High Accuracy Mobile Emissions Laboratory for Measurements of Greenhouse Gases, Isotopes, Fluxes, Pollutants

Doug Baer, Ph.D.
Los Gatos Research
67 East Evelyn Avenue
Mountain View, CA 94041-1529
www.LGRinc.com

- Overview/Motivation
- Construction of Mobile Lab
- Measurement theory
- LGR’s Gas and Isotope Analyzers
- Field deployments
- Summary and Conclusions
Need for quantification of emissions at local level

Emission targets may be established at the state or national scale, but measurement, monitoring and mitigation must be engaged at urban or individual industrial locations.

Thus reducing GHG emissions requires quantification/verification at regional and local levels.
Novel Instruments Provide New Opportunities

- Fast Greenhouse Gas Analyzer: CH$_4$, CO$_2$, H$_2$O at 10 Hz
- N$_2$O and CO Analyzer: measurements at 20 Hz
- Isotopic CO$_2$ ($\delta^{13}$C, CO$_2$) in air at 1 Hz (continuous)
- Isotopic CO$_2$ ($\delta^{13}$C, CO$_2$): 300 ppmv - 100% (discrete)
- Water Vapor Isotopes ($\delta^2$H, $\delta^{18}$O, H$_2$O) at 5 Hz
- Liquid Water Isotopes ($\delta^2$H, $\delta^{18}$O): >133 samples/day
- Methane Carbon Isotopes ($\delta^{13}$C, CH$_4$) in real time
- Nitrous Oxide Isotopes ($\delta^{15}$N, $\delta^{18}$N, N$_2$O) in real time
- Ammonia (NH$_3$) in air at 1 Hz
- Carbonyl sulfide (OCS) Analyzer: 1 Hz
- Perfluorocarbon tracers
Novel Instruments Provide New Opportunities

Novel Instruments Provide New Opportunities
(NASA staff in Antarctica)

Lake Untersee, Antarctica (NASA)
Novel Instruments Provide New Opportunities
(LGR instruments for flight)

On-board aircraft: UAV and planes
LGR’s Mobile Emissions Lab provides sensitive measurements anywhere

LGR’s Mobile Emissions Lab
Sponsored (in part) by:
California EPA Air Resources Board
Trailer + LGR Gas Analyzers and assorted metrology equipment = Mobile Emissions Laboratory

- Trailer (Cargo Wagon; 7’ wide) serves as Mobile Emissions Laboratory
Thermal insulation (RU13) added inside walls for operation in extreme environments.
Thermal insulation added inside walls of Mobile Lab

- Thermal insulation (RU13) added inside walls for operation in extreme environments.
Roof mounted gas input/output ports and vents

multiple gas input/output ports

vent input/output ports
Deep cycle marine batteries under floor provide power for long-term operation where AC power is limited.
Power connections to/from Mobile Emissions Laboratory

- **external power input/output**
- **breaker panels for AC input and internal power distribution**
- **inverter/charger converts AC to DC battery power**
• Multiport Inlet Unit combined with long-length inlet lines allow for measurements at multiple locations and at various distances from Lab
• Sonic anemometer provides measurements of wind direction and velocity
Onboard PC, data logger provides centralized data acquisition
LGR Mobile Lab provides sensitive field measurements at landfills, urban, rural locations.

LGR’s Mobile Lab includes several autonomous gas analyzers and accessories.
Mobile Emissions Lab includes several LGR Analyzers

On-board battery allows long term operation in the field
High Resolution Absorption Spectrometry: General Overview

Beer-Lambert Law:
\[
\frac{\Delta I}{I_0} = 1 - \exp(-\alpha L_{\text{eff}})
\]

- \(\Delta I/I_0\): fractional change in laser intensity
- \(S\): absorption line strength
- \(\chi\): mixing ratio (mole fraction)
- \(P\): total pressure
- \(L_{\text{eff}}\): effective optical path length
- \(\alpha(\lambda)\): absorption coefficient, \(S \cdot P \cdot \chi \cdot \phi(\lambda)\)

- Optical cavity provides pathlength enhancement: $L_{\text{eff}} = L / (1-R) = c \tau$
- Typical $R = 99.995\%$, $L_{\text{eff}} = 3$-25 kilometers (or greater)
- Extraordinarily robust - alignment insensitive, telecom-grade components
- Allows for near-IR measurements of overtone and combination bands
- Measurements using mid-IR QC lasers provide extremely high sensitivity
Advantages of Off-Axis ICOS (LGR patent)

