Greenhouse gas Laser Imaging Tomography Experiment DE-FE0012574

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GreenLITE

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
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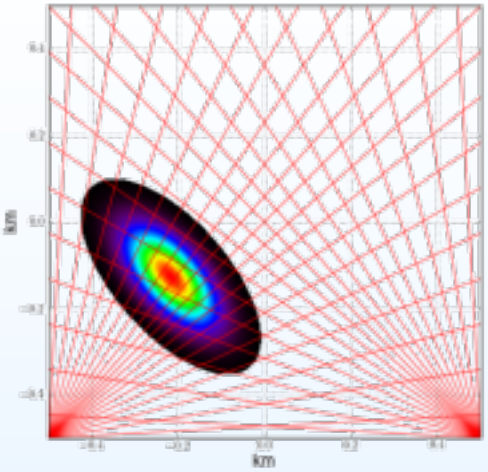
Presentation Outline

- Benefits of Program
- Project Overview
- Technical Status
- Progress to Date
- Summary
- Appendix

Benefit to the Program

- Monitoring, Reporting and Verification for 99% containment of Ground Carbon Storage sites (GCS)
- Addresses this DOE Program Goal:
  - *"The ability to detect potential or actual CO_2 leakage pathways with a high degree of accuracy, including remote sensing and satellite based systems for directly detecting and measuring CO_2 leakage from the storage formation(s) and/or quantifying CO_2 leakage across the storage field."*
- Approach and Benefit
  - Develop 2 scanning Laser Absorption Spectrometer (LAS) instruments with a series of retro-reflectors Designed for real-time, continuous, unattended, remote operation.
  - Develop a robust open web user-friendly interface for remote access and monitoring of site data.
  - The GreenLITE instrument can improve worker safety, reduce environmental and economic impact, and has potential to allow for proper accounting of CO_2 flux over long-term, large scale operations.



Project Overview: Goals and Objectives

- Project Duration: Oct. 1, 2013 – Sept. 30, 2015
- 4 main aspects
  1) Adaptation of the Exelis laser absorption spectroscopy approach, developed for airborne and space applications, to a ground-based system for monitoring Ground Carbon Sequestration sites
  2) Development of a web-based database, retrievals and dissemination application
  3) Testing and validation of system chord data, processing algorithms for concentration and 2D reconstructions
  4) Demonstration of the full ground-based prototype over an extended period at an actual GCS site
- Outcome: A fully operational prototype was developed and tested, both locally and in the field using controlled releases for validation. A fully operational prototype of the web-based user interface and processing was developed and tested. Extended field tests at GCS site complete 8/18/2015.

