# Phase II Field Demonstration at Plant Smith Generating Station: Assessment of Opportunities for Optimal Reservoir Pressure Control, Plume Management and Produced Water Strategies
# DE-FE0026140


## Robert C. Trautz, PI

## Electric Power Research Institute


ELECTRIC POWER RESEARCH INSTITUTE

BERKELEY LAB

Advanced Resources International, Inc.


U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

# Acknowledgment

Acknowledgment:  "This material is based upon work supported by the Department of Energy under Award Number DE-FE0026140."

Disclaimer:  "This presentation was prepared as an account of work sponsored by an agency of the United States Government.  Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.  Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof.  The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

# Presentation Outline

- Benefit to the Program
- Project Overview—Goals and Objectives
- Technical Status
  - Site ranking and selection
  - Produced water life-cycle analysis
  - Pressure control & optimization strategy
  - MVA program
- Accomplishments to date
- Synergies
- Summary – Phase II

# Benefit to the Program

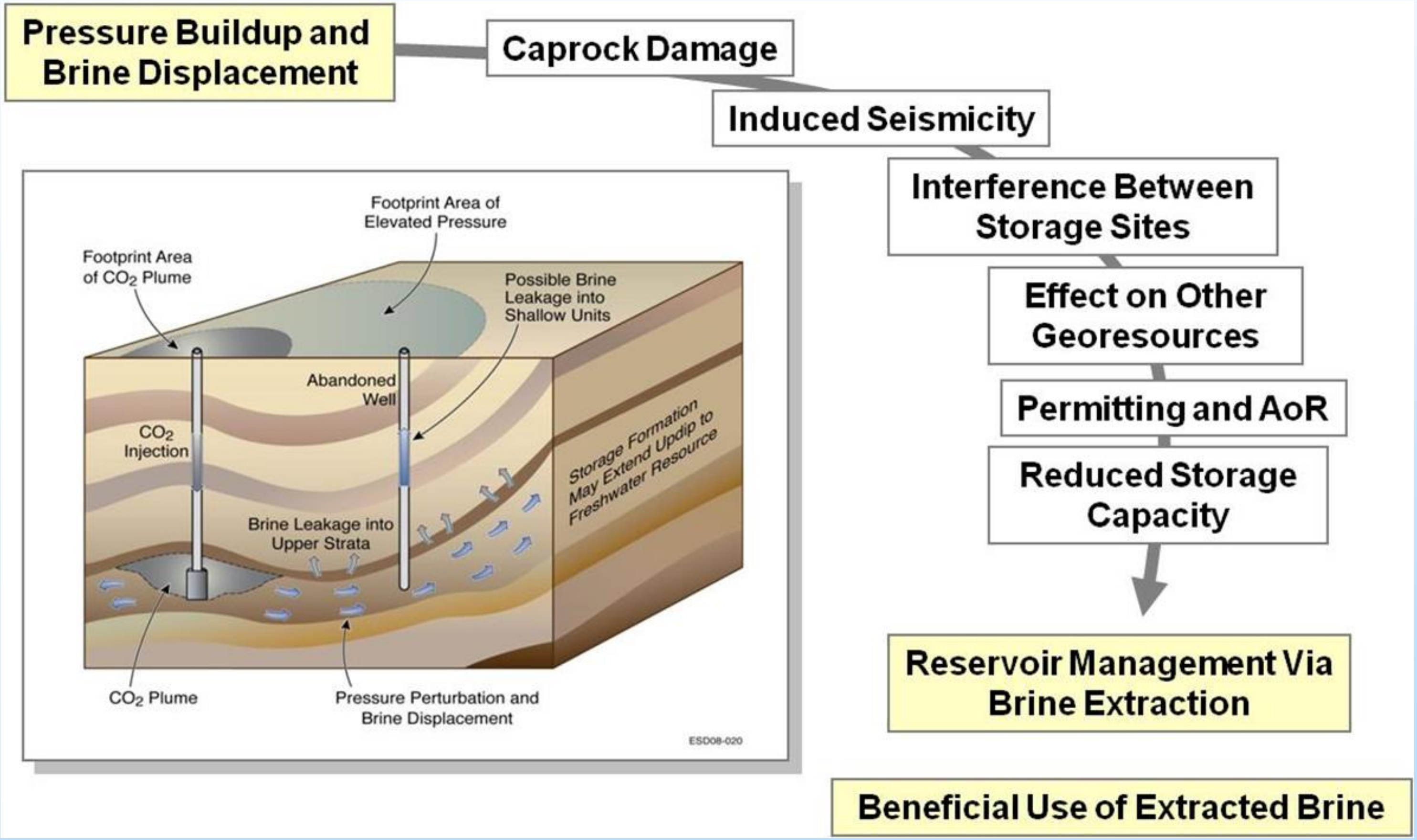
- Program Goals
  - Develop cost effective pressure control, plume management and produced water strategies that can be used to improve reservoir storage efficiency and capacity, and demonstrate safe, reliable containment of $CO_2$ in deep geologic formations with $CO_2$ permanence of 99% or better.
- 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 $CO_2$ 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 $CO_2$ in deep geologic formations with $CO_2$ 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

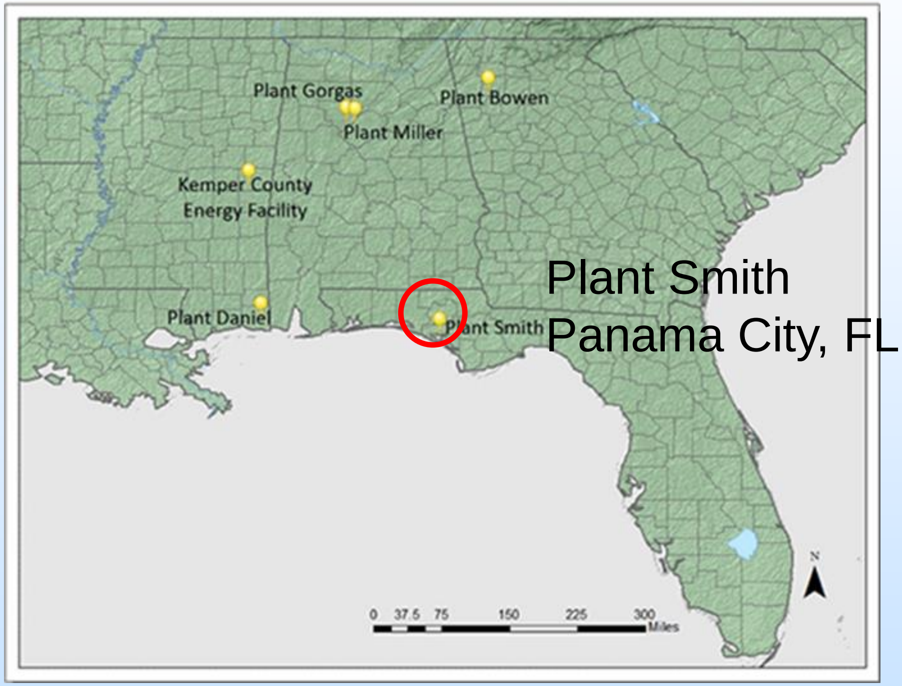
**Objective :** Develop cost effective pressure control, plume management and produced water strategies for: 1) Managing subsurface pressure; 2) Validating treatment technologies for high salinity brines

