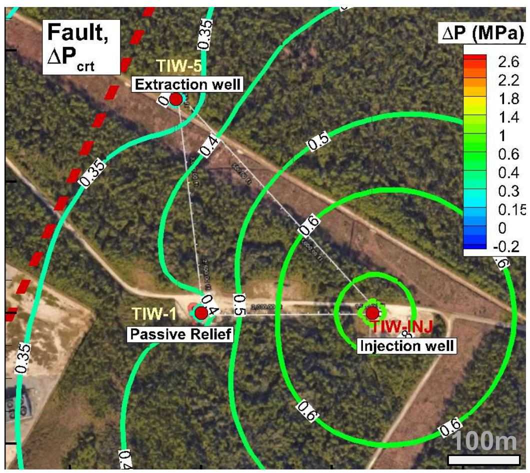


Preliminary Hydrogeological Model (Layered)

Caprock and reservoir fracturing unlikely for the targeted injection rate



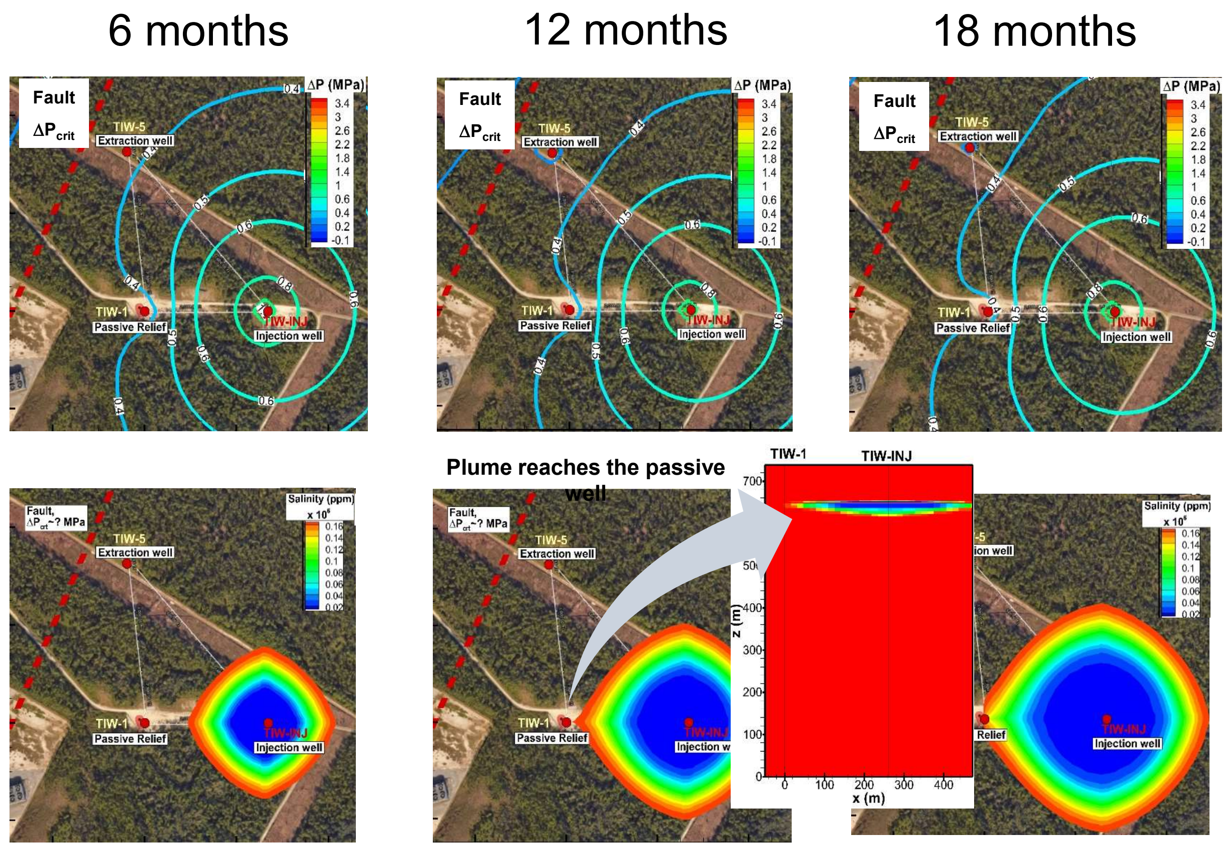
Pressure and plume control using active and passive extraction wells near a hypothetical fault