- All parameters (absorption, $L_{\text{eff}}$, $P$, $T$) determined quickly (300-Hz, typical)
- Robust optical alignment → negligible alignment drift, mechanically stable
- Off-axis alignment spatially separates beam paths through cell → lengthens time/distance before beam retraces itself → eliminates unwanted resonance interference effects
- Off-axis alignment eliminates optical feedback from cavity to laser source
LGR’s Off-Axis ICOS: typical raw data trace

Transmission Spectrum
- Measure absorption, baseline, detector offset
- Measured ringdown yields $L_{\text{eff}}$
- Measure/control gas flow parameters (T, P)
- Sweep laser wavelength at 100 – 1200 Hz

Measured Etalon Transmission
- Accurately determines laser tuning rate
- Solid etalon ($\text{SiO}_2$)
- Measure length and temperature
- Converts time to relative laser frequency
Instrumentation Packaging: Options

- Portable rugged package allows field operation
- On-board computer provides real-time data analysis & storage
- 90-200 Watts, 27 kg
- Simple user interface; analog, digital (RS232), Ethernet outputs
- Fully autonomous operation
- Remote access via internet
User Interface: Multiple Real-Time Displays

- Multiple display options: numeric, time chart, raw data/spectra
- Measurements of mixing ratio, gas temperature, pressure
- User-selectable data rate (0.01-20 Hz)
- Remote monitoring/control via internet
Analyzer Options

- Multiport Inlet Unit: automatic sampling from 16 locations
- Manual injection of discrete samples
- Remote monitoring/control
- Dynamic dilution system (quantification of high concentrations)
Remote Access and Control

- IP-KVM provides video, keyboard, mouse signals over Ethernet
- IP-KVM connects to LGR’s power plane allowing BIOS control
- Allows remote access and control of LGR Analyzers (past and present)
- ~$1k (includes separate external computer)

- May be applied with all LGR Analyzers: past and present
Fast Greenhouse Gas Analyzer: 1-Hz raw data

- $\text{CO}_2 = 377.49 \pm 0.16 \text{ ppm}_v$
- $\text{CH}_4 = 1.711 \pm 0.001 \text{ ppm}_v$
- $\text{H}_2\text{O} = 11749 \pm 33 \text{ ppm}_v$
Inlet switched from air to “zero air” to determine flow response
Concentration decays yield time constants sufficient for eddy flux
Fast Greenhouse Gas Analyzer: Stability

- CH$_4$ and CO$_2$ in air measured at a 1-Hz sampling rate (10-Hz possible)
- Data and associated Allan plots show stable operation and ability to reliably average over long times to improve precision
Fast Greenhouse Gas Analyzer: Stability

- CH₄ and CO₂ in air measured at a 1-Hz sampling rate (10-Hz possible)
- Data and associated Allan plots show stable operation and ability to reliably average over long times to improve precision.
Accurate CH$_4$ measurements from 0.01 to 1000 ppmv

- Measurements agree with ref values to better than 1% (up to 1000 ppmv)
- High CH$_4$ levels recorded in field (rice, peat, landfills)
- Off-Axis ICOS reports mixing ratios with extremely high optical depth
Fast, Accurate N$_2$O/CO Analyzer for Flux

- Real-time continuous measurements of CO and N$_2$O
- Extremely wide dynamic range
- Fast (20 Hz) allows eddy covariance flux
- Low power (200 watts) facilitates field operation
- No sample prep - direct measurements in air
CO + N₂O Analyzer: No cryogenic requirements

- Simultaneous, rapid, accurate measurements of CO and N₂O
- 0.3-ppbv precision in < 1 second (or better)
CO + N$_2$O Analyzer: real-time measurements in air

- Simultaneous measurements of CO and N$_2$O
- CO precision: < 0.3 ppbv in 1 second
- N$_2$O precision: < 0.3 ppbv in 1 second
CO + N\textsubscript{2}O Analyzer: Long-Term Performance

- Measurement precision vs integration time for dry air measurements
- Precision (1 second): 0.21 ppbv for N\textsubscript{2}O, 0.14 ppbv for CO
- Long term precision: 0.070 ppbv for both gases (without calibration)
Fast CO + N₂O Analyzer: CO Accuracy

