California CO_2 Storage Assurance Facility Enterprise (C2SAFE)

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Presentation Outline

- Technical Status
  - Regulatory driver
  - C2SAFE overview
  - Task description and status
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Project Summary
- Appendix

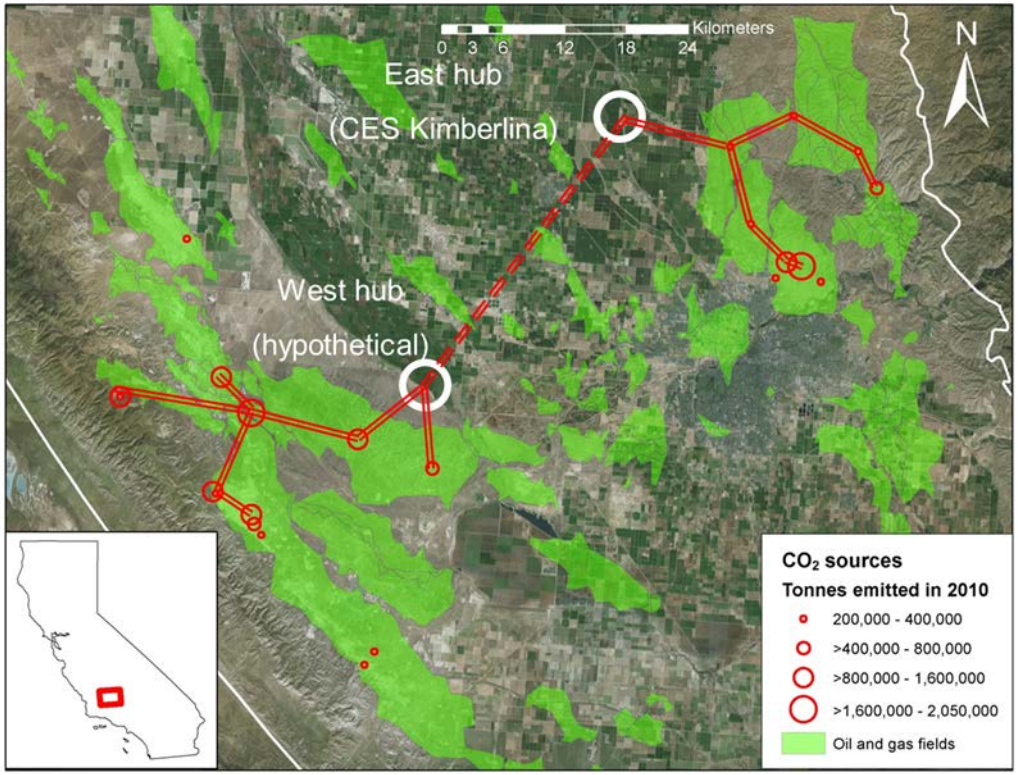
C2SAFE—Overview

California climate change regulations have evolved quicker than federal standards creating economic incentives for industry to act

- C2SAFE is conducting a techno-economic assessment of **four** commercial-scale CCS scenarios in the Southern San Joaquin Valley (SSJV)
  - East hub, west hub, combined hubs and dispersed source/sink model
- Develop business case for preferred scenario
  - Develop CO_2 capture costs based on studies for post-combustion capture
  - Phased CO_2 pipeline buildout: eastside and westside networks and interconnecting trunk line
  - Develop sub-basin geologic models to assess safe, reliable storage and wellfield buildout
  - California-specific credits considered (LCFS, cap-and-trade, etc.)
  - Identify regulatory and legal issues
  - Engage stakeholders, assess social impacts and prepare a stakeholder communication plan