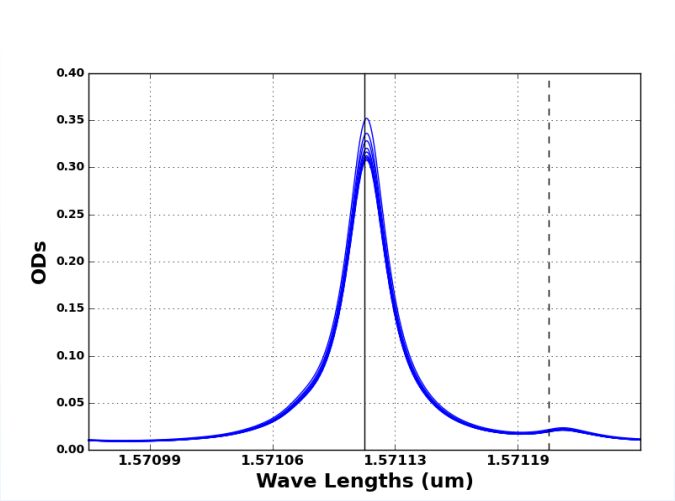
Project Overview: Goals and Objectives

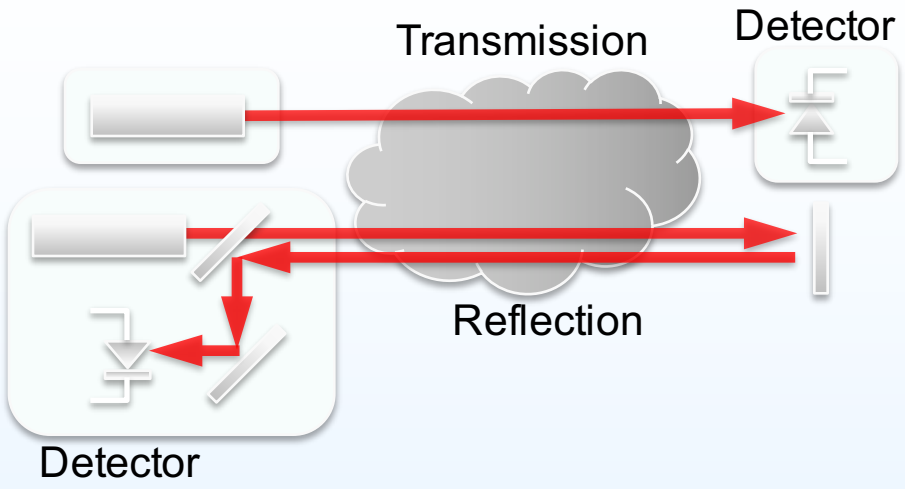
Task	M1 Name	Description	Planned Completion (Baseline)	Planned Completion (Revised)	Actual Completion	Status/Comments
4	Complete performance testing at sensor level	Complete performance testing at sensor level	3/21/2014	4/22/2014	4/22/2014	Sensors performance was verified and they exceed the required SNR of 1000 with 10 second integration periods. Delay in completion due to issues with using refractive optics for transmit receive system.
6	Complete performance assessment at system level	Complete Phase I data analysis and system level performance assessment	6/20/2014	7/31/2014	8/13/2014	Phase 1 interim report completed and submitted along with an updated algorithm description document for the 2D reconstructions. Delay is residual from the transmit receive optical redesign.
12	Complete ZERT testing	Complete testing at ZERT site and assessment of system level performance	10/31/2014	11/14/2014	12/5/2014	Phase 1 final report completed and submitted to the DOE, including quantified results of the system performance for local testing and testing at the ZERT test facility. Delay on this task was driven mainly by the volume of data obtained during the ZERT field test experiments and additional time required to analyze and compile the information.
16	Complete local testing of extended deployment system	Complete final retrieval software integration and test via local testing of extended deployment system	1/26/2015	1/26/2015	1/16/2015	Was met when autonomous operation over a multiple weeks were achieved with only remote interaction, while real time 2D CO2 concentration maps are publicly available via a web interface Dec 2014- Jan 2015
17	Initiate testing at Decatur site	Initiate autonomous remote field testing at Decatur site	3/16/2015	3/16/2015	2/25/2015	Was met when remote system started collecting data autonomously at Decatur site 2/25/2015
17	Complete testing at Decatur site	Complete autonomous remote field testing at Decatur site	9/30/2015	8/18/2015	8/18/2015	Remote system has completed autonomous data collection at Decatur site

Technical Status

1) Adaptation of the Exelis laser absorption spectroscopy approach, developed for airborne and space applications, to a ground-based system for monitoring Ground Carbon Sequestration sites
    1) Complete
2) Development of a web-based database, retrievals and dissemination application
    1) Complete
3) Testing and validation of system chord data, processing algorithms for concentration and 2D reconstructions
    1) Complete
4) Demonstration of the full ground-based prototype over an extended period at an actual GCS site
    1) Demonstration complete
    2) Working on data analysis and comparisons with other on site measurement technologies