- Linear measurements over wide range
- Agree with mixture values (to within tank uncertainty)
Fast CO + N\textsubscript{2}O Analyzer: N\textsubscript{2}O Accuracy

- Linear measurements over wide range
- Agree with mixture values (to within tank uncertainty)
CO + N₂O Analyzer: High Accuracy

Measurements at NOAA ESRL (A. Crotwell, E. Dlugokencky, P. Novelli)

Agreement with NOAA standards: better than 0.5 ppbv over 50-1000 ppbv

- Linearity measured using multiple NOAA air cylinders at NOAA ESRL (Boulder)
CO + N$_2$O Analyzer: High Accuracy

Measurements at NOAA ESRL (A. Crotwell, E. Dlugokencky, P. Novelli)

Agreement with NOAA standards better than 0.2 ppbv over 260-340 ppbv

- Linearity measured using multiple NOAA air cylinders at NOAA ESRL (Boulder)
N₂O/CO Analyzer

- Continuous N₂O and CO with precision better than 0.3 ppbv (1 sec)
- Long term precision better than 0.1 ppbv
- Only 200 watts
- Multiport-Inlet Unit allows spatial multiplexing
- Independent verification of performance by NOAA ESRL
Water Vapor Isotope Flux: $\delta^2H$, $\delta^{18}O$ and $H_2O$

- Fast, continuous measurements in air (non-condensing)
- Fast (2 Hz) allows (relaxed) eddy covariance flux
- Low power (180 watts) facilitates field operation
- No sample prep - direct measurements in air
- Simple to use
Water Vapor Isotopic Standard Source (WVISS)
model 908-0004-9001 (accessory to Water Vapor Isotope Analyzer)

- Quantitative evaporation of (isotopic) liquid water reference yields stable air flow with controllable humidity (H₂O: 500-30000 ppmv)
- Automatically provides reference source to WVIA at user-selectable intervals
- Large reservoir provides liquid reference for months under routine operation
- WVIA with WVISS: *dual-inlet operation* - automatic switch between unknown and reference
WVIA and WVISS provides absolute $\delta^{18}O$ and $\delta^2H$ measurements in Vapor and Liquid

**Water Vapor Isotope Analyzer (WVIA, 2^{nd} Generation)**
- rapidly (>2 Hz) quantifies $\delta^2H$ and $\delta^{18}O$ in air
- insensitive to temperature (5-40 °C)
- 180 watts
- resolves dynamic changes quickly (<0.5 sec) and over long time scales (months)
- unattended continuous measurements in field
- enables studies of ecohydrological processes and atmospheric mixing dynamics

**Water Vapor Isotope Standard Source (WVISS)**
- provides reference source $\delta^2H$, $\delta^{18}O$ for H$_2$O: 500-30000 ppmv (extended range available upon request)
- demonstrated long-term stability, repeatability
- unattended automatic operation and validation of WVIA

**Measurement System (WVIA+WVISS) provides:**
- dual inlet mode of operation provides absolute $\delta^2H$ and $\delta^{18}O$ measurements in air for H$_2$O: 500-30000 ppmv
- unattended long-term automatic operation
- opportunity for continuous $\delta$ measurements of liquid samples
Fast measurement response

- **5-Hz response** demonstrated for $\delta^{18}$O and [H$_2$O] by switching between samples of different $\delta$ and [H$_2$O]
- **4-Hz response** demonstrated for $\delta^2$H
Methane Carbon Isotope Analyzer: CH$_4$ and $\delta^{13}$CH$_4$

- $\delta^{13}$C precision: better than 1‰
- CH$_4$: ambient levels - 100%
- No consumables, no cryogens
- Direct measurements
- Applications: bio-gas, methane sourcing
- Low power: 120 watts

© 2010 Los Gatos Research, Inc. All rights reserved
Methane Carbon Isotope Analyzer: Accuracy

- Comparison with IRMS-characterized methane/air gas mixtures
- $\delta^{13}C$ accurate to better than ± 0.2 ‰
Methane Carbon Isotope Analyzer: ambient air

Raw data absorption spectra: $[\text{CH}_4] < 500 \text{ppm}$
Methane Carbon Isotope Analyzer: precision

