Abstract:
We are developing a new open-path laser absorption sensor for measurement of unspeciated hydrocarbons for oil and gas production facility fence-line monitoring. Such measurements are necessary to meet regulations, to quantify greenhouse gas emissions, and to detect volatile organic compounds (VOCs) that may have adverse health effects or act as precursors to ozone formation. Our initial design employs a single path measurement system though future implementations may use multiple paths for large scale facility monitoring. The sensor uses a compact mid-infrared laser source in the spectral region of ~3.3 μm to measure absorption of several hydrocarbon species over open-paths of ~1 km. Spectral simulations show that for typical conditions the hydrocarbons cause a transmission reduction of greater than 10% allowing a robust measurement.

The initial prototype system uses a helium-neon (He:Ne) laser at 3.391 μm for which signal contributions from methane and non-methane hydrocarbons are comparable. Closed-cell tests were performed with diluted methane (~150-250 ppm) to validate the transmission signals and showed good agreement with expected (calculated) values to within ~10 %. The system employs a reference leg, with a 2nd detector (near the source) to normalize for laser power fluctuations. For improved signal-to-noise, particularly for small concentrations and transmission changes, we employ phase-sensitive detection with a mechanical chopper and software based lock-in amplifier. This detection scheme allows measurement of transmission signals with stability <0.5% (based on coefficient of variation over 60 s).

The portable, field sensor system uses two refractive (Keplerian) telescopes (2” diameter optics), a transmitter and receiver co-located on a mobile optical breadboard, and a reflector dictating the path length. We have performed initial tests with path lengths up to ~25 m (one way) though the design should allow paths in excess of 100 m (one way). For initial field tests, methane was released at known flow rates near the center of the beam path. Transmission signals in rough agreement with expectation (given uncertainties in the wind and plume dispersion) were observed. The system should allow detection of leaks (emissions) for mass flows as low as ~1 g/s of methane (or equivalent optical signal from other species) for the case where the source is ~150 m from the beam path, for typical atmospheric conditions. The sensitivity to small leaks will be experimentally verified in upcoming field work.

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Open-Path Hydrocarbon Laser Sensor for Oil and Gas Facility Monitoring

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EPA United States Environmental Protection Agency

ENERGY INSTITUTE Colorado State University

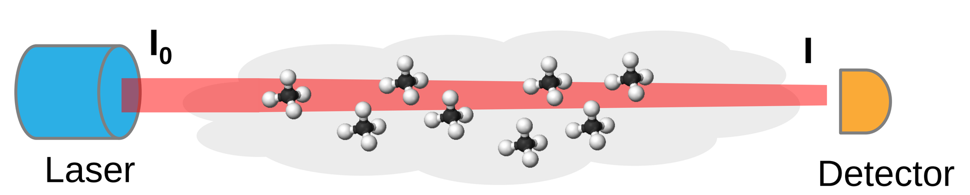
CENTER FOR LASER SENSING AND DIAGNOSTICS

Goals & Impacts

We are making an open-path laser sensor for detecting unspeciated hydrocarbons at oil and gas facilities. The work presented details the design, lab validation, and fielded proof-of-concept version of this sensor.

- Increased oil and gas production in the United States can lead to increased emissions of air pollutants and greenhouse gases.
- If unintended emissions of methane and other hydrocarbons from leaks and malfunctions can be detected and mitigated efficiently, emission impacts from oil and gas production can be minimized.
- There is a growing need for cost-effective and continuous facility fugitive leak and malfunction detection approaches to support environmentally responsible energy development.
- Low-cost design and customizable configurations will allow for this open-path technique to be employed where and when it is needed most.

