

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

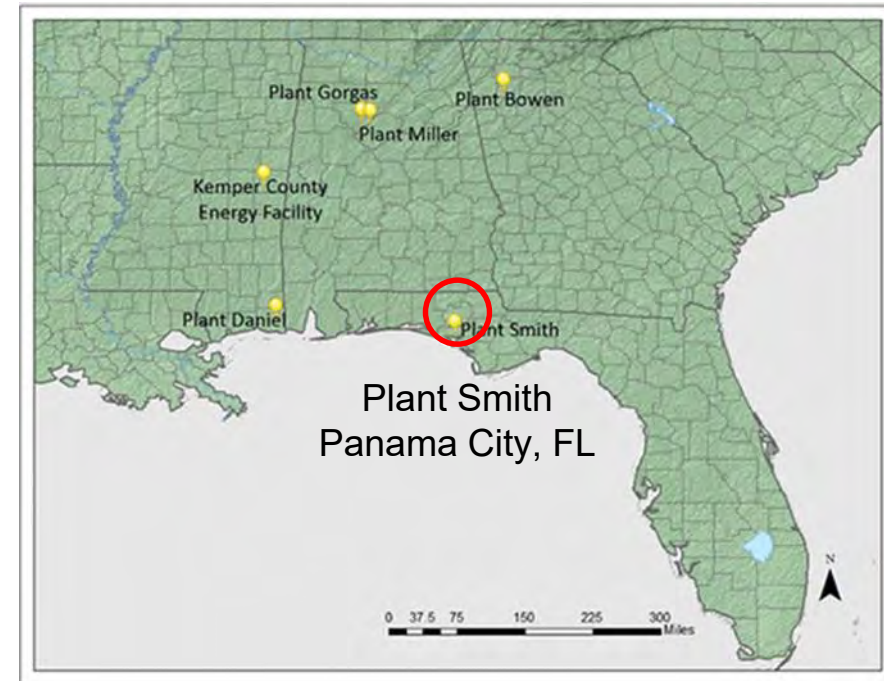
- Technical Status
 - Project overview
 - Adaptive pressure/plume management
 - Joint inversion
 - Experimental design
 - Well field infrastructure
- Accomplishments to Date
- Next Steps
- Appendix – Supplemental Slides
 - Lessons learned
 - Synergy opportunities
 - Benefits to Program
 - Etc., etc.



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

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

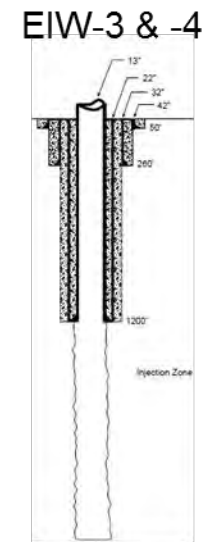
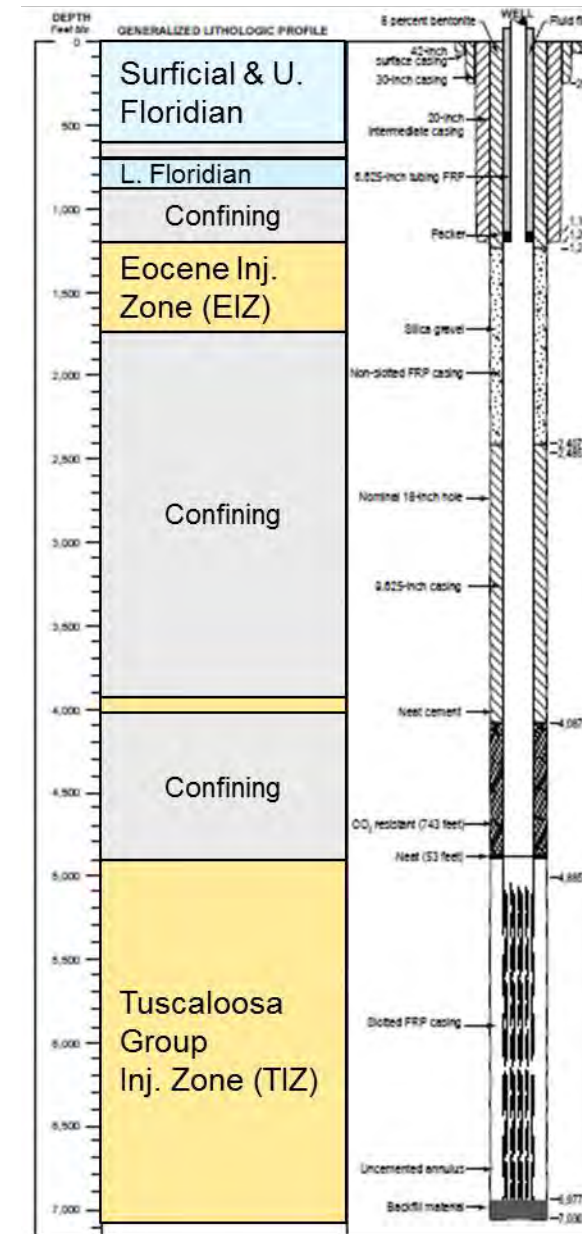


Plant Bowen, Euharlee GA
Plant Daniel, Escatawpa MS
Plant Gorgas, near Parrish AL
Plant Miller, near West Jefferson AL
Kemper Co Energy Facility, MS

Plant Smith Overview

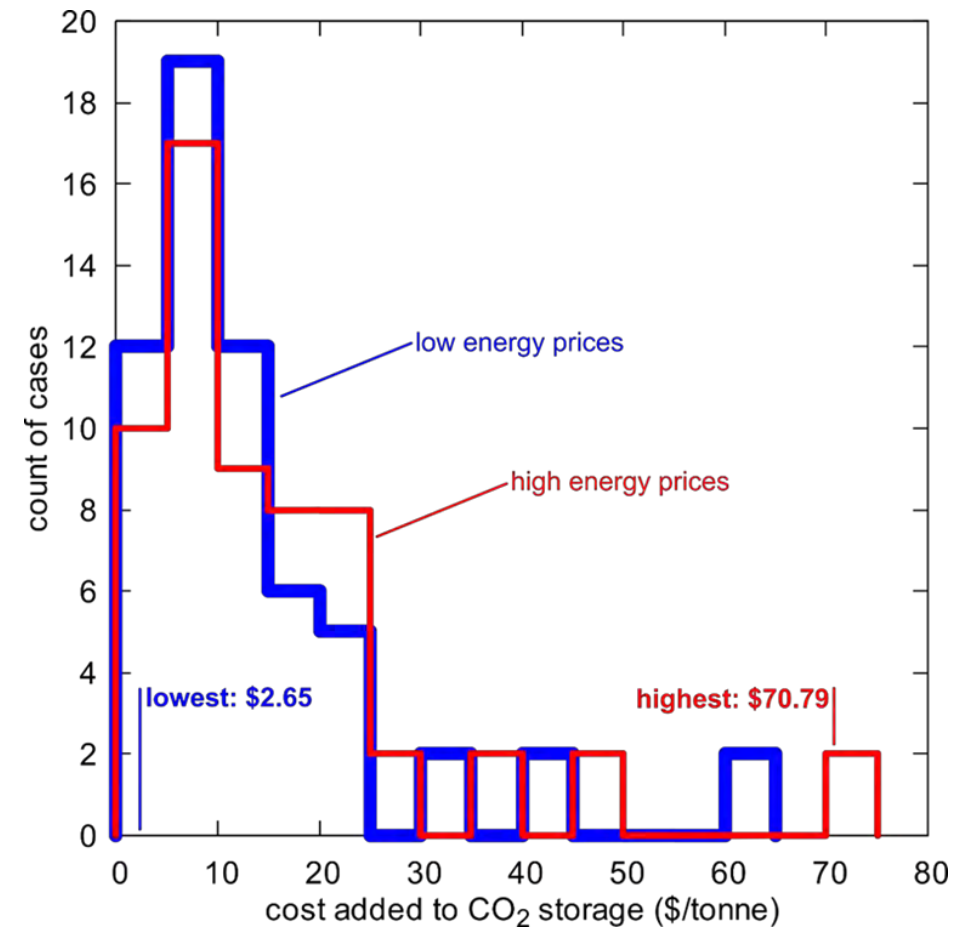
- Multiple confining units
- Thick, permeable saline aquifers
 - Eocene Series (870-2,360)
 - Tuscaloosa Group (4,920-7,050 ft)
 - Represent significant CO₂ storage targets in the southeast US
- Large Gulf Power Co. waste water injection project under construction (infrastructure)
- Water injection pressures will be managed as a proxy for CO₂ injection (~500k-1M gal/day)