- $\delta^{13}C$ precision (2 ppmv): 1 ‰ (100 sec)
- $\delta^{13}C$ precision (10 ppmv): 0.2 ‰ (100 sec)
Measurement precision ($\text{CH}_4 = 2 \text{ ppmv}$)

- $\delta^{13}\text{C}$ precision (2 ppmv): < 1 ‰ (100 sec)
- $\delta^{13}\text{C}$ precision (2 ppmv): < 0.5 ‰ (100 sec)
Carbon Dioxide Isotope Flux: $\delta^{13}\text{C}$ and CO$_2$

- Continuous measurements of $(^{13}\text{CO}_2/^{12}\text{CO}_2)\ \delta^{13}\text{CO}_2$ and CO$_2$
- Fast (2 Hz) allows eddy covariance flux
- Low power (150 watts) facilitates field operation
- No sample prep - direct measurements in air
- Precise: $\delta^{13}\text{CO}_2 < 0.2$ per mil (60 seconds)
Carbon Dioxide Isotope Flux: $\delta^{13}C$ and CO$_2$

- Continuous $\delta^{13}CO_2$ and CO$_2$
- Fast (1 Hz) measurements provide rapid response
- Low power (150 watts) facilitates field operation
- No sample prep - direct measurements in air
- Precise: $\delta^{13}CO_2 < 0.2$ per mil (60 seconds)
Field Deployment: CO₂ Isotope Analyzer at ZERT (Carbon Sequestration Study)

Zero Emissions Research and Technology (ZERT) test site
Bozeman, Montana (July 2009)

Month-long release of CO₂ (buried pipe) for testing various schemes of leak detection in carbon sequestering

- Quantify δ¹³C signature of CO₂ release
- Measure δ¹³C from ambient sources (plant respiration)
- Record spatial profile transverse to pipe
- Record temporal variations at several locations
- Compare co-located measurements with other groups
ZERT: 0.2 tons/day release of CO$_2$

Month-long release of CO$_2$ (buried pipe) for testing various schemes of leak detection in carbon sequestering
Multi-location continuous $\delta^{13}$CO$_2$ and CO$_2$

13 Sample Inlets

1 LPM/line

Diaphragm Pump

Solenoid Valve Array

Reference cylinders (360 ppm, 1000 ppm)

350 ppmv -37 %

1000 ppmv -37 %

Nafion

Off-Axis ICOS CO$_2$ Isotope Analyzer

Pump

second pump provides fast flow through all sampling lines
Carbon Dioxide Isotope Analyzer w/ Multiport Input Unit (16 valve array)
Layout of Sample Inlets: Grid, Tower, Controls

- Inlets A, C, D, E, F, H, I, J spaced by 0.5 m intervals
- Inlets B, G are 30 cm above A, F
- Inlet K is located with tower shared by other teams
- Inlets L, M are controls located 50 m away
Transverse Grid
Inlets A-K before release: observation of plant respiration

- Measurements of ambient CO₂ and δ¹³C for Inlets A–K prior to CO₂ release.
- Overlaid traces show small spatial variation (delocalized C source = vegetation)
- Keeling plot indicates δ¹³CO₂ consistent with site’s latitude and C₃ vegetation
**CO$_2$ and $\delta^{13}$C during release: near leak (inlet H)**

- Measurements near leak demonstrate ability to record real-time Keeling plots in field
- Keeling plot intercept yields $\delta^{13}$C (-58‰ vs PDB) of released CO$_2$ at ZERT
CO₂, δ¹³C during release: far from leak (inlet M)

- Measurements generate real-time Keeling plots due to plant respiration.
- Keeling plot intercept yields δ¹³C (-28‰ vs PDB) of the C3 plants.
CO$_2$ and $\delta^{13}$C during release (inlet J; downwind)

- Measurements of ambient CO$_2$ and $\delta^{13}$C during CO$_2$ release and Keeling plots
- Inlet J located 1.5 m downwind of release
- $\delta^{13}$C indicates that the measured CO$_2$ was due to leak
- Diurnal cycles suggest CO$_2$ might be trapped in soil and released due to fluctuations in temperature or soil moisture
CO₂ and δ¹³C during release (inlet D; upwind)