Using optimization algorithms, optimal extraction rates are calculated to meet the pressure constraints along the faults

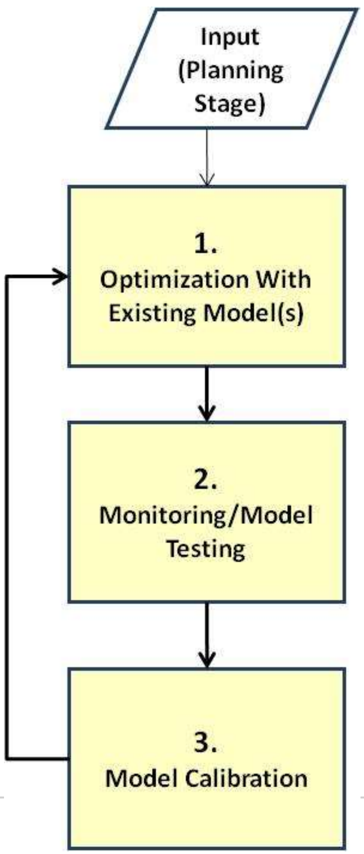
Pressure and Salinity Changes for the Base Case Pressure Management Scenario

- Developed a preliminary reservoir model based on the existing data and simulated density and viscosity-dependent brine flow
  - Injection =200 gal/min
  - Max. Extraction Rate ~20 gal/min
  - Starting at time = 6 months
- Passive extraction may reduce the total volume extracted up to 40%, according to the base case scenario

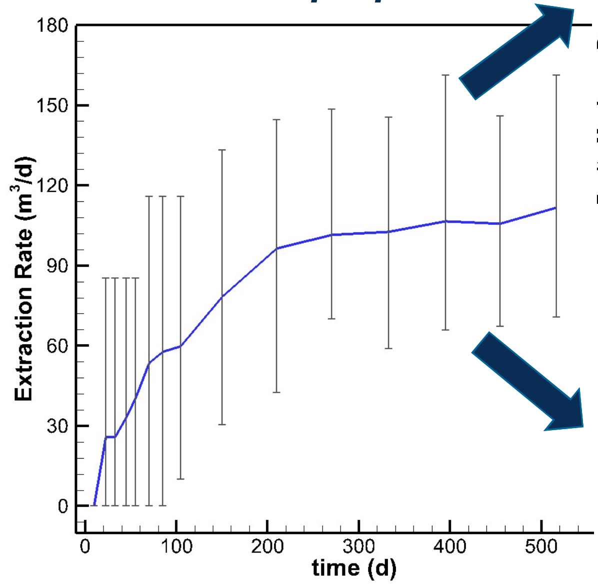


Optimization Algorithms Provide Minimum Extraction Rates as a Function of Time to Satisfy the Constraints for the Given Reservoir Conditions