No CO₂ 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

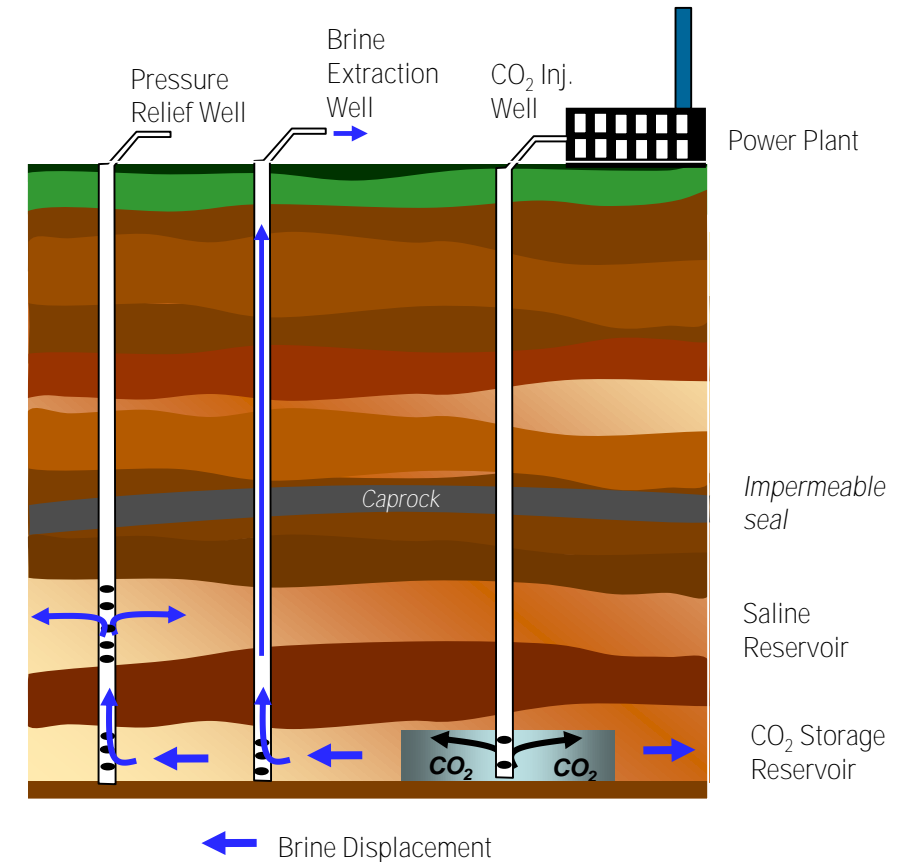


Added cost of water treatment can be significant

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

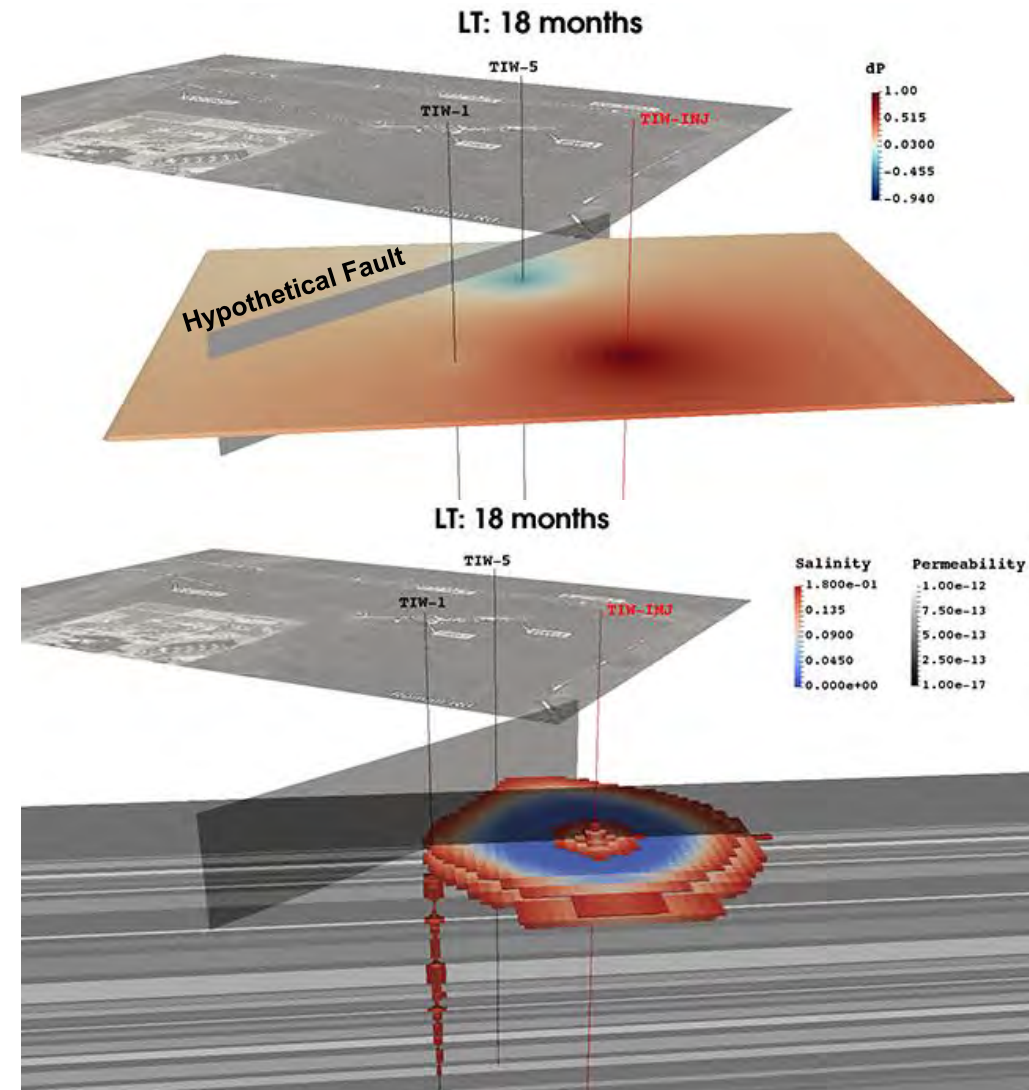
Pressure relief well has the potential to reduce extraction volume by 40%



Hypothetical CO₂ 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

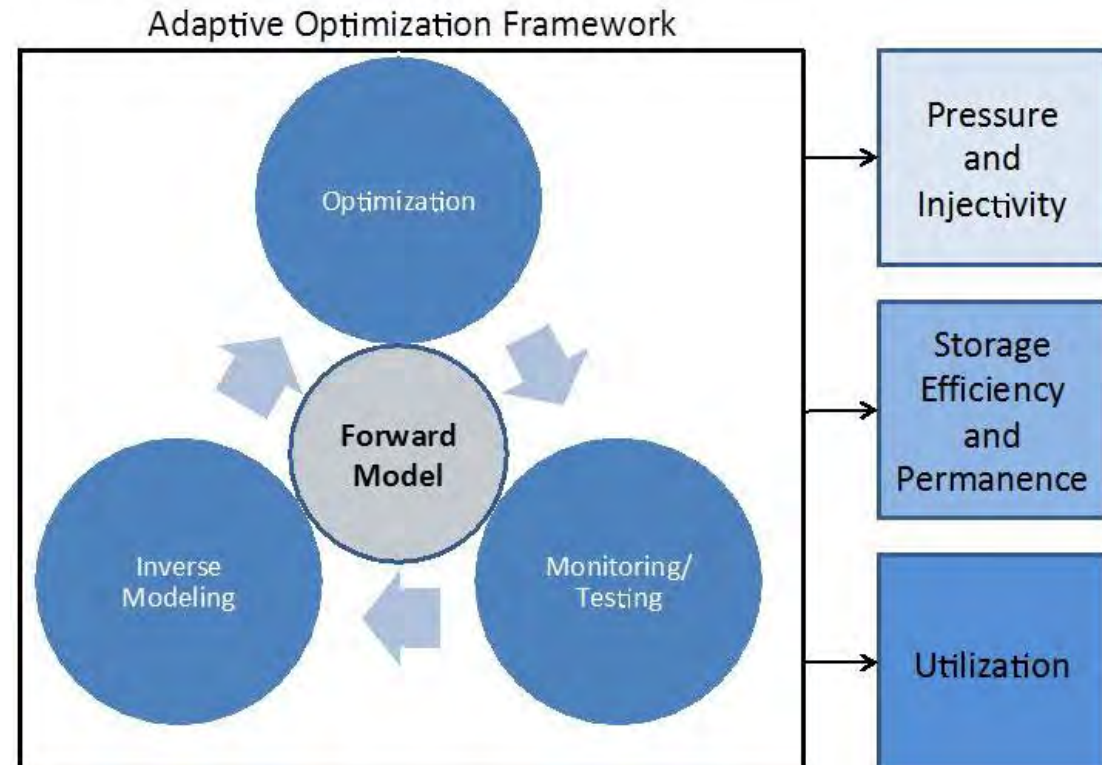


Adaptive Pressure Management will Ensure Proper Control of Pressure and Plume Migration

- The adaptive management workflow integrates modeling + optimization + monitoring + inversion
- The adaptive workflow for optimized management of CO₂ storage projects utilizes the advanced automated optimization algorithms and suitable process models

Why is adaptive management needed?