Sensing of Column CO2

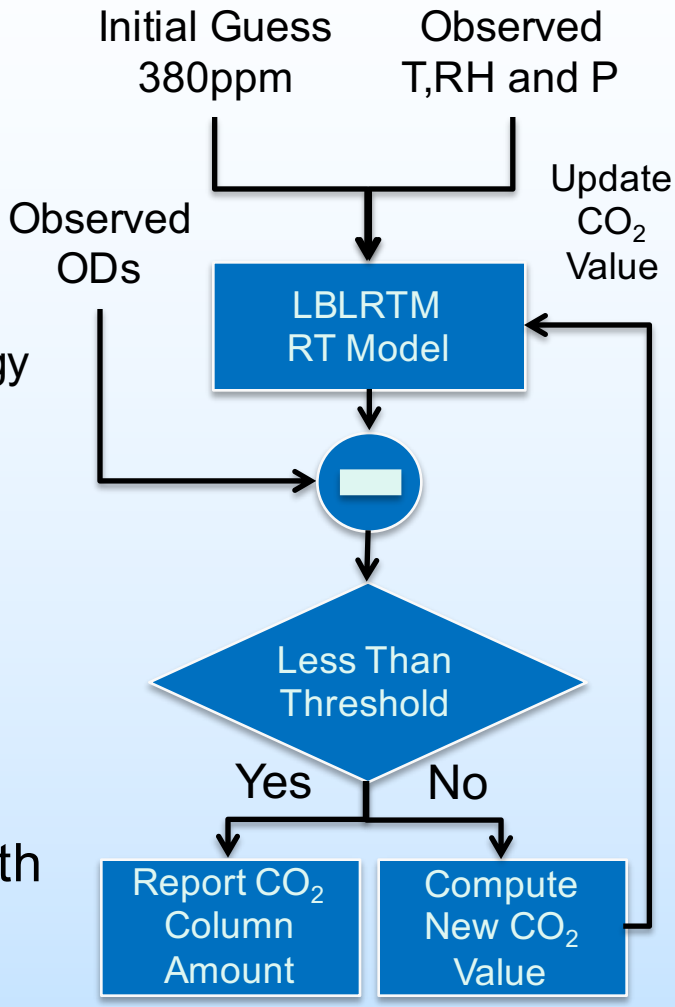




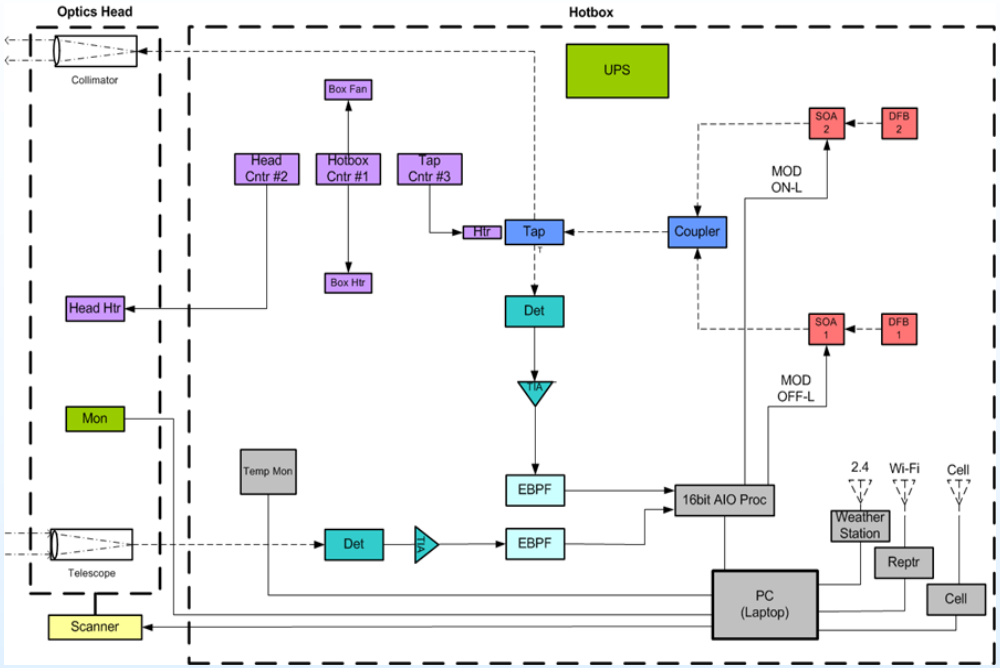
- **Approach**: Retrieve CO_2 (or other trace gas) column amount from active measurements of optical depths
  - Column amount is proportional to path length and molecular density
    - "On"-line wavelength λ (on absorption feature of interest)
    - "Off"-line λ±Δλ (in the continuum)
- **Instrument**
  - Employ telecommunication technology at wavelengths in a weak CO_2 feature (1.57um)
  - Designed to work in either Transmission or Reflection
    - *Transmission*: Eliminates partial column returns at cost of path length
    - *Reflection*: Increases path length, simplifies instrument and enclosure design

CO_2 Concentrations from Optical Depth

- Iterative Radiative Transfer-based approach is used to estimate chord concentrations
  - Ingest
    - Observed optical depths
    - In situ measurements of surface meteorology (T, RH and P)
  - Model expected optical depth given path configuration and T, RH and P
  - Assess difference between model and measured values
  - Adjust CO_2 column amount based on gradient so that model best matches measured values
  - Approach has been demonstrated for both airborne and ground implementations

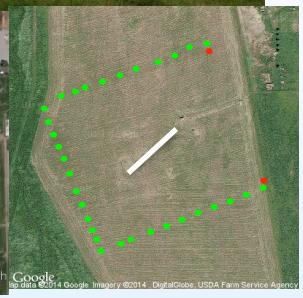


Transceiver Development



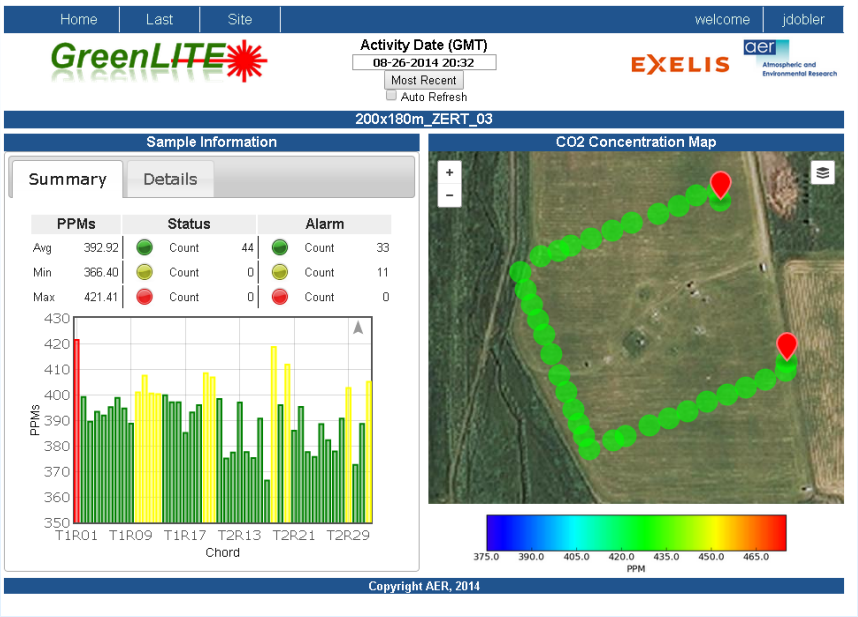
- Designed for :
  - Autonomous long-term remote operations
  - Simultaneous transmission of on and off λ
  - Eye-safe 1571 nm, 5mW CW transmitter
- Measures differential transmission and range
- 3G/4G wireless data streaming
- Interfaced directly with local weather station

