Deep, Controlled Source Electro-Magnetic Sensing: A Cost Effective, Long-term Tool for Sequestration Monitoring

Project Number: DE-FE0012266

Russell Brigham

Multi-Phase Technologies, LLC

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

Presentation Outline

- Project objectives
- Progress to Date on Key Technical Issues
- Plans for Remaining Technical Issues
- Project wrap-up

Benefit to the Program

- The research is intended to develop and test a robust, cost-effective sensor array for long-term monitoring of CO_2 inventories in deep geologic formations using controlled source electromagnetic methods (CSEM) to measure the electrical properties of CO_2 reservoirs. This approach, which draws heavily on recent advances in marine CSEM, uses electrical and magnetic field signals created by transmitting electric current through borehole electrodes in or below the CO_2 reservoir. This technology contributes to the goal of accounting for 99 percent of injected CO_2.

Project Overview: Goals and Objectives

- Develop, cost-effective sensor array for long-term monitoring of CO_2 (carbon dioxide)
- Use controlled source electromagnetic methods (CSEM) with a borehole source to measure the electrical properties of CO_2 reservoirs
- Designed to operate as a permanent, autonomous monitoring and data collection system
- Provide much higher temporal data density than can be achieved economically with alternatives (3-D seismic surveys).
- Demonstrate System at Ketzin Site
- Post closure monitoring including simulation of release.
- Background and at least two follow-on surveys

Technical Status

- Field Tests: Ketzin Germany
  - Background
  - Post Extraction (CO_2 release)
  - Autonomous Operation

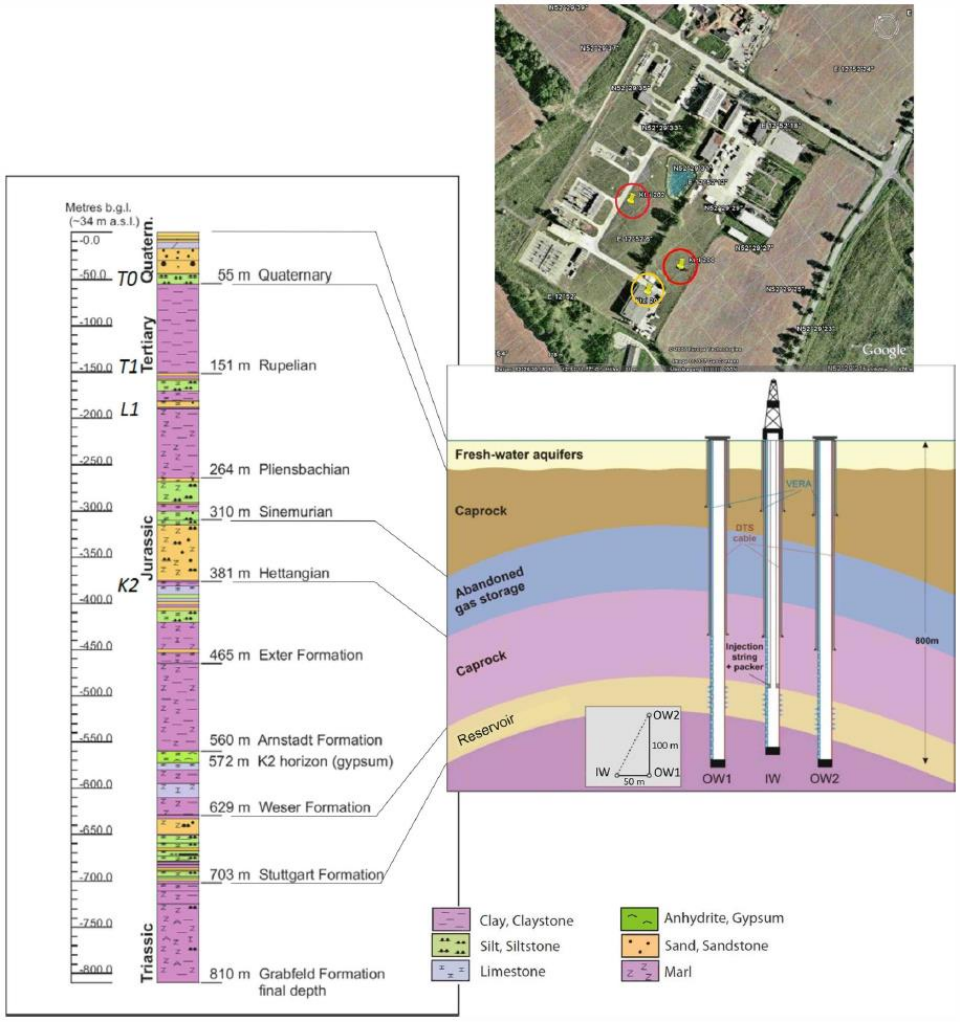
- Hardware/Software Modifications
  - Additional development for communication of the multisource units
  - Added an autonomous method for multisource units
  - Added alternative energy (solar panels) for multisource receiver units

- Field Tests: Ketzin Germany
  - Testing autonomous operation
  - Testing alternative energy methods

Accomplishments to Date

- Initial Full-Scale CSEM Field Tests (Phase I) – Ketzin, DE
  - Pre-release data sets
  - Post-release data sets
  - Follow up CSEM Field Tests – Study of a release of CO_2
- High Density Multi-Source CSEM Field Tests (Phase II) – Ketzin, DE
  - Collected HDMS CSEM data, August 2015
  - Placed autonomous receivers in the field
  - Data processing and development of HDMS CSEM background
- Final High Density Multi-Source CSEM Field Tests (Phase III) – Ketzin, DE
  - Follow up on HDMS CSEM data, April 2016
  - Autonomous Units collected data from September 2015 to April 2016.
  - Data processing and development of HDMS CSEM second data acquisition