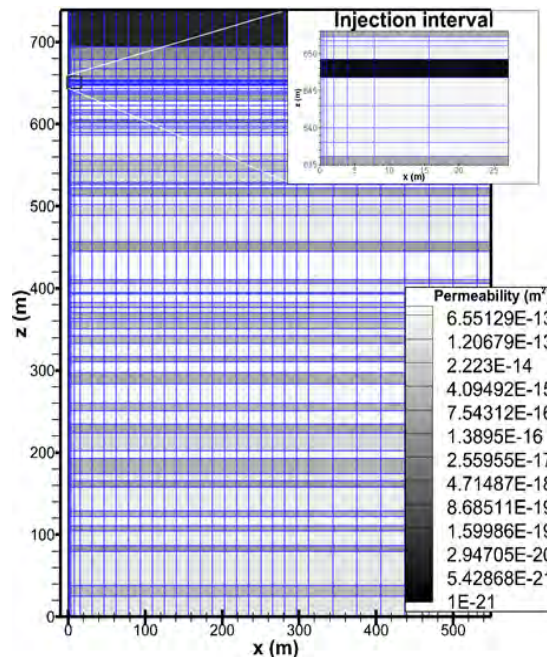
- Incomplete knowledge of subsurface properties exist, especially during the planning stages of CO₂ projects
 - During operations, the subsurface system behavior needs to be monitored continuously, and the models need to be frequently updated



Base Case Injection and Pressure Management Scenario

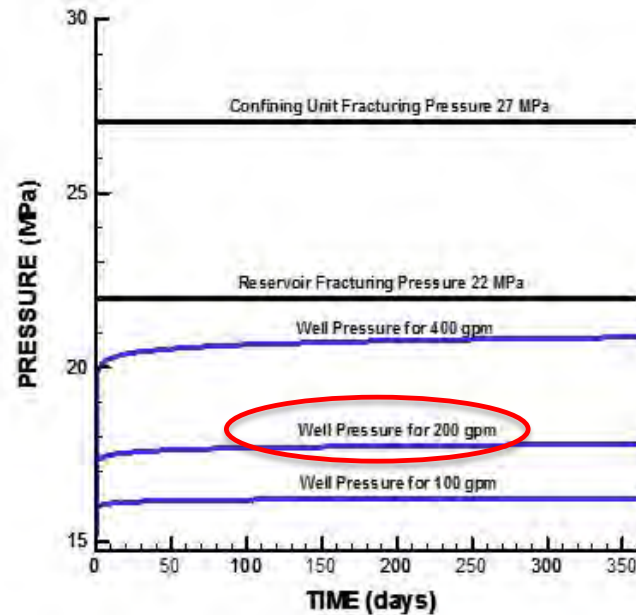
- Involves an 18-month injection of $\sim 1,090 \text{ m}^3/\text{d}$ (200 gal/min) of water disposal
- Injection into relatively thin and confined layers ensures generation of easily detectable differential pressures
- Strong contrast between low salinity injected fluid ($\sim 1,200 \text{ mg/L}$) and the Tuscaloosa brine (about $166,000 \text{ mg/L}$ 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

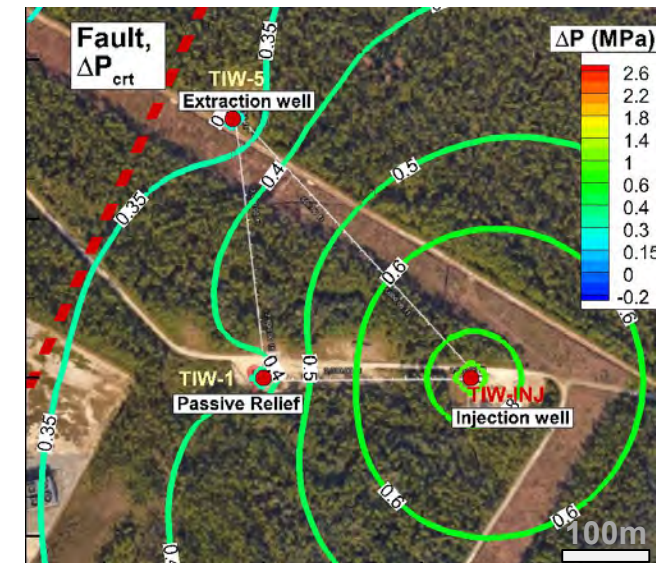


Preliminary Hydrogeological Model (Layered)

Caprock and reservoir fracturing unlikely for the targeted injection rate



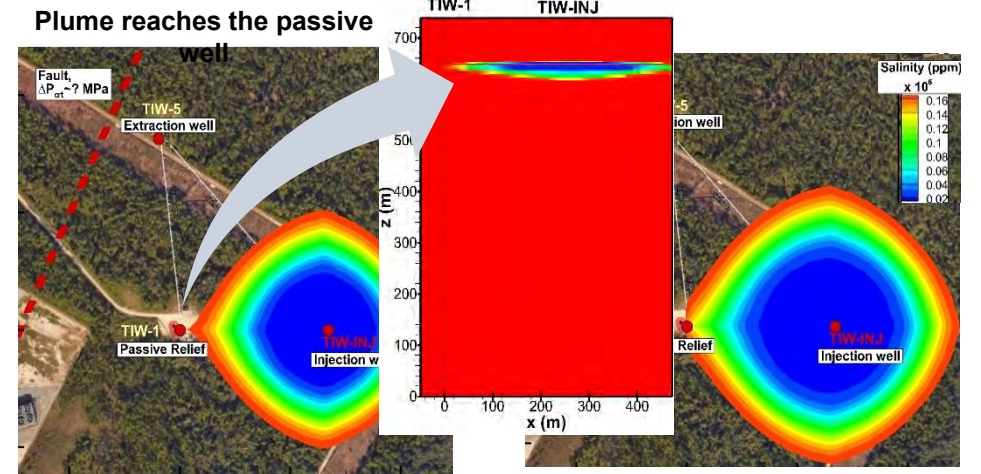
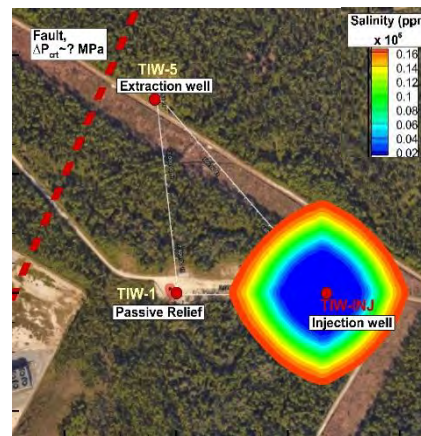
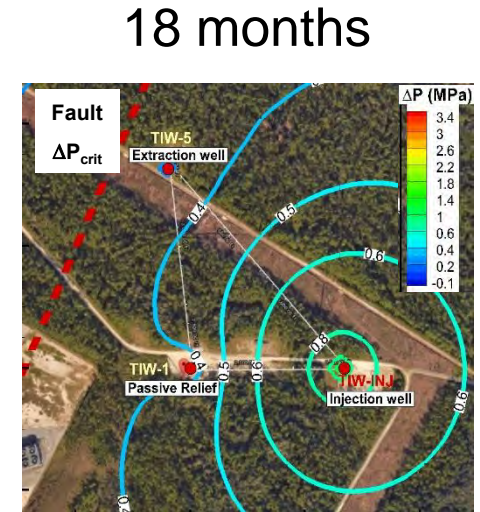
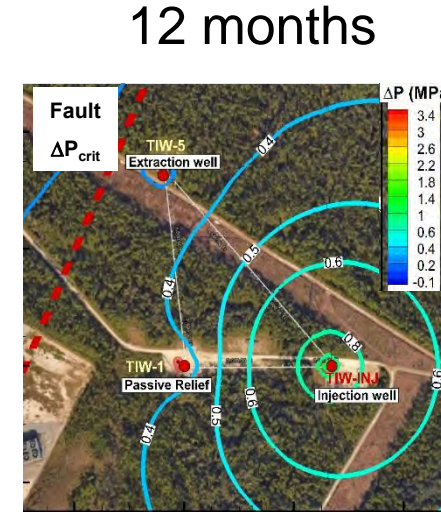
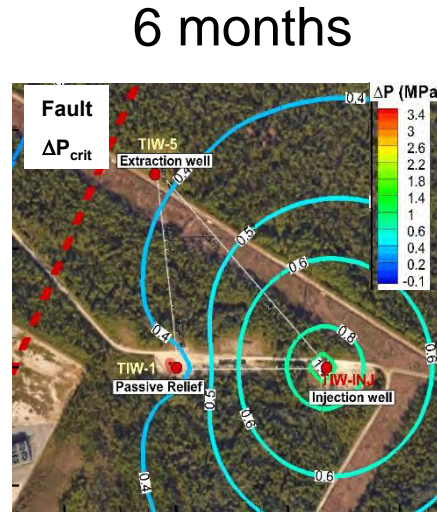
Pressure and plume control using active and passive extraction wells near a hypothetical fault