**Reservoir Integrity Issues Related to Industrial-Scale $CO_2$ Injection**



# Site Screening and Down Selection Evaluated Six Flagship Power Stations

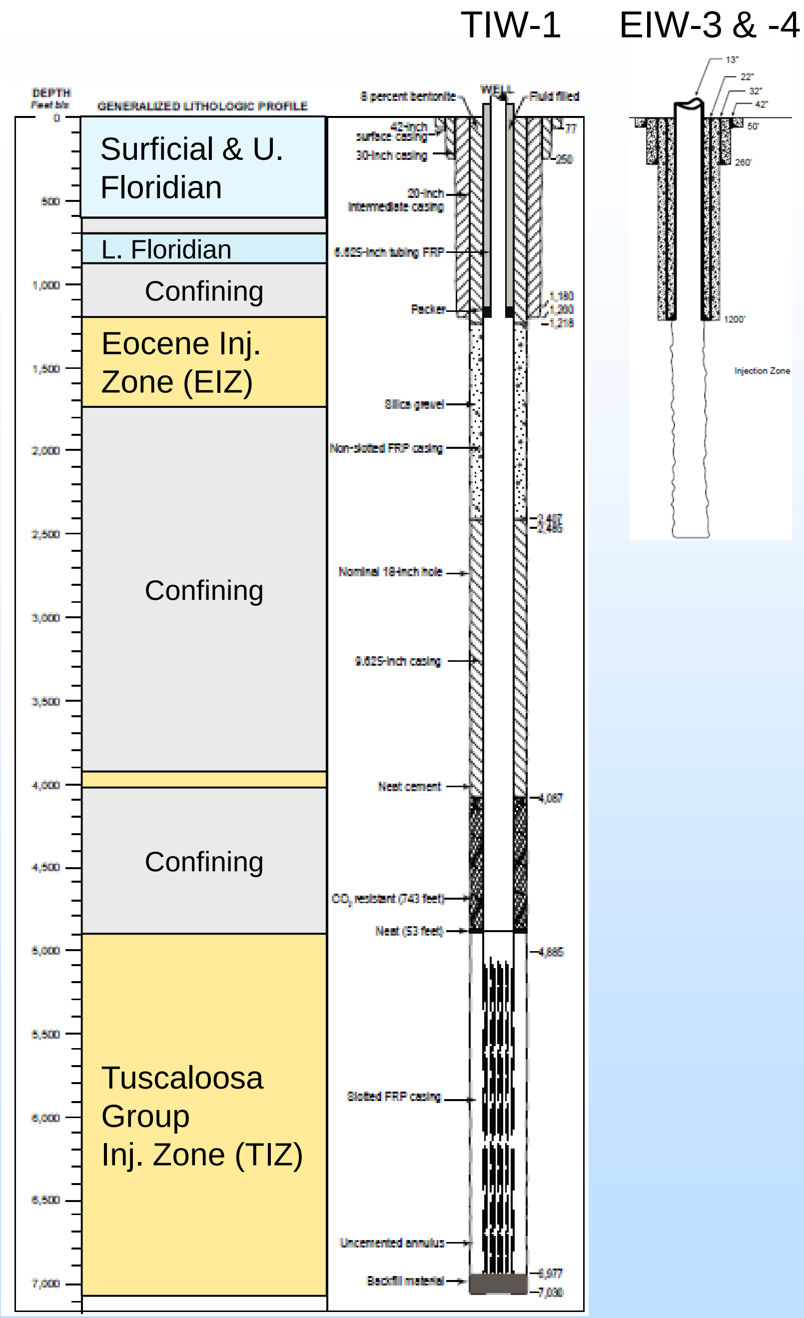
- Evaluated existing geologic, geophysical and hydrologic data in the vicinity of each site, including
  - Well records, logs, core data, regional structural and stratigraphic studies and subsurface production/injection data
- Examined existing surface infrastructure at each plant
- Gaged plant commitment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

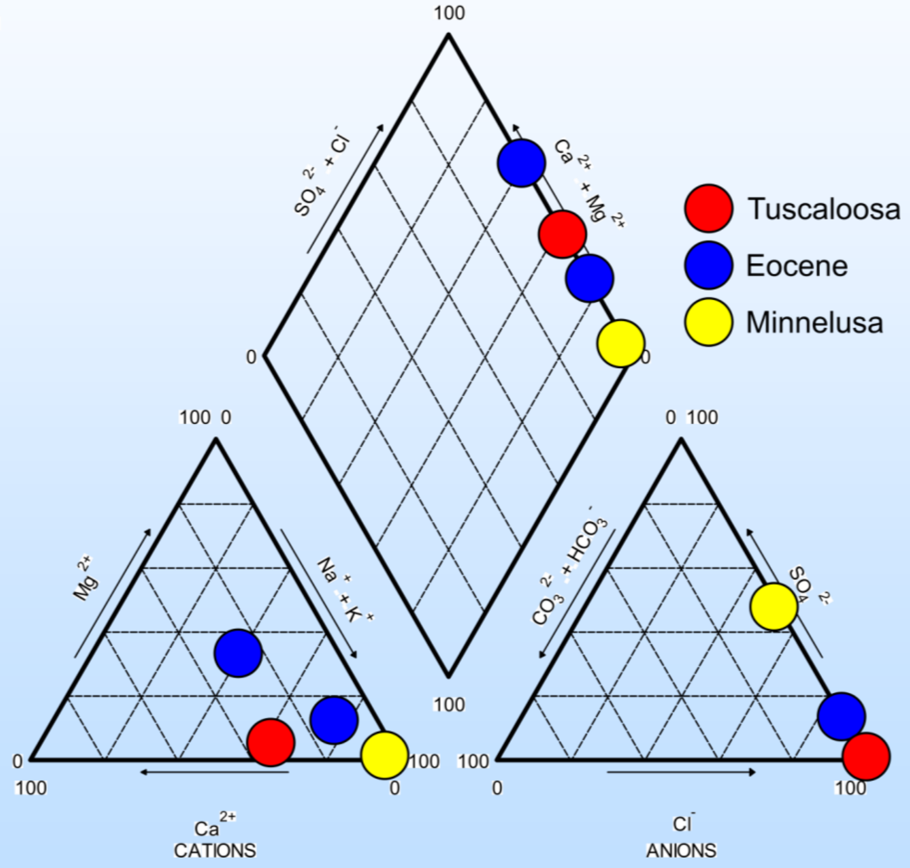
# Plant Smith

- 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-1,000 gal/day)



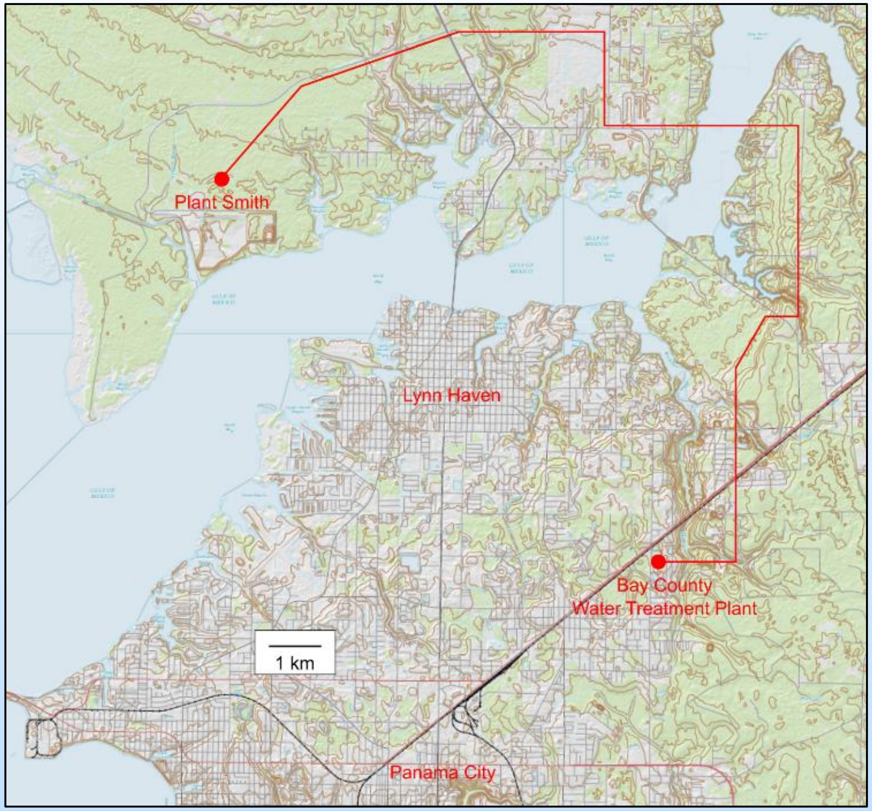
# Life cycle analysis of extracting and treating brine, transmitting treated water