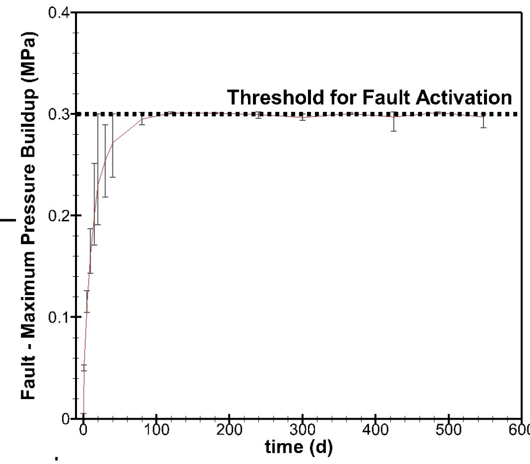
Adaptive optimization algorithm

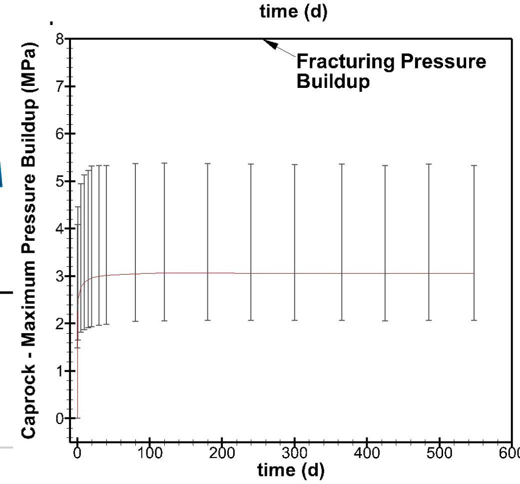


Initial estimation of the projected extraction rates with uncertainty in reservoir properties



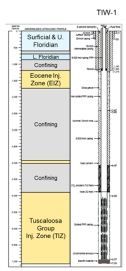
Error bars indicate potential variability in extraction rates

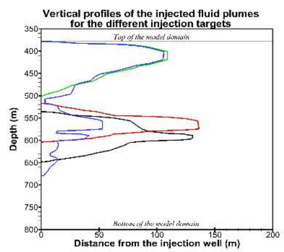




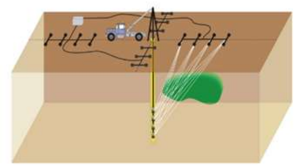
Monitoring – Inversion for Pressure & Salinity

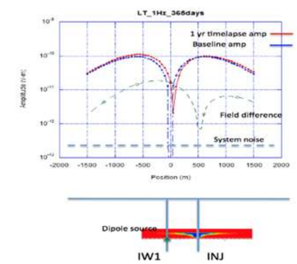
- **Borehole -** Continuous and time-lapse (discrete) borehole measurements of fluid pressure, flow rate, temperature, and electrical conductivity will be used to provide high-resolution, ground-truth, direct measurements at discrete locations (1D).



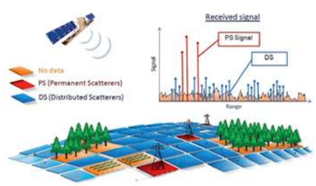


- **EM** - Time-lapse crosswell and borehole-to-surface EM will provide indirect measurements of the higher resistivity injected ash pond water with spatial resolutions in 2D and 3D approaching several meters to tens of meters, respectively.

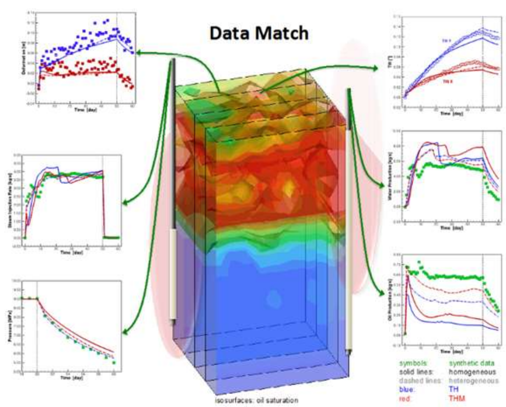




- **InSAR** - InSAR will be used to map surface deformations resulting from subsurface pressure increases over 16 day intervals



Joint Inversion - We will use LBNL's powerful inverse modeling and parameter estimation tool iTOUGH (in its parallel version MPiTOUGH2) for the automated joint inversion of hydrological, large-scale geophysical (EM) data, and surface deformation data.