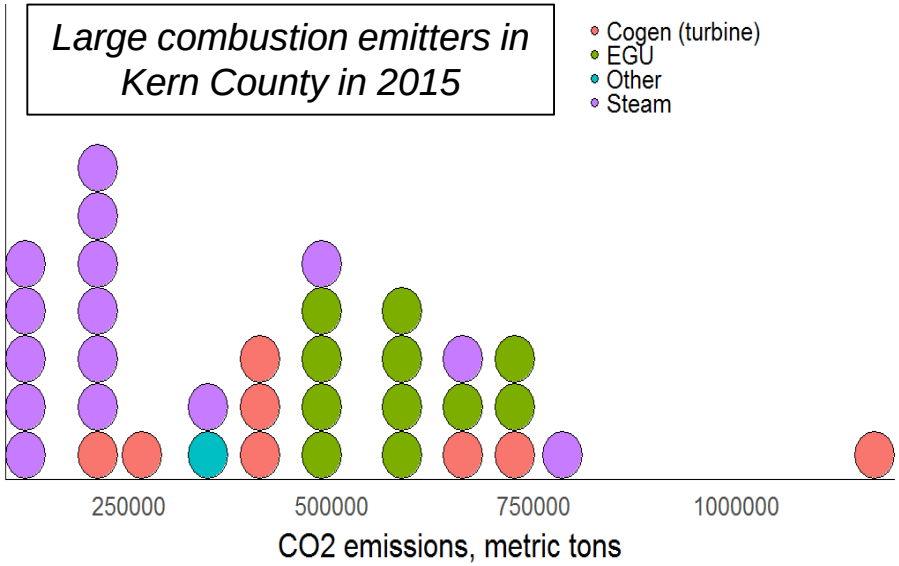
CO_2 Source Characterization and Capture Techno-Economics Status

- Identified individual emitters >100,000 tonne-CO_2/yr. Virtually all are natural gas NGCC units, cogen units, or oilfield steam generators
- Oilfield operators report cogen units and steam generators are not operating at full capacity or air permit limits; hence it is practical to make extra steam for CO_2 solvent regeneration