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

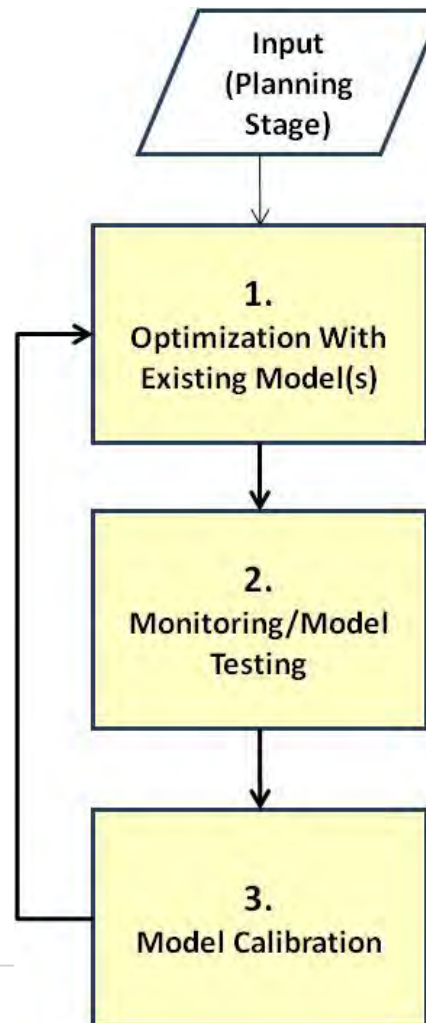
Pressure and Salinity Changes for the Base Case Pressure Management Scenario

- 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

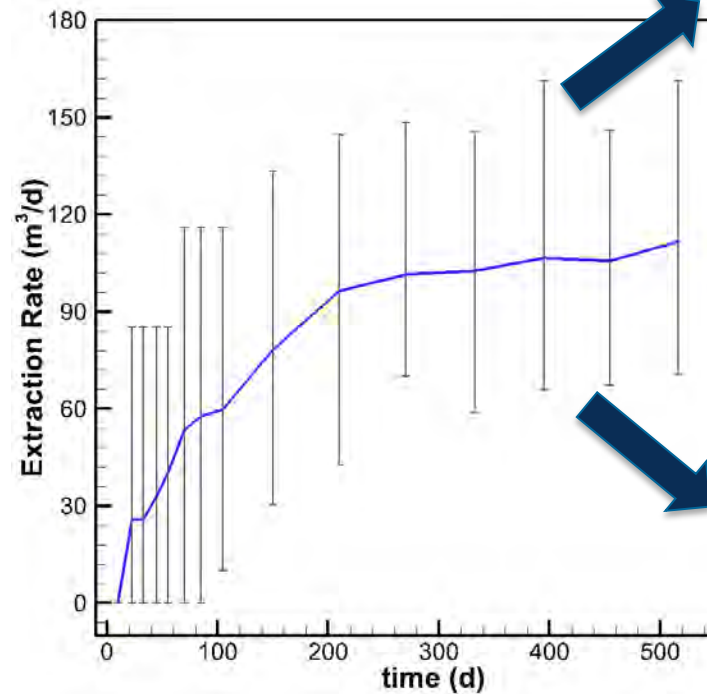


Optimization Algorithms Provide Minimum Extraction Rates as a Function of Time to Satisfy the Constraints for the Given Reservoir Conditions

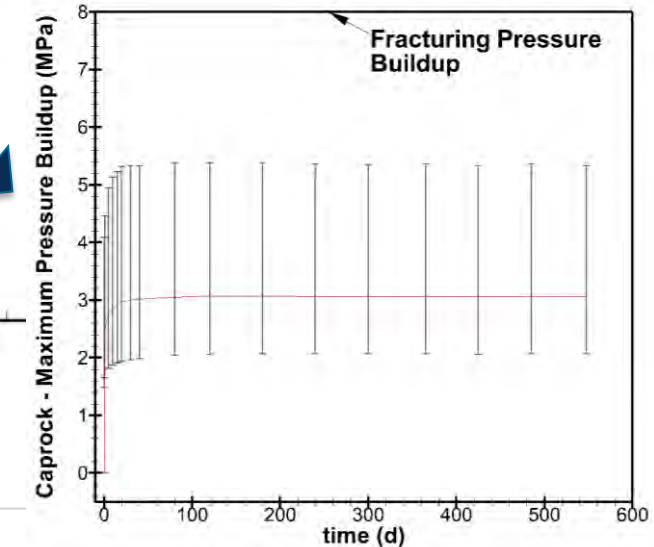
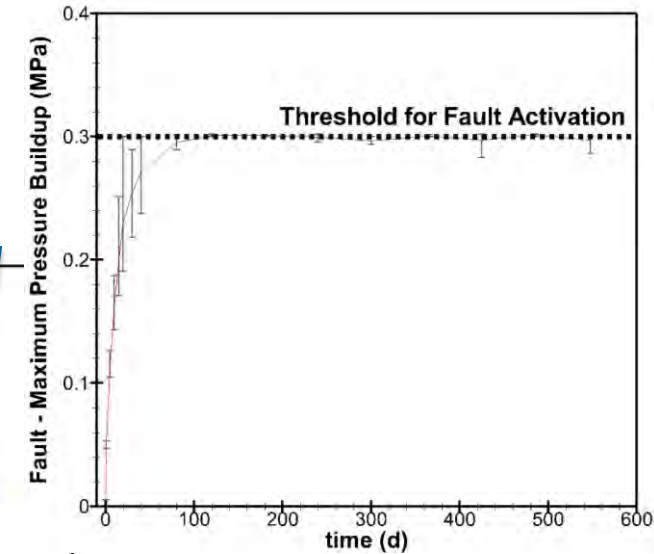
Adaptive optimization algorithm



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

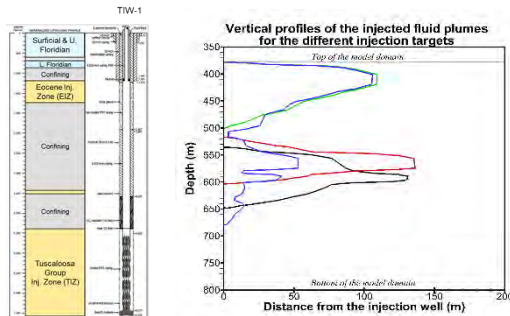


Error bars indicate potential variability in extraction rates

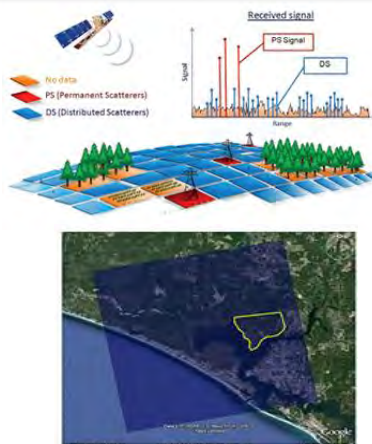


Monitoring – Inversion for Pressure & Salinity

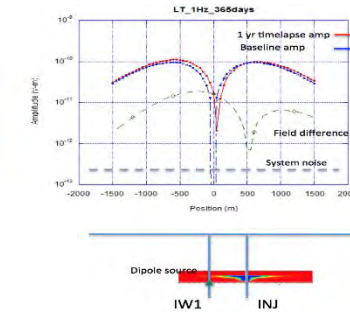
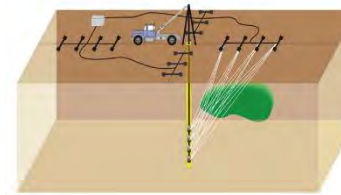
- **Borehole** - Continuous and time-lapse (discrete) borehole measurements of fluid pressure, flow rate, temperature, and electrical conductivity will be used to provide high-resolution, ground-truth, direct measurements at discrete locations (1D).