Initial Full-Scale CSEM Field Tests – Ketzin, DE



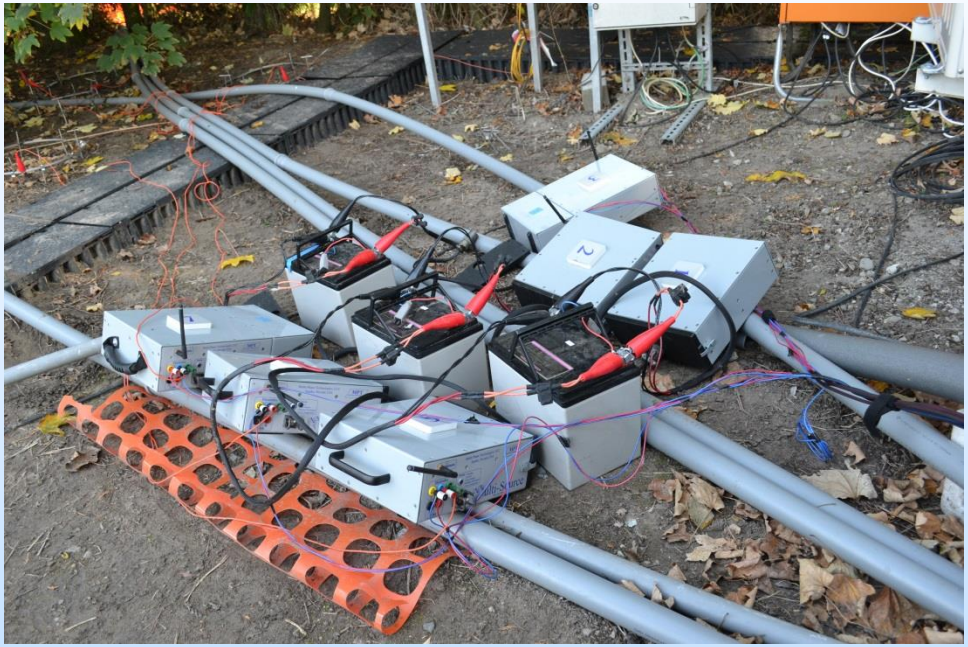
- Former gas storage site, located in the shallower zone
- CO_2 storage site located in the deeper zone

Klapperer et al. (2011)

Initial Full-Scale CSEM Field Tests – Ketzin, DE

Initial Full-Scale CSEM Field Tests – Ketzin, DE

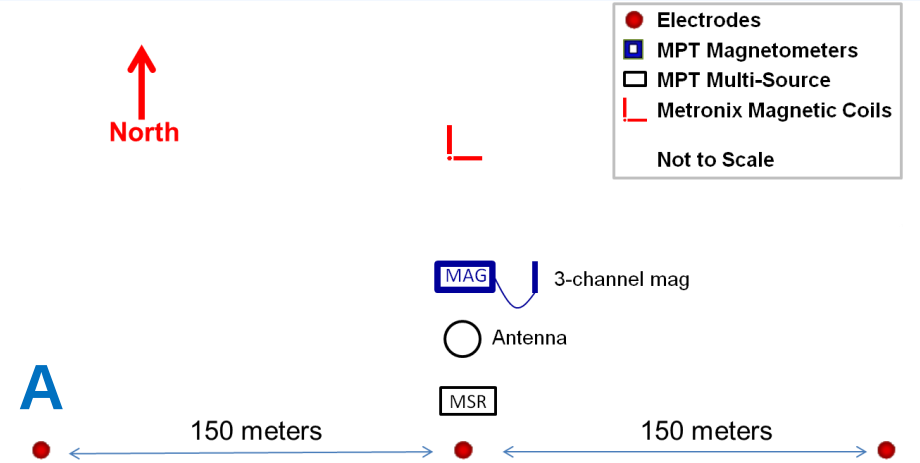
- Set-Up

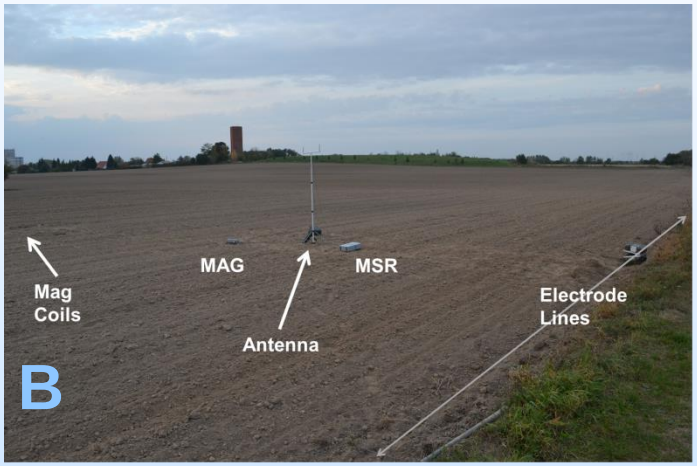


– At Well 201, wireless-controlled multisource units.

Initial Full-Scale CSEM Field Tests – Ketzin, DE

- Set-Up





– A) Map view sketch diagram of a typical field survey site and B) Set up of equipment at Site GFZ12A.

Initial Full-Scale CSEM Field Tests – Ketzin, DE

- 14 remote sites
- Base site (at Well 201) with 6 multisource units
- Types of arrays
  - Borehole-borehole
  - Borehole-surface
  - Surface-borehole
  - Surface-surface
- The surface-borehole provided the best results

Gas Pipe Map – Ketzin, DE

- 7 remote sites located on the gas pipelines.
- Base set at the intersection of all the pipes.
- Electric trains (16.66 Hz)
- Very noisy data

Initial Full-Scale CSEM Field Tests – Ketzin, DE

- Challenges and Issues
  - Land access (private property) was limited
  - RF communication rules/hardware in Europe are different than the US
  - Metronix Magnetic coils used a separate data acquisition system
  - Comparing MPT and Metronix magnetic results required additional processing
  - Several sites were not conducive to electromagnetic data acquisition (i.e. next to high traffic roads or railroad tracks)
  - Current flow limited in the GFZ wells were set 1 ampere per electrode pair