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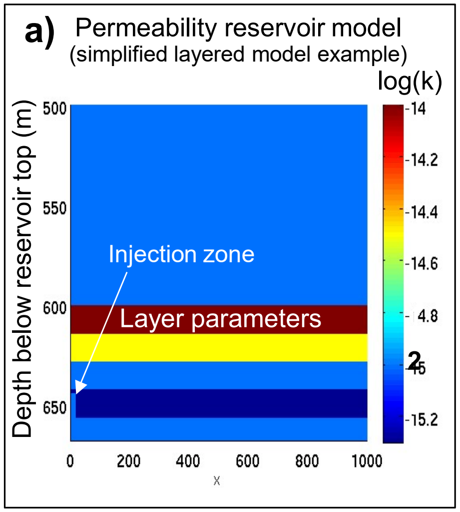
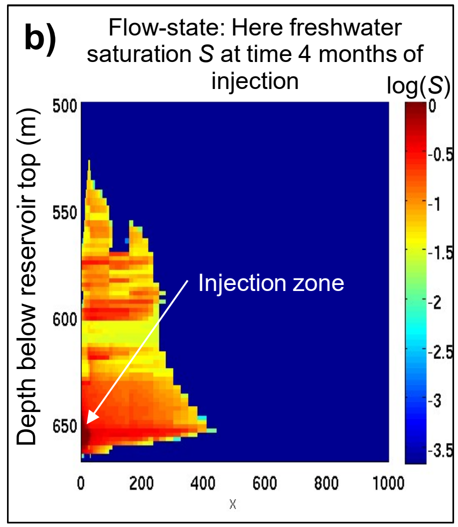
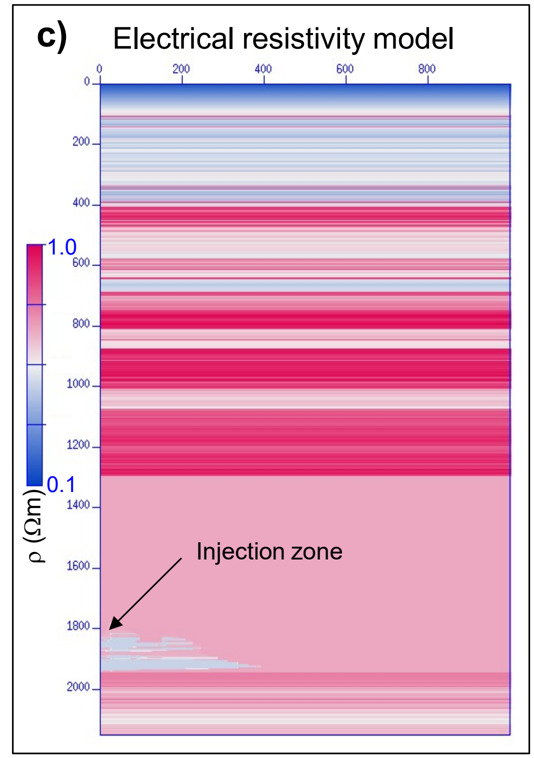
Reservoir Parameter Estimation Inverts Hydrological and Geophysical (EM) Data Simultaneously