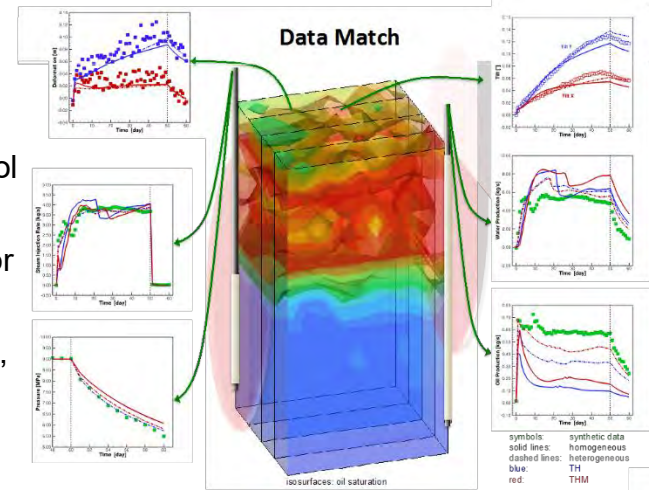
- **InSAR** - InSAR will be used to map surface deformations resulting from subsurface pressure increases over 16 day intervals



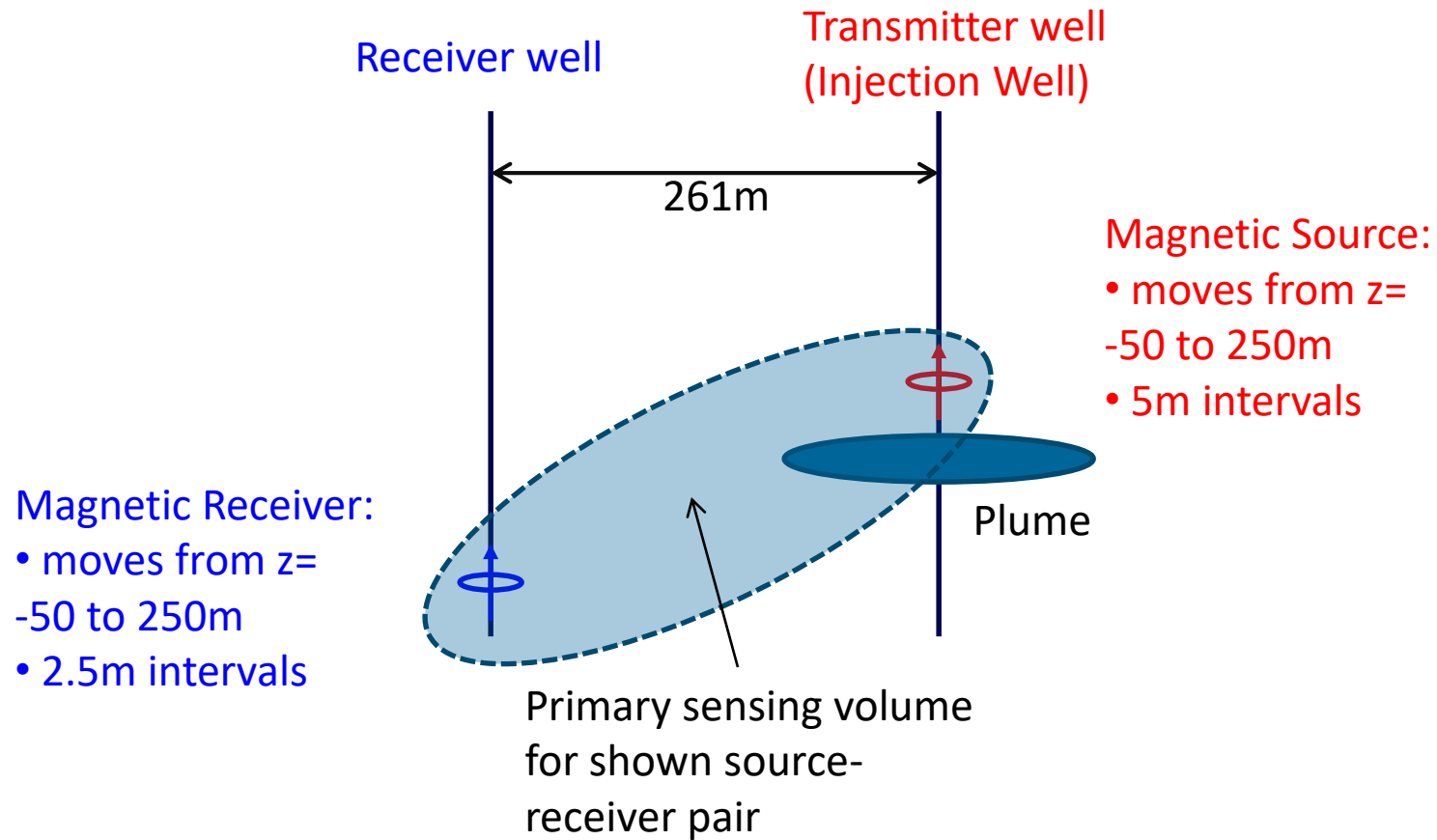
- **EM** - Time-lapse crosswell and borehole-to-surface EM will provide indirect measurements of the higher resistivity injected ash pond water with spatial resolutions in 2D and 3D approaching several meters to tens of meters, respectively.



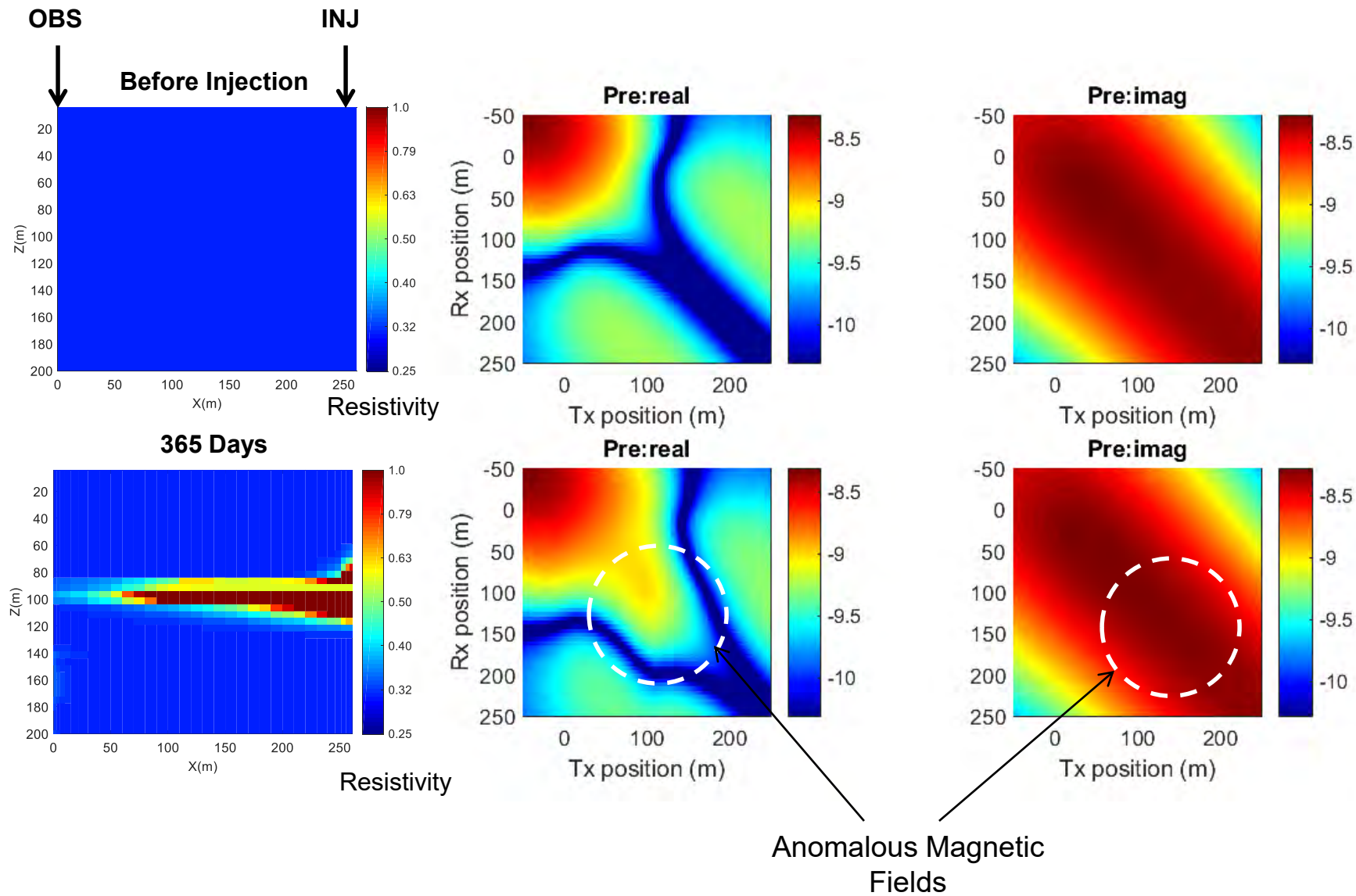
Joint Inversion - We will use LBNL's powerful inverse modeling and parameter estimation tool iTOUGH (in its parallel version MPiTOUGH2) for the automated joint inversion of hydrological, large-scale geophysical (EM) data, and surface deformation data.