- We considered a range of moderate to high TDS brines (between 30,000 and 166,000 mg/L)
- Eocene and Tuscaloosa Formation brines from Smith were predominately NaCl brines with high levels of $Ca^{2+}$
- Three brine to $CO_2$ extraction to injection ratios (1:5, 1:2 and 1:1)
- Highest extraction rate ~2.5M gallons/day (1:1)
  - Represents 41% $CO_2$ capture from a 1,000 MW plant to meet the EPA Clean Power Plan (1,305 $tCO_2$/MW-hr)



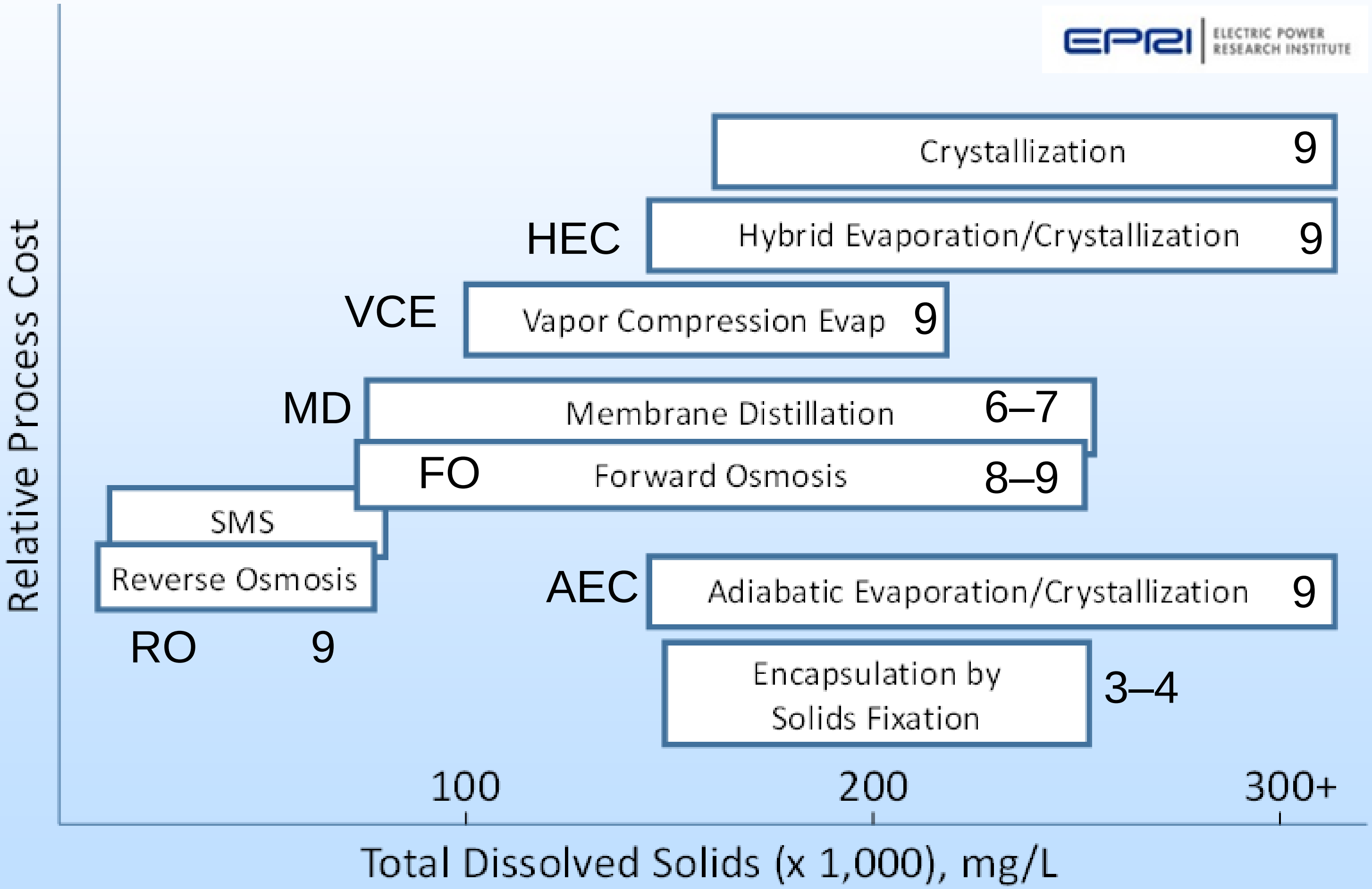
# Scenario for Extracting, Transmitting and Treating Brines

- Performed techno-economic assessment of pre- and secondary treatment of brines using commercially available technologies
- Treated water was pumped through a standard pipeline to a municipal water treatment plant
- Examined residual waste disposal and ZLD
- Computed the power required over 30 years of operation
- Calculated CapEx/OpEx costs for entire system




Hypothetical pipeline alignment in Bay County, FL.