Flow-simulation



Rock-physics model transformation

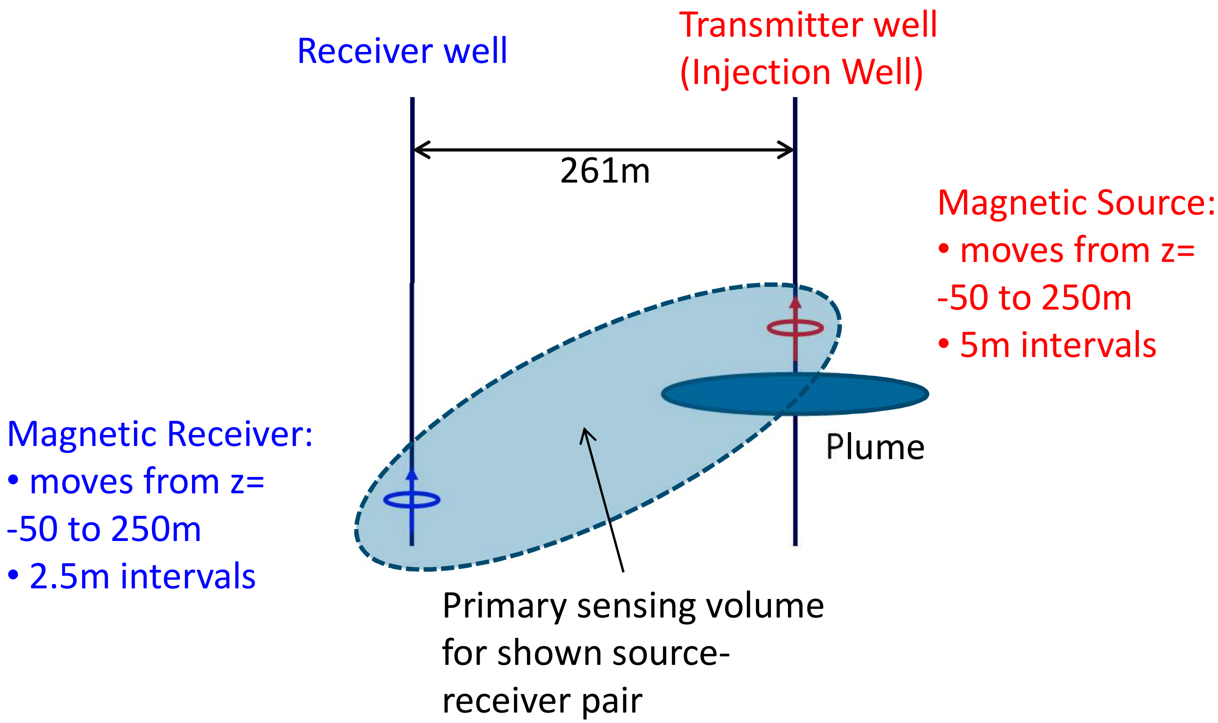


Repeat model update until field-data fit is satisfactory

Iterative deterministic parameter estimation work flow:

- Simulate EM data from electrical resistivity model (c)
- Combine EM data with pressure (& local salinity and temperature) monitoring data
- Carry out inversion step of combined data
- Update the permeability model (a)

