Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE)  
DE-FE0012574

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Presentation Outline

• Benefits of Program
• Project Overview
• Technical Status
• Progress to Date
• Summary
• Appendix
Benefit to the Program

• Develop and validate technologies to ensure 99 percent storage permanence.
  – Our work is aimed at providing a piece of the overall system used to validate 99 percent containment for a given carbon ground storage project.
• The Exelis instrument seeks to improve worker safety, reduce environmental and economic impact, and allow for proper accounting of CO2 flux over long-term, large scale operations. Further, the Exelis AER team seeks to accomplish this in a user-friendly, set-up-and-forget package at minimal cost to set up and only hours a month to maintain. The goals of this proposal perfectly match those of the DOE objectives outlined in section 2 of the FOA.
Project Overview:
Goals and Objectives

• The overall program objective is to provide a laser based measurement of carbon concentrations across a plane over ~1.6 km² using 2 sensors and a series of retro reflectors along with tomographic like methods to generate 2D concentration maps across the area.

<table>
<thead>
<tr>
<th>BP &amp; Phase</th>
<th>Task</th>
<th>M1 Name</th>
<th>Description</th>
<th>Planned Completion (Baseline)</th>
<th>Planned Completion (Revised)</th>
<th>Actual Completion</th>
<th>Status/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 4</td>
<td></td>
<td>Complete performance testing at sensor level</td>
<td>Complete performance testing at sensor level</td>
<td>3/21/2014</td>
<td>4/22/2014</td>
<td>4/22/2014</td>
<td>Will be met when quantified data shows the sensor meets design specifications. Proceed with system development</td>
</tr>
<tr>
<td>1 6</td>
<td></td>
<td>Complete performance assessment at system level</td>
<td>Complete Phase I data analysis and system level performance assessment</td>
<td>6/20/2014</td>
<td>7/31/2014</td>
<td></td>
<td>Will be met upon completion of Phase I report and updated version of algorithm description document provided to DOE including 2D concentration maps from post processing.</td>
</tr>
<tr>
<td>1 12</td>
<td></td>
<td>Complete ZERT testing</td>
<td>Complete testing at ZERT site and assessment of system level performance</td>
<td>10/31/2014</td>
<td>10/31/2014</td>
<td></td>
<td>Will be met when quantified assessment of 2D concentration estimates from ZERT controlled release experiments are delivered to DOE</td>
</tr>
<tr>
<td>2 16</td>
<td></td>
<td>Complete local testing of extended deployment system</td>
<td>Complete final retrieval software integration and test via local testing of extended deployment system</td>
<td>1/26/2015</td>
<td>1/26/2015</td>
<td></td>
<td>Will be met when autonomous operation over a full week is achieved with only remote interaction, while real time 2D CO2 concentration maps are publicly available via a web interface</td>
</tr>
<tr>
<td>2 17</td>
<td></td>
<td>Initiate testing at Decatur site</td>
<td>Initiate autonomous remote field testing at Decatur site</td>
<td>3/16/2015</td>
<td>3/16/2015</td>
<td></td>
<td>Will be met when remote system is collecting data autonomously at Decatur site</td>
</tr>
<tr>
<td>2 17</td>
<td></td>
<td>Complete testing at Decatur site</td>
<td>Complete autonomous remote field testing at Decatur site</td>
<td>9/30/2015</td>
<td>9/30/2015</td>
<td></td>
<td>Will be met when remote system has completed autonomous data collection at Decatur site</td>
</tr>
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</table>
General Overview

This project serves to demonstrate a system utilizing 2 scanning laser-based differential absorption sensors, combined with a series of retro-reflectors and intelligent algorithms to generate real time 2D concentration and flux maps over a carbon sequestration storage facility. The final phase will demonstrate an autonomous, remote measurement of the entire storage field with high precision and accuracy, while making the data available in near real time via a web-based interface.
TECHNICAL STATUS
Sensor Design

- The Green LITE sensor design was based on prior work with Exelis’ airborne Multifunctional Fiber Laser Lidar (MFLL) and, more specifically, the ground-based prototype of the Laser Atmospheric Transmitter and Receiver-Network (LAnTeRN).
- The first task was to review and modify the LAnTeRN prototype design for the Green LITE specific application of Ground Carbon Sequestration monitoring.
- The design was reviewed and refined given the objectives of the Green LITE program for remote operation, and the required components were identified.
General Instrument Architecture

High reliability telecom components, CW operation requires low peak power and allows for more robust, less expensive laser components and higher system efficiency.
Sensor Detailed Block Diagram
Component Selection

- As the design was refined and component specifications were developed, suitable commercial components were identified which met the design criteria and were then procured if not already on hand from prior development.
- Components were custom built if not commercially available.
- Components were characterized to verify specifications and tested for sensitivity to environmental conditions.
- Examples of characterization results are shown on next slide.
Component Characterization

Wavelength stability requirement was +/- 0.02 pm/degC

Ratio Impact Requirement for Fiber Tap Over 0-40C was 0.001
Component Integration

- Components were integrated and installed in 2 modular chassis inside a thermally controlled “hot box.”
- The hot box maintains a constant 38 °C +/-0.2 °C, which is above any ambient temperatures expected during remote deployment. This provides a constant thermal environment for the hardware components and prevents condensation from humid air.
- Temperatures of critical components also have closed loop control in addition to the controlled ambient temperature (Optics Head, Fiber taps, Lasers)
Hotbox maintains temperatures and prevents condensation.
Optical Design

• The original optical design for the transmitter and receiver used refractive optics.