# Commercial Water Treatment Technologies Evaluated and TRLs

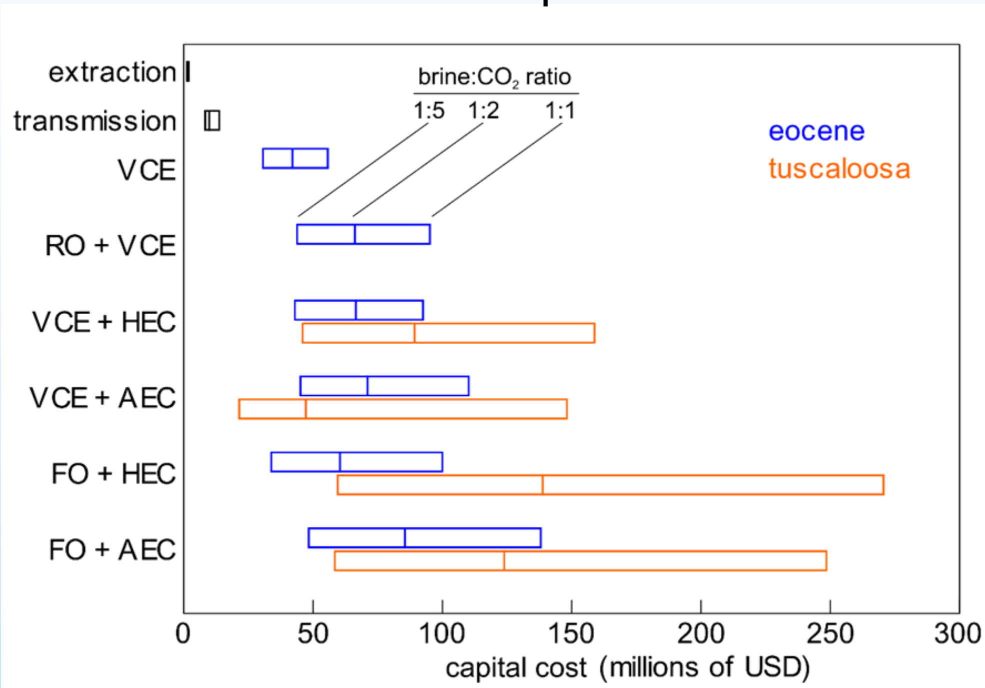



SMS = stacked membrane systems

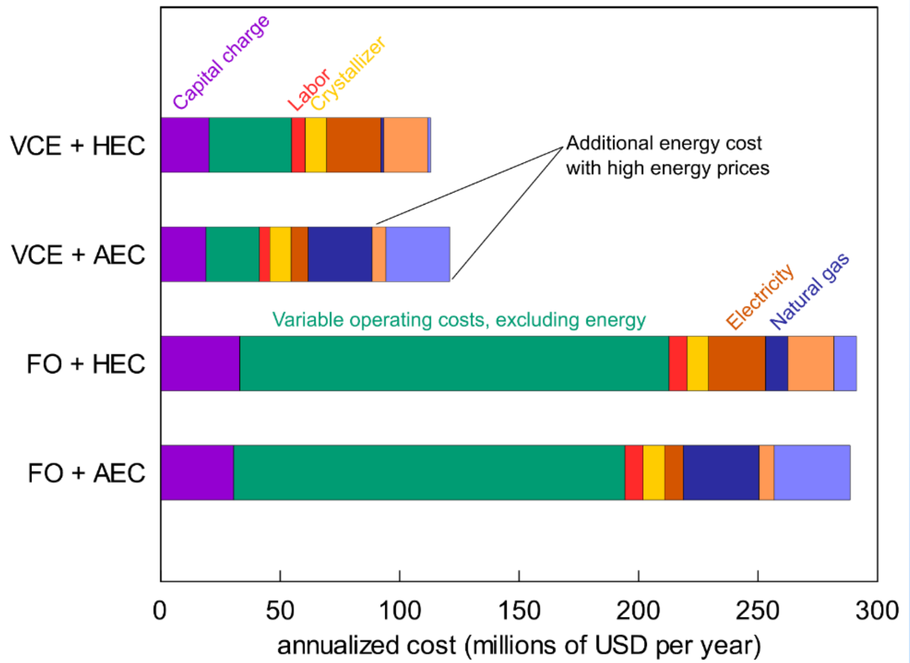
# Costs for Pre- and Primary-Treatment of Produced Brines will be Significant

Annualized cost of extracting and treating Tuscaloosa brine in the 1:1 extraction scenario

CapEx



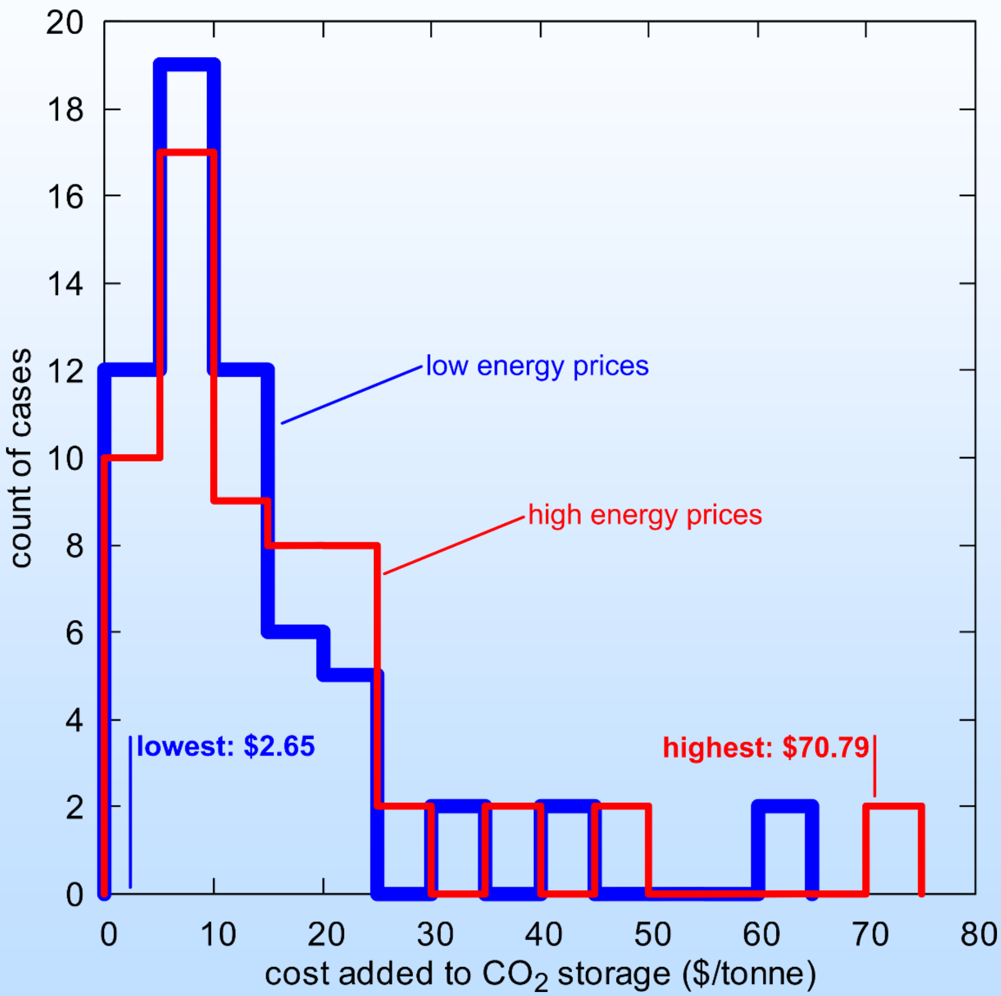

OpEx




- **Capital costs for treatment far exceed extraction and transmission combined**
- **High salinity waters are challenging and costly to treat with limited options available for treatment**

- **Membrane technologies have large OpEx costs for pre-treatment**

# Contributions to the cost of $CO_2$ capture



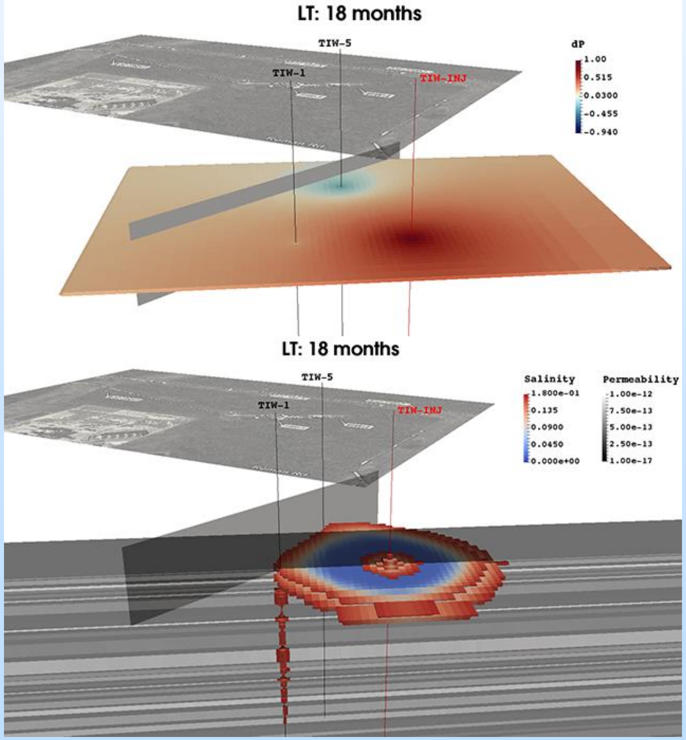

- Considered two price regimes for energy: low prices representing current averages and high prices that might spur the widespread adoption of CCS
- There is a wide range of possible additional cost to storing $CO_2$, depending on the processes used and the quantity of brine extracted

**Brine quality may be a factor when choosing a storage site**

# Objectives of Subsurface Pressure Management Via Brine Extraction at Plant Smith

- Manage pressure-related impacts away from the point of injection, such as the potential for inducing seismic events and leakage along hypothetical faults
- Control the plume migration behavior of the injected fluid
- Limit the size of the Area of Review
- Limit the volume extracted

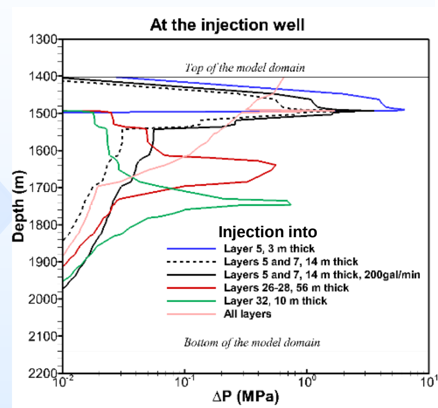
*3D view of the differential pressure distribution (in MPa) (top) and the injected fluid plume in terms of salinity ( $\times 10^6$ parts per million, ppm) (bottom) in the Lower Tuscaloosa injection layer, at the end of the selected 18-month pressure management base case scenario*