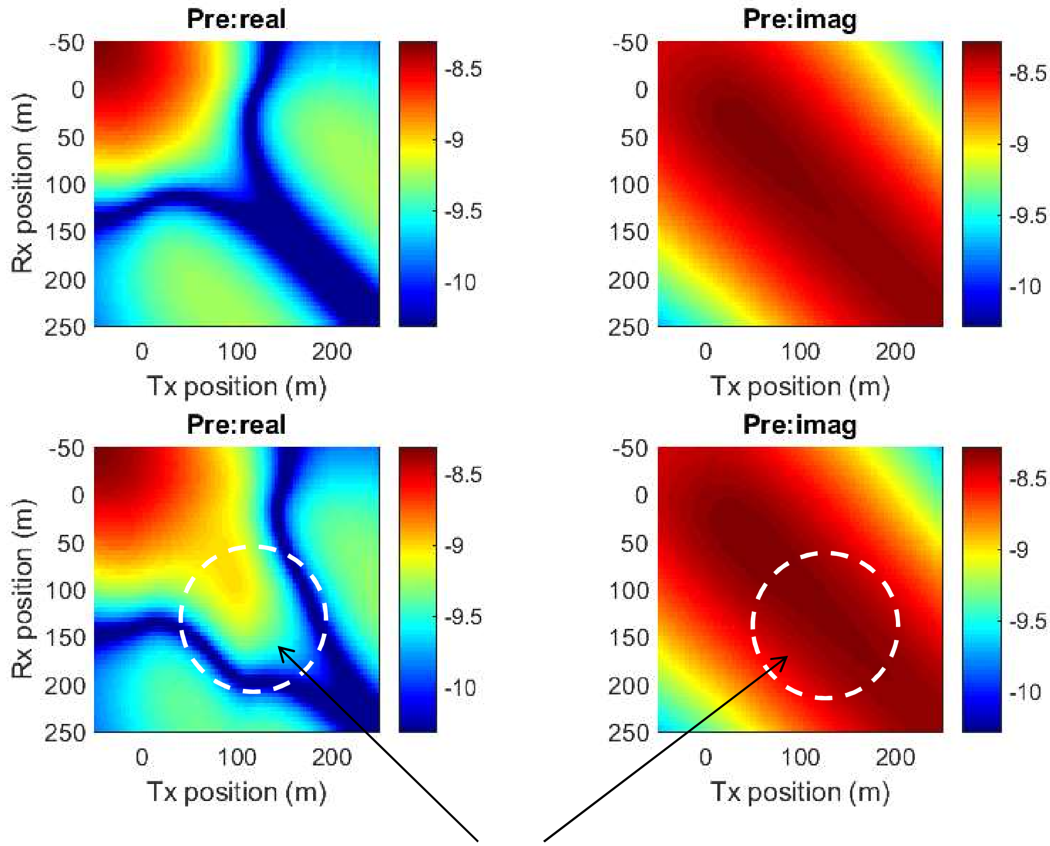
Crosswell Electromagnetic (EM) Method



Crosswell EM Measurements Before and After Injection

Before Injection

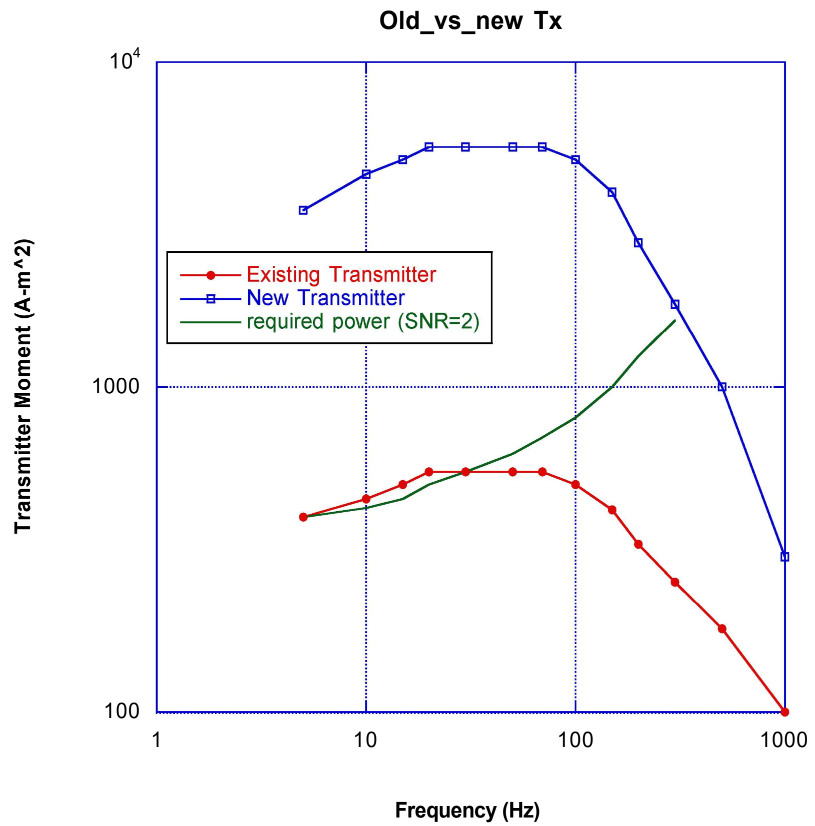
365 Days



Anomalous Magnetic Fields

Plant Smith Crosswell Survey Requires Higher Power Transmitter for Imaging Plume

- Existing transmitter does not have sufficient power to be effective at Plant smith
  - SNR expected to be 2 at 10 Hz, we need at least 5
- Designed a new, more powerful and resilient transmitter
- The new tool will:
  - Maximize Tx output at 10-200 Hz
    - Required range for Plant Smith surveys
  - Be compliant to well conditions at Plant Smith
    - Pressure temperature, well diameter
  - Suitable for deployment for standard wirelines rigs



New EM Borehole Transmitter: Design and Manufacture

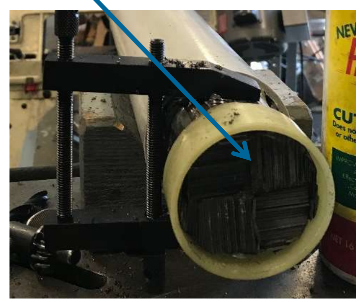
- Core is transformer steel
- Length is 4.5 m, diameter 8.5 cm
- Number of wire turns about 8000
  - Moment 4000-8000
  - Weight ~100 kg (heavy!)
  - Pressure rating 2 km, temp 125 C.