Open-Path Direct Absorption Spectroscopy

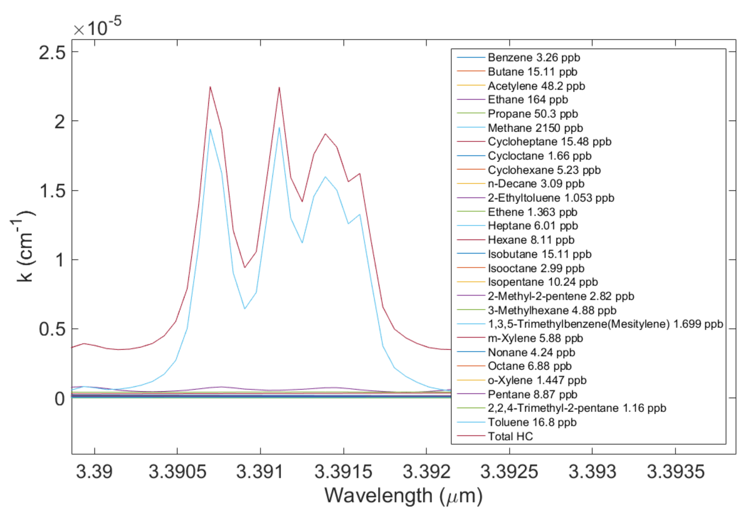


Light absorption is defined by

$$\frac{I}{I_0} = exp(-k(\lambda, c) * L)$$

Where I is light intensity, k [cm^{-1}] is the absorption coefficient dependent on wavelength λ [μm] and c [$ppbv$] the concentration of a given species, and L [cm] is a given path length.

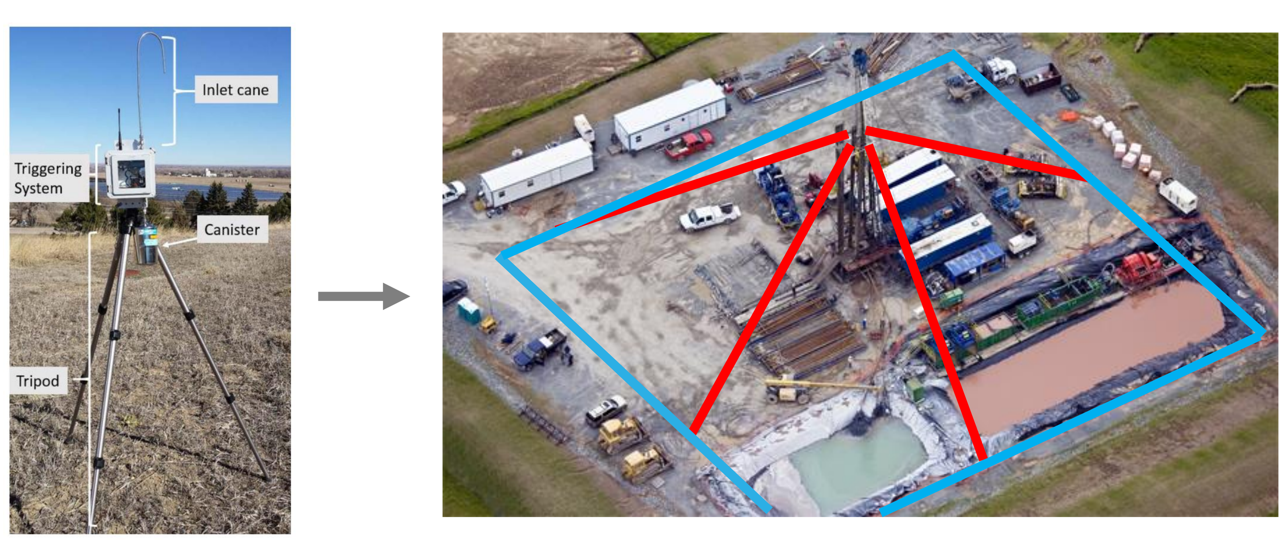
Absorption due to the hydrocarbons of interest is extremely broad and similar in the mid-infrared. Therefore, scanning the laser over a feature would not discern individual species. Measuring intensity allows for a total concentration measurement without speciation. This is possible due to the strength of the absorption in the region.