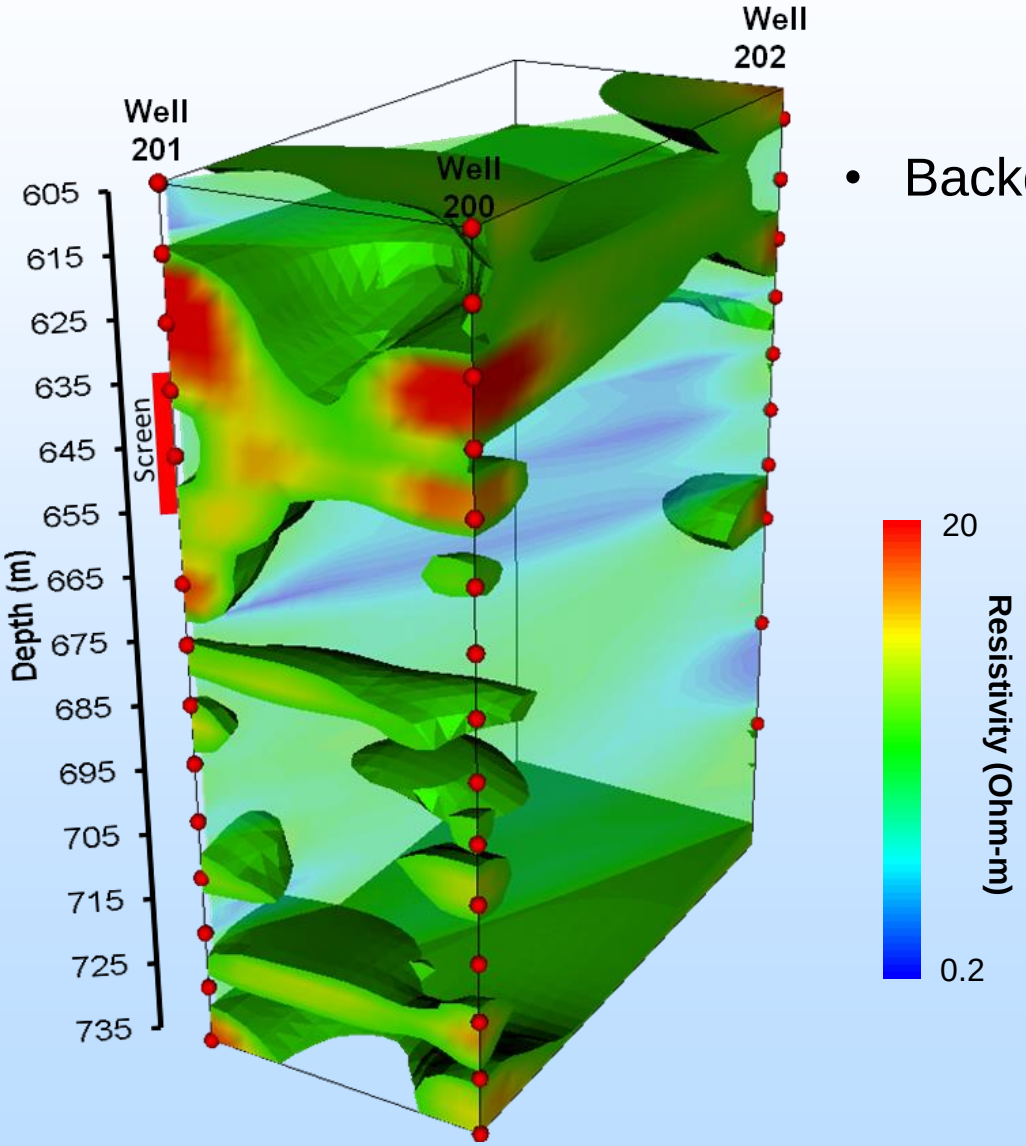
Initial Full-Scale CSEM Field Tests – Ketzin, DE

- Technical Issues Resolved
  - Communication fixes include change in antennas and antenna stands
  - Metronix mag data were time synchronized to data collection times
  - The non-conducive sites were removed from data acquisition plans or the site set up was moved to a more advantageous (electromagnetic/magnetic quiet) site (relocated sites <150 m from original location)
  - Transmitted on 3 pairs simultaneously in borehole
  - Added a borehole to surface dipole
  - Included reciprocal and multi-source measurements

Initial Full-Scale CSEM Field Tests – Ketzin, DE

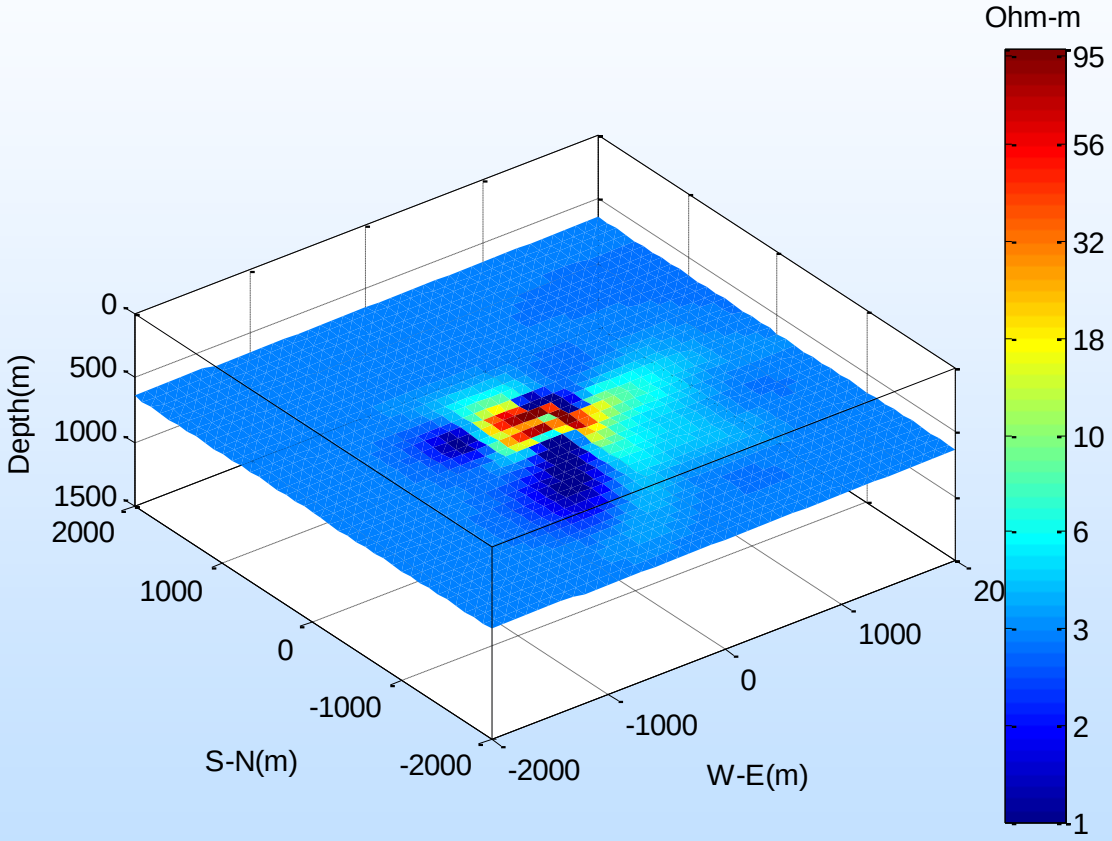
- Phase I Field Test Accomplishments
  - Field data have been collected from both pre- and post-CO_2 extraction
  - Wireless communication worked well even to the most remote sites (~2.5 km) from the command module
  - Created our own module-to-module data transfer algorithm
  - Data collected from 0.125 to 37.5 Hz