• Component testing revealed that refractive optics caused a variation of the wavefront significant enough to bias the measured transmission ratio.

• Further testing and several iterations of the design resulted in a reflective transmitter/receiver design that works very well.

• This design change also impacted mechanical and thermal design, and ultimately led to about a 1 month delay to the first and second milestones for the project.
Similarly to the hardware development, the Green LITE software development leveraged as much of the existing software from MFLL and LAnTeRN as possible.

The software is written in LabVIEW and uses an event-based architecture.

The software allows for 2 modes of operation:
- Manual: no automated movement of the scanner
- Automatic: the scanner automatically scans through a list of pre-determined pointing locations at a user-specified time interval

Manual mode is useful for testing and debugging while automatic mode is used for normal operation.
Software functional block diagram shows different operations performed and how execution control and data are passed between operations.

Yellow blocks are for receiving weather data from weather station and pushing to database. Another method of accessing weather data is currently being used, but this will be implemented prior to remote deployment at IBDP site.
Software Screenshots
Software Screenshots
Sensor Unit Testing

- When the first sensor build was complete and the software was fully functional, the sensor was tested at the Exelis Farm test facility.
- The sensor was scanned back and forth between 2 retro-reflectors and consistently demonstrated an SNR for the differential transmission measurement of > 3000 with 10-second averages, exceeding the design specification by a factor of 3.
- All data was loaded directly to the web-based database and retrieval site via a 3G/4G wireless connection.
- Testing then progressed to system level testing consisting of both transceivers and multiple retro reflectors.
Local Sensor and System Level Testing

Select Site Location

240mx130m_Grid_00_FARM
680m_01_FARM
680m_02_FARM
680m_03_FARM
ExelisSite00_FARM
ExelisSite01_FARM
ExelisSite02_FARM
ExelisSite03_FARM
ExelisSite04_FARM
ExelisSite05_FARM
ExelisSite06_FARM
MockSite_Farm00
Local Sensor and System Level Testing
Local Sensor and System Level Testing
Local System Testing Setup

Exelis Farm Test Site Used for Preliminary Sensor and System Level Testing
Looking at Individual Chord Data on Web-based Tool

GreenLITE

Sample Location and Time Series

PPM Time Series

Activity Date (GMT)
06-04-2014 19:56

Most Recent
Auto Refresh
Looking at Individual Measurement Data
Comparison With In Situ
Weather Data Collected for Retrievals
Preliminary 2D Reconstructions from Local System Testing
Accomplishments to Date

- Sensors designed and requirements specified at component level
- Component performance validated in laboratory
- System design and trade studies completed
- Sensors assembled and integrated with software
- Sensor level testing exceeded design specification by 3X
- Retrieval algorithms developed and tested
- Database and Web tools developed with user interface
- System level testing nearing completion
- Preliminary 2D mapping algorithms developed and tested with simulated and measured data
Summary

– System is capable of providing concentration and 2D maps of CO2 concentration over hundreds of square meter area.
– Truth data is difficult to obtain using currently available hardware.
– Source determination highly dependent on wind speed and height above ground level.
– All web-based real-time processing, storage and dissemination of data is convenient and viable.
Organization Chart
Bibliography

No peer reviewed publications have been generated from the project yet. Several presentations are planned and peer reviewed publications will follow testing at the ZERT site and analysis of the results.

- We are submitting two abstracts for the American Geophysical Union Annual Meeting to be held in San Francisco, CA Dec. 15-19.
  - “A Laser Absorption Spectroscopy System for 2D Mapping of CO2 Over Large Spatial Areas for Monitoring, Reporting and Verification of Ground Carbon Storage Sites”
  - “Assessing Methods for Mapping 2D Field Concentrations of CO₂ Over Large Spatial Areas for Monitoring Time Varying Fluctuations”

- Another abstract is being submitted to the American Meteorological Society Meeting to be held in Phoenix, Arizona January 4 – 8th. We will also look for an opportunity to publish the results of the Zero Emissions Research and Technology site testing and results.
  - “Intensity Modulated Continuous Wave Laser Absorption Spectroscopy for Addressing Currently Unmet Carbon Monitoring Needs”
Starting with the basic lidar equation

\[ P_{\text{rec}\,\lambda}(Z) = P_{o\,\lambda} \cdot C \frac{A}{Z^2} \cdot \rho_\lambda \cdot \tau_\lambda^C(z) \cdot \tau_\lambda(z) \]

We are interested in the last term which is the transmission from range 0 to the target Z and back due to absorption.

When a simultaneous measurement is made at two closely spaced wavelengths, all other terms are common to both channels, and thus taking the ratio yields the differential transmission.

\[ \Delta \tau_{\lambda_{\text{on}}-\lambda_{\text{off}}}(z) = \frac{\tau_{\lambda_{\text{on}}}}{\tau_{\lambda_{\text{off}}}} = \frac{P_{\text{rec}\,\lambda_{\text{off}}}}{P_{\text{rec}\,\lambda_{\text{on}}}} \cdot \frac{P_{o\,\lambda_{\text{on}}}}{P_{o\,\lambda_{\text{off}}}} \]

The total integrated column number density of the absorbing molecule can then be determined if the absorption cross section is known.