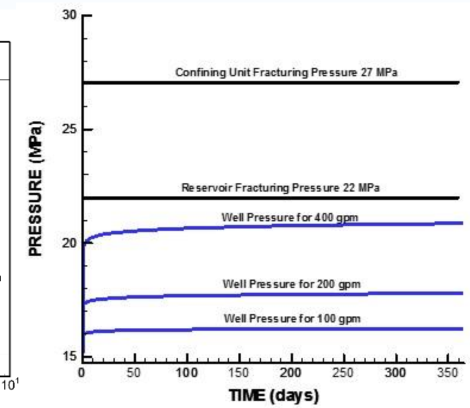


# General Approach Used to Develop Preliminary Pressure Management Scenarios for Plant Smith

**Reservoir sensitivity analyses**

- Identify potential injection interval(s)
- Assess geomechanical constraints to prevent fracturing
- Assess spatial and temporal extent of the pressure/water plume
- Assess effects of active extraction and passive pressure relief

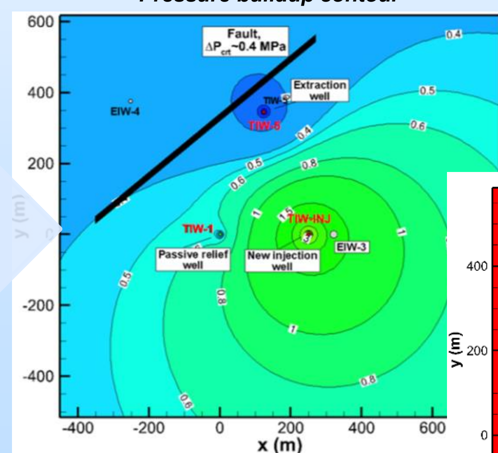


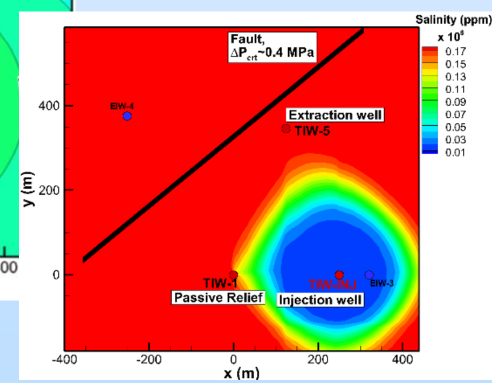

**Development of pressure management strategies**

- Apply reservoir modeling and optimization tools
- Design management strategies, optimal well placement and control parameters based on
  - Minimum extraction rate and minimize costs (e.g., drilling)
  - No pulling of injected fluid at active extraction well

*Pressure buildup contour*

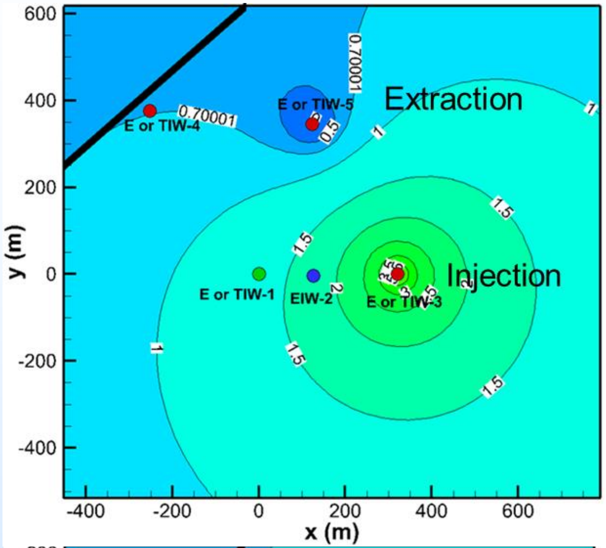



**Base case scenario:** Pressure buildup and salinity plume at 18 months, with optimized active and passive extraction

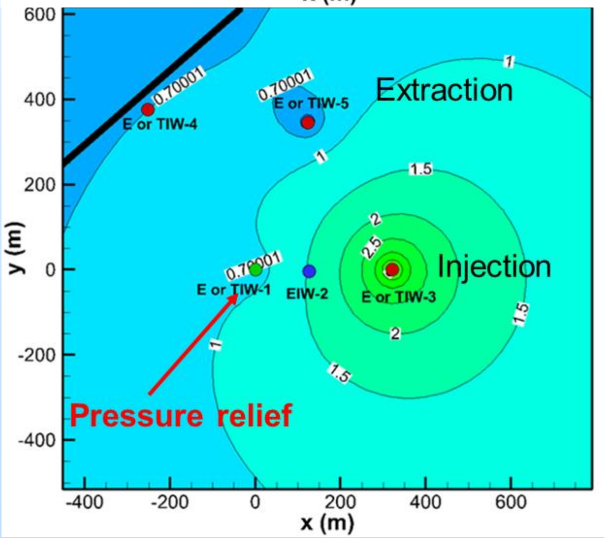


# Base Case Pressure Management scenario for Plant Smith

- 18-month injection at ~200 (gal/min) into two layers of the Lower Tuscaloosa creates radially extensive pressure plume
- Large contrast between injected water and native brine enables geophysical monitoring and plume steering
- Existing "pressure relief well" and "new" extraction well will be used to validate passive and active pressure management strategies



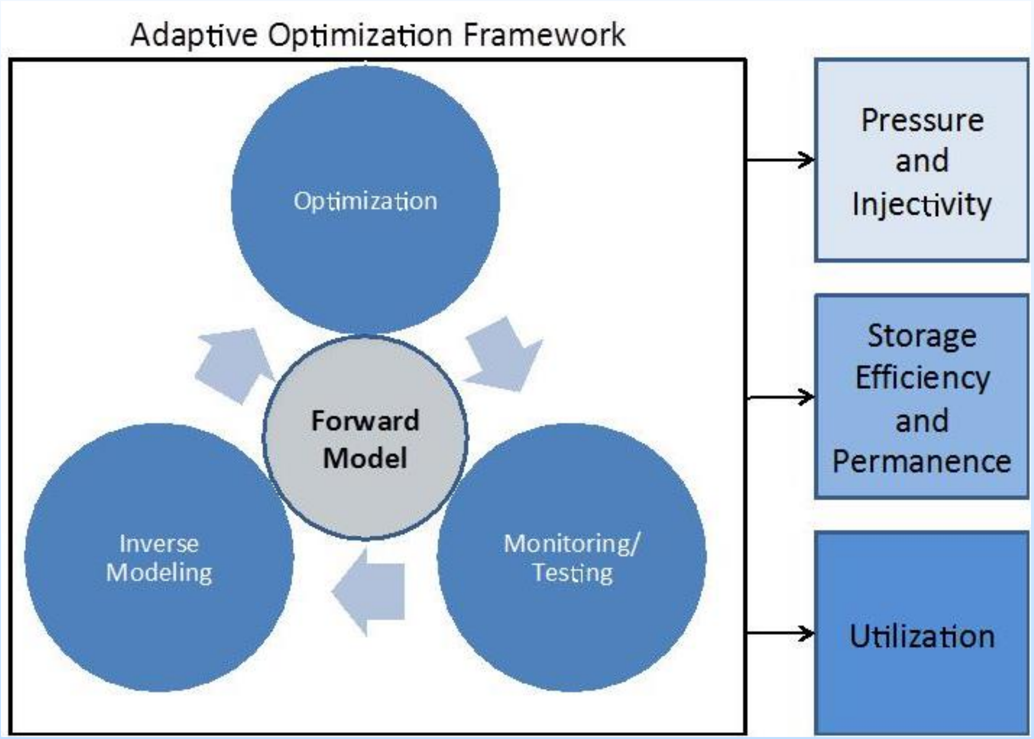

Pressure distribution from active injection & extraction




Addition of passive relief well reduces pressure on a hypothetical fault

**Passive well (bottom) decreases extraction ratio by about 40%**

# Implementation of an adaptive pressure management scheme will ensure proper control of pressure and plume migration during Phase II field demonstration



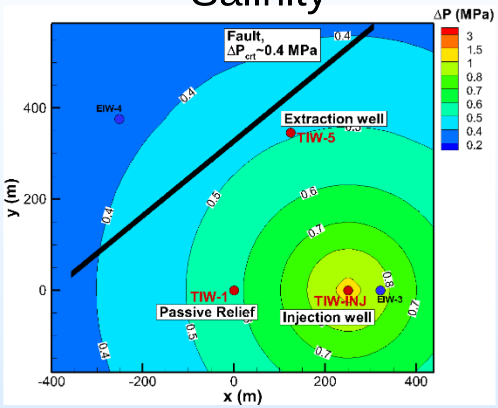

- Incomplete knowledge of the subsurface properties exist, especially during the planning stages of $CO_2$ projects, because of often quite limited site characterization data and related uncertainties.
- During the operation of the project, the subsurface system behavior needs to be monitored continuously, and the models need to be frequently updated.
- The adaptive management workflow that will be developed for Phase II demonstration will integrate monitoring + modeling + inversion + optimization.
- The adaptive workflow for optimized management of $CO_2$ storage projects utilizes the advanced automated optimization algorithms and suitable process models.