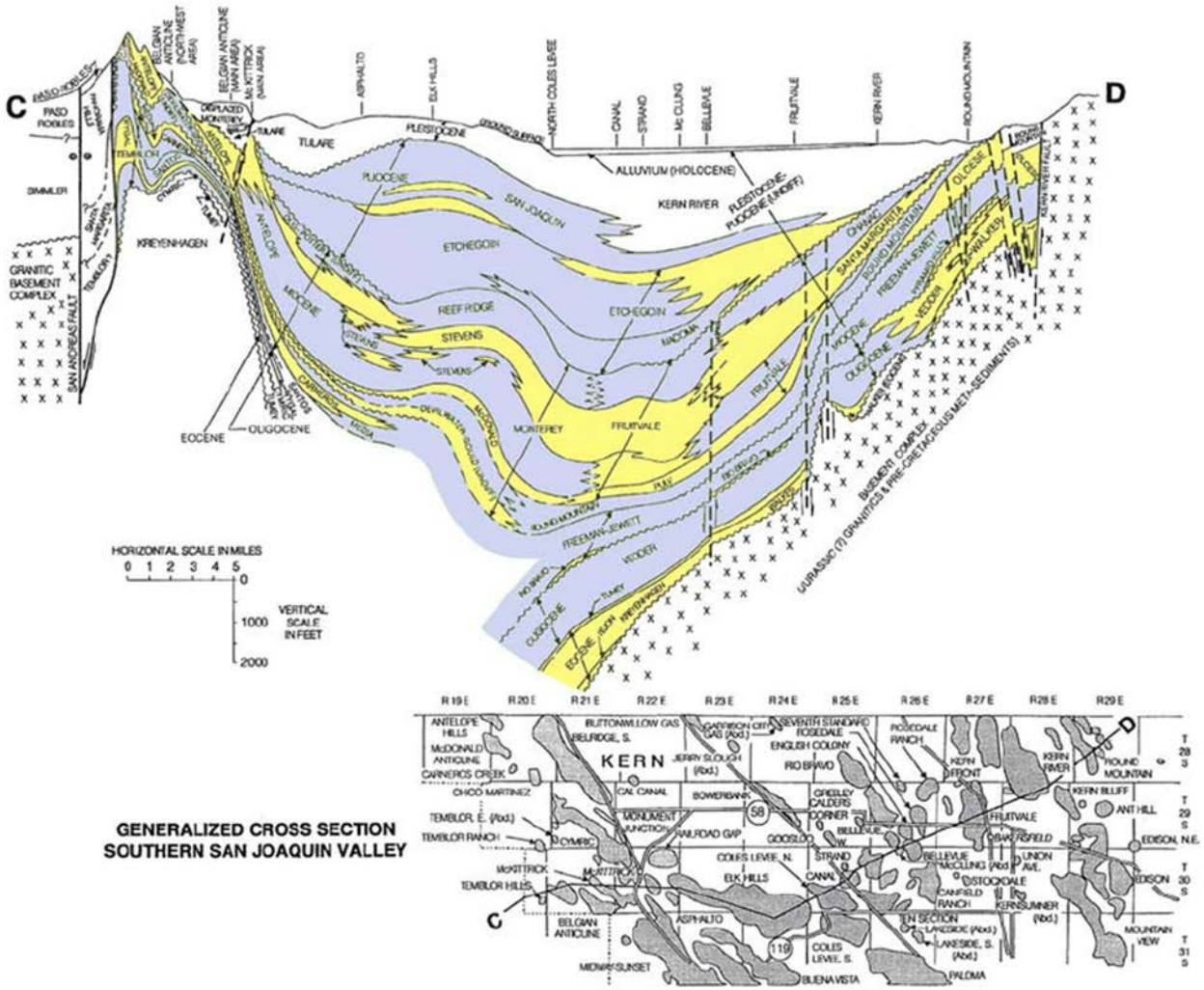


CO_2 Sources and Capture Cost: Initial Findings

- Created a model for the cost of capture/compression to deliver CO_2 at pipeline conditions
  - Capital cost scaling based on NETL data for Cansolv process
  - Operating cost based on model of steam, chemical, and electrical consumption per unit of CO_2
- Capital costs dominate the levelized cost of capture (~50% on $/tonne-$CO_2$ basis)