Follow-Up Full-Scale CSEM Field Tests – Ketzin, DE



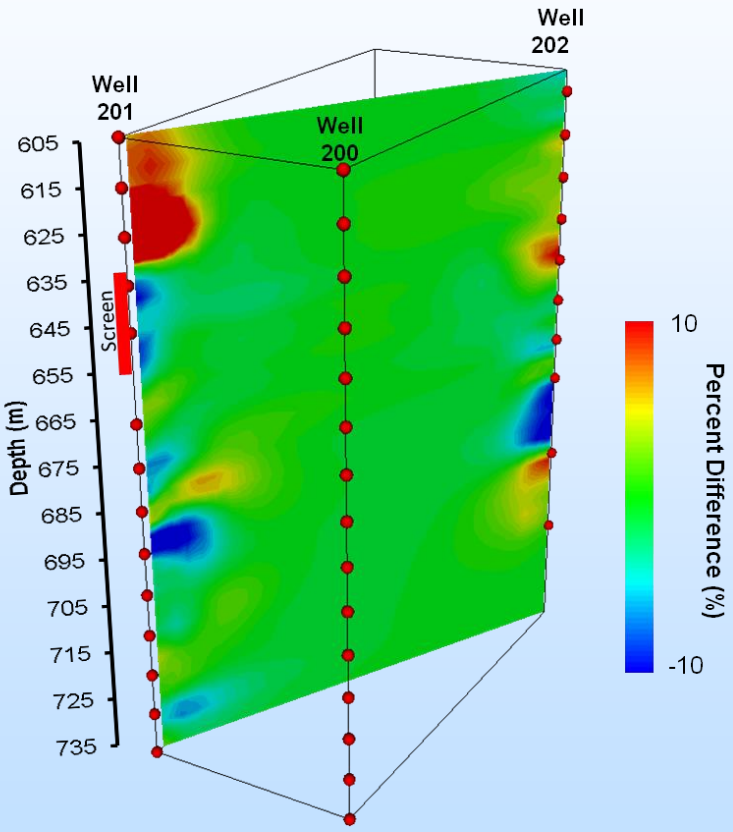
- Background resistivity

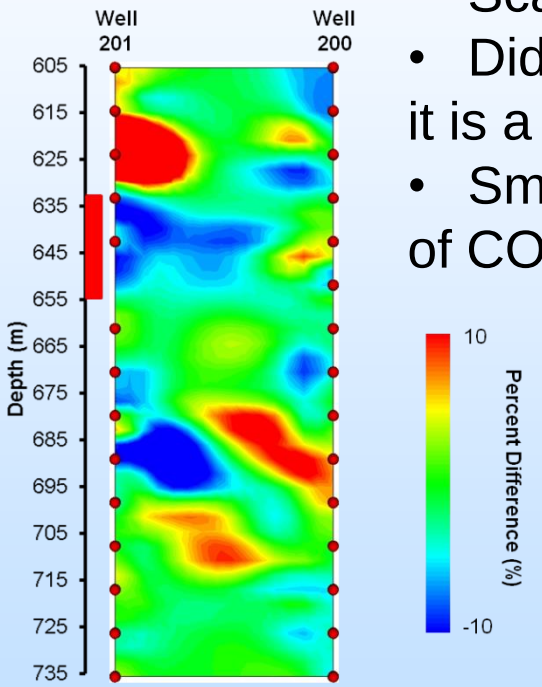
Follow-Up Full-Scale CSEM Field Tests – Ketzin, DE



- Preliminary plot from Evan Um (LBNL) of the data over a large scale area
- The red area indicates the CO_2 storage reservoir.