# MVA Objectives for Phase II

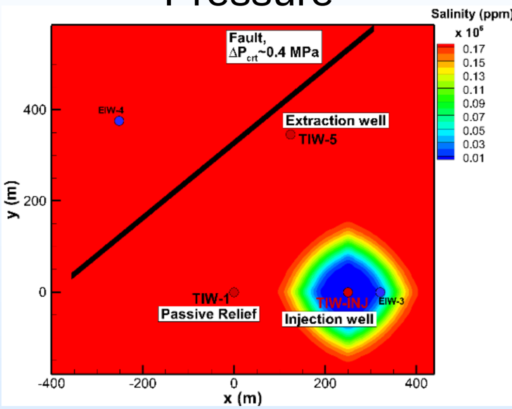
## Requirements of MVA:

1. **Tracking the Fronts** - track the position of the pressure front and low-salinity plume created by injected wastewater with sufficient spatial and temporal resolution such that adaptive pressure management strategies can be demonstrated.

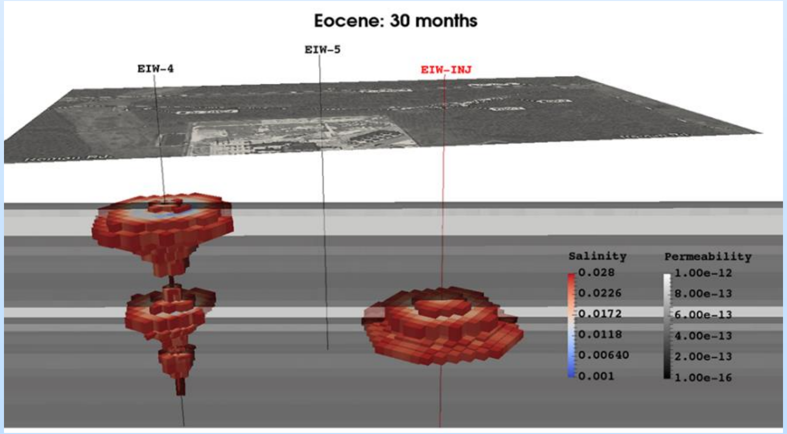
Salinity




Pressure




2. **Resolution Across Scales** - validate predictions of pressure, fluid movement, and differential pressure plumes in the reservoir using monitoring methods over a range of spatial scales and at a number of time steps.



# MVA Method Selection

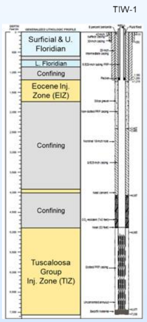
| TUSCALOOSA / EOCENE | | | 1. Sensitivity | 3. Site Compatible | 4. Costs per Survey | Rank |
|---|---|---|---|---|---|---|
| 2. Resolution (Spatial) | Borehole | Flow + Temp | H / H (fluid Δ) | Yes / Yes | < $15K | H / H |
| | | Resistivity or Fluid Sampling | H / H (fluid Δ) | Yes / Yes | < $15K | H / H |
| | | Pressure | H /H (pressure Δ) | Yes / Yes | < $15K | H / H |
| | | Gravity | L / L (fluid Δ) | Yes / Yes | --- | L / L |
| | Crosswell | EM/ERT | H / H (fluid Δ) | Yes / Yes | < $100K | H / H |
| | | Seismic | L / L (fluid Δ; pressure Δ) | Yes / Yes | < $250K | L / L |
| | | Tracers | M / M (fluid Δ) | Yes / Yes | --- | L / L |
| | Borehole-Surface | EM/ERT | H / H (fluid Δ) | Yes / Yes | < $200K | H / H |
| | | Seismic (3D VSP) | L / L (fluid Δ; pressure Δ) | No / No | < $750K | L / L |
| | Surface | Seismic | L / L (fluid Δ; pressure Δ) | No / No | < $1MM | L / L |
| | | InSAR | M / M | Yes / Yes | < $200K (2 yr monitor) | M / M |

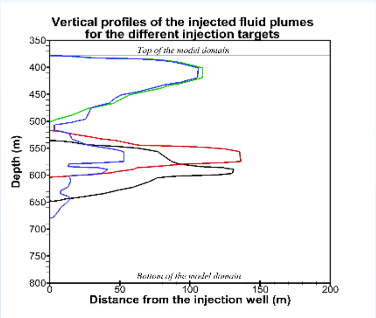
## Selection Criteria:

1. **Sensitivity** - required to track low-salinity plumes and differential pressure fronts
2. **Resolution** - spatial and temporal resolution across multiple scales ↖ select best in each class
3. **Compatibility** - with surface (environmental restrictions, terrain, accessibility), subsurface (geology, wells) and Plant Smith operations requirements
4. **Cost** - associated with data collection, processing and analysis are within scope of budget
5. **Maturity** - of technology is beyond early development stage ↖ considered only established methods

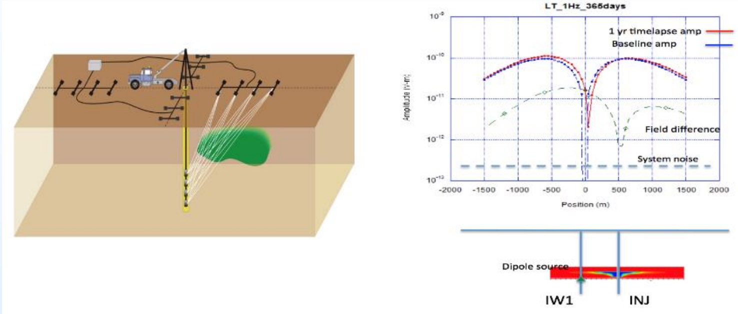
# MVA Inversion for Pressure & Salinity

- **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).

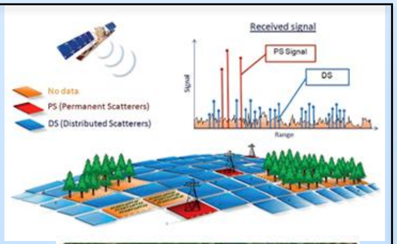


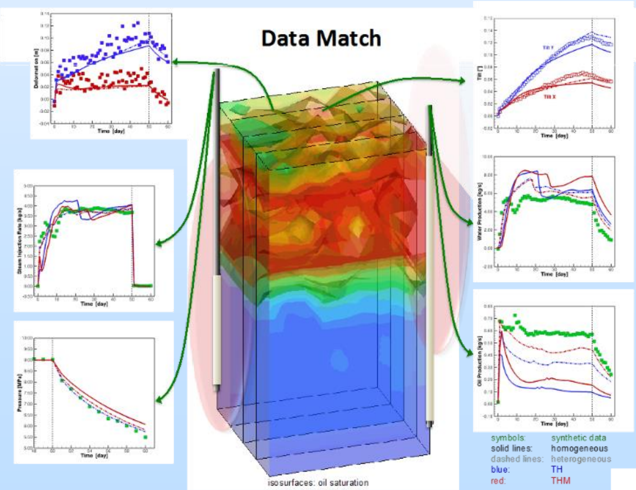

- **EM** - Time-lapse crosswell and borehole-to-surface EM will provide indirect measurements of the higher resistivity injected ash pond water with spatial resolutions in 2D and 3D approaching several meters to tens of meters, respectively.




