Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation

Project Number DE-FE-00026517

Barry Freifeld

Lawrence Berkeley National Lab

Scott McDonald, Salil Arora

Archer Daniels Midland

U.S. Department of Energy

National Energy Technology Laboratory

DOE Annual Review Meeting

August 16-18, 2016

Presentation Outline

- Benefits to the DOE CCS Program
- Project Overview
- Methodology & Expected Outcomes
- Project Tasks Updates
- Project Milestones
- Project Timeline

Benefit to the Program

Carbon Storage Program Goal Support:

Goal (1) Develop and validate technologies to ensure 99 percent storage permanence by reducing leakage risk through early detection mitigation.

Goal (2) Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness by advancing monitoring systems to control and optimize CO_2 injection operations.

Goal (4) Contributing to the Best Practice Manuals for monitoring, verification, and accounting (MVA) with regard to IMS.

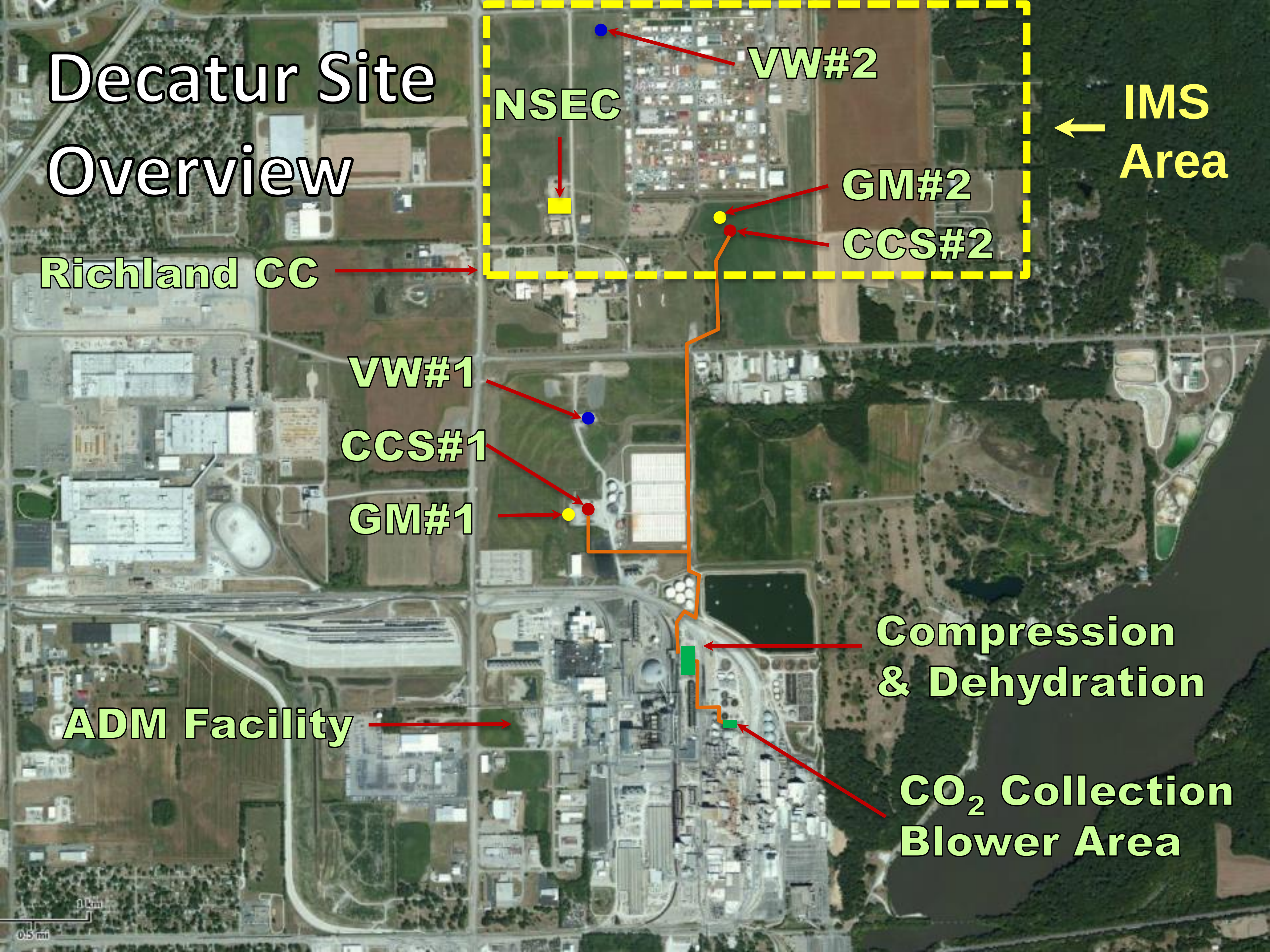
Benefit to the Program

IMS System Benefits:

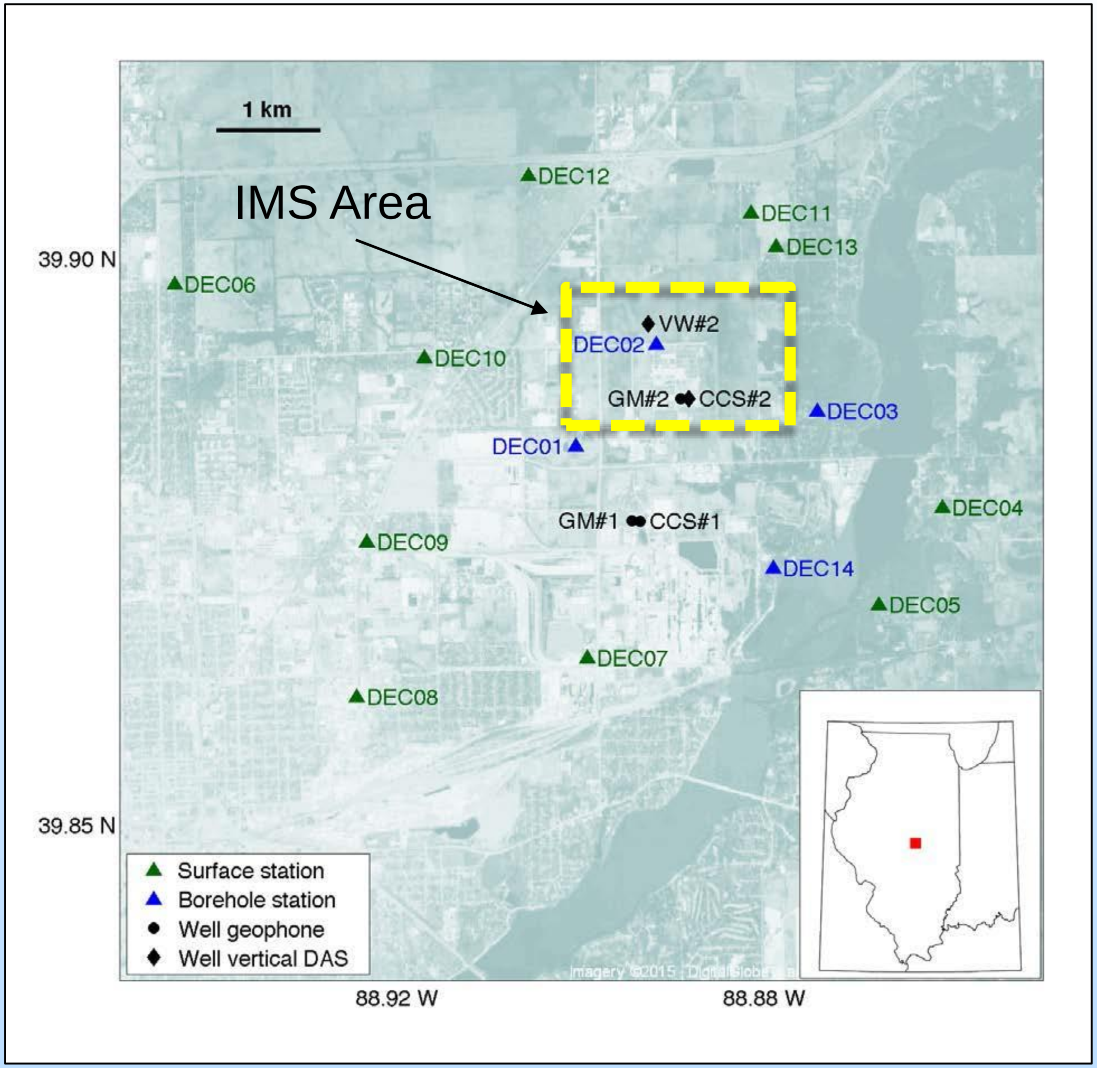
- Reduce overall storage cost.
- Increase monitoring sensitivity.
- Increase monitoring reliability by using an integrated system.
- Optimize operation and maintenance activities.
- Reduce project risk during and after the injection of CO_2.

Project Overview: Goals and Objectives

- Develop an integrated IMS architecture that utilizes a permanent seismic monitoring network, combines the real-time geophysical and process data with reservoir flow and geomechanical models.
- Create a comprehensive monitoring, visualization, and control system that delivers critical information for process surveillance and optimization specific to the geologic storage site.
- Use real-time model calibration to provide reservoir condition forecasts allowing site optimization.


Decatur Site Overview
NSEC
VW#2
IMS Area
GM#2
CCS#2
Richland CC
VW#1
CCS#1
GM#1
Compression & Dehydration
ADM Facility
CO_2 Collection Blower Area
1 km
0.5 mi

USGS Seismic Monitoring



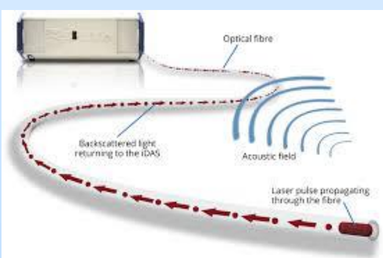
Methodology

- The proposed ICCS IMS program is transformative. It integrates into a single real-time processing framework the following emergent technologies.
  - DAS seismic imaging (VSP & surface reflection)
  - Permanent surface orbital vibrator
  - Hybrid geophone/DAS microseismic array
  - DTS well integrity monitoring

Existing vs. New Technology

Convention Seismic

DAS Seismic



Seismic surveys are considered the backbone technique for CO_2 storage monitoring programs.