1. Absorption Coefficient at Average Concentrations from Garfield County Study [2]

Sensor Features

- Can be used for continuous fence-line monitoring
- Configurable for tower monitoring stations or for custom, specific measurement locations with multiple retro-reflectors
- Serves as a replacement for canister measurements with unspeciated, real-time measurements expediting the remediation of leaks or emitters
- Can be used as a continuous “alarm system” as opposed to periodic deployment



Single Canister Sampling System [2]

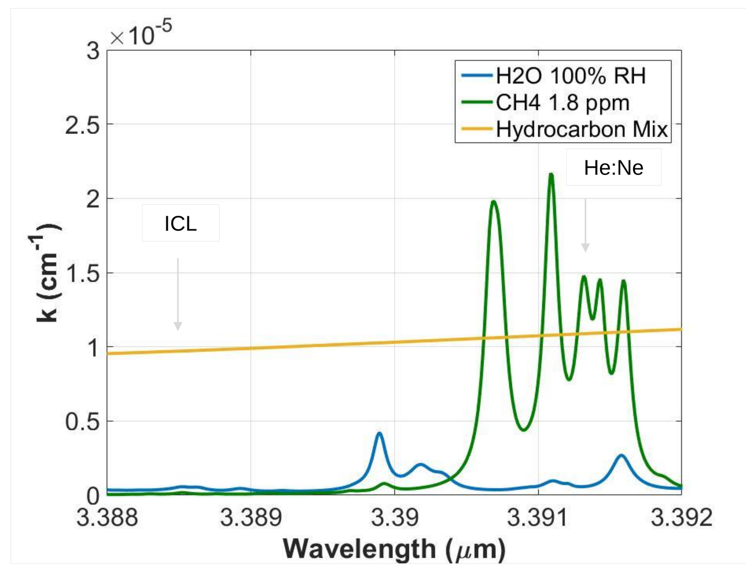
Fence line or perimeter monitoring

Targeted tower-based measurements

2. Potential End Use of System

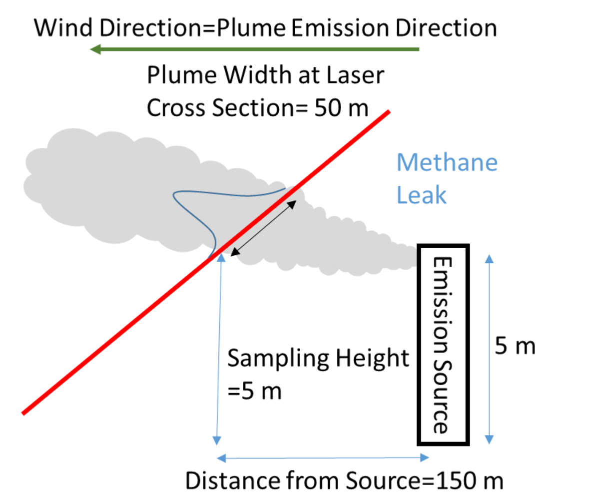
Sensor Design

Absorption Spectra Modeling

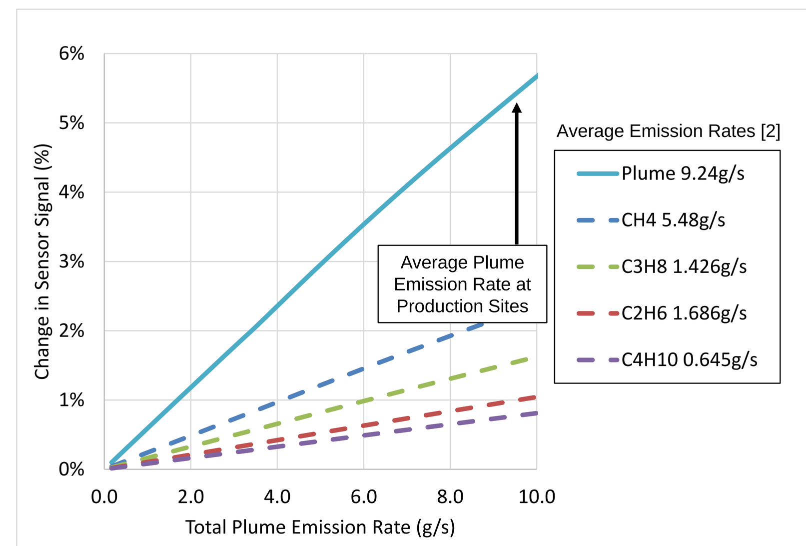


- An interband cascade laser (ICL - Nanoplus) would be capable of measuring the absorption due to the unspeciated hydrocarbons.
