Methane Leaks from the U.S. Natural Gas Value Chain

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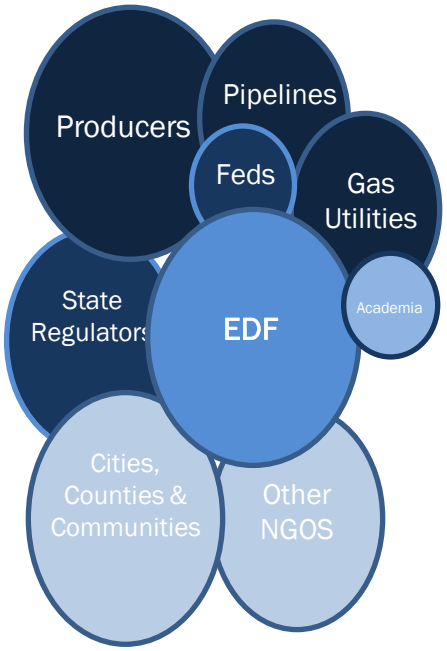
Finding the ways that work

EDF natural gas projects & goals



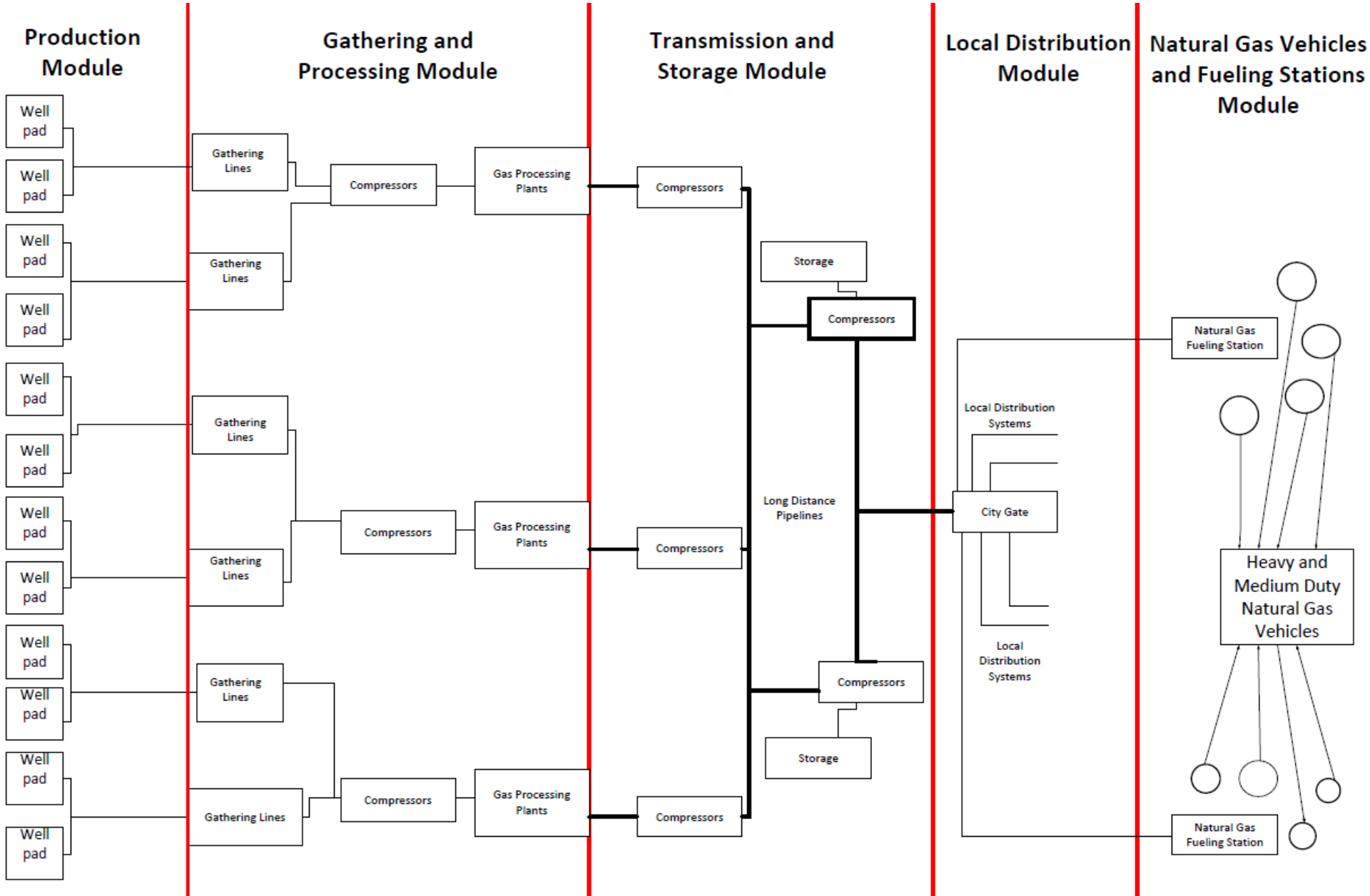
- Public Disclosure of Chemicals & Emissions
- Well Construction & Completion
- Water & Waste Management
- Air Standards
- Cumulative Impacts
- Strengthen /Leverage State Regulatory Associations
- Advise Industry Leaders
- Supply Chain Methane Study