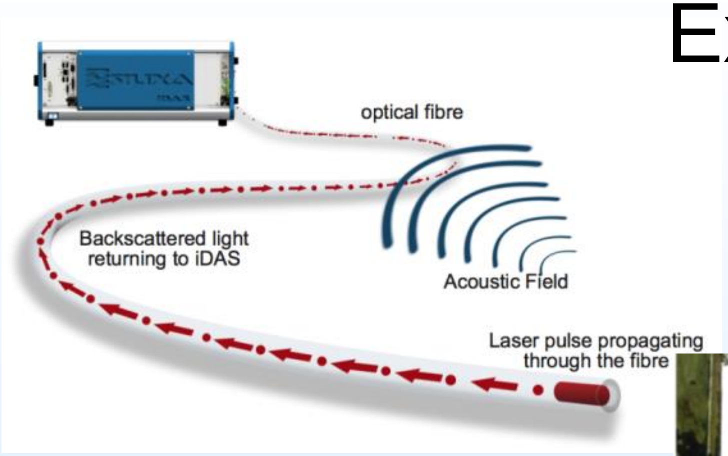
Stringing thousands of cables and running thumper trucks every few years can test the limits of good neighbors. Costs are high.

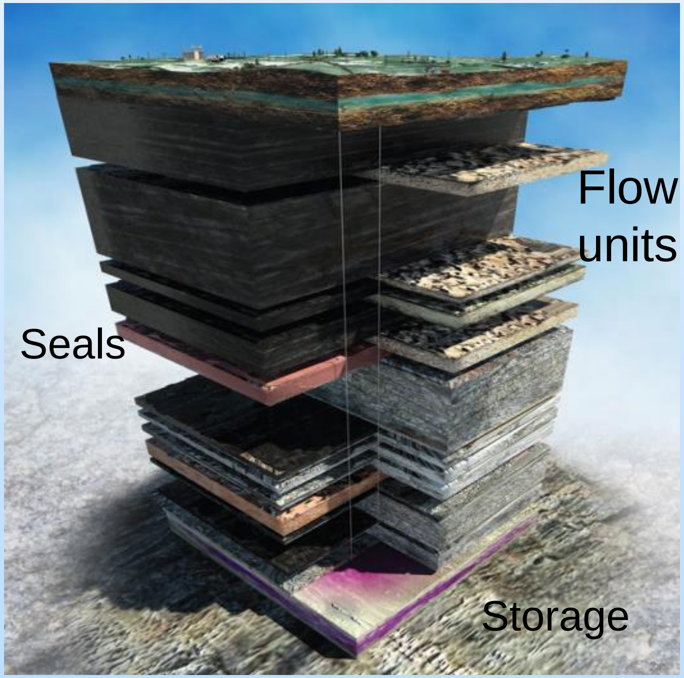
Permanent reservoir monitoring offers a way to obtain higher quality information with minimal intrusion into surrounding lands –

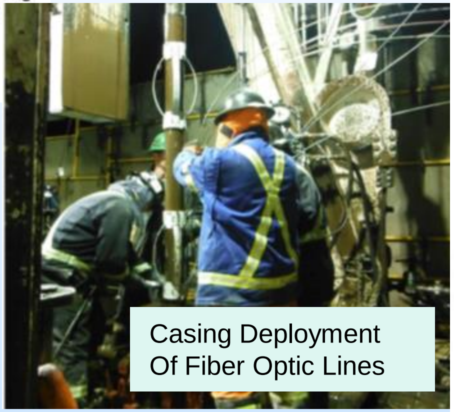
- **DAS provides high spatial and temporal resolution.**
- **Installation can be in horizontal directionally drilled boreholes beneath bodies of water, existing infrastructure.**
- **Excitation of DAS cables can be achieved through permanent fixed rotary sources for continuous monitoring.**

Distributed Acoustic Sensing (DAS)

Example from PTRC Aquistore
DAS Baseline 3D-VSP

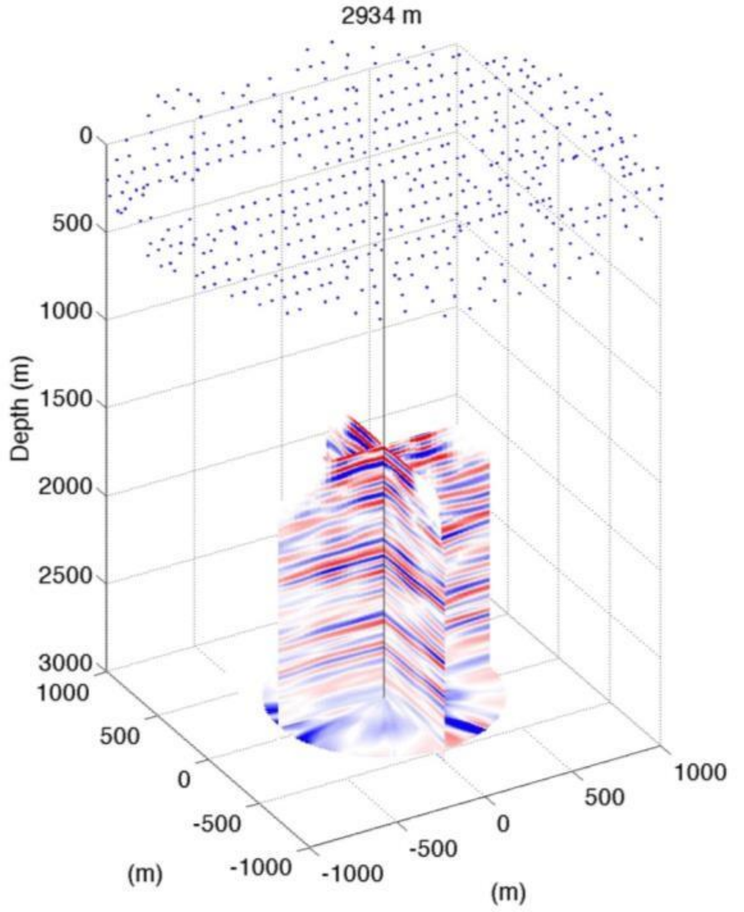






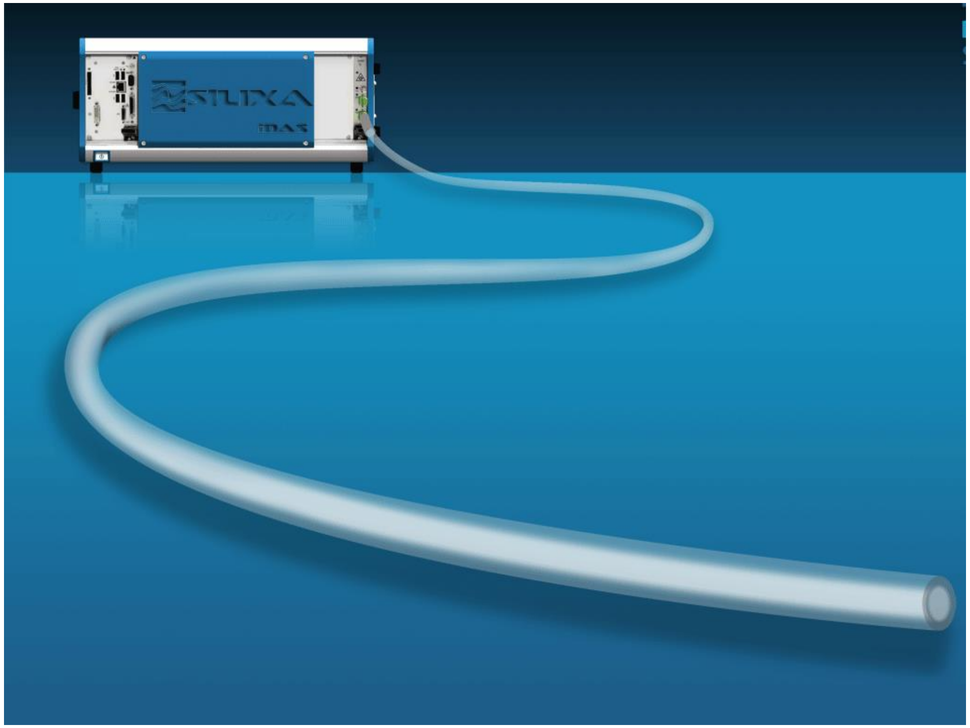
Casing Deployment
Of Fiber Optic Lines

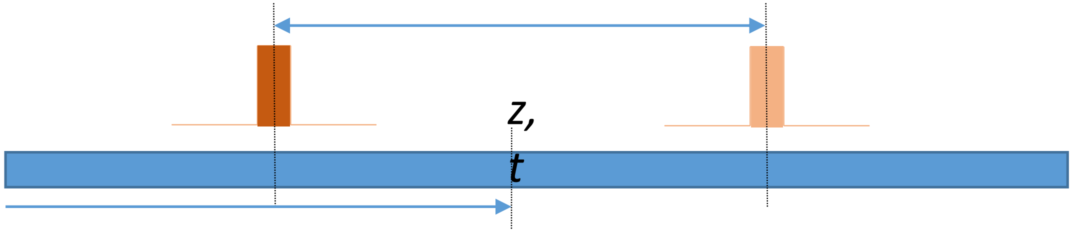
DAS VSP is becoming accepted technology.



Distributed Acoustic Sensing

- Standard optical fibre acts as the sensor array
  - Typical sampling at 10kHz on 10,000m fibre
  - Standard gauge length of 10m
  - Spatial sampling of 25cm
  - DAS measures change in average elongation per 10m gauge length per 0.1ms acoustic time sample, sampled every 0.25 m in distance