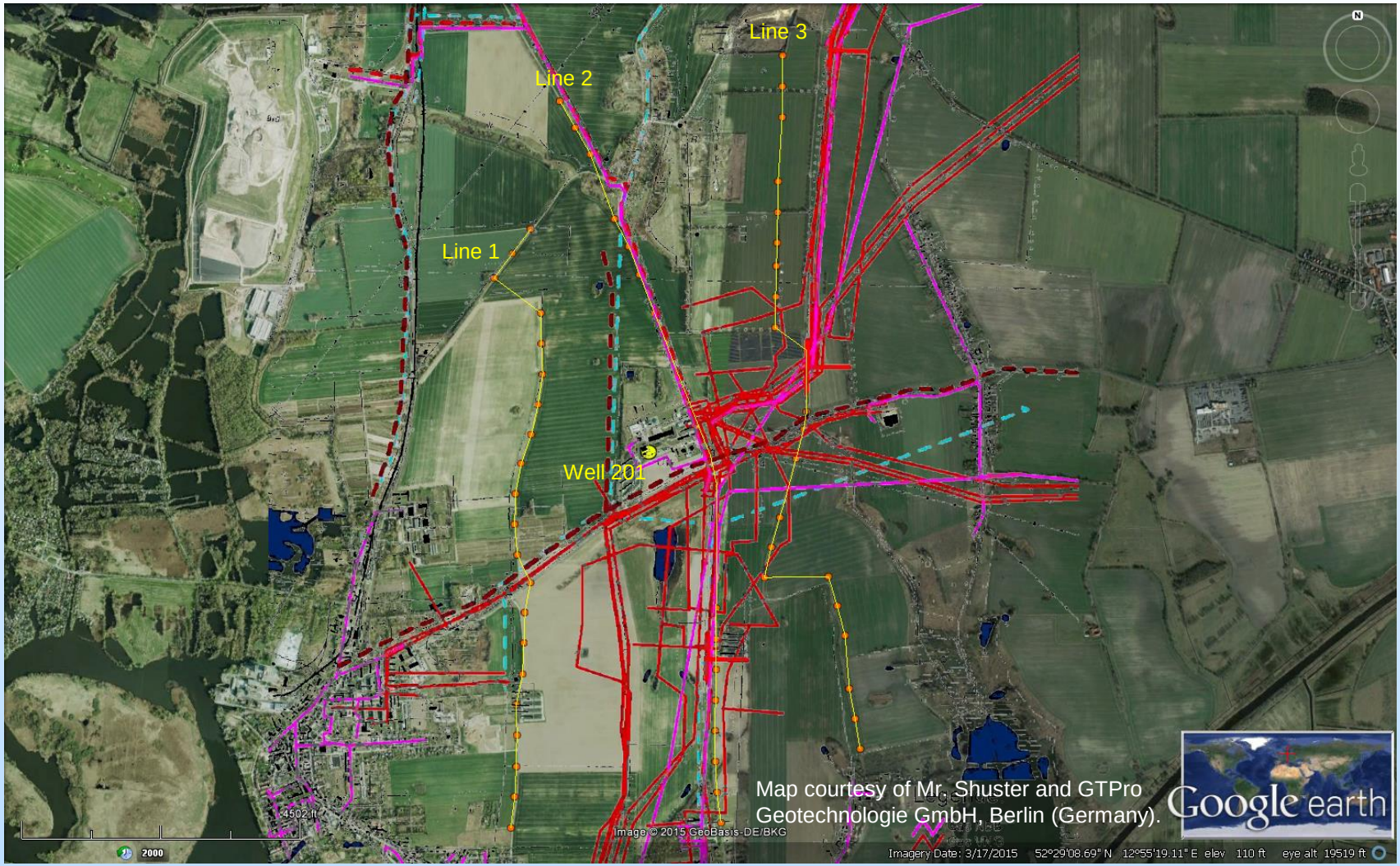
Follow-Up Full-Scale CSEM Field Tests – Ketzin, DE





- Percent –Difference Image
- Scale is small +-10%
- Did have a response but it is a weak response
- Small (fraction) release of CO_2

High Density Multi-Source CSEM Field Tests (Phase II) – Ketzin, DE



High Density Multi-Source CSEM Field Tests (Phase II) – Ketzin, DE

- Analysis of data from the previous acquisition periods showed parts of the data were strongly influenced by noise from regional gas pipelines.
- Changed to a High Density Multi-Source method.
  - Place array in three lines trending north-south along roads and easy access areas.
  - Use 69 surface electrodes with 150 meter spacings and electrodes in the Well 201 borehole.
  - Remove magnetometers and magnetic coils to allowed for quicker placement of the electrodes in remote locations.
- The high density surface array sets most of the surface electrodes away from the gas pipelines.
- Provided a better signal-to-noise ratio.

High Density Multi-Source CSEM Field Tests (Phase II) – Ketzin, DE

- Placement of the Autonomous Units

High Density Multi-Source CSEM Field Tests (Phase II) – Ketzin, DE

- Placement of the Autonomous Units

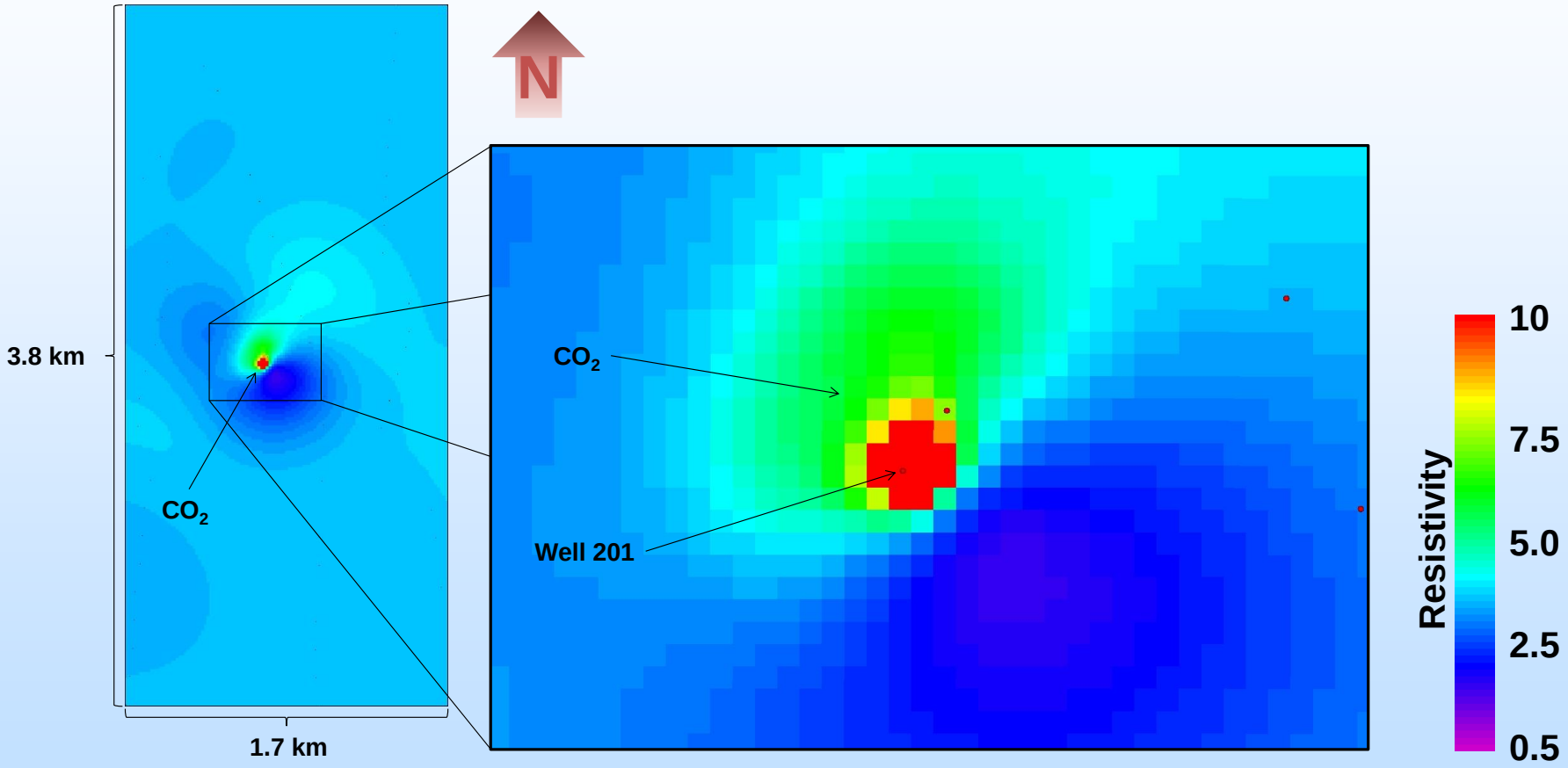
- Unit 22 located within the GFZ fenced area