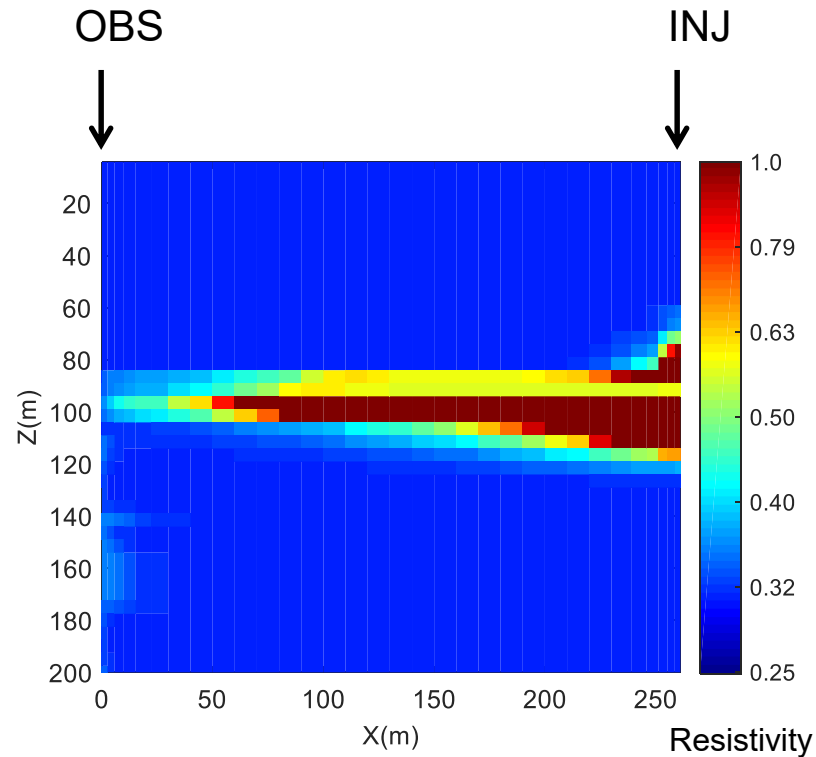
Crosswell Electromagnetic (EM) Method



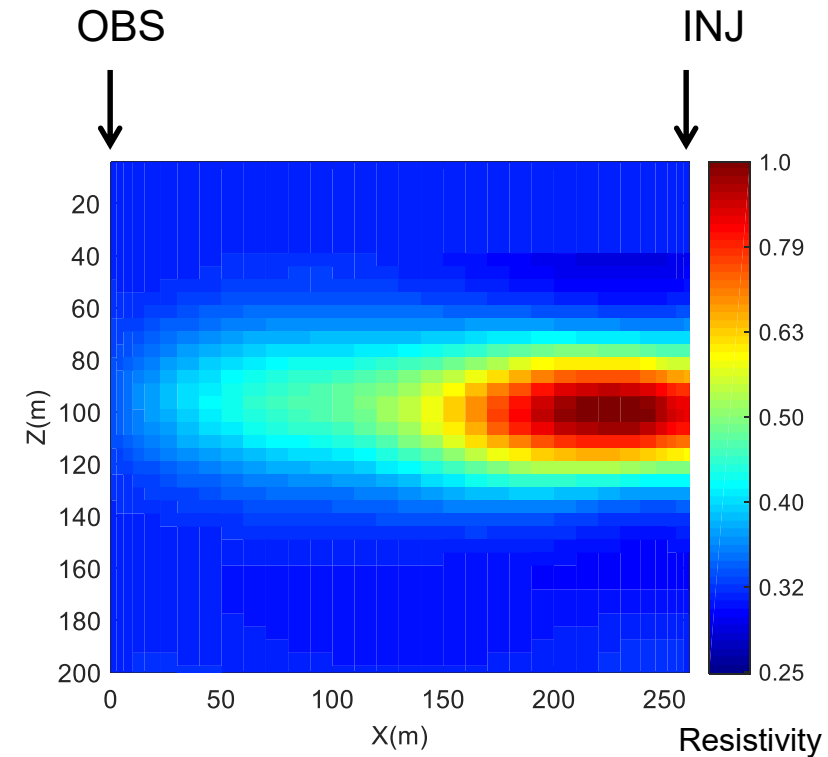
Crosswell EM Measurements Before and After Injection



Preliminary Results: Crosswell EM Measurements Before and After Injection (600 Days)



True Model



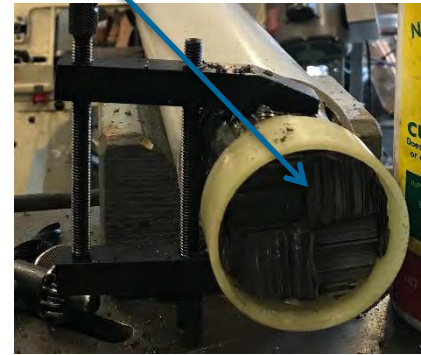
Crosswell EM Imaging

New EM Borehole Transmitter: Design and Manufacture

- 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
 - 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 nearing completion**
- **First field test planned for Oct. 2018**