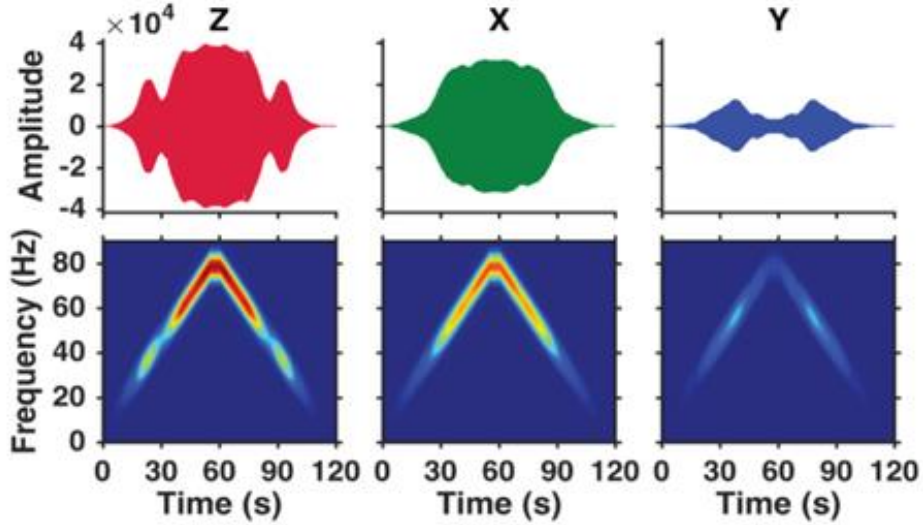




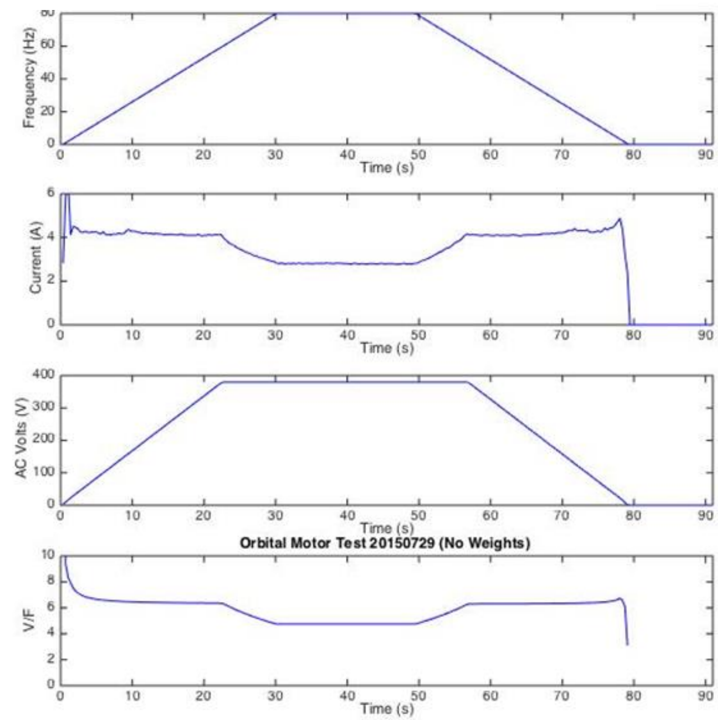
$$\left[u\left(z+\frac{dz}{2},t+dt\right)-u\left(z-\frac{dz}{2},t+dt\right)\right]-\left[u\left(z+\frac{dz}{2},t\right)-u\left(z-\frac{dz}{2},t\right)\right]$$

Parker et al., Distributed Acoustic Sensing – a new tool for seismic applications, *first break* (32), February 2014

Surface Orbital Vibrator – VFD Controlled AC Induction Motor



Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained. Operate 2.5 hr/d



Force is adjustable

$F = m\omega^2 r$

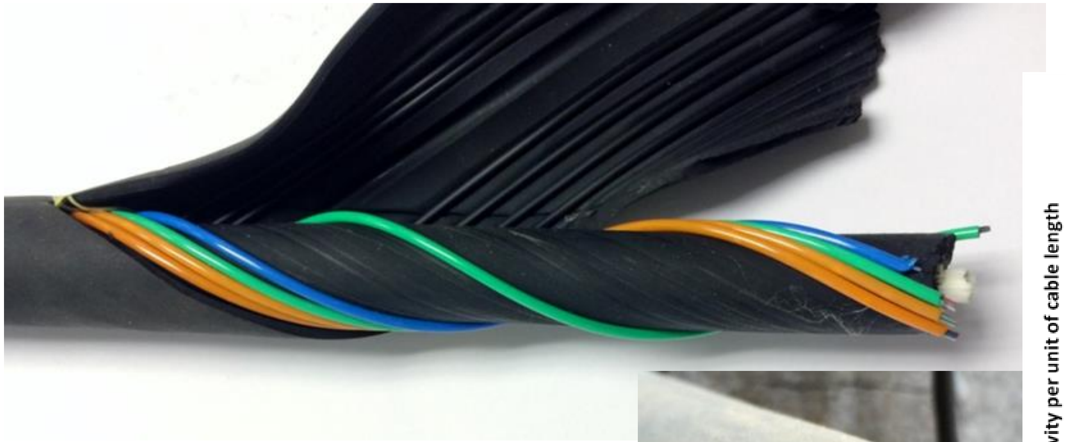
FAT Helical Wound Cable

Anderson and Shapiro – HWC on soft mandrel 1980 US Patent 4375313

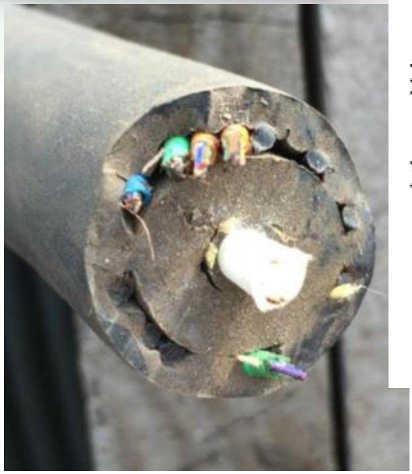
Hornman et al. (2013 75th EAGE) introduced a helical wound FO cable

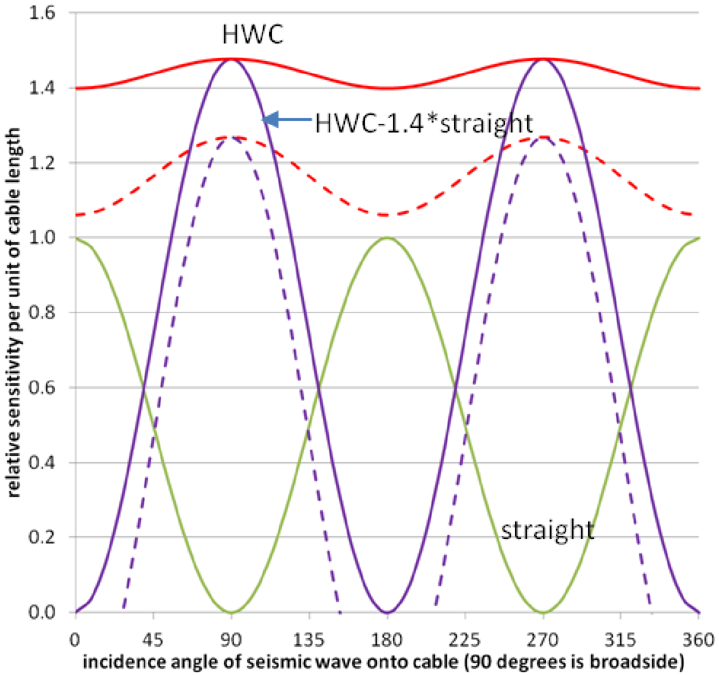
LBNL trialed multiple designs with varying physical properties

Line 5 installed one length of HWC for comparison to straight fiber



30° spiral wound on 58 Shore A rubber mandrel.