- **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.



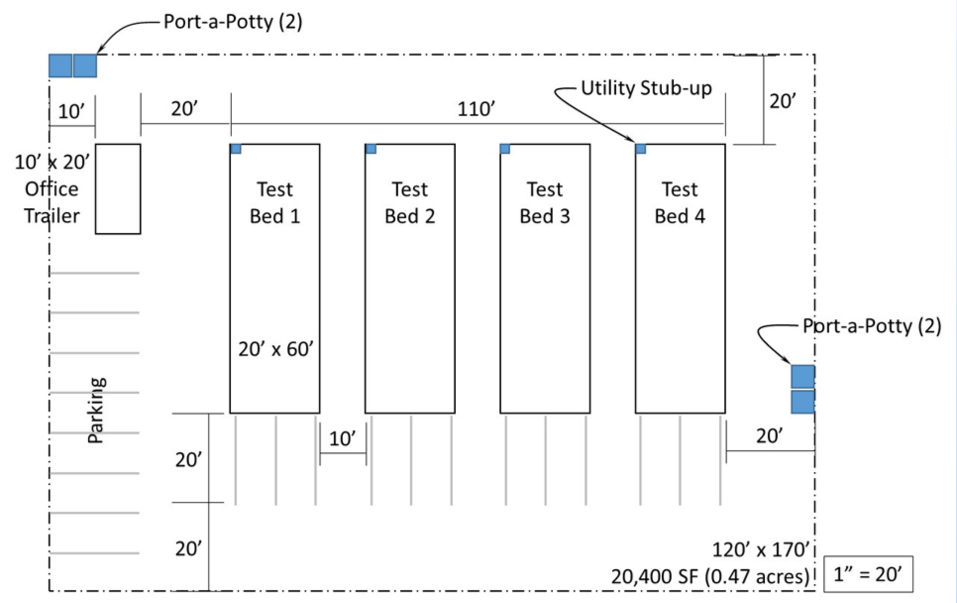
# Accomplishments to Date

- Site Screening resulted in down selection to Plant Smith
- Produced an integrated life-cycle economic analysis for treating high salinity Plant Smith brines
- Developed pressure management scenarios that will be validated using MVA during the Phase II field demonstration
- Created an implementation plan for Phase II execution
  - Site characterization plan to fill in data gaps
  - Drilling and testing plan
  - MVA plan
  - Preliminary design for a water treatment user facility

Berkeley Lab
Advanced Resources International, Inc.
EPRI | Electric Power Research Institute

# Synergy Opportunities

- EPRI is developing a brine treatment user facility at Plant Smith for use by water technology vendors to validate their equipment/processes
  - Host annual or semi-annual meetings with BEST sister project led by EERC
    - Tech transfer and cross-fertilization of approaches and ideas
    - Provide project updates, technology transfer, lessons learned and experiences



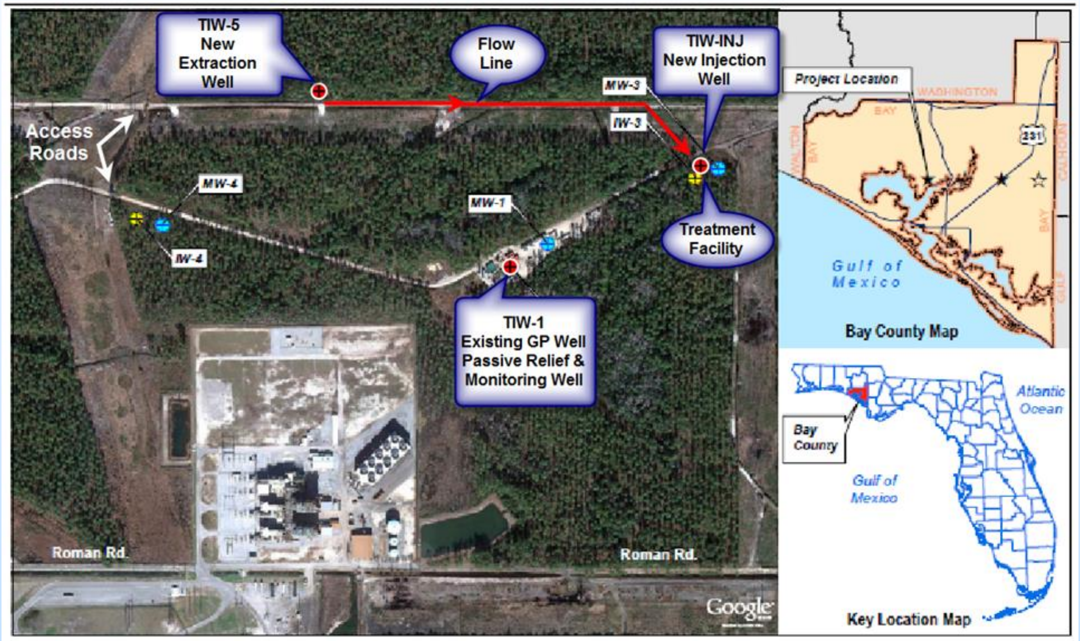

Test bed layout at Plant Smith

# Summary

## Future Plans

Phase II Field Demonstration

- Duration 48 mos (2016-2020)
- Permit and install two new wells (injection & extraction)
- Site characterization
- Construct and operate pipeline
- Build/operate water Injection, extraction and treatment sys.
- Execute MVA
- Implement the Adaptive Management Strategy
- Analysis & Reporting
- Site Closure




Proposed infrastructure for Phase II field demonstration at Plant Smith

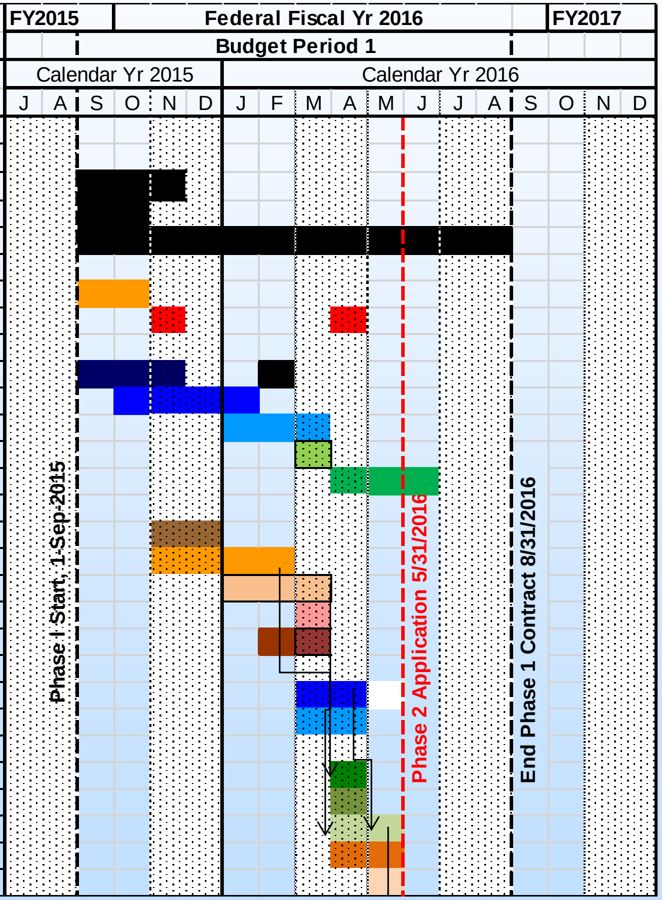
# Appendix

# Project Team

- Department of Energy, NETL
  - A. McNemar, PM
- Electric Power Research Institute
  - R. Trautz, PI
  - A. Bhown
  - R. Breckenridge
  - J. Swisher
  - J. Preece
  - M. DiFilippo
- Advanced Resources International
  - M. Godec, TL
  - R. Petrusak
  - D. Riestenberg
  - S. Cyphers
  - G. Koperna
- Lawrence Berkeley National Laboratory
  - J. Birkholzer, TL
  - A. Cihan
  - M. Commer
  - T. Daley
  - K. Nihei
  - M. Reagan
  - J. Rutqvist
  - M. Wilt
  - Q. Zhou
- Southern Company
  - Richard Esposito, Southern Company
  - M. Markey, Gulf Power Co.