Initial System Testing

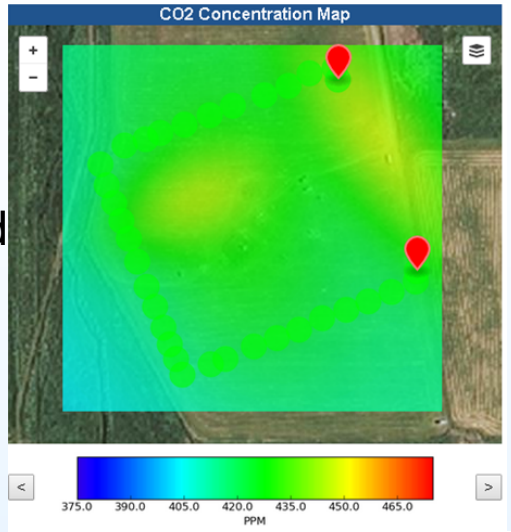


- System and software designed and built in 10 months
- Initial testing began at the Exelis Farm in New Haven, IN, June 2014
- Additional testing was performed at the Zero Emission Research and Technology facility operated by Montana State University, in Bozeman, MT, 8/18/2014 – 9/9/2014
  - Horizontal well for controlled releases ~2m below the surface up to 0.3T/day from 70 m pipe split into 6 segments.
- Over 600 hours of data over a wide range of conditions were collected.
- System was operating remotely at the Exelis Farm unattended for 2 months.
- 2D reconstructions were completed for all data sets.