- The mid-infrared Helium Neon laser (He:Ne), i.e. 3.39 µm would include methane in its absorption.
- Interference from ambient species was modeled.
- Hydrocarbon absorption data from Pacific Northwest National Laboratory Vapor Phase Infrared Spectral Library was combined with HITRAN data to model absorption at ambient temperature and pressure.

3. Absorption for Selected ICL and He:Ne Lasers and Interfering Species at Ambient Conditions



4. Example Plume Model Conditions

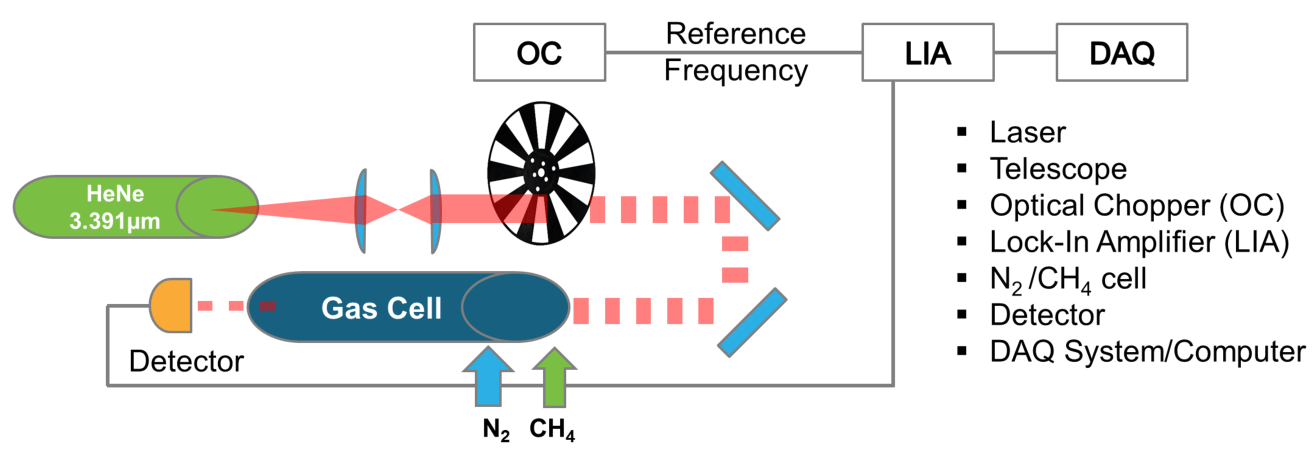


5. Change in Signal from Modeled Plume and Potential Species Contribution to Plume Emission

- In typical direct absorption applications, the reduction in light transmission due to absorption must be greater than 1% (0.01) for detection of a given species.
- The reduction from total unspeciated hydrocarbons spans 6-15% in this region assuming 100 m path length.
- A basic plume model was developed to compare potential detection limits for varies sensor configurations.