- Measurements of ambient CO₂ and δ¹³C during CO₂ release upwind of release
- Keeling plot shows mixing between biogenic and released CO₂
- Dashes: linear, 2-member mixing for biogenic (-27 ‰) and released (-58 ‰) CO₂
Deployment of CCIA for Carbon Sequestration

Real-time spatial, temporal measurements of $\delta^{13}C$ and CO$_2$ at ZERT test site

- Ability to record distinct $\delta^{13}C$ signature of CO$_2$ release
- Measures $\delta^{13}C$ from ambient sources (plant respiration)
- Records physical map of release (leak) transverse to pipe
- Records temporal variations ($\delta^{13}C$, CO$_2$) at several locations
- Multi-port unit: spatial & temporal measurements in real time
Field Deployment:
Measurements during journey to Caldecott Tunnel

- CO$_2$, CO, N$_2$O recorded by Mobile Lab from LGR to Caldecott Tunnel
- Reference cylinders in Mobile Lab sampled periodically as validation checks
- Provides sensitive measurements while driving or stationery.
Field Deployment: Measurements at Caldecott Tunnel

- Teflon lines sample air inside tunnel, 10 cm above grate outside tunnel and far from Tunnel along with reference gases.
Field Deployment: Measurements at Caldecott Tunnel

- Teflon lines sample air inside tunnel, 10 cm above grate outside tunnel and far from Tunnel along with reference gases.
Measurements on site (Tunnel) using Mobile Lab

CO₂, CO, N₂O during journey to Caldecott Tunnel, setup, deployment, and return LGR

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas.
- Mobile Lab provides sensitive measurements while driving or stationery
Measurements on site (Tunnel) using Mobile Lab

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas.
- Mobile Lab provides sensitive measurements while driving or stationery.
- Reference Gas cylinders in Mobile Lab sampled periodically as validation checks.
Measurements on site using Mobile Lab

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas.
- Measurements during commute hour of ambient and inside tunnel (“Tunnel”)

© 2010 Los Gatos Research, Inc. All rights reserved
Measurements on site using Mobile Lab

- CO₂ recorded by Carbon Dioxide Isotope Analyzer and Fast Greenhouse Gas Analyzer
- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas.
- Measurements during commute hour of ambient and inside tunnel (“Tunnel”)
Measurements on site using Mobile Lab

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas
- Mobile Lab provides sensitive measurements while driving or stationery
Methane measurements on site using Mobile Lab

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas
- Mobile Lab provides sensitive measurements while driving or stationery
N₂O measurements on site using Mobile Lab

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas
- Mobile Lab provides sensitive measurements while driving or stationery
CO₂ and δ¹³CO₂ measurements on site using Mobile Lab

- “Measuring in Tunnel” includes ambient air near tunnel and of reference gas
- Mobile Lab provides sensitive measurements while driving or stationery
CO₂ and δ¹³CO₂ measurements on site using Mobile Lab

- Keeling plot (δ¹³C vs 1/[CO₂]) 25 meters from tunnel, in air near tunnel inlet and in tunnel air using data shown in previous plot
N₂O and CO measurements on site using Mobile Lab

- Measurements of N₂O and CO in tunnel air recorded by N₂O/CO Analyzer
- Correlations of N₂O and CO in tunnel and 10 cm above tunnel inlet
Field Deployment: Altamont Landfill (Oct 2009; Livermore, CA)

- Deployment (collaboration with CARB) characterized variations of methane fugitive emissions and acetylene tracers due to intentional (plume) release.
Deployment at Altamont Landfill Site

- Deployment (collaboration with CARB) characterized variations of methane fugitive emissions and acetylene tracers due to intentional (plume) release
Deployment at Altamont Landfill Site

- Deployment (collaboration with CARB) characterized variations of methane fugitive emissions and acetylene tracers due to intentional (plume) release
Deployment at Altamont Landfill Site
(using LGR’s Fast Methane and Acetylene Analyzer)

- Measurements of methane and acetylene recorded from locations 100 feet apart
- Autonomous measurements at multiple locations using a single analyzer
• Measurements of methane and acetylene recorded from locations 100 feet apart
• Autonomous measurements at multiple locations using a single analyzer
Deployment at Altamont Landfill Site  
(LGR’s Fast Methane and Acetylene Analyzer)