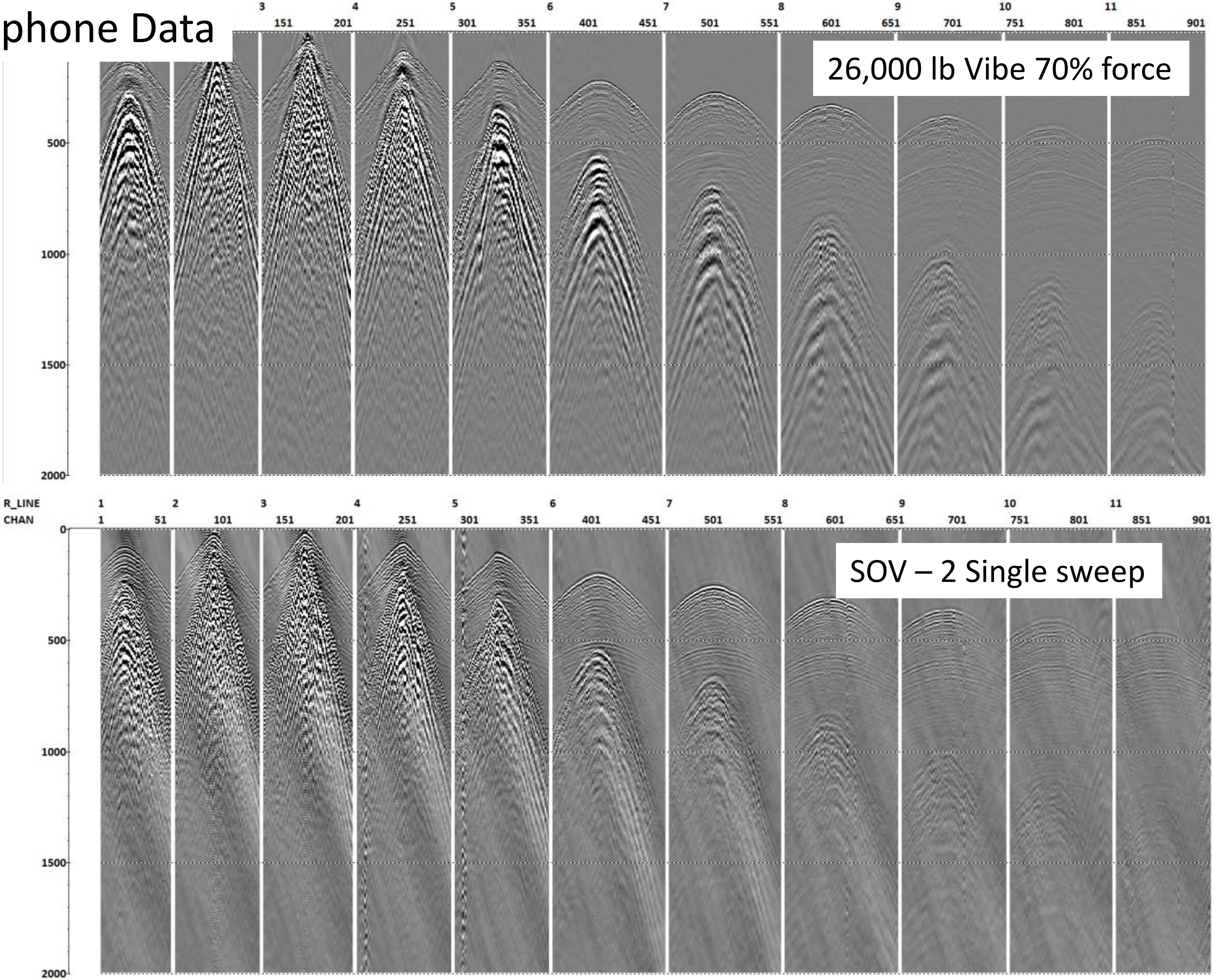




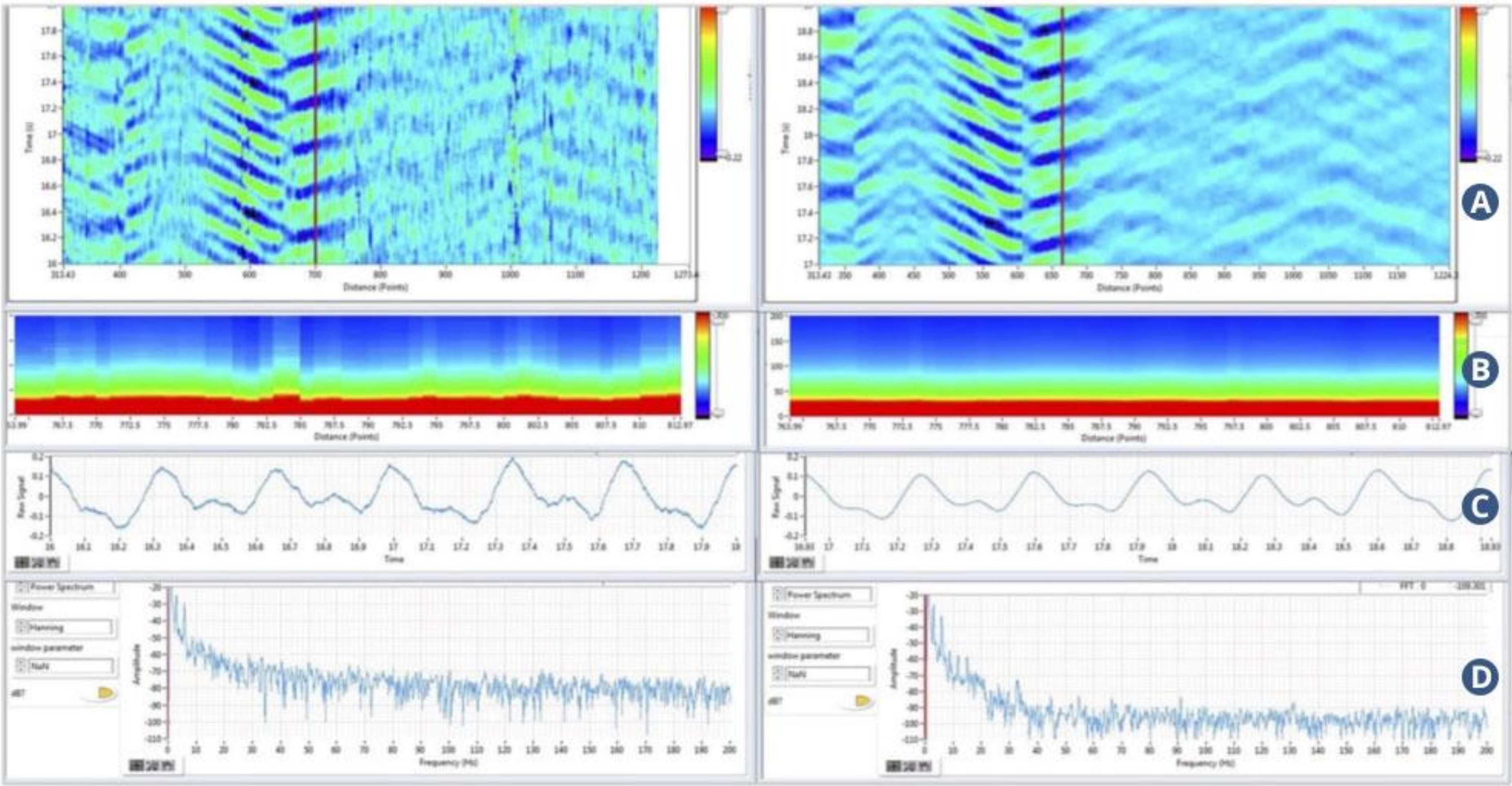
Lessons learned – acoustic impedance of cable and surrounding soil is important

Hornman et al. 75th EAGE 2013

Geophone Data

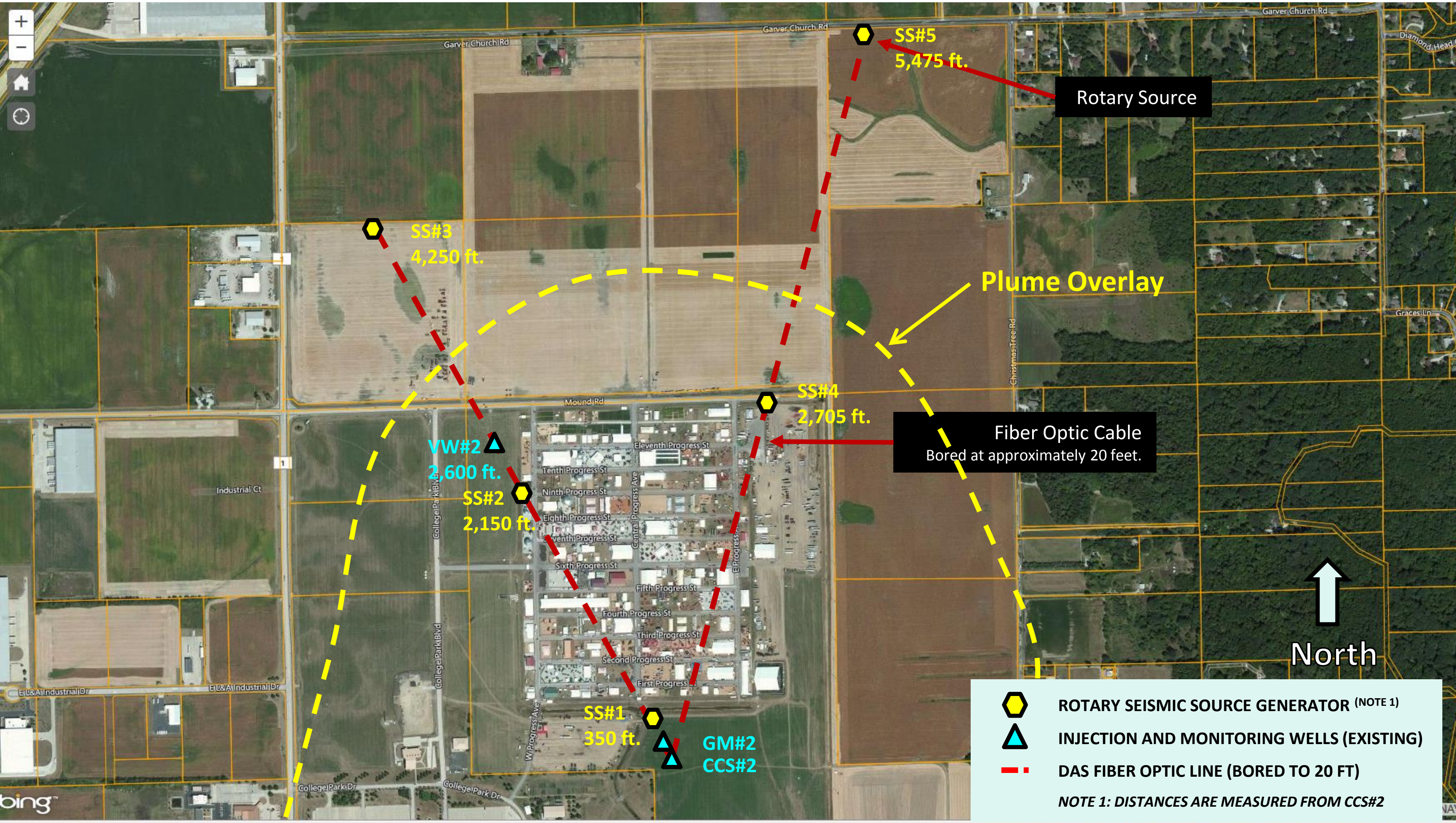


New Silixa Ltd. Carina Sensing System
100X Lower noise floor



Data collection courtesy Aquistore Project: PTRC/GSC/LBNL and JOGMEC

IMS Fiber Optic and CASS Layout



Expected Outcomes

- ICCS IMS project will provide a new approach towards comprehensive monitoring using automated workflows.
- Providing real-time support for operations.
- Maturing of DAS permanent reservoir monitoring for surface reflection seismic from a TRL of 6 to 8.
- Best practices report detailing IMS – CASSM technology.

PROJECT TASKS UPDATES

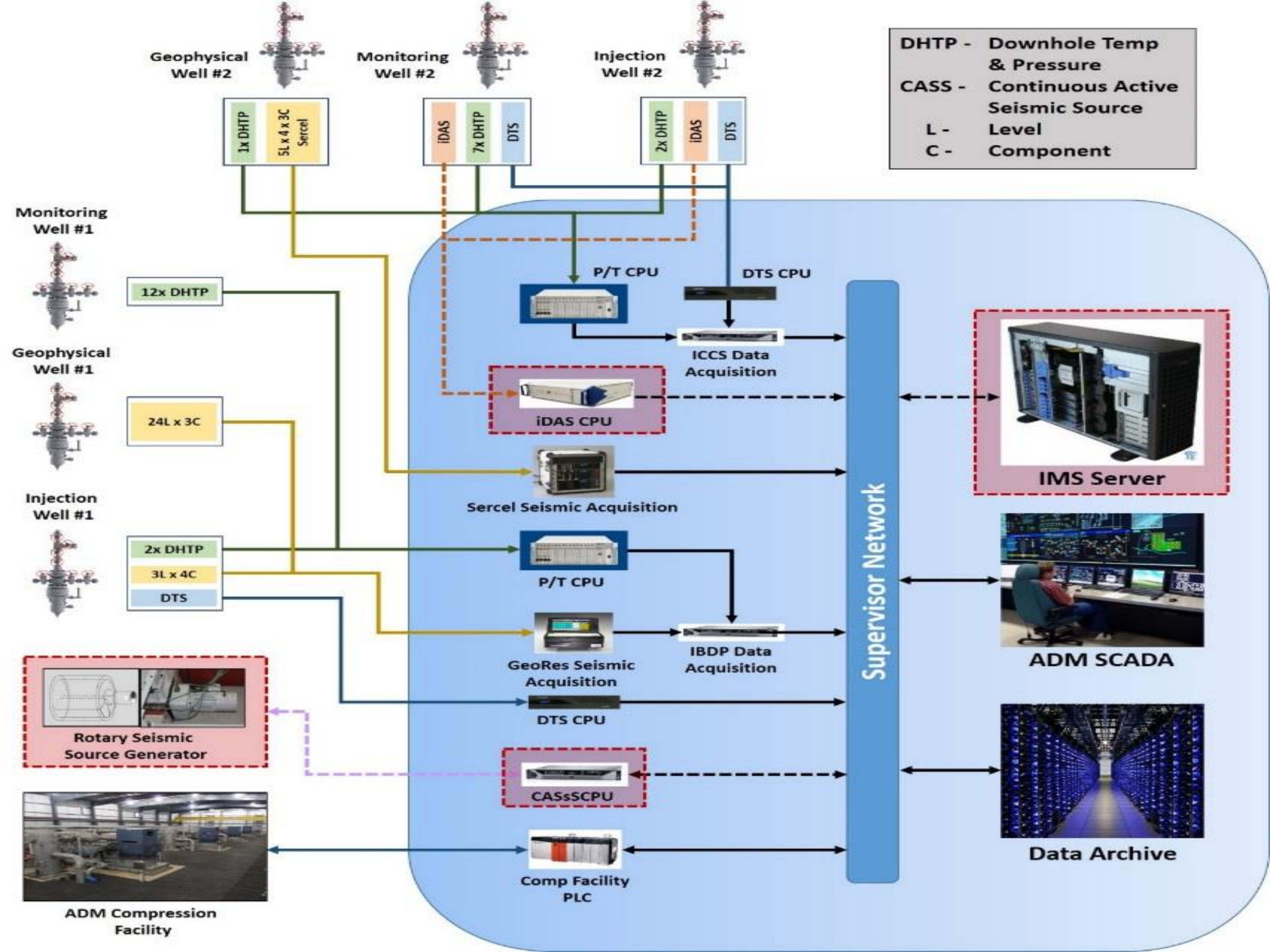
Task/Subtask Breakdown

Task 2.0 - IMS Design

- *Design an IMS that utilizes seismic and process monitoring data to create a comprehensive monitoring, visualization, and control system that delivers real time information for process surveillance and optimization.*

Subtask 2.1 - IMS Data Acquisition and Processing Equipment

- Identify the IMS's required process and reservoir monitoring data feeds. Specify the IMS's hardware requirements related to data acquisition, processing, and storage, which includes programmable logic controllers (PLC), device CPU, servers, and storage devices.