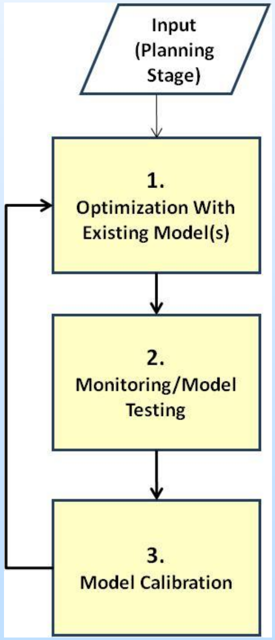
# Project Schedule

| Phase I Project Schedule | | | |
|---|---|---|---|
| **Description** | **Start Date** | **End Date** | **Dur. Mos.** |
| **Task 1.0 Project Management** | | | |
| Revise Project Management plan | 9/1/2015 | 11/30/2015 | 3 |
| NEPA approval | 9/1/2015 | 10/31/2015 | 2 |
| Project management | 9/1/2015 | 8/31/2016 | Ongoing |
| **Task 2.0 - Site Screening and Down-Selection** | | | |
| 2.1 - Regional and Local Data Availability | 9/1/2015 | 10/31/2015 | 2 |
| 2.2 - Site Ranking and Selection | 11/1/2015 | 4/30/2016 | 1.0 |
| **Task 3.0 - Produced Water Life Cycle Analysis** | | | |
| 3.1 - Define Finish Water Specifications | 9/1/2015 | 2/28/2015 | 3.5 |
| 3.2 - Produced Water Extraction Scenario Development | 10/1/2015 | 1/31/2016 | 4 |
| 3.3 - Water Treatment Technology Screening | 1/31/2016 | 3/31/2016 | 3 |
| 3.4 - Transportation Infrastructure | 2/1/2016 | 3/31/2016 | 1 |
| 3.5 - Integrated Economic Analysis | 4/1/2016 | 6/30/2016 | 3 |
| **Task 4.0 - Pressure Control and Optimization Strategy** | | | |
| 4.1 - Static Geologic Model Development | 11/1/2015 | 12/31/2016 | 2 |
| 4.2 - Reservoir and Geomechanical Predictions | 11/1/2016 | 2/28/2016 | 4 |
| 4.3 - Development and Optimization of Pressure Management Strategies | 1/1/2016 | 3/31/2016 | 3 |
| 4.4 - Predicting Detectability of Reservoir Response for MVA Planning | 3/1/2016 | 3/31/2016 | 1 |
| 4.5 - Advanced Well Technology Feasibility Analysis | 2/15/2016 | 3/31/2016 | 1.5 |
| **Task 5.0 - Advanced MVA Program** | | | |
| 5.1 - Injection Monitoring and Optimization | 3/1/2016 | 4/30/2016 | 2 |
| 5.2 - Far-Field Monitoring Program | 3/1/2016 | 4/30/2016 | 2 |
| **Task 6.0 - Develop Phase II Field Demonstration Work Plan, Cost & Schedule** | | | |
| 6.1 - Site Characterization Plan | 4/1/2016 | 4/30/2016 | 1 |
| 6.2 - Drilling Plan | 4/1/2016 | 4/30/2016 | 1 |
| 6.3 - Testing, Monitoring & Sampling Plan | 4/1/2016 | 5/31/2016 | 2 |
| 6.4 - Surface Infrastructure & Implementation Plan | 4/1/2016 | 5/31/2016 | 2 |
| 6.5 - Field Demonstration Cost and Schedule | 5/1/2016 | 5/31/2016 | 1 |

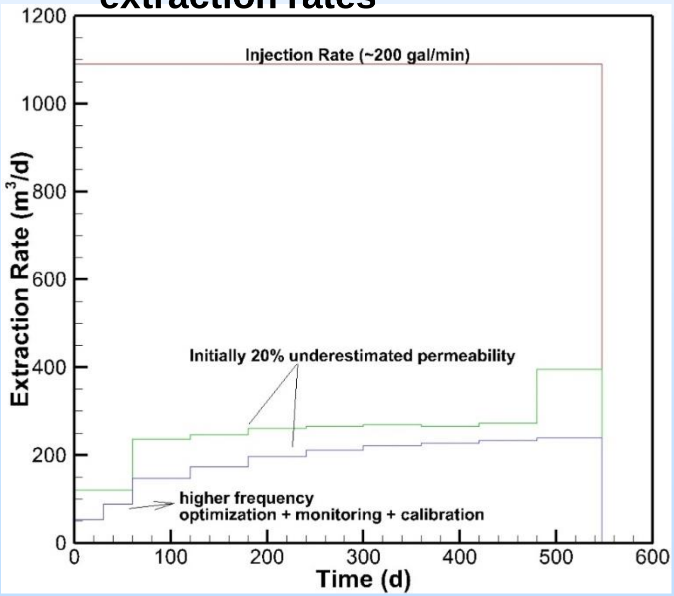


# Example demonstration of a preliminary adaptive optimization scheme

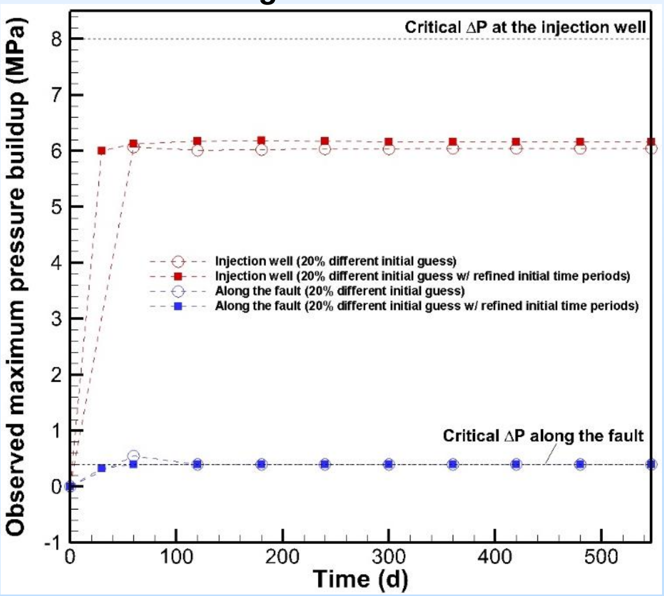
- For simple demonstration example, we assumed that the reservoir properties for the Lower Tuscaloosa from the preliminary static model developed are actual parameters of the reservoir system
- We employed the model with actual parameters at each required time period to generate the observation data. We only used the pressure data, but more robust testing and applications of the adaptive management framework in Phase II will involve other types of data including but not limited to point measurement of salinity and flow rates at the wells as well as salinity plume assessment with the geophysical measurements
- The adaptive algorithm starts with optimization calculations based on the prior information collected during the planning stage. Initial guesses different from the actual values with some certain percentages are set for the unknown hydraulic properties in the approximate forward model. If the model predictions significantly deviate from the observed data based on an arbitrary error tolerance, the model calibration process takes place by the fitting the model to the data.
- To understand the importance of the estimated aquifer properties during the initial site characterization, we simulated a scenario where the initially estimated permeability and compressibility of the reservoir layers in the Tuscaloosa static geologic model are 20% different from the actual values of these parameters. We assume that the permeability values are underestimated while the pore compressibility values are generally overestimated.




**Optimized time-dependent extraction rates**




**Higher frequency model update needed at earlier stages**



# Bibliography

List peer reviewed publications generated from project per the format of the examples below

- None