- Operation design 5-500 Hz
- Well separation max ~ 1 km
- Will (soon) have downhole signal generation

- **Manufacture completion mid May 2008**
- **First field test planned for mid June 2018**

Installing winding substrate

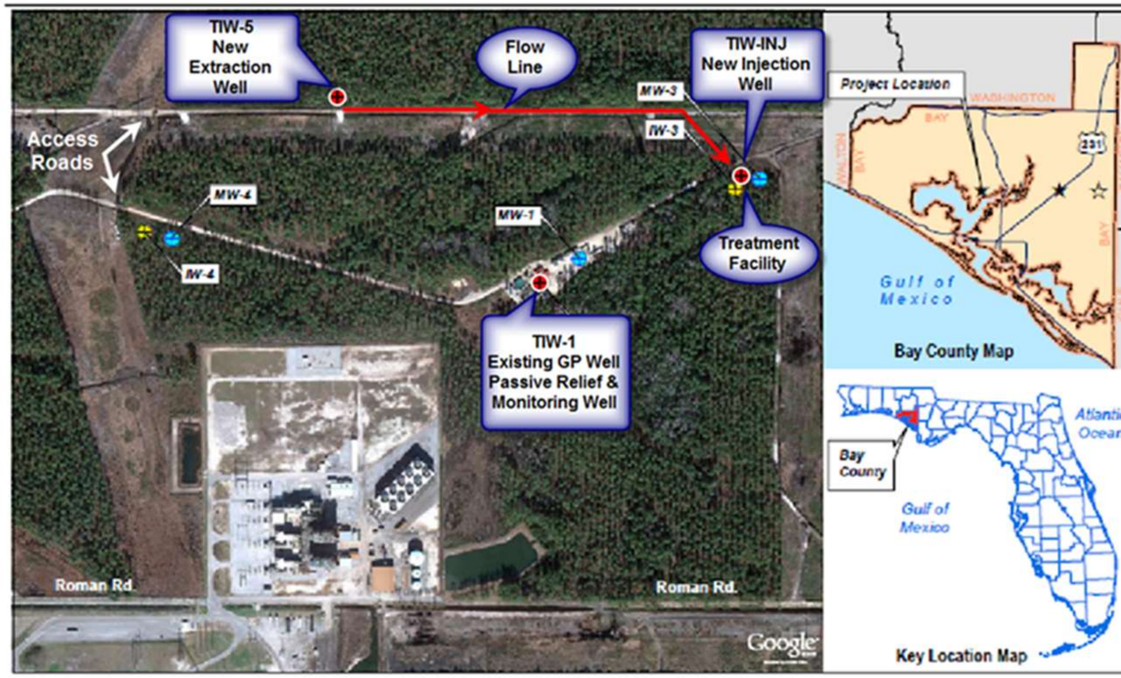
Tx core



Bundling core elements

Well Field Infrastructure Design

- Developed detailed technical specifications for:
  - Well pads
  - Extraction well
  - Injection well including four casing/tubing options
  - Flowline
  - Submersible pump
  - Power requirements
- Plant Smith site visit and pre-bid meeting with perspective drillers
  - Four drilling firms attended
  - Only two Florida-based firms responded with bids
  - Large disparity between prices



BEST project infrastructure layout showing the proposed location of the extraction well (TEMW-A), injection well (TIW-2) and flowline, and the existing passive-relief well (TIW-1)