DHTP - Downhole Temp & Pressure
CASS - Continuous Active Seismic Source
L - Level
C - Component
Geophysical Well #2
1x DHTP
5L x 4 x 3C Sercel
Monitoring Well #2
iDAS
7x DHTP
DTS
Injection Well #2
2x DHTP
iDAS
DTS
Monitoring Well #1
12x DHTP
Geophysical Well #1
24L x 3C
Injection Well #1
2x DHTP
3L x 4C
DTS
P/T CPU
DTS CPU
ICCS Data Acquisition
iDAS CPU
Sercel Seismic Acquisition
P/T CPU
GeoRes Seismic Acquisition
IBDP Data Acquisition
DTS CPU
CASsSCPU
Comp Facility PLC
Supervisor Network
IMS Server
ADM SCADA
Data Archive
Rotary Seismic Source Generator
ADM Compression Facility

Task/Subtask Breakdown

Subtask 2.2 - IMS DAS Surface Cable and Rotary Sources CASSM

- Design the layout and integration scheme for the surface DAS cable with the site's existing well deployed DAS system. Design and specify rotary source equipment related to motor, bearings, coupling, oscillating source, instrumentation, and electrical.

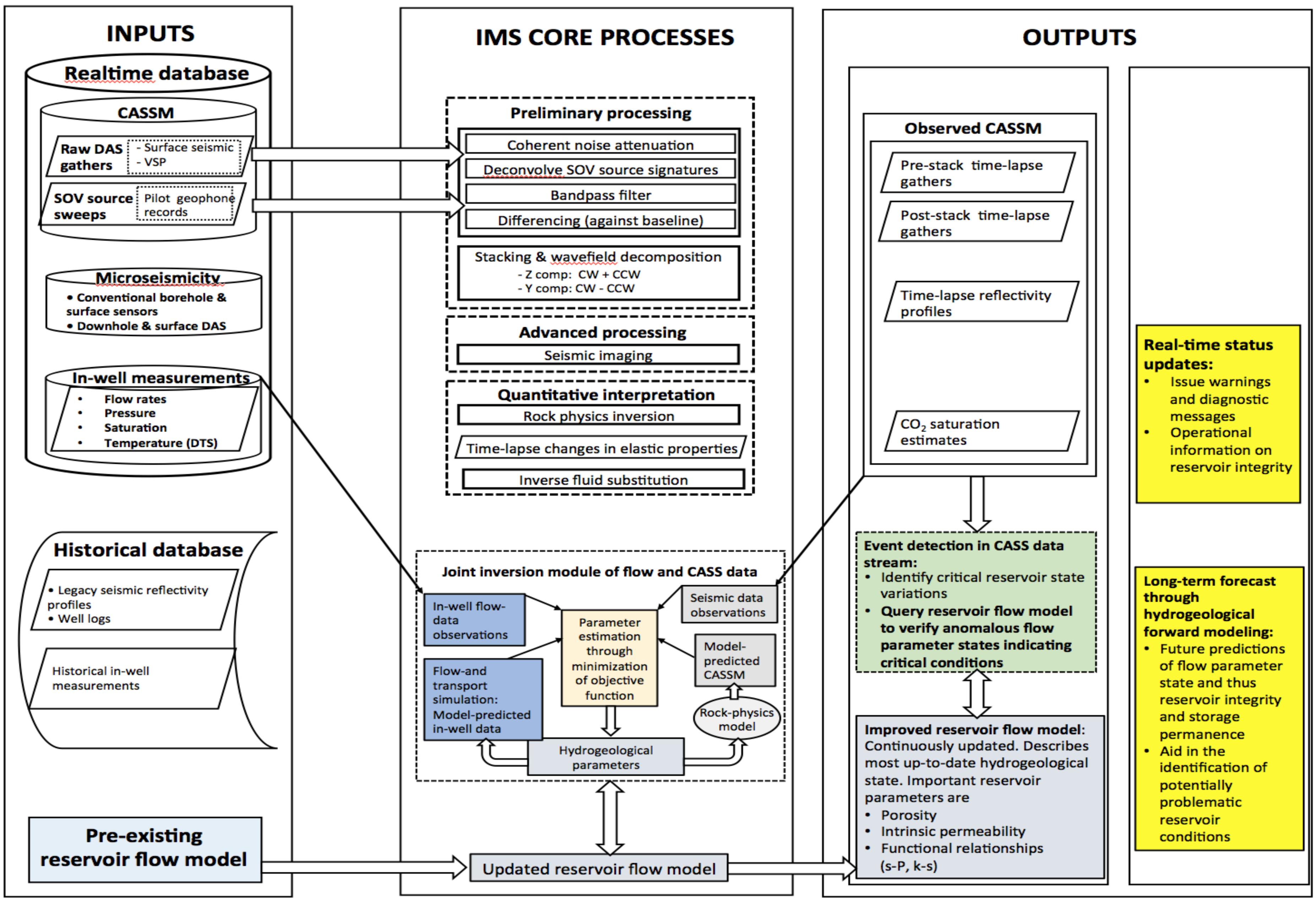
Subtask 2.3 - IMS Software Design and Development

- Develop real-time data pre-processing, filtering, and stacking system for CASSM DAS data including automated reflection vertical seismic profile (VSP) analysis flow, horizon-based inversion code, integrated IMS graphical user interface, and inverse modeling to improve constraints on $scCO_2$ plume extent.

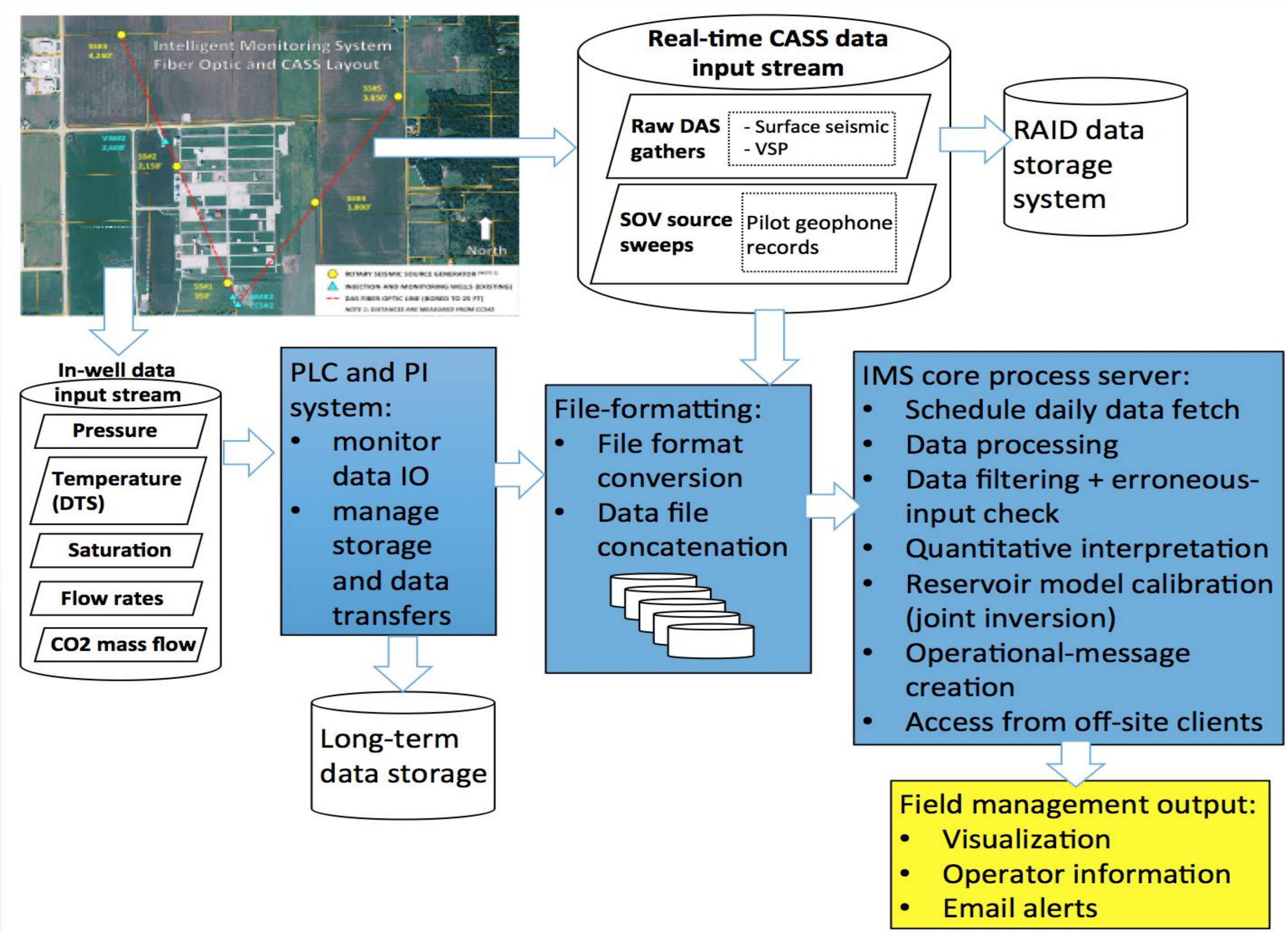
Subtask 2.3 – IMS Software Design and Development

- Main IMS software design challenge: Integrate heterogeneous data streams
- 3 major components: (1) Data input, (2) Core process, (3) Monitoring information output
- Core analysis processes
  - Monitor reservoir integrity in near-real time
  - Continuously update reservoir model through parameter estimation scheme