SSJV CO_2 Storage Complex Assessment Status

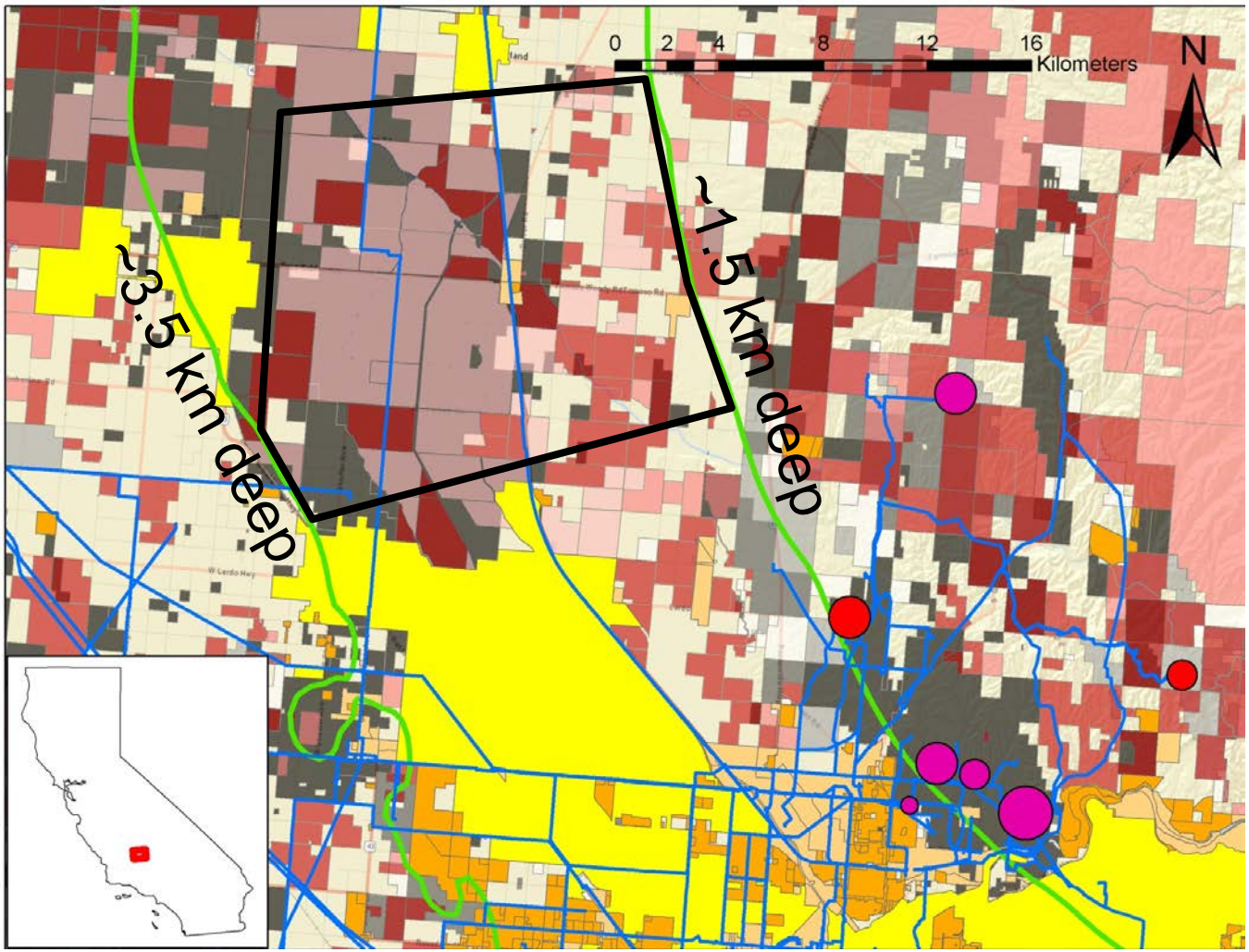


Produced fluids to date suggest large storage capacity in the SSJV

- ~∑production (million barrels)
  - Stevens: 5,030
  - Vedder: 630
  - Temblor: 630

Isopachs mapped

Spatial Mapping Identifies Prospective Storage Hub Locations (East Hub Example)



Surface Ownership

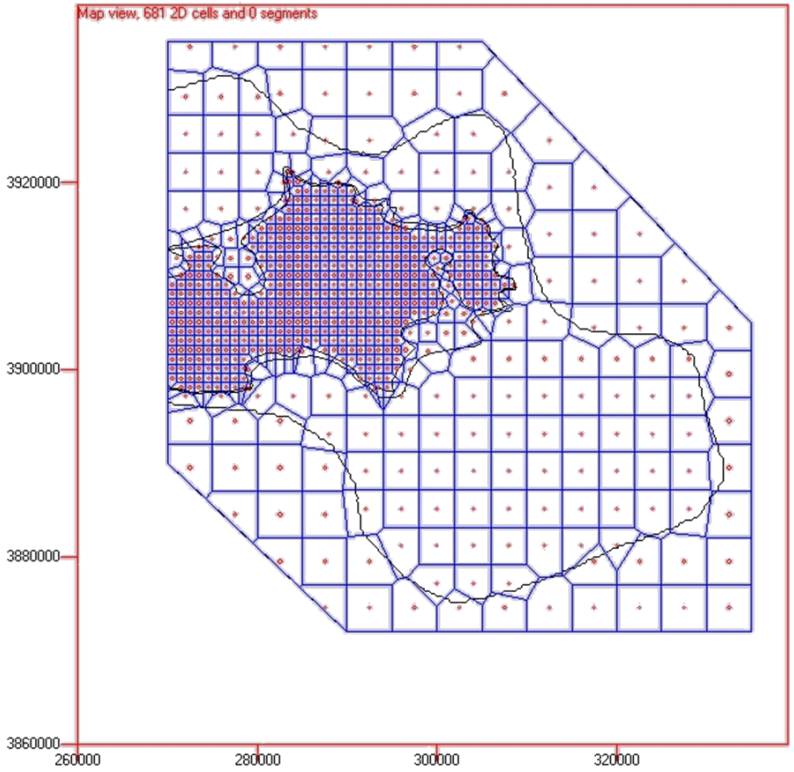
Lighter = larger owner area

Except white = small holdings

Exploration Area

Sub Basin Storage Assessment Status

- Finding: Eastside distributed source-sink model likely not feasible
- Finding: Production data suggests potential for reservoir compartmentalization in some areas of SSJV
  - Pressure management strategies may be needed and scenarios have been defined
  - Simulation mesh for east and west hub locations completed
  - Initial calibration simulation for one hub completed