- **FAMA**: fast, sensitive, linear measurements over extremely wide range
- $\sigma_{\text{CH}_4} = 0.6 \text{ ppbv}$ and $\sigma_{\text{C}_2\text{H}_2} = 0.2 \text{ ppbv}$ in 2 seconds measurement time
- High sensitivity (< 0.1 ppbv in 10-seconds measurement time)
Field Deployment: Twitchell Island with UC Berkeley

measurements in rice paddy fields
using LGR's FGGA (methane, carbon dioxide and water)
Field Deployment: Twitchell Island with UC Berkeley

measurements in rice paddy fields
using LGR's FGGA (methane, carbon dioxide and water)

© 2010 Los Gatos Research, Inc. All rights reserved
measurements in rice paddy fields using LGR's FGGA (methane, carbon dioxide and water vapor)
$\delta^2H$, $\delta^{18}O$ and $H_2O$ measurements at flux tower site

- WVIA and WVISS provide continuous unattended calibrated measurements in the field
- Fast, continuous measurements (2-Hz data rate) of $\delta^2H$, $\delta^{18}O$ and $H_2O$ in air
- Dual flux tower setup in a semi-abandoned field near invasive pepperweed
Rapid $\delta^2H$, $\delta^{18}O$ and $H_2O$ measurements at flux site

- photo from balloon above dual tower flux site
Continuous $\delta^2$H, $\delta^{18}$O, H$_2$O recorded at dual flux tower site

- Continuous unattended calibrated measurements in real time
- Fast, continuous measurements (2-Hz rate) of $\delta^2$H, $\delta^{18}$O and H$_2$O in air
- Dual flux tower in a semi-abandoned field near invasive pepperweed
δ²H, δ¹⁸O and H₂O measurements in the field

- Continuous unattended absolute measurements at Sherman Island, CA
- Fast, continuous measurements (2-Hz rate) of δ²H, δ¹⁸O and H₂O in air
- Local δ¹⁸O, δ²H measurements compared with Global Meteoric Water Line

δD = 8 × δ¹⁸O + 10 (GMWL)
δD = 6.4 × δ¹⁸O - 15.5
2-Hz measurements of $\delta^2H$, $\delta^{18}O$, $H_2O$ at dual flux site

- Continuous unattended absolute measurements at Sherman Island, CA
- Fast, continuous measurements (2-Hz rate) of $\delta^2H$, $\delta^{18}O$ and $H_2O$ in air
- Local $\delta^{18}O$, $\delta^2H$ provides d-excess measurements
Measurements at CalNEX (June 2010) with CARB/NOAA/UCB

- \(\text{N}_2\text{O}, \text{CO}, \text{CO}_2, \text{CH}_4\) recorded by Mobile Lab from LGR
- Reference cylinders in Mobile Lab sampled periodically as validation checks
- Provides sensitive measurements while driving or stationery
Measurements at CalNEX (June 2010) with CARB/NOAA/UCB

- $\text{N}_2\text{O}$ recorded by LGR Mobile Lab
Measurements at CalNEX (June 2010) with CARB/NOAA/UCB

- CO recorded by LGR Mobile Lab
Summary: Novel Instruments Provide New Opportunities

- Fast, accurate, continuous real-time data in the field
- Measurements up to 20 Hz (fluxes)
- Precise, accurate over wide concentration ranges
- Measurements of discrete samples (via syringe)
- Measurements of $\delta^{13}C$, $\delta^{2}H$, $\delta^{18}O$ at 2 Hz
- Low power requirements
Results and Conclusions

LGR’s Mobile Emissions Lab provides:

• continuous measurements of multiple gases -- anywhere.

• measurements while stationary and moving.

• CH₄ (and δ¹³CH₄), CO₂ (and δ¹³CO₂), N₂O, CO, H₂O (and δ²H, δ¹⁸O), C₂H₂, NH₃, H₂S, ... 

• on-board batteries allow operation without external power.

• measurements of many species simultaneously
Results and Conclusions

LGR’s Mobile Emissions Lab provides:

• long-term monitoring of mobile and fixed-location (fugitive) emissions and pollutant sources with high accuracy, precision, sensitivity in real time.

• ability of regulatory agencies, monitoring stations, scientists to report temporally and spatially resolved measurements of GHG and pollutants for compliance monitoring, as well as cap and trade, at any location.
Questions/Comments

Dr. Doug Baer
d.baer@LGRinc.com