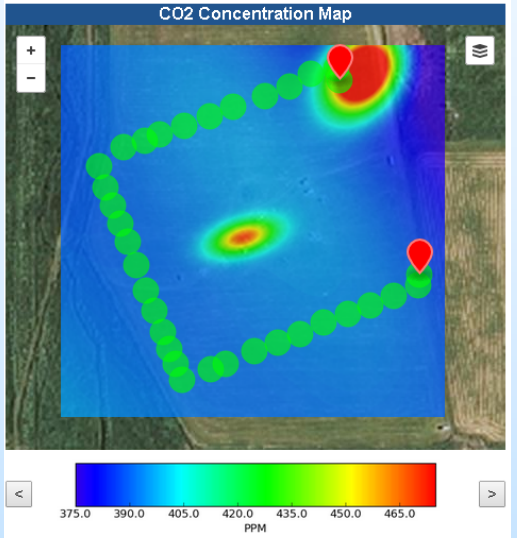
ZERT 2D Reconstructions



7 am
No wind



3 pm
0.4 m/s
wind
from NW

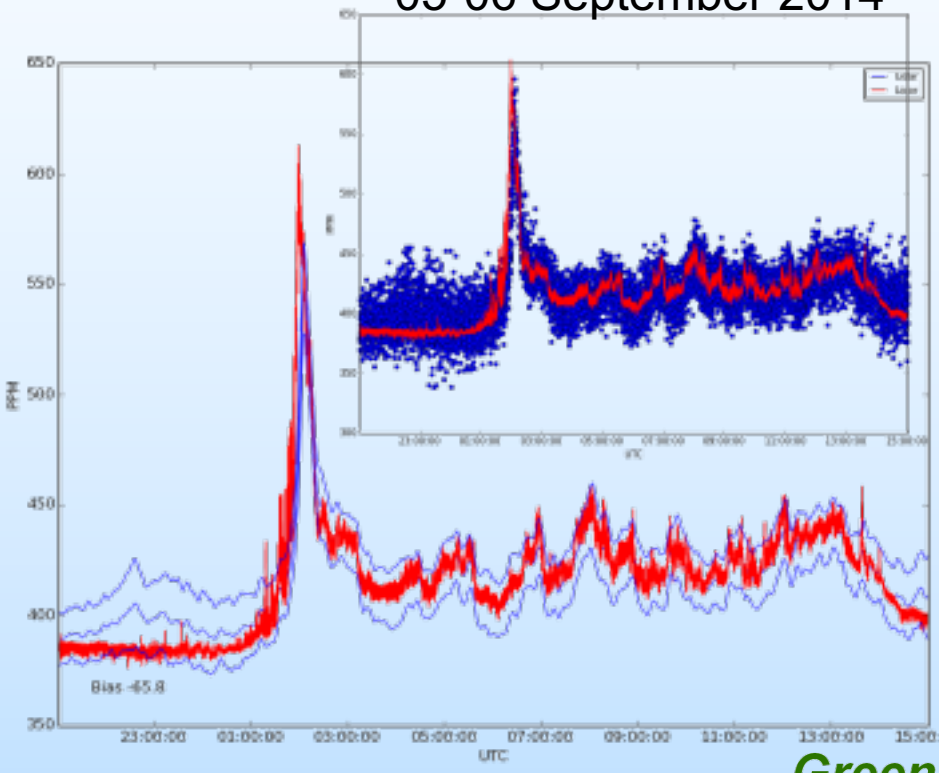


ZERT test results showed that the 2D reconstruction algorithms could see persistent features from both the controlled release and from a large manure pile in the Northeast corner, but wind and natural variation in background make independent validation of reconstructions challenging.

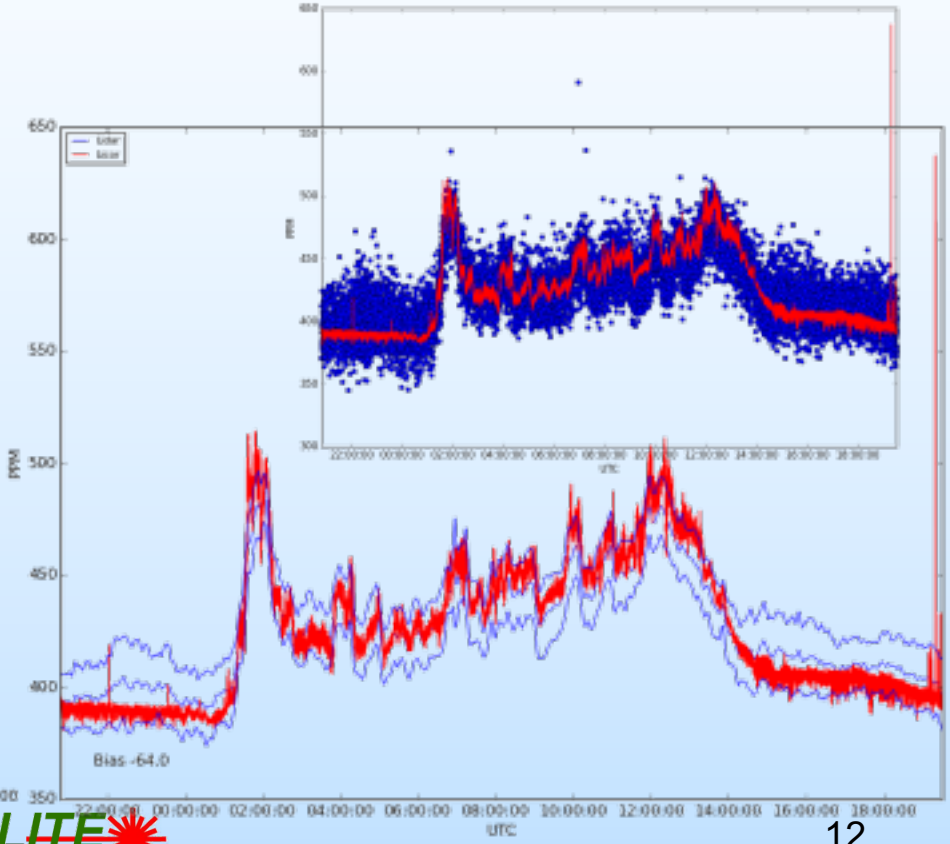
Comparison with LI-COR

Average of all chords closely matches trends of LI-COR-based system, capturing large respiration signal at sunset. However, spatial variation is seen in lidar data chords.