→ Reduce Risk to Public Health & The Environment

→ Maximize GHG Value by Reducing Methane Emissions Below 1%

→ **Safer, Environmentally Sound Natural Gas Supply**

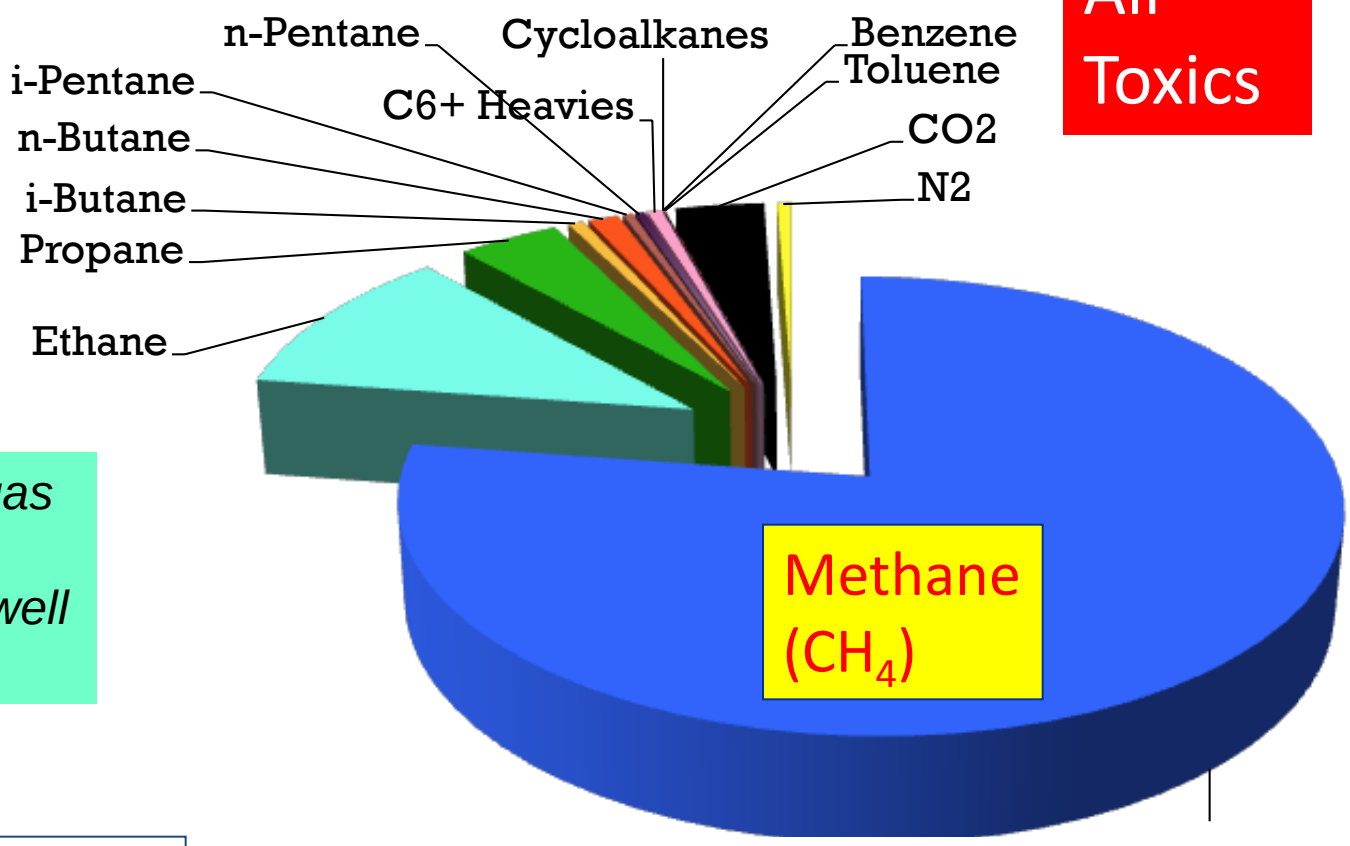
EDF's CH_4 Emissions Field Studies



What's in natural gas?

Surface ozone precursors

Air Toxics



NGLs

Composition of gas varies from one basin/formation/well to another.

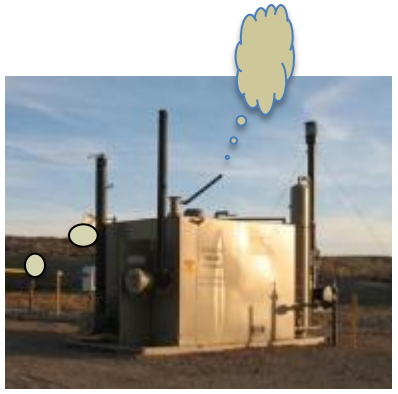
Produced "raw gas" is composed of 70-90% methane

Distribution gas is >90% methane

U.S. natural gas system infrastructures

How much gas is leaking from US natural gas infrastructures?

- 500,000 oil and gas wells,
- 493 processing plants
- over 20,000 miles of gathering pipelines,
- ~ 300,000 miles transmissions pipelines,
- > 1,400 compressor stations
- ~ 400 underground storage facilities
- ~ 2,000,000 miles of local distribution pipelines