High Density Multi-Source CSEM Field Tests (Phase II) – Ketzin, DE

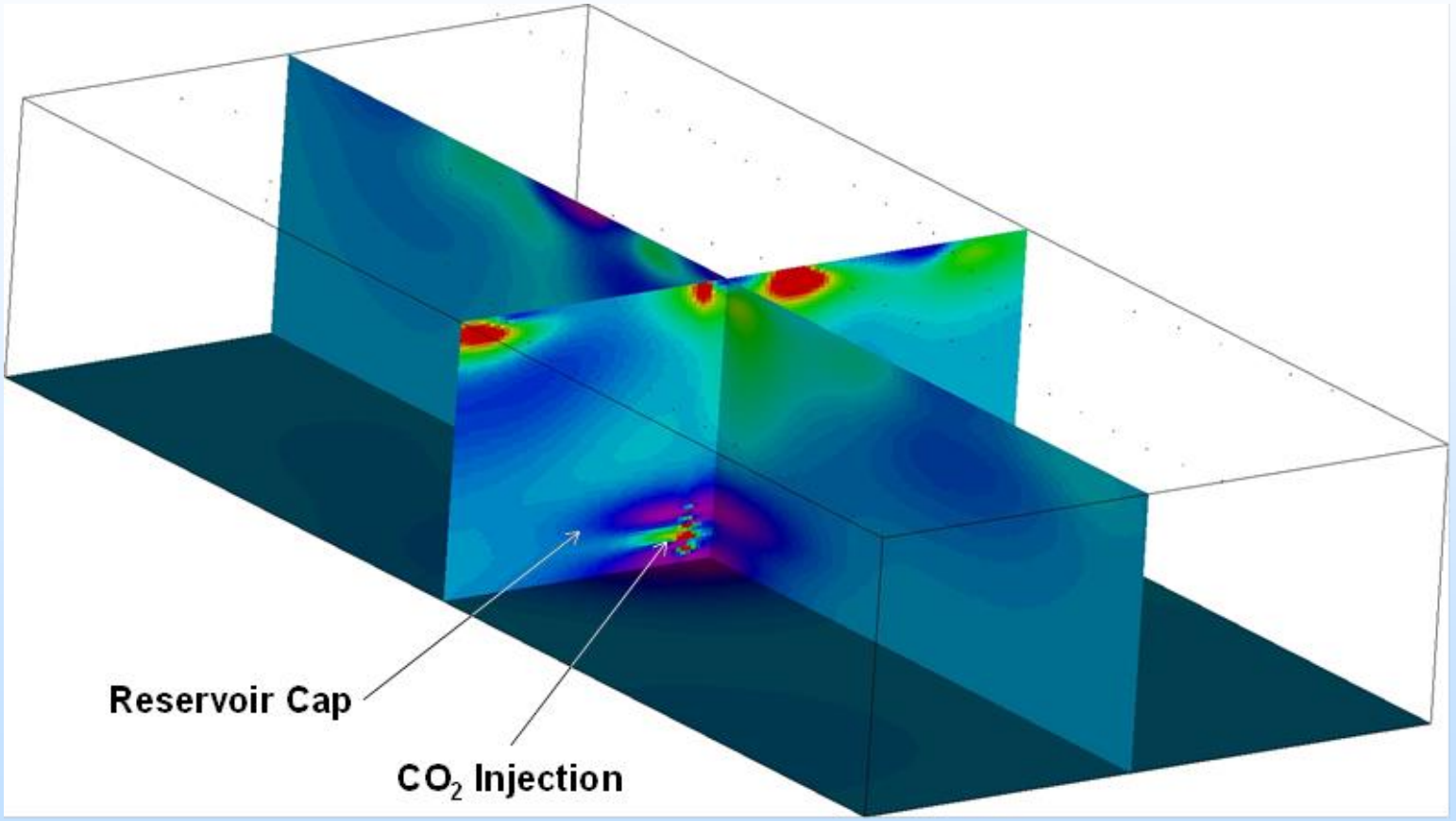
- Placement of the Autonomous Units

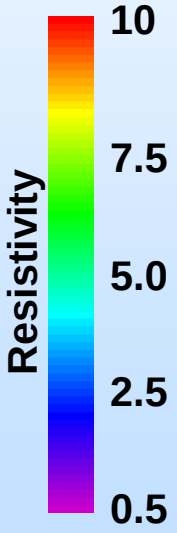
- Unit 21 located within the solar panel farm

High Density Multi-Source CSEM Field Tests (Phase II) – Results – Ketzin, DE



High Density Multi-Source CSEM Field Tests (Phase II) – Results – Ketzin, DE





High Density Multi-Source CSEM Field Tests (Phase III) – Ketzin, DE

- Use the same High Density Multi-Source method from Phase II.
- Acquire data from Autonomous Units from September 2015 to April 2016.
- Process data and determine differences between Phase II and Phase III.

Plans for Remaining Technical Tasks

- Integration of Results, Validation and Feasibility of CSEM Methodology

Synergy Opportunities

- Controlled Source Electromagnetic Methods (CSEM) uses typical borehole electrodes which has been proven to work with any other borehole geophysical method. CSEM uses these electrodes as transmitters and can be set in a schedule if collection timing is needed. This project uses the surface electrodes as receivers for the electrical and magnetic field signals.