05-06 September 2014

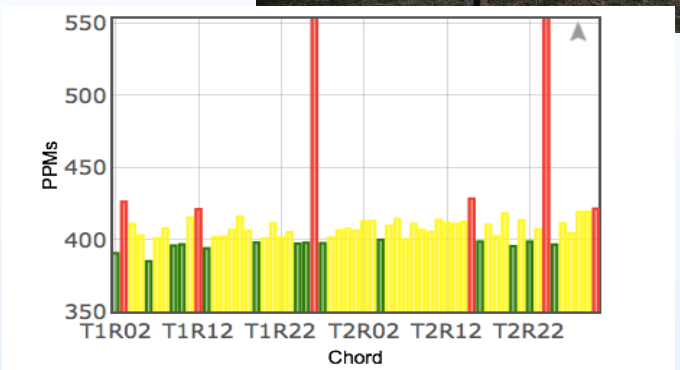


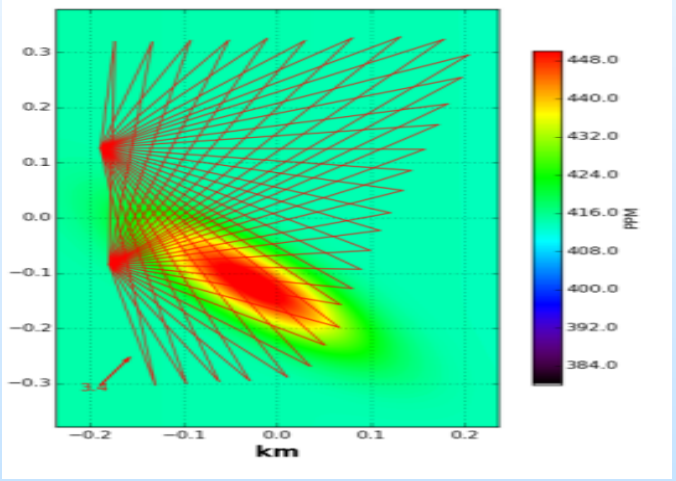
06-07 September 2014



Testing of 2D Reconstructions – Local Post-ZERT Testing

- Validation of 2D distributions are challenging
  - Most current measurement approaches are at a single point, making it difficult to get enough simultaneous measurements needed to establish truth.
  - Difficult to ensure stationary environment for release



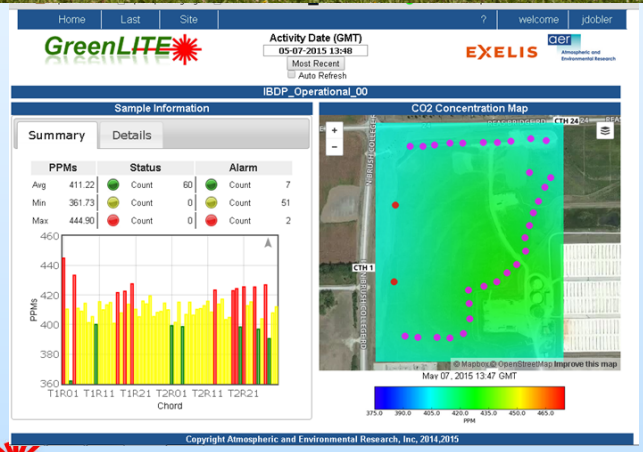


- Our solution was to develop movable open air cavities to enhance column amount along selectable chords simultaneously to simulate plume

- Demonstrated that 2-D reconstruction mechanism can detect and locate plumes in field of interest based on integrated column amounts

Deployment to the IBDP Site

- Illinois Basin - Decatur Project, Decatur, IL
- Transceivers are mounted to three-pole cemented structures
- Retro-reflectors are mounted to 1” diameter pushed-in poles
- Uses 4G LTE for data transfer and remote instrument access
- Area covered is ~0.25 km^2 (limited by site)
- Installation occurred in Feb 2015
- 2 days to install and have operational
- 1 month check out
- Since fully operational >95% duty cycle
- Average of ~4 hours/month spent onsite for maintenance



Testing at IBDP

- Feb---Aug 2015: Illinois Basin – Decatur Project (IBDP) (Decatur, IL)
  - Raw Samples: 2M
  - Retrieved Samples: 1.8M+
  - Site Reconstructions: 72K
  - Up-Time ~95%
- Demonstrated real-time autonomous operation
- No critical system failures during this time
- Detailed review of the data and system performance is ongoing.

Accomplishments to Date

- Team developed a unique monitoring tool that produces high-resolution 2D mapping of atmospheric CO_2 over an area up to 1 km^2
- The ability to identify leaks of the size required to verify 99% containment has been demonstrated via testing at the ZERT site and local site testing.
- Demonstrated ability to deploy the system at an active GCS site
  - Long term autonomous operation 24/7 through a wide range of environmental conditions, while allowing multiple users direct remote access to the data via a secure cloud based processing and data dissemination tool.
- All major program milestones have been met.

Synergy Opportunities

- Collaboration with Montana State University ZERT facility enabled validation
- Collaboration with the Illinois Basin – Decatur Project and Archer Daniels Midland has been essential to the success of this project.
- Collaboration with NIST has provided a more robust algorithm set to track plumes in varying wind fields, locate source and estimate leak rate
- Further collaboration comparing to other spatial sampling methods such as airborne systems is desirable.

Summary

- Key Findings
  - GreenLITE proved capable of long term remote monitoring of an active GCS site and to accurately identify persistent sources even in natural varying backgrounds
  - 2D estimations can be obtained over areas up to 1 km^2 and provide real-time information to site operators
  - GreenLITE results demonstrate excellent correlation with independent in situ atmospheric CO_2 measurements