Permitting

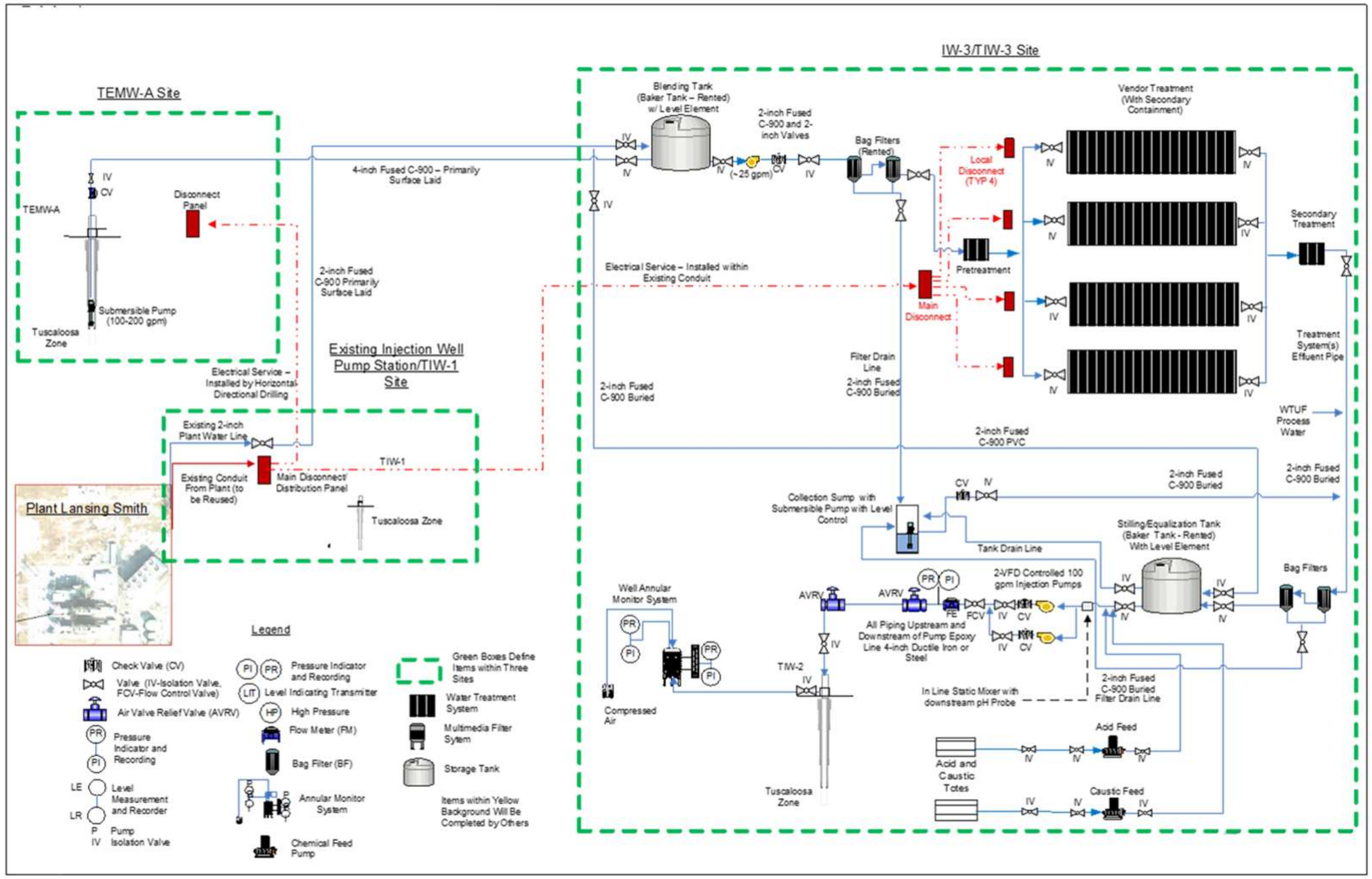
- Florida Department of Environmental Protection (FDEP) has primacy over Class I non-hazardous waste wells
- State has rigorous UIC standards to protect water resources
  - Well construction (casing/tubing diameters & thickness, cement thickness, materials of use)
  - Temporary monitoring wells to evaluate potential impacts during drilling
  - Permanent monitor well to evaluate potential impact from injection
  - Construction standards are being applied to BEST project's extraction well

Permanent monitor well installed within 150 ft of injection well is sampled quarterly for water quality impacts associated with injection

BEST obtained a minor modification to Gulf Power's existing well permit

Water Treatment User Facility Design

- Preliminary design provides different water qualities for testing by DOE researchers and commercial water treatment vendors
  - High salinity (166,000 mg/L TDS) Tuscaloosa water only
  - Low salinity fresh or waste water (30-1,000 mg/L TDS) from Plant Smith
  - Intermediate salinity (30-166,000 mg/L TDS) by mixing in a blending tank



Next Steps

- BP3 (2018-2020) plans include:
  - Installation of the well field infrastructure
  - Site characterization
  - Final design and installation of the water treatment user facility
  - Equipment commissioning
  - 6 months of injection followed by 12 months of injection and extraction
- BP4 (2020-2021) plans include:
  - Site restoration
  - Final reporting

Newly constructed drill pad at Plant Smith
for injection well TIW-2

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