Summary

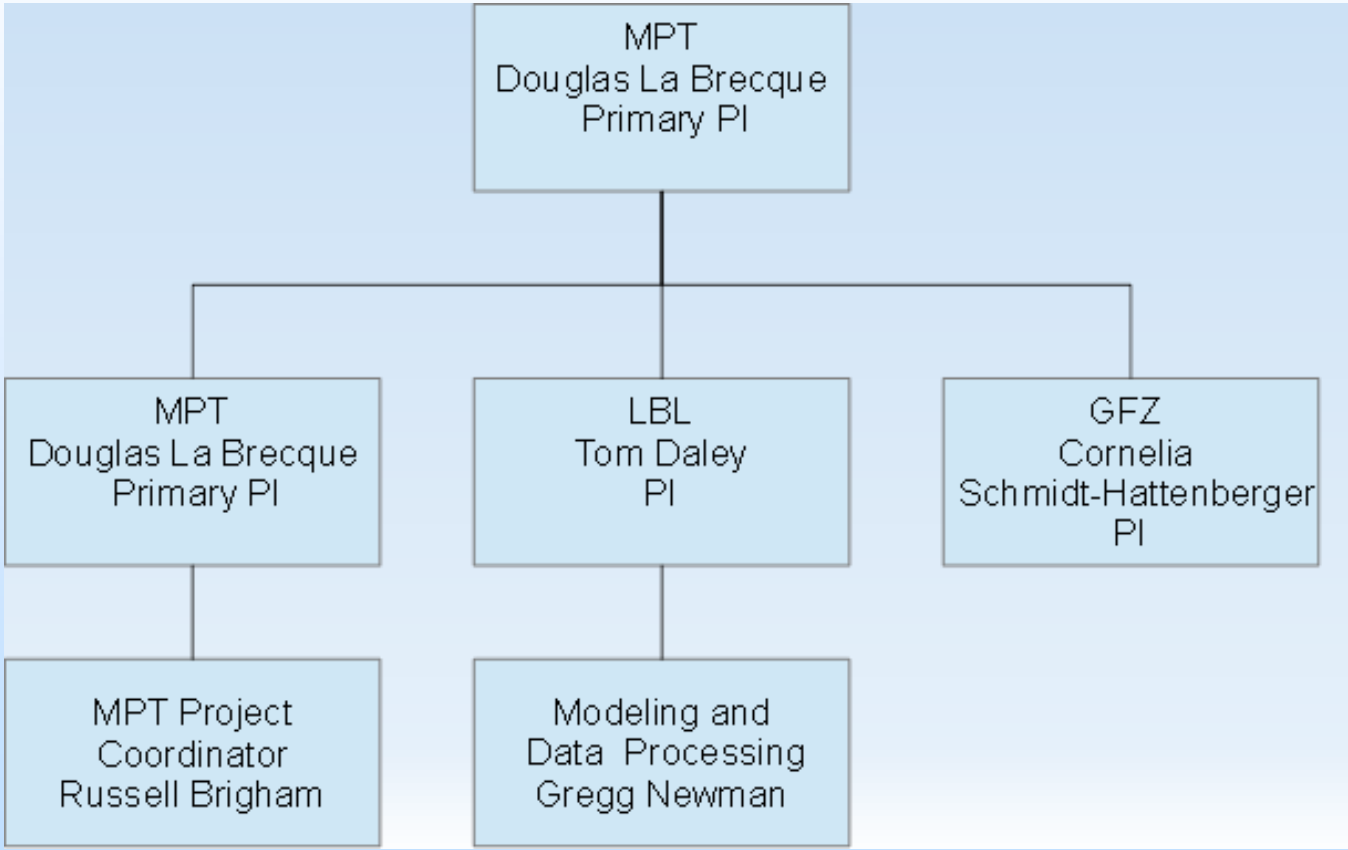
- Key Findings
  - The Model Study Showed Significant Changes in Both Electric and Magnetic Field Responses Between Model Scenarios and Transmitter Types
  - Measuring the Magnetic Field Components With Sufficient Accuracy Was Found To Be Challenging Particularly for Long Offsets and High Frequencies
  - Best Data Were Surface to Borehole Due to Constraints on Borehole Current Flows
  - High Density Multi-Source CSEM test provided the best data for this project
- Lessons Learn
  - Autonomous system requires more robust hardware for long periods of data collection

Summary

- Future Plans
  - Review the Phase III data and report on the data integration.
  - Determine the validation and feasibility of CSEM Methodology