IMS general software layout



Geophysical and in-well data pre-processing layout



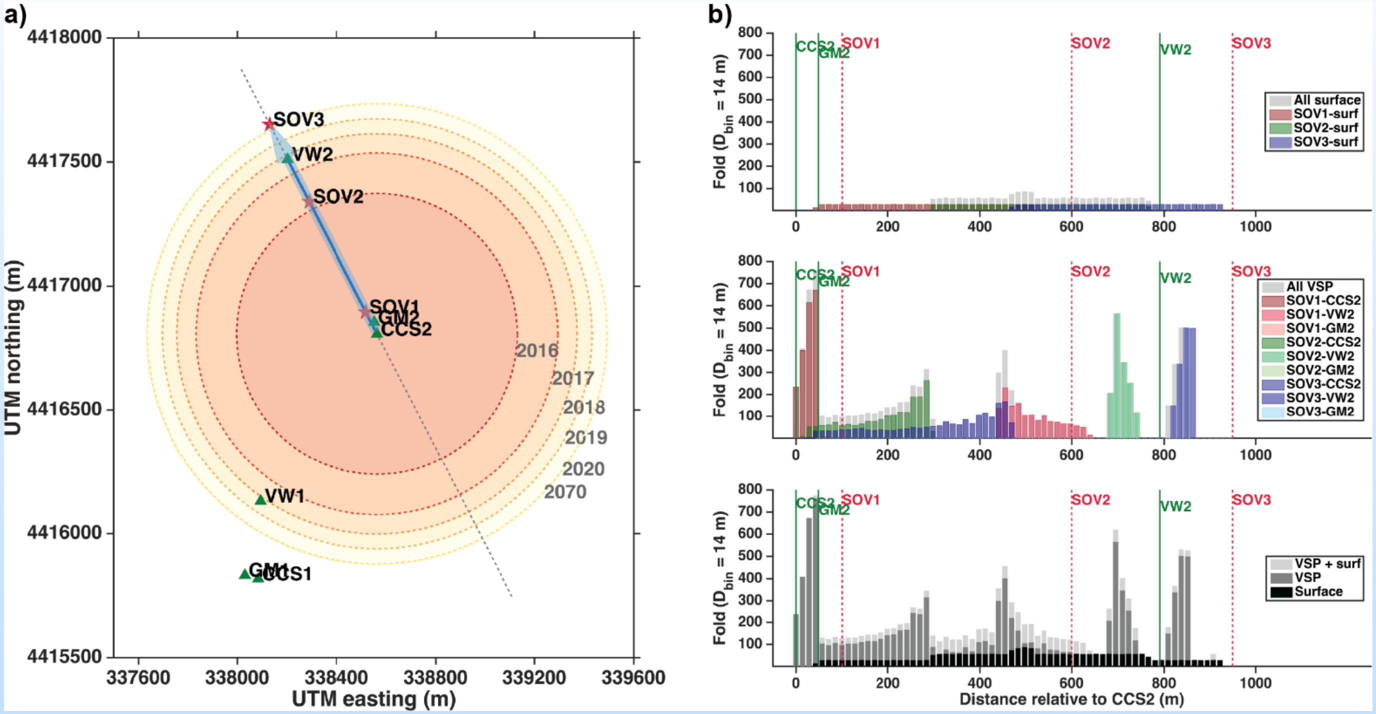
Task 2.0 IMS Design
Subtask 2.3: IMS Software Design and Development

Time-lapse feasibility evaluation using synthetic seismic data

- *Detectability* of the time-lapse changes
- *Interpretability* of the time-lapse signals
- *Repeatability requirements* imposed on the CASSM system

Fold Analyses → Superb Spatial Sampling

- Focus: southeast-northwest branch of the "L-shaped" ADM acquisition layout
- Sources: 3 surface orbital vibrators (SOV)
- Receivers:
  - 2 downhole DAS array at CCS2 (1919 m) and VW2 (1493 m)
  - 1 buried surface DAS array (CCS2→SOV3; offset range = 791 m)

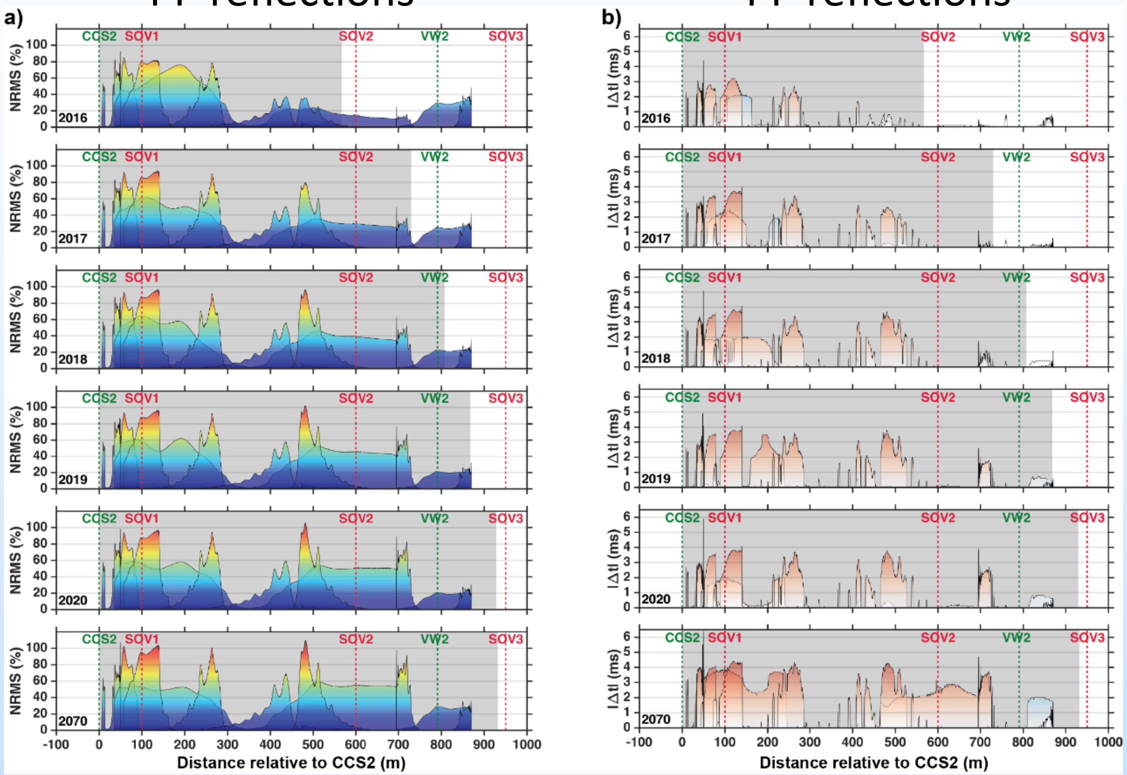


- High fold count (>= 100) within 850-meter radius of the injection well CCS2
- Fold count as high as 750 in the 50-meter vicinity of CCS2

Time-Lapse Analyses → Promising Detectability and Interpretability

NRMS evolution of PP reflections

Time-shift evolution of PP reflections

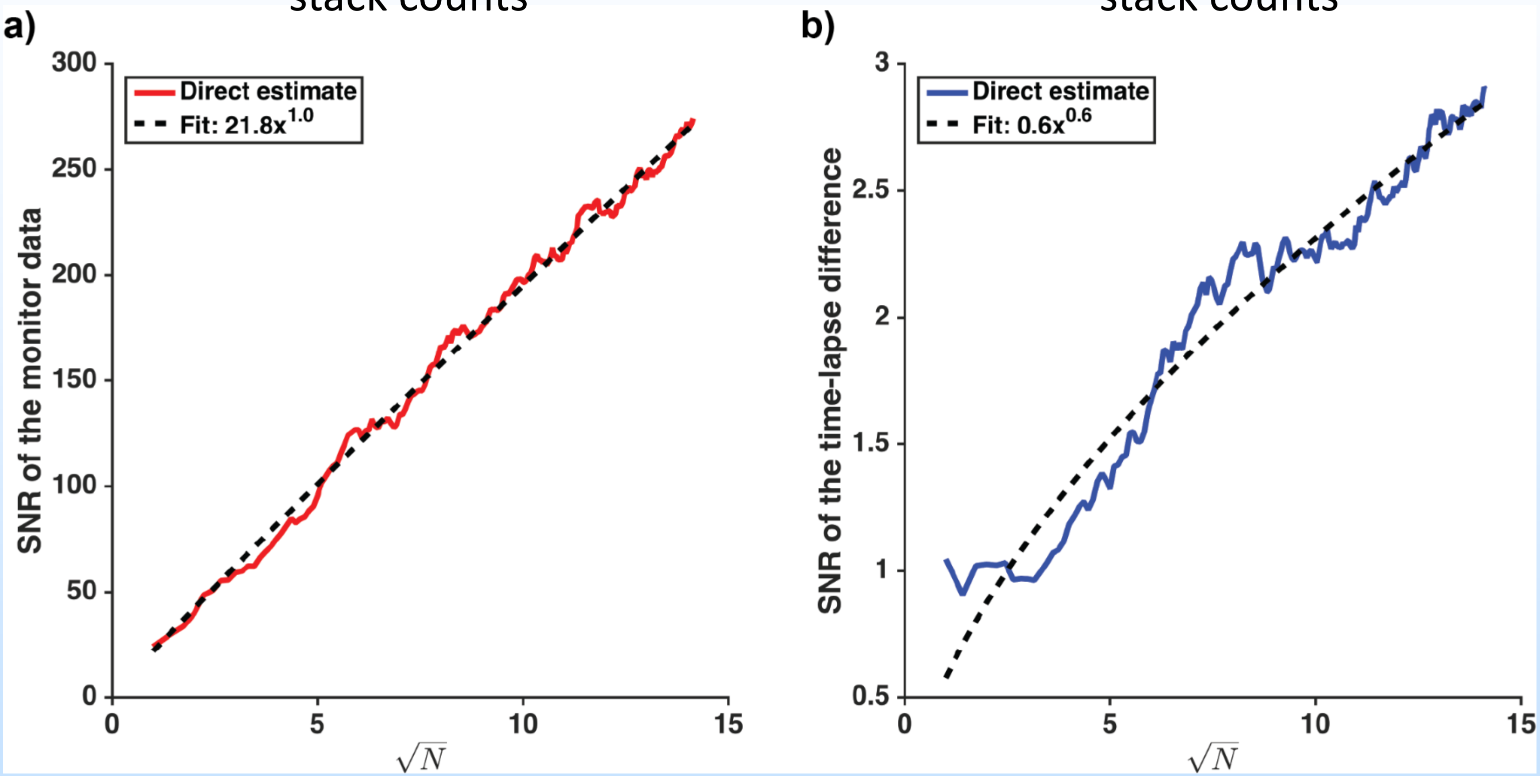


- Both time-lapse metrics (NRMS and time shift) show good sensitivities to the migration of the scCO2 plume front ($NRMS_{max}$: 30%-110%; Δt_{max}: 1 ms to 5 ms)
- Majority of NRMS > 10%–30% detectability thresholds (literature values for surveys of "good" repeatability)