Summary

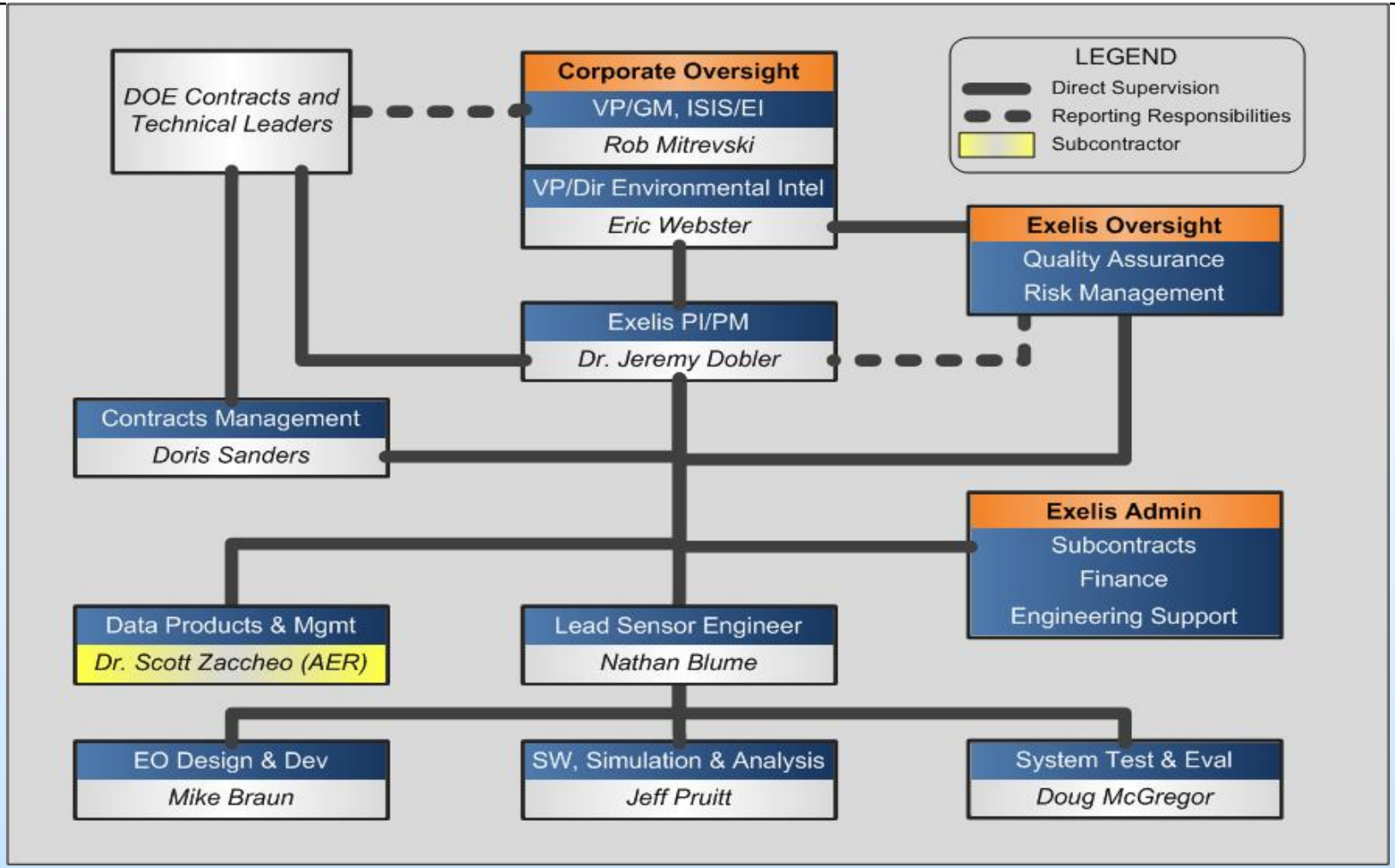
- Lessons Learned
  - Wavelength locking or monitoring would enhance system performance and reduce uncertainty
  - Background concentration variations due to natural and other sources complicates interpretation of the data, but evaluation of wind driven plumes can lead to source localization and estimates of source strength
  - Site infrastructure and things such as vegetation need to be taken into account for long term deployment planning
  - Protective coating on retro-reflectors oxidizes, reducing SNR, Luckily we had margin!

Summary

- Future Plans
  - Complete data evaluation, comparisons and final report
  - Harris and AER have invested in developing an enhanced version of GreenLITE to extend to 5km path
    - Modelling shows expansion to 10 km is feasible
    - Simulations and testing needed to evaluate the trades for GCS sites using longer path systems.
  - The 5 km system is planned for testing in an urban plume later this year.