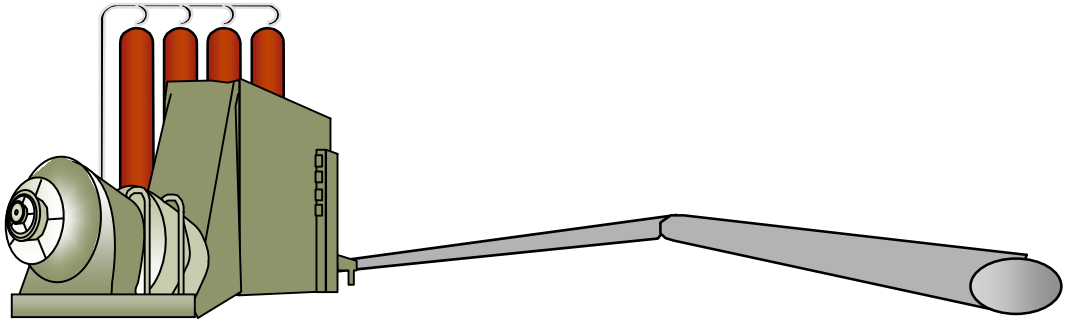


Stevens Sands (west storage hub): Mesh for simulating pressure management scenarios

Southern California Gas Company Pipeline Analysis

- Established basic CO_2 pipeline assumptions: 2M tonne/yr for east hub, 2200 psig pressure, dry conditions
- Modified in-house NG pipeline EPC-type cost model for differences between NG and CO_2
- Determined least-cost routing using existing rights-of-way
- Interviewed developers of Petra Nova CO_2 pipeline in Texas
- Preliminary pipeline sizing/costing developed using SoCalGas in-house model and NETL tools/data

Integrated Economic Assessment: Initial Observations



Oil producers expect to steamflood for decades; limited prospects for CO_2-EOR; adding CO_2 capture would create steady storage demand

Four NGCC plants in area, but capacity factors declining

Biomass/biofuel projects increasing; adding CCS yields net negative GHG

NG pipeline ROW on east and west sides of SSJV

Modest elevation drop from sources to hubs, may save 2” in pipe D

Learnings from Petra Nova CO_2 pipeline reduce cost uncertainty

Mineral estates well established in area; subsurface rights transactions common

Drilling costs understood but market-dependent

MVA costs for Kimberlina estimated during WESTCARB

CA cap-and-trade law now extended to 2030

LCFS, cap-and-trade credits available once CARB GCS QM approved

Implementation Scenario Status

- An initial, small-scale CO_2 capture project would take place at Clean Energy Systems' Kimberlina power plant
  - Former 5 MWe biomass plant on 30+ acres surrounded by agriculture fields and processing plants
  - Site used to demonstrate CES oxy-combustion technology
  - A Class V UIC permit application was developed in 2009 for 1M tonne injection

Phased approached would gain operational experience at small-scale before initiating large-scale commercial storage

Initial Small-Scale CO_2 Injection Planning Status

- Inject up to 100,000 tonne-CO_2 at the Kimberlina site from onsite equipment

- Use existing biomass and oxy-fuel combustion systems at site

Initial Small-Scale CO_2 Capture Project at CES Kimberlina Plant

Existing biomass unloading station, conveyors, and storage silos

Biomass gasifier and fuel upgrading system supplied by Carson US

Initial Small-Scale CO_2 Capture Project at CES Kimberlina Plant (cont'd)

- Gasification technology: Selection and fabrication of initial, small-scale system (100 ton/day biomass) started
  - Staged delivery and assembly expected Fall 2017
- Proof-of-concept and system performance testing expected Spring 2018, with 3 months of operation
  - Successful results will release project financing and air permits
- Scale gasification and fuel upgrading system for pilot plant long-term operation (300 ton/day biomass total)
  - Installation and commissioning Summer-Fall 2018
  - Expected 100% online by year-end 2018
- CES oxy-combustion system to be integrated in 2019
  - Same basic technology can be used in fossil-fueled co-gen facilities for oilfield steamflood operations in SSJV