Appendix

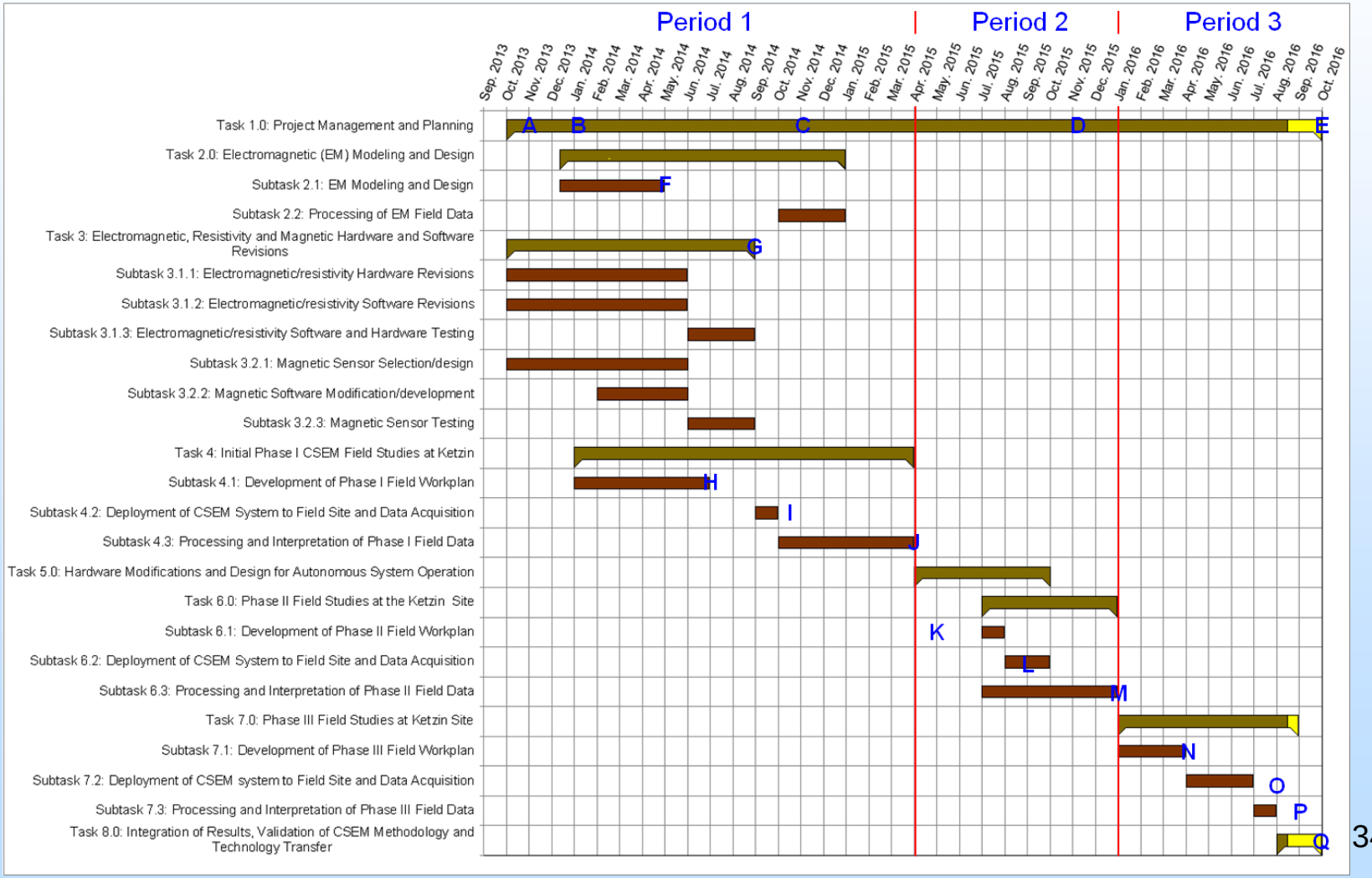
Organization Chart



Organization Chart

- Dr. Douglas LaBrecque from Multi-Phase Technologies, LLC (MPT) is the primary PI. He will be in charge of staff at MPT and coordinate the project with Lawrence Berkeley National Laboratory (LBNL), and the German Research Centre for Geosciences (GFZ) in Potsdam, Germany.
- Tom Daley from LBNL is a Co-PI and the primary point of contact for modeling and lab operations at LBNL.
- Dr. Cornelia Schmidt- Hattenberger from GFZ is a Co-PI and the primary point of contact for field operations at the Ketzin site.
- Russell Brigham from MPT will be the Project Coordinator and will assist Dr. LaBrecque.
- Gregg Newman from LBNL will be responsible for modeling and data reduction.

Gantt Chart


Period 1
Period 2
Period 3
Sep. 2013
Oct. 2013
Nov. 2013
Dec. 2013
Jan. 2014
Feb. 2014
Mar. 2014
Apr. 2014
May. 2014
Jun. 2014
Jul. 2014
Aug. 2014
Sep. 2014
Oct. 2014
Nov. 2014
Dec. 2014
Jan. 2015
Feb. 2015
Mar. 2015
Apr. 2015
May. 2015
Jun. 2015
Jul. 2015
Aug. 2015
Sep. 2015
Oct. 2015
Nov. 2015
Dec. 2015
Jan. 2016
Feb. 2016
Mar. 2016
Apr. 2016
May. 2016
Jun. 2016
Jul. 2016
Aug. 2016
Sep. 2016
Oct. 2016
Task 1.0: Project Management and Planning
Task 2.0: Electromagnetic (EM) Modeling and Design
Subtask 2.1: EM Modeling and Design
Subtask 2.2: Processing of EM Field Data
Task 3: Electromagnetic, Resistivity and Magnetic Hardware and Software Revisions
Subtask 3.1.1: Electromagnetic/resistivity Hardware Revisions
Subtask 3.1.2: Electromagnetic/resistivity Software Revisions
Subtask 3.1.3: Electromagnetic/resistivity Software and Hardware Testing
Subtask 3.2.1: Magnetic Sensor Selection/design
Subtask 3.2.2: Magnetic Software Modification/development
Subtask 3.2.3: Magnetic Sensor Testing
Task 4: Initial Phase I CSEM Field Studies at Ketzin
Subtask 4.1: Development of Phase I Field Workplan
Subtask 4.2: Deployment of CSEM System to Field Site and Data Acquisition
Subtask 4.3: Processing and Interpretation of Phase I Field Data
Task 5.0: Hardware Modifications and Design for Autonomous System Operation
Task 6.0: Phase II Field Studies at the Ketzin Site
Subtask 6.1: Development of Phase II Field Workplan
Subtask 6.2: Deployment of CSEM System to Field Site and Data Acquisition
Subtask 6.3: Processing and Interpretation of Phase II Field Data
Task 7.0: Phase III Field Studies at Ketzin Site
Subtask 7.1: Development of Phase III Field Workplan
Subtask 7.2: Deployment of CSEM system to Field Site and Data Acquisition
Subtask 7.3: Processing and Interpretation of Phase III Field Data
Task 8.0: Integration of Results, Validation of CSEM Methodology and Technology Transfer
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q

Bibliography

– LaBrecque, D., Brigham, R., Schmidt-Hattenberger, C. and Labitzke, T., 2016, CSEM Surveys at the Ketzin Storage Site Using a Wireless Multi-Source System. Greenhouse Gas Control Technologies (GHGT) Conference, November, 4 – 18, 2016, available at: www.ghgt.info.

References Cited

- Klapperer, S., Moeck, I. and Norden, B. 2011, Regional 3D Geological Modeling and Stress Field Analysis at the CO_2 Storage Site of Ketzin, Germany; GRC Transactions, Vol. 35 pp. 419-424.