Noise Analyses (AWGN) → Time-Lapse Signals Require More Stacks

SNR improvements of stand-alone monitor survey with increasing stack counts

SNR improvements of time-lapse signals with increasing stack counts

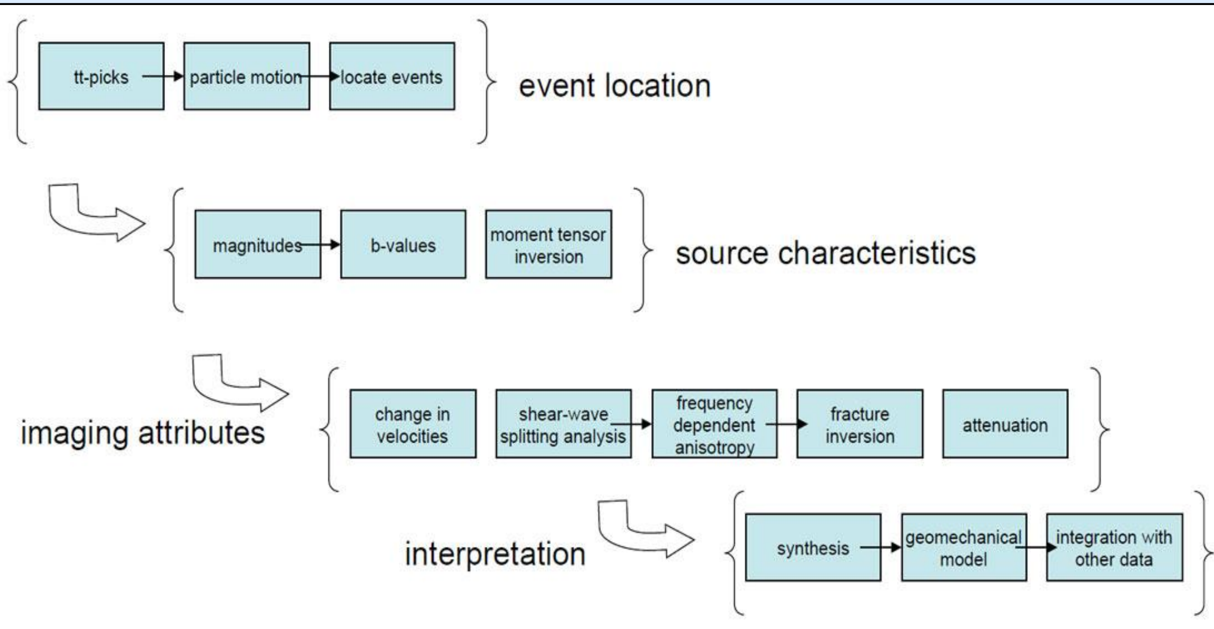


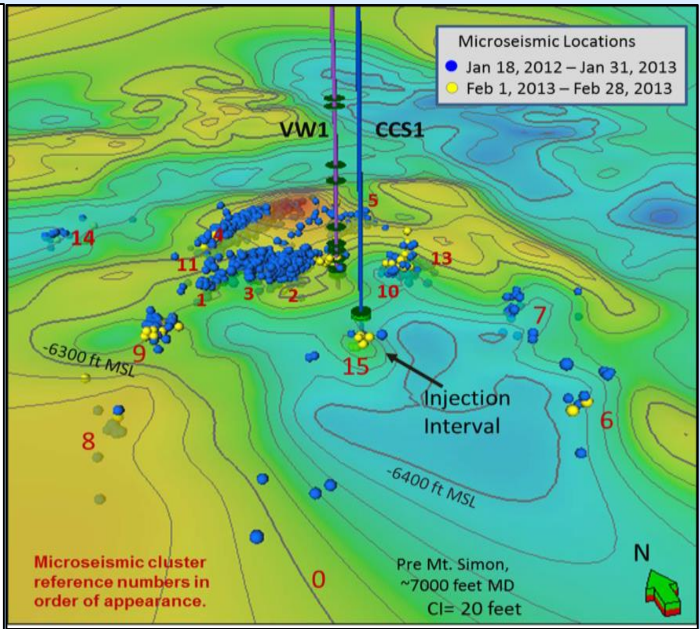
- Small plume thickness → Time-lapse signal intensity lower than primary reflections of stand-alone survey → Require 3-4 times more stacks than conventional surveys
- Achievable with SOV

Task/Subtask Breakdown

Subtask 2.4 – Design of Passive Microseismicity Monitoring System

- Develop near real-time extraction of DAS derived data into detection and location processing system. Develop processing, filtering, stacking, cross-correlation tools to automatically pick phase arrival on DAS channels. Test detection and location weighting for improved event location uncertainties.

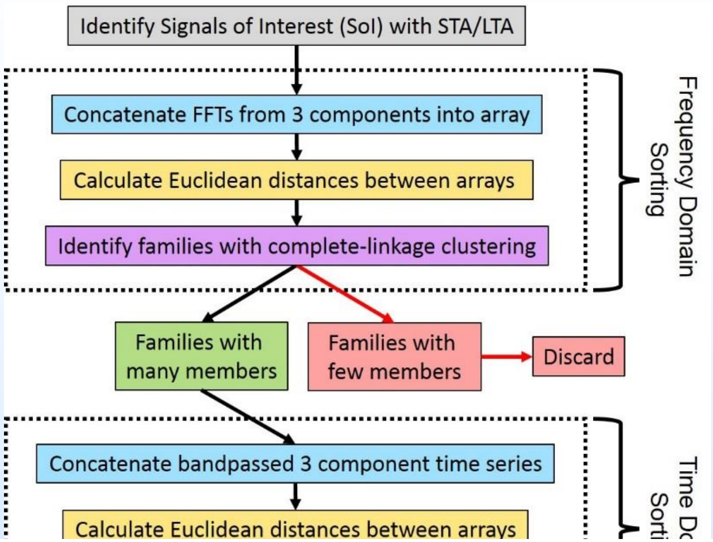


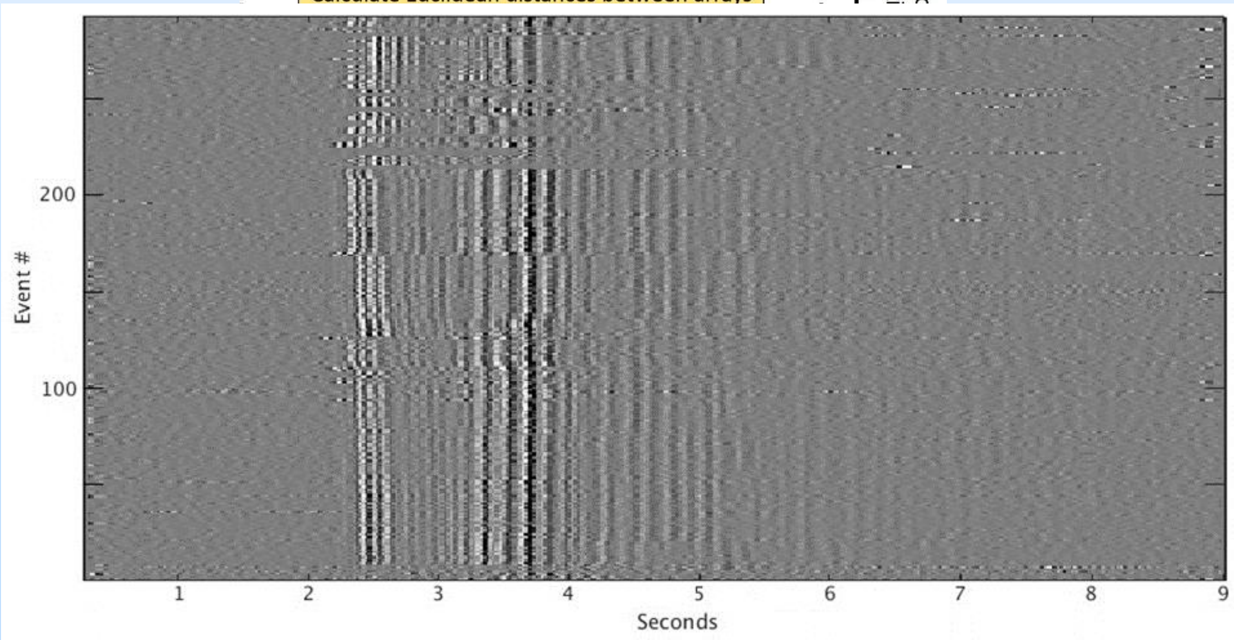


Subtask 2.4 updates

Subtask 2.4 – Design of Passive Microseismicity Monitoring System

- Automated detection of seismic signals of interest
- Grouping in families and subfamilies of similar characteristics
- Template matching on stacked subfamilies to arrive at group of similar waveforms (used to extract travel times, etc.)
- Likely detection threshold lowering by an order of magnitude





Deliverables / Milestones / Decision Points

Task 1.0 - Project Management and Planning

- Updated project management plan.
- Complete NEPA documentation.

Task 2.0 – IMS Design

- Final design documentation including but not limited to: process instrument diagrams, equipment specifications, and IT network diagram.
- Algorithm description and testing results for the data pre-processing, filtering, stacking, and VSP analysis tools for CASSM DAS data and horizon-based inversion tools for the IMS.

Deliverables / Milestones / Decision Points

Task 3.0 – IMS Construction

- Topical report detailing the final constructed design including as-built design documentation such as process instrument diagrams, equipment specifications, and IT network diagram. The report will include a section on the integration of all components of the IMS.

Task 4.0 – IMS Operation

- Topical report detailing the commissioning and operation of the IMS. The report will include sections on plume tracking and best practices for utilization of the IMS CASSM system.
- Passive Seismic Monitoring – Quarterly Seismic Event Catalog.

Briefings & Technical Presentations

- DOE annual briefings to review and explain the plans, progress, and results of the technical effort.