Accomplishments to Date

- Largest SSJV CO_2 emitters identified using EPA Greenhouse Gas Reporting data; combustor/stack configurations verified using satellite imagery and other sources
- Preliminary capture and conditioning/compression cost model developed in Excel, drawing upon NETL studies of post-combustion Cansolv process and equipment scaling factors
- Sub-basin assessment indicates large aggregate CO_2 storage capacity. Localized reservoir compartmentalization and pressure management strategies are being assessed
- Scaled approach to CCS buildout for region is being evaluated
- More than a dozen key industry and state agency stakeholders interviewed

Lessons Learned

- Local producers see decades of life in SSJV oilfields under steamflood; hence, if CO_2 were captured, there would a steady demand for storage services
- Local industry stakeholders have no concern about the adequacy of SSJV geologic formations for CO_2 storage capacity or about long-term storage security
- Although California rules for low carbon fuel standard credits (~$80/tonne) are somewhat complex, regulators are working to establish approved protocols for geologic CO_2 storage
- Petra Nova CO_2 pipeline personnel provided numerous insights to SoCalGas, who is costing the C2SAFE pipeline(s)

Synergy Opportunities

- Clean Energy System's biomass gasification project
  - Renewable Natural Gas (RNG) production for transportation
  - Syn gas production for power generation

Project Summary

Summary

- California law requires deep reductions in GHG emissions
- California low carbon fuel standard and GHG emissions cap and trade program provide economic incentives for industry to act
- SSJV is an vital energy producing region, creating jobs and transportation fuels that drive California's economy
- C2SAFE's capture, transportation, storage and integrated economic assessment uses stakeholder input to develop realistic business scenarios for the SSJV

Next Steps

- Storage reservoir compartmentalization is being simulated to evaluate the need for pressure management, including water extraction
- Work continues on the cost of capture, transportation and storage with a goal toward reporting the levelized cost ($/tonne-$CO_2$) across the entire supply chain
- Formal stakeholder outreach meetings are planned in the near future to gather additional information needed for the Phase I business scenarios and garner support for Phase II

Together…Shaping the Future of Electricity

Appendix

Benefit to the Program

- Program goals and benefits statement:
  - C2SAFE will assist DOE and industry in developing cost-effective storage solutions that improve reservoir storage efficiency and predictive storage capacity methodologies to within +/-30%:

    This goal will be partially realized during Phase I by conducting a scenario analysis involving reservoir simulations and an integrated techno-economic assessment of CO_2 emission sources, transportation routes, and Sub Basin storage complexes in the southern San Juaquin Valley (SSJV).The pre-feasibility study will produce a high-level implementation plan for the region that identifies the most cost effective approach to capturing, transporting and storing large volumes of CO_2 in high-capacity storage formations from sources emitting greater than 50,000 tonnes of CO_2 per year. Such a CCS implementation plan is not currently available for the SSJV region.

  - A second programmatic goal is to demonstrate safe, reliable containment of CO_2 in deep geologic formations with CO2 permanence greater than 99%:

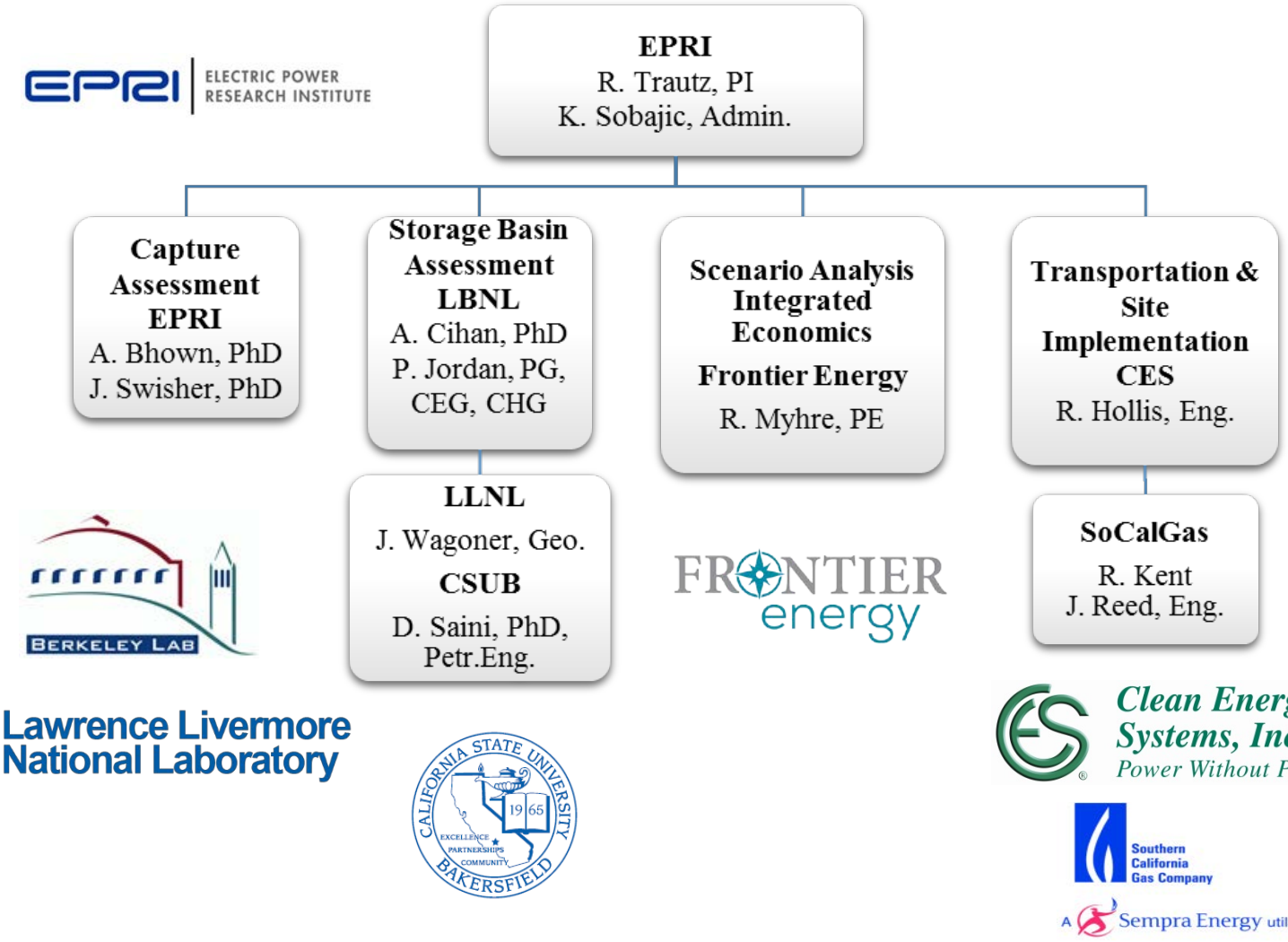
    C2SAFE will realize the second goal as it implements subsequent phases (II– IV) at the Kimberlina Power Plant near Bakersfield, California. Operational experience gained from implementing the project at the novel Clean Energy System's oxy-combustion power plant will provide realistic and practical learnings that can be incorporated into future updates of DOE best practice manuals related to CO_2 storage. A plan for upscaling the initial injection at Kimberlina will be developed for the broader SSJV region during the Phase I pre-feasibility study, allowing other CO_2 emission sources to be phased in over time.