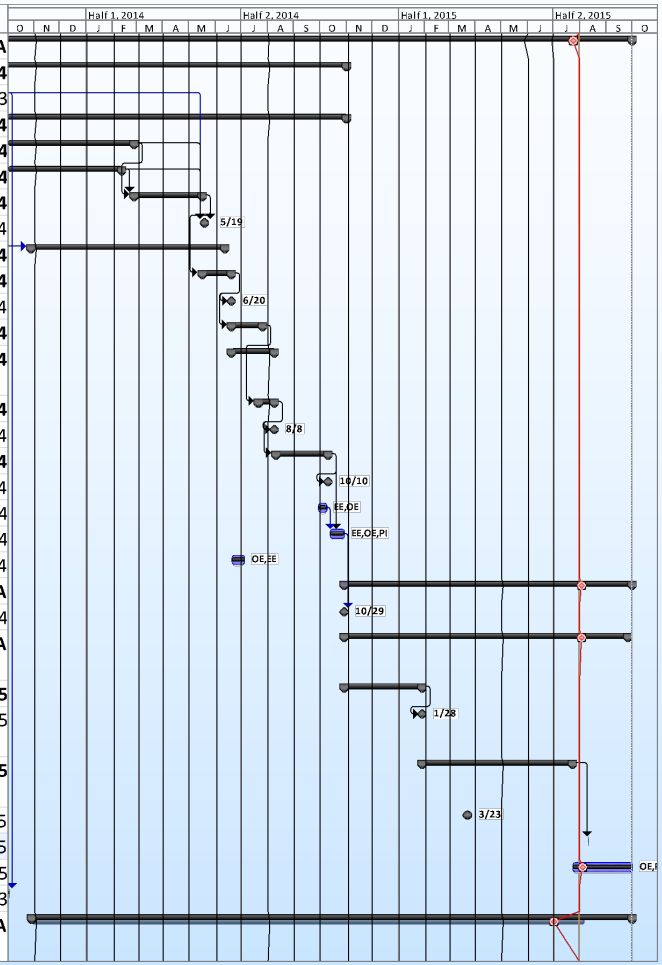
Appendix

Organization Chart



Gantt Chart

ID	Task Name	Act. Start	Act. Finish
1	**DOE CO2 Sequestration Green LITE**	**Tue 10/1/13**	**NA**
2	**Phase 1**	**Tue 10/1/13**	**Fri 10/31/14**
3	**Phase 1 Start Date**	Tue 10/1/13	Tue 10/1/13
4	**Project Management and Planning**	**Tue 10/1/13**	**Fri 10/31/14**
15	**HW Design and Build**	**Wed 10/2/13**	**Tue 2/25/14**
21	**SW Development**	**Wed 10/2/13**	**Tue 2/11/14**
25	**Sensor Integration**	**Wed 2/26/14**	**Fri 5/16/14**
28	Sensor integration and test complete	Mon 5/19/14	Mon 5/19/14
29	**CO2 Retrieval Algorithm Dev**	**Tue 10/29/13**	**Thu 6/12/14**
33	**System Test**	**Fri 5/16/14**	**Fri 6/20/14**
36	**System test with baseline algorithms complet**	Fri 6/20/14	Fri 6/20/14
37	**Upgrade System for Remote Deployment**	**Fri 6/20/14**	**Fri 7/25/14**
43	**Update, Integrate and Test Retrieval & CO2 Monitoring Subsystem**	**Fri 6/20/14**	**Fri 8/8/14**
46	**Local Testing of Integrated System in Field Set**	**Mon 7/21/14**	**Fri 8/8/14**
49	**Local testing with integrated algorithms comp**	Fri 8/8/14	Fri 8/8/14
50	**ZERT Field Campaign**	**Mon 8/11/14**	**Fri 10/10/14**
54	**Zert testing and analysis complete**	Fri 10/10/14	Fri 10/10/14
55	**Decature ICCS Site Investigation**	Mon 9/29/14	Wed 10/8/14
56	**Phase 1 Final Report**	Mon 10/13/14	Wed 10/29/14
57	**Interim Report**	Fri 6/20/14	Fri 7/4/14
58	**Phase 2**	**Wed 10/29/14**	**NA**
59	**Start of Phase 2**	Wed 10/29/14	Wed 10/29/14
60	**Project Management and Planning - Phase 2**	**Thu 10/30/14**	**NA**
71	**System Preperation for Extended Deploymen**	**Thu 10/30/14**	**Wed 1/28/15**
75	**Local System testing for remote deployment complete**	Wed 1/28/15	Wed 1/28/15
76	**MGSC Illinois Basin – Decatur Project Field Campaign**	**Thu 1/29/15**	**Wed 7/22/15**
80	**Remote system deployed**	Mon 3/23/15	Mon 3/23/15
81	**Remote System deployment complete**	Mon 8/10/15	Mon 8/10/15
82	**Phase 2 Final Report**	Thu 7/23/15	Wed 9/30/15
83	**Material**	Wed 10/2/13	Wed 10/2/13
84	**Subcontract**	**Wed 10/30/13**	**NA**



Bibliography

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  Dobler, J., Blume, N., Braun, M., Zaccheo, T. S., Pernini, T., and Botos, C.: Greenhouse Gas Laser Imaging Tomography Experiment (GreenLITE), 2015, in: Proc. 27th Intl. Laser Radar Conf., p. S13, 2015.

- Atmospheric Measurement Technology :

  Levine Zachary H. , Pintar A., Dobler J., Blume, N., Braun M., Zaccheo T. S., and Pernini T. G., 2015, The detection of carbon dioxide leaks using quasi-tomographic laser absorption spectroscopy measurements in variable wind, In: Atmospheric Measurement Technology, in review

  – Many presentations (AGU 2014, AMS 215, NACP 2015, IEAGHG Monitoring Network, ILRC 27