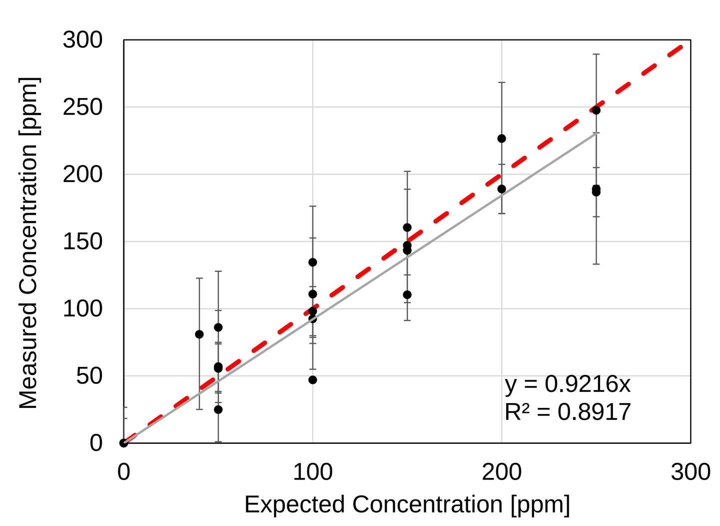
Laboratory Validation

Closed-path Cell for Methane Sensing

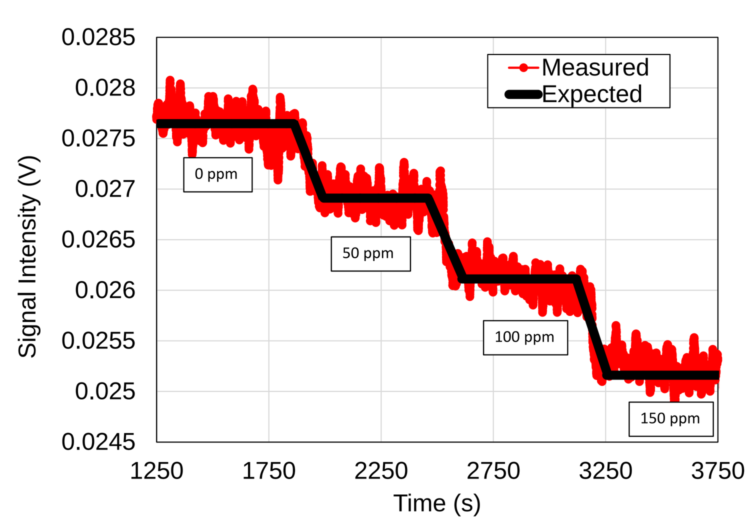


- Laser
- Telescope
- Optical Chopper (OC)
- Lock-In Amplifier (LIA)
- N_2/CH_4 cell
- Detector
- DAQ System/Computer

