Quantifying the relative contribution of natural gas fugitive emissions to total methane emissions in Colorado and Utah using mobile $\delta^{13}$CH$_4$ analysis

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Oil & Gas Activities in the Denver – Julesburg Basin

- **> 20,000** active oil and gas wells
- Yearly natural gas production (2008):
  - **~3,625** Gg / yr
  - (~1% of US production)
  - CH$_4$ emissions
- Bottom-up estimate:
  - **46 – 86** Gg / yr
- Top-down estimates:
  - derived from non-methane hydrocarbon measurements and inventories; $\Delta^{14}$CO$_2$
  - **40 – 272** Gg / yr

Sources: Pétron et al. (2012) “Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study” JGR v117, D04304
La Franchi et al. (2013) “Constraints on emissions of carbon monoxide, methane, and a suite of hydrocarbons in the Colorado Front Range using observations of 14CO2, ACP discussions.”
Other Sources of Methane

- **O & G**$^{[1]}$:
  - **46 – 252** Gg / yr

- **Landfills**$^{[2]}$:
  - **16 – 22** Gg / yr
  - based on EPA mandatory GHG reporting

- **Cattle Feedlots & Manure Mgmt.$$^{[3]}$$**:
  - **41 – 58** Gg / yr
  - 565,000 head of cattle in Weld Co.

- **Total**:
  - **103 – 332** Gg / yr
  - O&G fraction 37-82%

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Using Stable Isotopes to Identify Sources

\[ \delta^{13}CH_4(\text{‰}) = 1000 \left( \frac{^{13}CH_4 / ^{12}CH_4}{r_{PDB}} - 1 \right) \]

\[ \delta_{tot} \approx \frac{E_{O&G}\delta_{O&G} + E_{cow}\delta_{cow} + E_{land}\delta_{land}}{E_{O&G} + E_{cow} + E_{land}} \]

Mobile Laboratory – the Picarro G2132-i isotopic CH₄ analyzer

Precision, δ¹³C in CH₄ (1-σ, 1 hr window)

| < 0.8 ‰ guaranteed precision at > 1.8 ppm 5 min. average |
| < 0.5 ‰ guaranteed precision at > 1.8 ppm, 15 minute average |

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G2132-i

inverter

tubing inside

Ref. tank

gps & roof inlet

pump
Step #1: Individual Source Characterization

Drive-by isotope analysis with Air Core (thanks P. Tans & NOAA team)!

source = -37.9 +/- 0.47 permil
Individual Sources (33 sources total)

- Feedlots (N = 14 of M = 9 sources)
- Oil & Gas (N = 30 of M = 22 sources)
- Landfills (N = 5 of M = 2 sources)

**δ_{cow}**
- -45 to -55
  (C4 diet)

**δ_{O&G}**
- -30 to -60

**δ_{land}**
- -48 to -56

Quay et al. (1988)

(10-15 minutes of analysis / sample)
Step #2: Characterize the Overall iCH$_4$ Signature

Early morning drive (light wind / low boundary layer)
MegaCore: A Really Big Air Core

- 1500’ ft of ½ O.D. synflex tubing
- Sample ambient air during ~2 hour drive
- Playback sample into iCH4 analyzer for 15 hours in the laboratory
  - Reference gas used during recording AND replay

![Graph showing methane levels over time](image)

- Bottle = -45.1 ± 0.53 permil
Two MegaCore Campaigns: May 14th and 18th 2012

Size = magnitude of CH₄ signal | color = delta

Single Keeling plot
05/14 $\rightarrow -42.3 \pm 0.2\%$
05/18 $\rightarrow -40.4 \pm 0.2\%$

Greeley and Johnstown
Emissions & Isotopes Model

Monte Carlo simulation of feedlot and landfill emissions and isotope signatures to generate combined feedlot & landfill source profile

\[ \delta_{C&L} = \frac{E_{cow}\delta_{cow} + E_{land}\delta_{land}}{E_{cow} + E_{land}} \]

Bayesian analysis of O&G Emissions Fraction (hypothesis) given the MegaCore data (evidence)

\[ \delta_{tot} = R_{O&G}\delta_{O&G} + (1 - R_{O&G})\delta_{C&L} \]

- O&G is \(78 \pm 13\)% of total emissions
- With \(E_{land} = 19\) and \(E_{cow} = 47\) Gg / yr

\[ E_{O&G} = 239\ \text{Gg / yr} \]

Cf.: inventory : 46 - 86
    top-down : 72 - 252
Concentrations 3-5X above background levels over 100’s of square miles

Oil wells and gas wells

Uintah Basin, Utah

Winter 2013 – 4 daytime drives

8 – 25 ppm range
Uintah Individual Source Isotopes

45 measurements of 30 individual sources

- Gas: $-39.4 \pm 3.6$
- Oil: $-50.9 \pm 5.1$
Gas wells are 96 ± 15% of total emissions
Barnett Shale – Individual Source Signatures

Map showing distribution of Barnett Shale sources in Texas and adjacent states. The map includes various geological features and regions such as Oklahoma, New Mexico, and the Permian Basin. A bar chart on the right side shows δ¹³C₄ (uncalibrated) values for landfills (N = 6) and O&G (N = 23).
Barnett Shale – 4.5 hour drive (1 APR 2013)

- Primary sources are Landfills (Trucks) and O&G (yellow points)
- Very few feedlots (F)
Barnett Shale – Geospatial Heterogeneity of Isotope Signatures

[Graph showing isotope signature data with O&G signature and landfill signature marked.]
Emissions Estimate - Barnett

• Emissions Estimate = 74 +/- 3.5 % from Oil and Gas

• Working on alternative analysis methods to handle spatial inhomogeneity
Thank You!!