Installing winding substrate

Tx core



Bundling core elements

Well Field Infrastructure

- 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



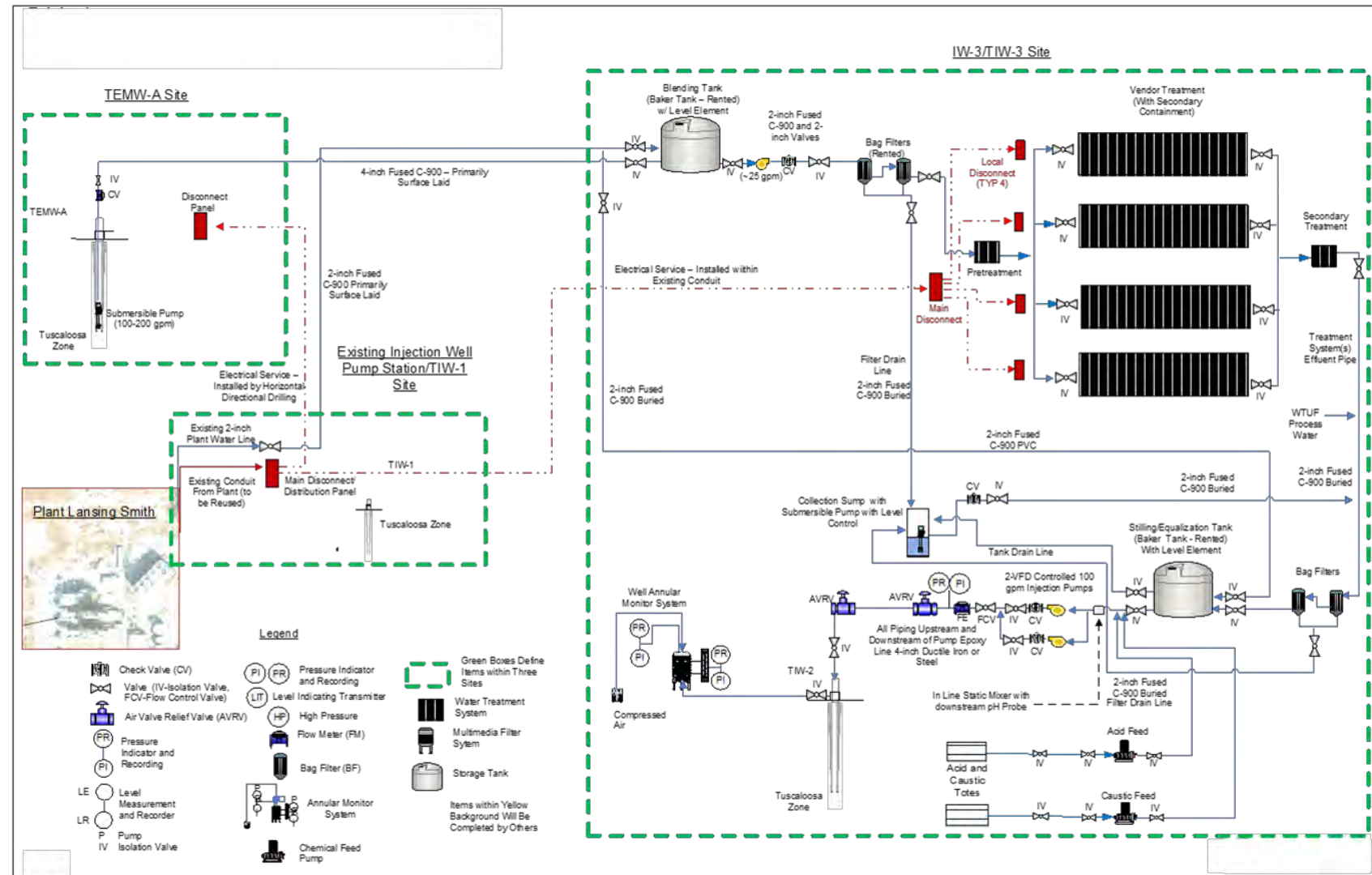
BEST project infrastructure layout showing the proposed location of the extraction well (TEMW-A), injection well (TIW-2) and flowline, and the existing passive-relief well (TIW-1)

Drilling of Injection Well TIW-2 is Underway



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



Accomplishments to Date

✓ Permitting

- Submitted minor modification to existing permit (May 2017)
- Permit modification approved (Oct. 2017)

✓ Experimental Design

- Scoped extraction rates to select submersible pump size
- Design and build of new EM transmitter

✓ Well field infrastructure design

- Developed well design and technical specifications
- Selected qualified Florida certified driller (July 2017)
- Drilling of TIW-2 started (July 2018)

✓ Water treatment user facility design

- Preliminary design and costs completed
- Users are being solicited for pre-treatment requirements



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

Appendix

Supplemental Slides

Lessons Learned

■ Project cost drivers

- Each state has unique UIC regulatory requirements and guidelines that can impact well construction and project costs
- Florida drilling market for waste-water injection wells is not very competitive as shown by the large disparity in bids (\$6.9M vs. \$11.0M)
- Cost of small diameter extraction well drilled to 5,400 ft with 5-inch production casing is \$2.8M. Much higher than expected!!!!

Project anticipated high injection well costs but not for the extraction well

Synergy Opportunities

- EPRI and EERC are developing water treatment user facilities to test and validate water desalination technologies
- EERC and EPRI jointly developed a technology screening questionnaire and selection criteria for hosting the water treatment technologies at the BEST project sites
- EERC hosted the IEA-GHG risk and monitoring network meeting in June 2018
 - Tech transfer and cross-fertilization of approaches and ideas
 - Provide project updates, technology transfer, lessons learned and experiences



Benefit to the Program

■ Program Goals

- Develop cost effective pressure control, plume management and produced water strategies that can be used to improve reservoir storage efficiency and capacity, and demonstrate safe, reliable containment of CO₂ in deep geologic formations with CO₂ permanence of 99% or better.

■ Benefit Statement

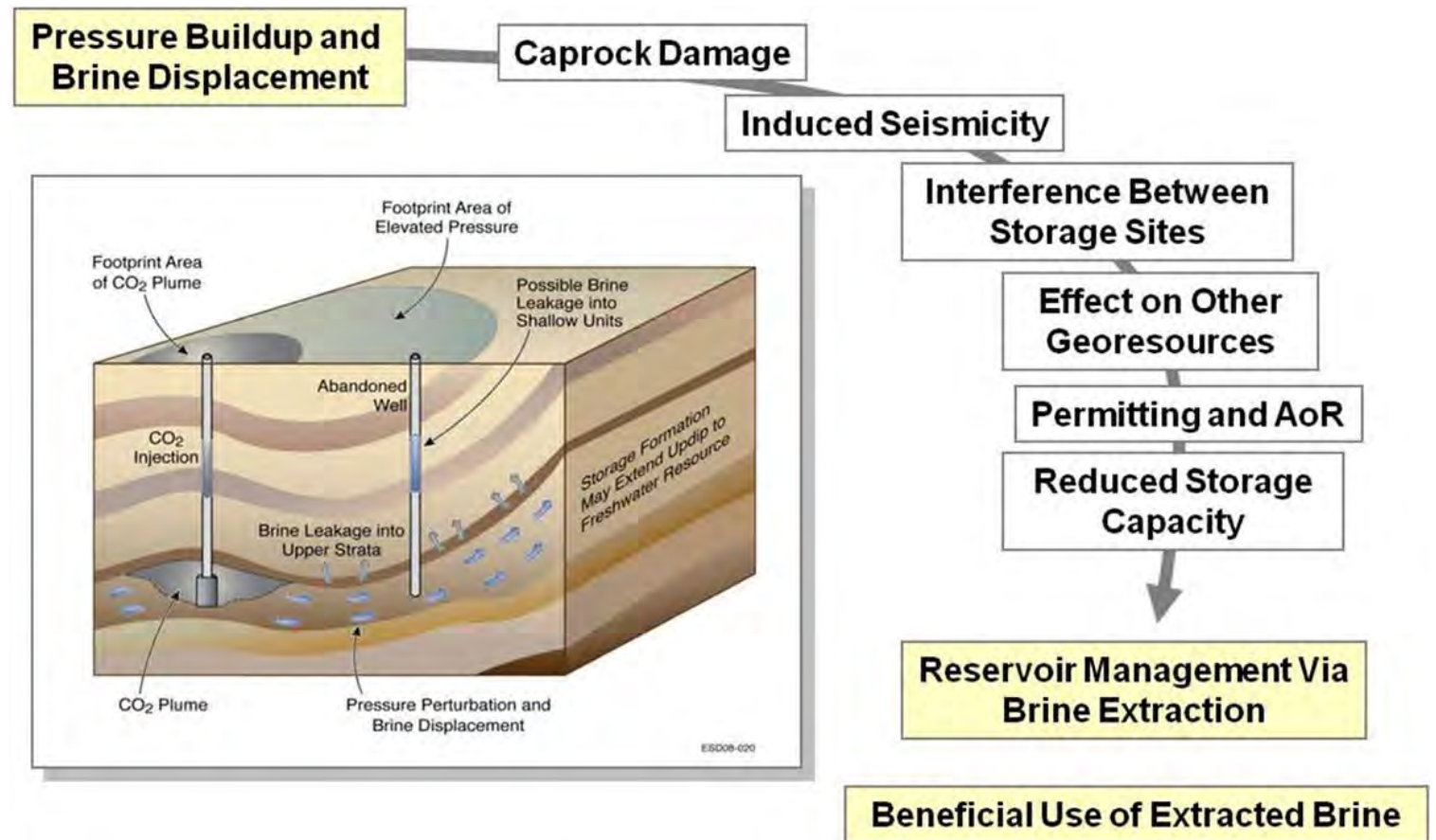
The project will...

- Use optimization methods and smart search algorithms coupled with reservoir models and advanced well completion and monitoring technologies to develop strategies that allocate flow and control pressure in the subsurface.
- Address the technical, economic and logistical challenges that CO₂ storage operators will face when implementing a pressure control and plume management program at a power station and increase our knowledge of potential storage opportunities in the southeast region of the U.S.
- Contribute to the development cost effective pressure control, plume management and produced water strategies that can be used to improve reservoir storage efficiency and capacity, and demonstrate safe, reliable containment of CO₂ in deep geologic formations with CO₂ permanence of 99% or better.
- And the operational experiences of fielding a water management project at a power station can be incorporated into DOE best practice manuals, if appropriate.