6. Lab Sensor Schematic for Initial Validation



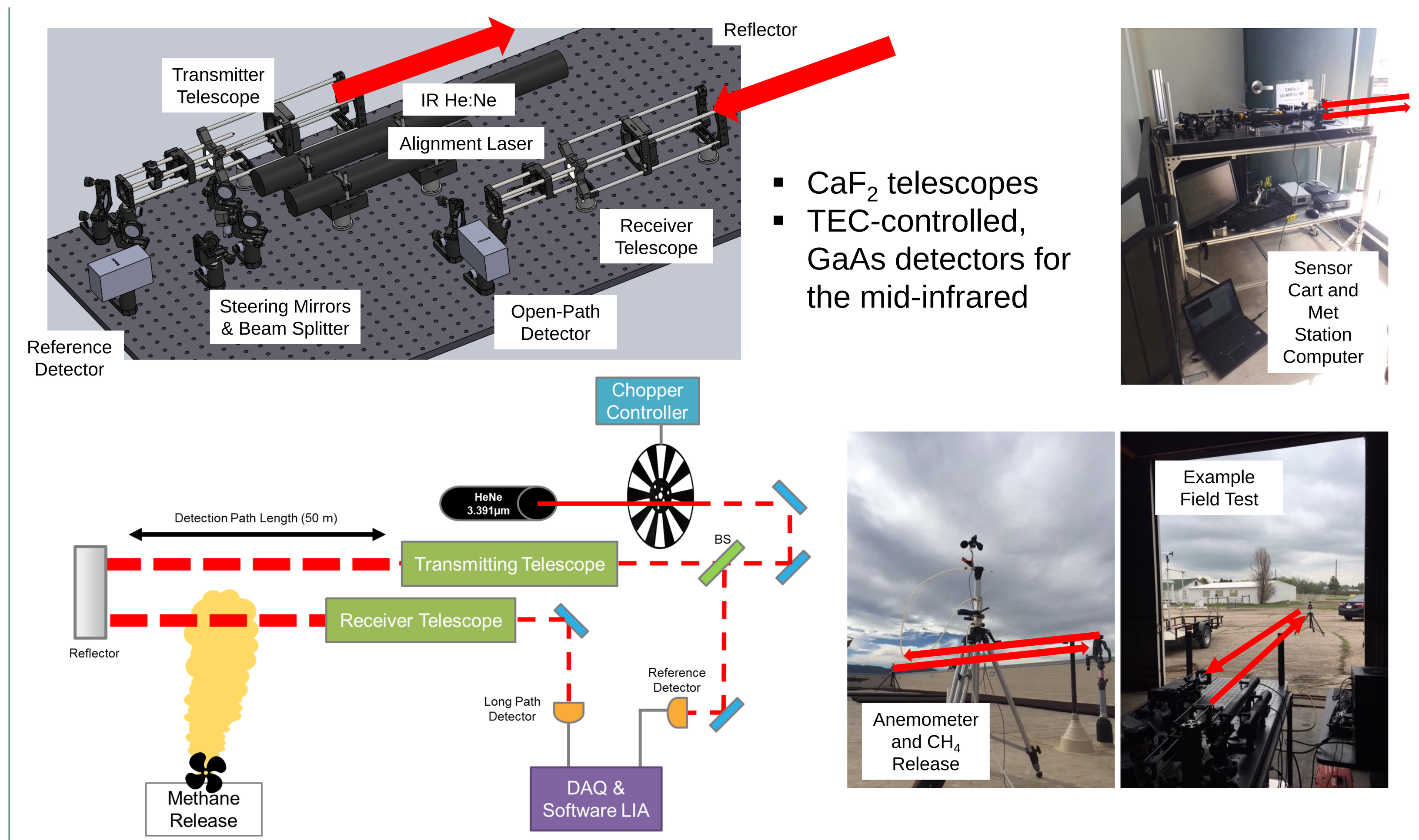
7. Methane Cell Concentration Tests



8. Example Methane Cell Test

Concentration measurements were made with a closed-path, methane gas cell. A range of concentration values were created by controlling the flow rates CH_4 and N_2 through the cell proportional to the mixing ratio CH_4. The variation for each test, represented with vertical error bars, is due to a discrepancy in baseline values.

Field Demonstration



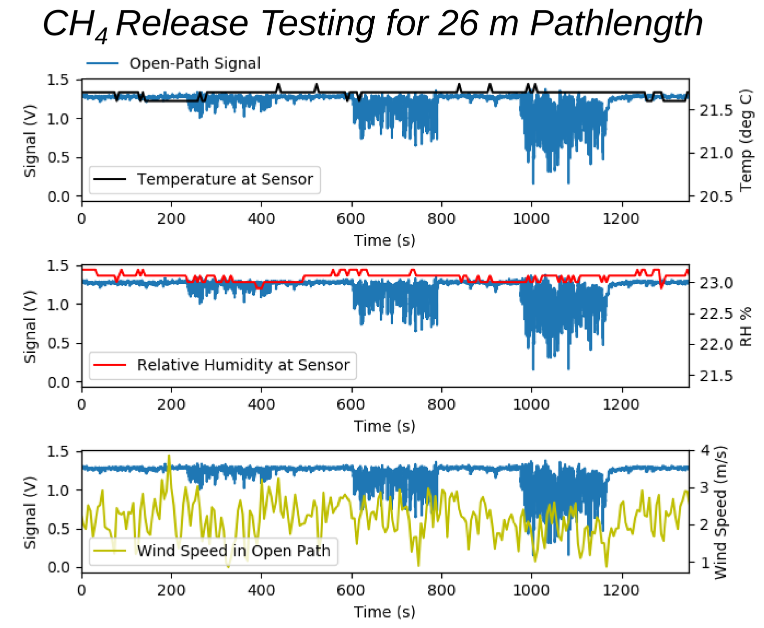
- CaF_2 telescopes
- TEC-controlled, GaAs detectors for the mid-infrared