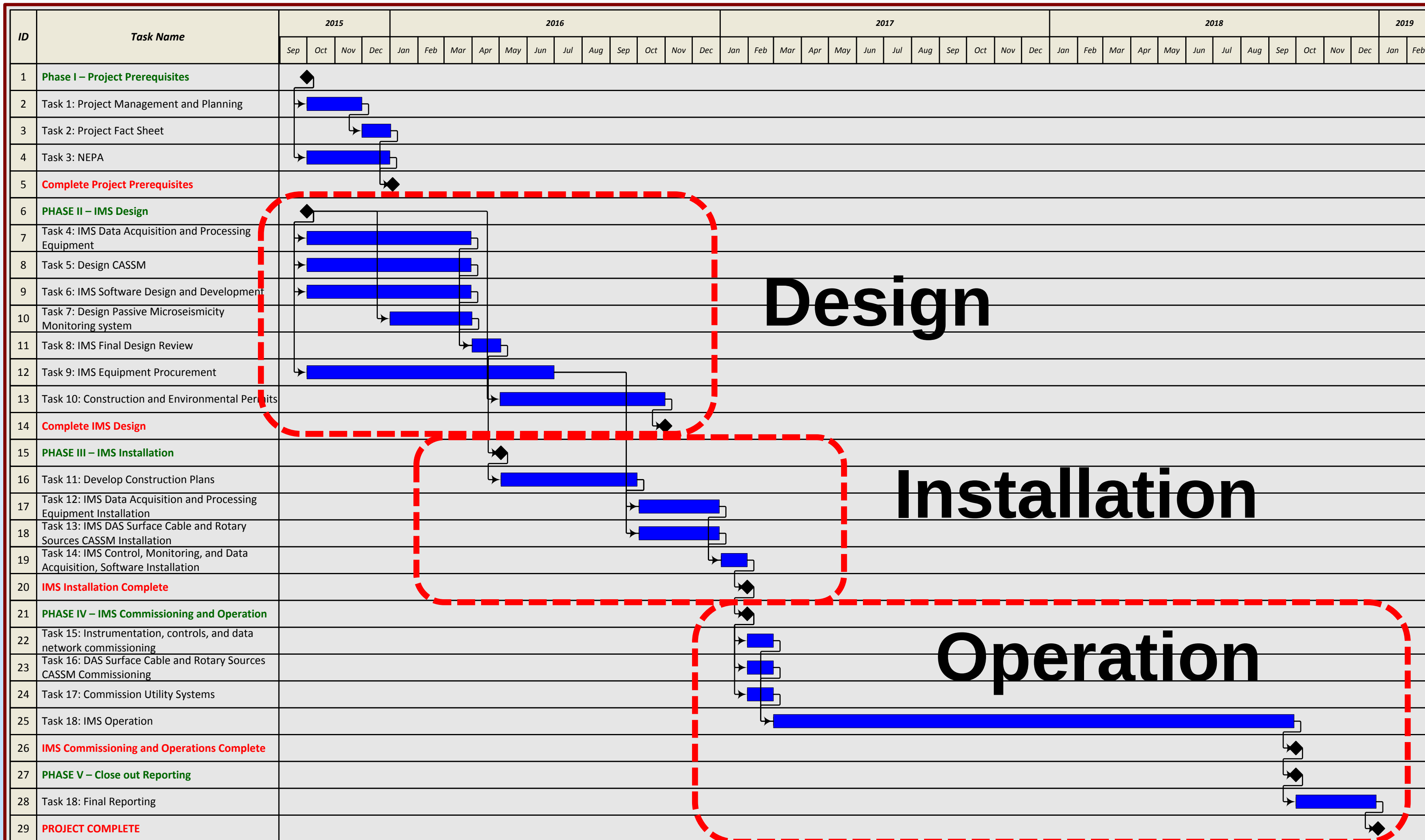
Milestone Status – Q3 2016

Milestone Description	Planned Completion	Actual Completion	Verification Method	Comments
Milestone 1-2 (B): Kickoff Meeting	12/31/15	12/31/15	Presentation file	
Milestone 1-1 (A) Project Management Plan	3/31/16	7/31/16	PMP document and sub-award agreements	Delays in obtaining funding and AFE approval
Milestone 2-1 (C) Completion of installation plan	6/30/16	8/31/16	Quarterly progress report and supplement	Delay in obtaining easements, revisions to rotary source and foundation design

Milestone Status – Q3 2016

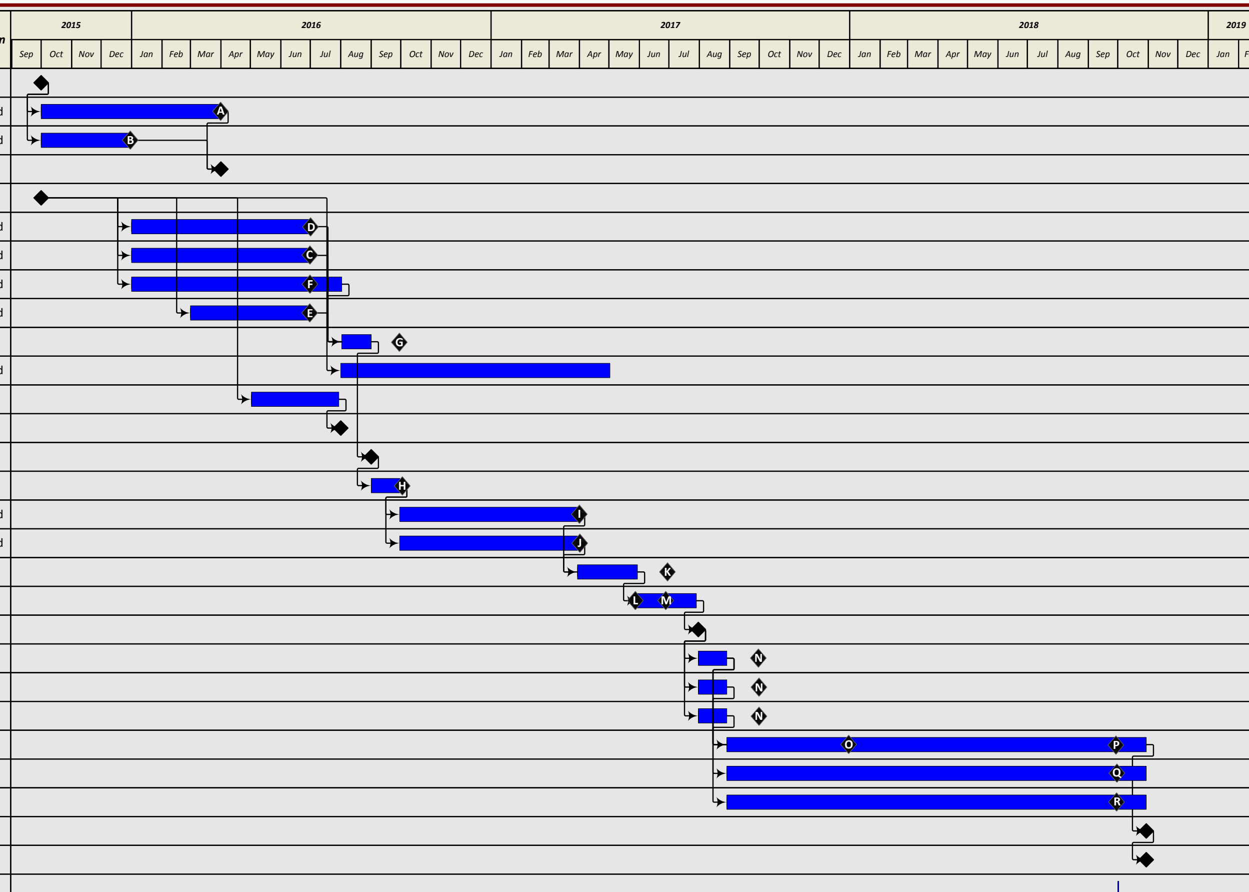
Milestone Description	Planned Completion	Actual Completion	Verification Method	Comments
Milestone 2-2 (D) Completion of design of the planned architecture	6/30/16	6/30/16	Quarterly progress report and supplement	
Milestone 2-3 (E) Microseismic monitoring system	6/30/16	6/30/16	Quarterly progress report and supplement	
Milestone 2-4 (F) Software Design and Development	6/30/16	6/30/16	Quarterly progress report and supplement	
Milestone 2-5 (G) Final Design Review	7/31/16	9/30/16	Quarterly progress report and supplement	**Critical design phase milestone**

Project Timeline



Updated Project Timeline

ID	Task Name	Resource Names	Start	Finish	Duration
1	**Task 1.0 – Project Management and Planning**		10/1/2015	10/1/2015	0w
2	Subtask 1.1: Project Management Plan	ADM	10/1/2015	3/31/2016	26w 1d
3	Subtask 1.3: Kickoff Meeting	ADM	10/1/2015	12/31/2015	13w 1d
4	**Complete Project Prerequisites**		4/1/2016	4/1/2016	0w
5	**Task 2.0 – IMS Design**		10/1/2015	10/1/2015	0w
6	Subtask 2.1: IMS Data Acquisition and Processing Equipment	LBNL	1/1/2016	7/1/2016	26w 1d
7	Subtask 2.2: Design CASSM	LBNL	1/1/2016	7/1/2016	26w 1d
8	Subtask 2.3: IMS Software Design and Development	LBNL	1/1/2016	**8/1/2016**	30w 2d
9	Subtask 2.4: Design Passive Microseismicity Monitoring system	USGS	3/1/2016	7/1/2016	17w 4d
10	Subtask 2.5: IMS Final Design Review	ALL	**8/2/2016**	**8/31/2016**	4w 2d
11	Subtask 2.6: IMS Equipment Procurement	ADM	8/1/2016	5/1/2017	39w 1d
12	Subtask 2.7: Construction and Environmental Permits	ADM, RCC	5/2/2016	7/29/2016	13w
13	**Complete IMS Design**		8/1/2016	8/1/2016	0w
14	**Task 3.0 – IMS Installation**		9/1/2016	9/1/2016	0w
15	Subtask 3.1: Develop Construction Plans	ADM	9/1/2016	9/29/2016	4w 1d
16	Subtask 3.2: IMS Data Acquisition and Processing Equipment Installation	ADM, LBNL	9/30/2016	3/29/2017	25w 4d
17	Subtask 3.3: IMS DAS Surface Cable and Rotary Sources CASSM Installation	ADM, LBNL	9/30/2016	3/29/2017	25w 4d
18	Subtask 3.4: IMS Control, Monitoring, and Data Acquisition, Software Installation	LBNL, ADM	3/30/2017	5/29/2017	8w 3d
19	**IMS Installation Complete**		5/30/2017	7/28/2017	8w 4d
20	**Task 4.0 – IMS Commissioning and Operation**		7/31/2017	7/31/2017	0w
21	Subtask 4.1: Instrumentation, controls, and data network commissioning	ADM	7/31/2017	8/28/2017	4w 1d
22	Subtask 4.2: DAS Surface Cable and Rotary Sources CASSM Commissioning	ADM	7/31/2017	8/28/2017	4w 1d
23	Subtask 4.3: Commission Utility Systems	ADM	7/31/2017	8/28/2017	4w 1d
24	Subtask 4.4: IMS Operation	ALL	8/29/2017	10/29/2018	61w
25	Subtask 4.5 Validate IMS real-time reduced order models	LBNL, ADM, SCS	8/29/2017	10/29/2018	61w
26	Subtask 4.6 Passive Microseismicity Monitoring	USGS, ADM	8/29/2017	10/29/2018	61w
27	**IMS Commissioning and Operation Complete**		10/30/2018	10/30/2018	0w
28	**Final Reporting**		10/30/2018	10/30/2018	0w
29	**PROJECT COMPLETE**		10/1/2018	10/1/2018	1d



IMS Project Summary

Supports Carbon Storage Program Goals.

- Reduce overall storage cost.
- Increase monitoring sensitivity.
- Increase monitoring reliability by using an integrated system.
- Optimize operation and maintenance activities.
- Reduce project risk during and after the injection of CO_2.