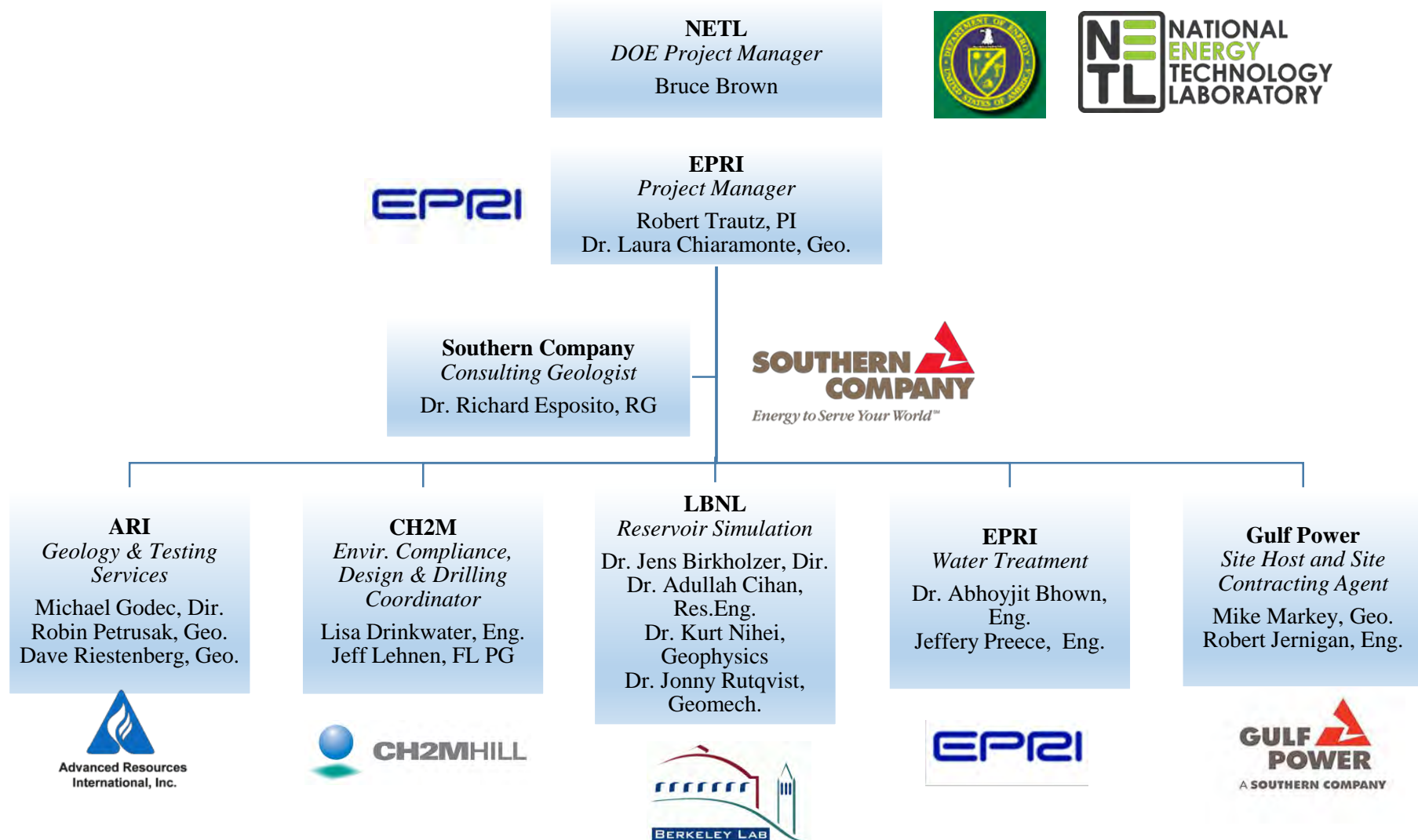
Project Overview—Goals and Objectives

- 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

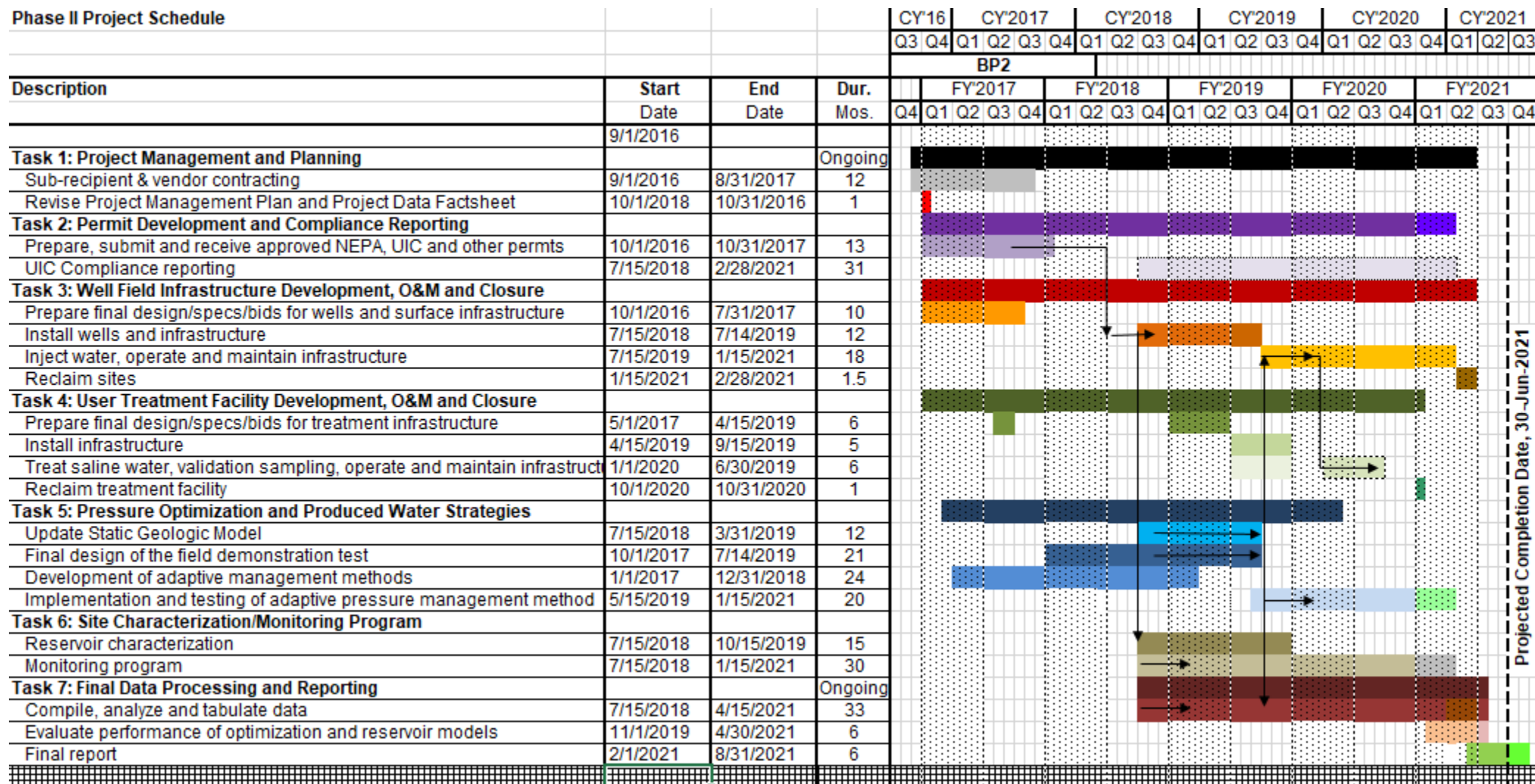
Pressure management practices are needed to avoid these potential risks. Brine extraction is a possible remedy for reducing or mitigating risk



Organization Chart



Gantt Chart



Bibliography

- González-Nicolás, A., Cihan, A., Petrusak, R., Zhou, Q., Trautz, R., Riestenberg, D., Godec, M., Birkholzer, J., (Submitted for peer review 2018), Pressure Management via Brine Extraction in Geological CO₂ Storage: Adaptive Optimization Strategies under Poorly Characterized Reservoir Conditions,, Int. J. Greenhouse Gas Control.



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