9. Current Field System

Proof-of-Concept Testing

The proof-of-concept sensor was fitted on a cart for outdoor validation. Tests were performed with 10, 25, and 50 m. For preliminary evaluation of the sensor, a controlled release of methane was done perpendicular to the pathlength. Release flow rates (2, 6, 10 Lpm, see right) were proportional to the sensor response. An insulated enclosure was added to the cart to maintain isothermal conditions for the sensor as well as a basic meteorology system (temperature, humidity and wind speed).

10. Example Meteorology Data with Preliminary CH_4 Release Testing for 26 m Pathlength



Future Work

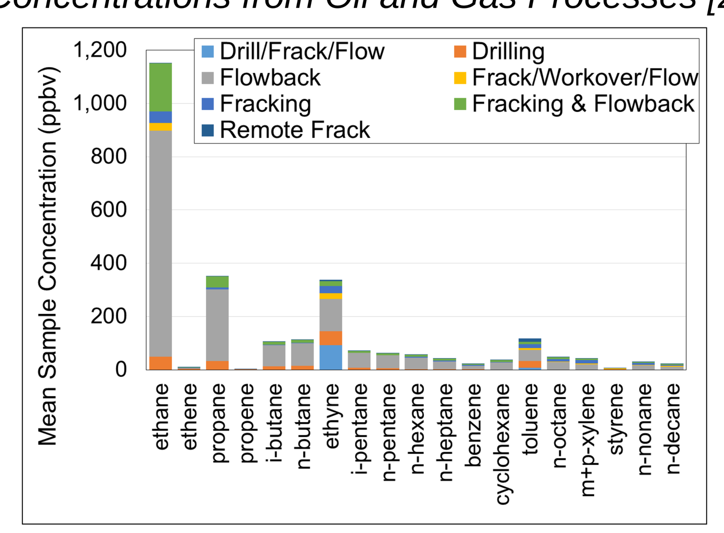
Real-Time Analysis & Signal Processing

- Investigate lock-in amplifier alternatives such as averaging and filtering schemes
- Examine possibility of using time-dependent information (from Fourier transform) to counter slow instrument drift and better identify and quantify leaks
- Test for detection limit for various pathlengths, validate with model
- Compare sensor with other mobile, point measurement systems (CRDS)

Test & Model Refinement

The initial sensor design was based on canister measurements from produced water ponds [1]. More recent studies from oil and gas operations, e.g. by Professors Collet and Ham from Colorado State University [2], can be used to update speciation fractions and concentrations for spectral models. Future field validations will be done with other hydrocarbon mixtures and more advance release methods.

11. Example Average Non-methane VOC Concentrations from Oil and Gas Processes [2]



Challenges

- Correcting for aerosol extinction
- Including a reference cell for a monitored baseline
- Implementing a temperature and humidity controlled enclosure
- Incorporating a self-aligning system to decrease setup time
- Altering telescope design to use larger reflective optics allowing for longer pathlengths

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1. Thoma, “Measurement of Emissions from Produced Water Ponds: Upstream Oil and Gas Study #1”, Pg. A-9, 2009.
2. Collett and Ham, “Characterizing Emissions from Natural Gas Drilling and Well Completion Operations in Garfield County, CO”, 2016.