Project Overview—Goals and Objectives

- California provides a unique opportunity
  - Climate change policy at the state level has evolved quicker than federal policy
  - Cap & trade, low carbon fuel standard, aggressive state-mandated CO_2 emission reduction targets by 2030 (40%) and 2050 (80%)
  - CO_2 emissions from natural gas represent 50% of US total

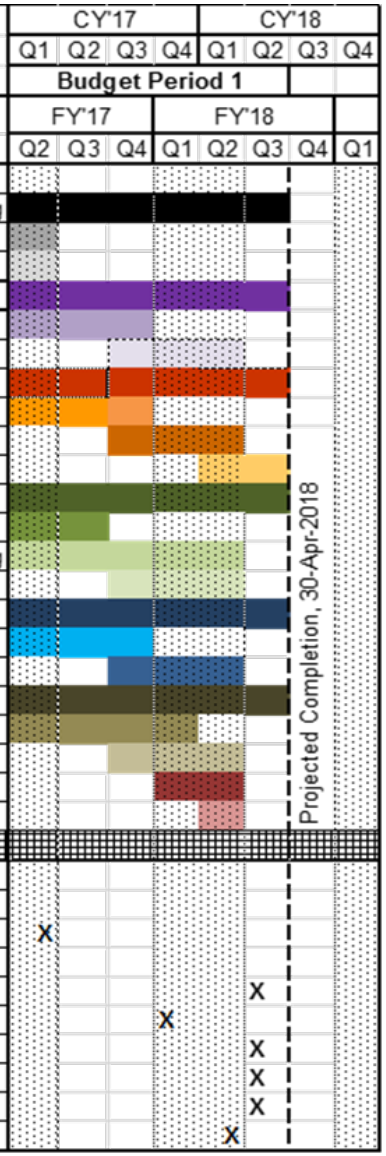
- Project goals and objectives
  - Assess the challenges that must be addressed and develop solutions that enable commercial-scale CO_2 storage in California's Southern San Joaquin Valley (SSJV)
  - Identify and assess storage complexes used to safely inject over 50 million metric tonnes of CO_2 over decadal time scales
  - Lay the ground work for subsequent project phases leading to a licensed CO_2 storage complex(es) by 2025
  - Form a qualified Carbon Capture and Storage (CCS) project team

Organization Chart



Gantt Chart

Estimated Phase I Project Schedule			
Description	**Start Date**	**End Date**	**Dur. Mos**
	1/1/2017	4/30/2018	
Task 1: Project Management and Planning			Ongoing
Sub-recipient & vendor contracting	1/1/2017	2/15/2017	1.5
Revise Project Management Plan and Project Data Factsheet	1/1/2017	2/28/2017	2
Task 2 – CO2 Source Characterization and Capture Techno-Economics			
Source data collection and compilation	1/1/2017	12/31/2017	12
Techno-Economic assessment	10/1/2017	3/31/2018	6
Task 3 – Sub-Basin Storage Assessment and Storage Economics			
Geologic data collection and compilation	2/1/2017	12/31/2017	11
Capacity estimates and reservoir simulation	10/1/2017	3/31/2018	6
Techno-Economic assessment	1/1/2018	4/1/2018	3
Task 4 – Scenario Analysis			
Scenario development	2/1/2017	7/6/2017	5
Identify social, legal and public perception challenges	3/1/2017	3/31/2018	Ongoing
Techno-Economic assessment	10/1/2017	3/31/2018	6
Task 5 – Preliminary Site Screening/Risk Assessment			
Geologic data collection and compilation	2/1/2017	12/31/2017	11
Risk analysis using NRAP tools	10/1/2017	3/31/2018	6
Task 6 – Implementation Plan			
Compile, analyze and tabulate data	2/1/2017	12/31/2017	11
Pre-feasibility assessment for Kimberlina	9/1/2017	1/31/2018	5
Develop upscaling plan for SSJV	12/1/2018	2/27/2018	3
Prepare implementation plan	2/15/2018	3/15/2018	1
Key Milestones and Deliverables		**Completion**	
Submit PMP and DMP		2/28/2017	
DOE Kickoff Meeting		TBD	
Data submittal to NETL-EDX		4/15/2018	
Milestone: Submit Phase 2 application		12/1/2017	
CO2 Source Characterization and Capture Techno-Economics Report		4/1/2018	
Sub-Basin Storage and Preliminary Risk Assessment Report		4/15/2018	
Integrated Scenario Analysis Report		4/15/2018	
Phased Implementation Plan for Kimberlina and SSJV		3/15/2018	



Bibliography

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