US Statistics: EIA, DOT, OGJ

Bottom-Up Production Study

Academic lead

THE UNIVERSITY OF TEXAS AT AUSTIN

Steering Committee

Technical working group co-chairs

Ramon Alvarez
EDF
Emily Rodgers
Anadarko

Science Advisory Panel

Professor Matthew Fraser
Arizona State University

Professor A. Daniel Hill
Texas A&M University

Professor Brian Lamb
Washington State University

Professor Jennifer Miskimins
Colorado School of Mines

Professor Robert Sawyer
University of California, Berkeley

Professor John Seinfeld
California Institute of Technology

Partner companies

Anadarko Petroleum Corporation
BG GROUP
Chevron
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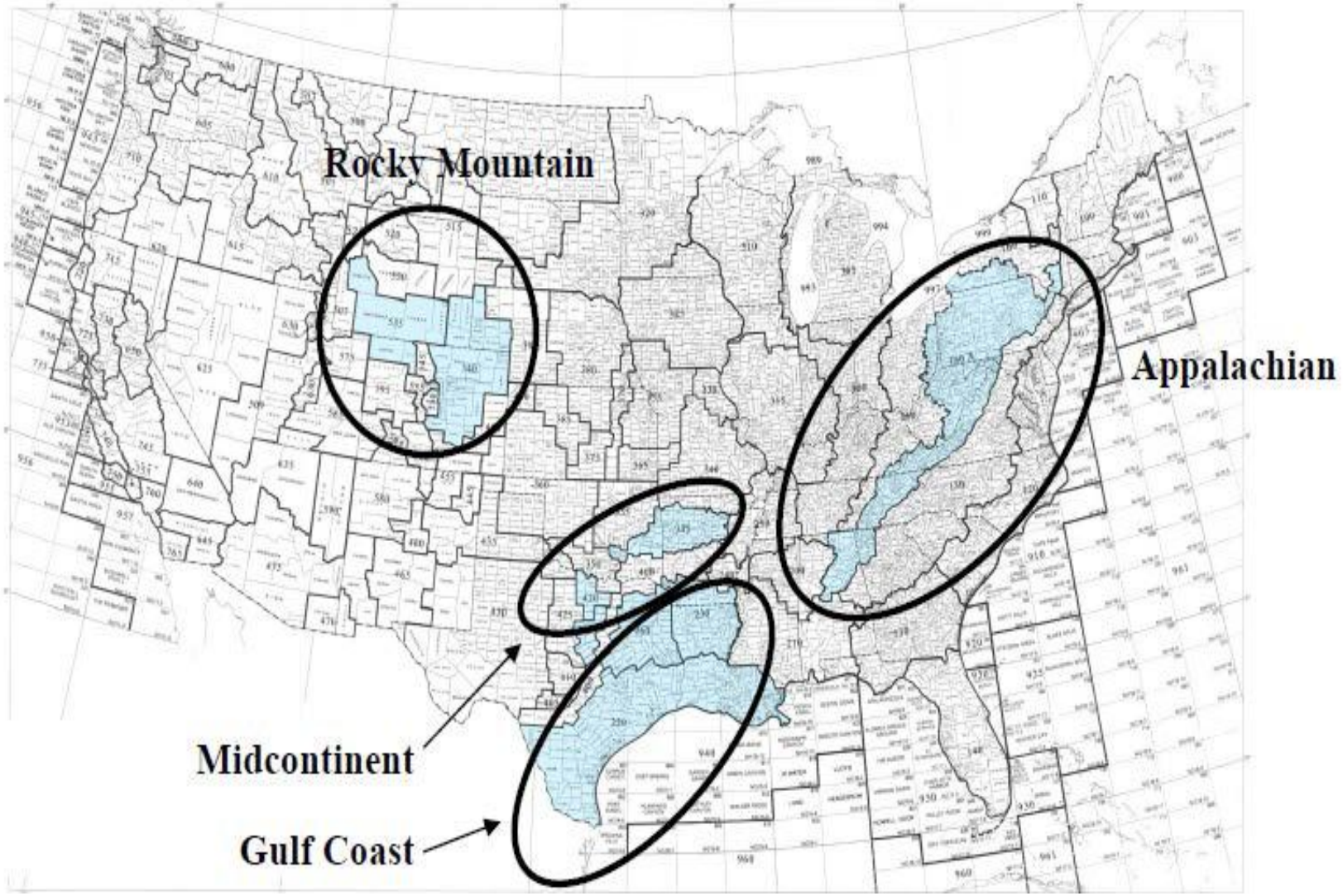
encana natural gas
PIONEER NATURAL RESOURCES
swn Southwestern Energy
TALISMAN ENERGY
ExxonMobil


Rocky Mountain
Appalachian
Midcontinent
Gulf Coast

Summary of Results

Direct, on-site measurements of CH4 emissions from gas production operations were made; for some sources (well completions and unloadings) these are the first measurements reported.

67% of well completions sampled during the study had equipment in place that reduces CH4 emissions by 99%. The well completions were 97% lower than calendar year 2011 EPA national emission estimates, released in April 2013.

Emissions from pneumatic devices were 70% higher than current EPA net emissions estimates, and equipment leaks are 50% higher than current EPA net emission estimates; collectively these emissions accounted for more than 40% of methane net emissions from natural gas production.

Summary (cont.)

Total methane emissions from gas production measured in this study were comparable (957 Gg ± 200 Gg)to the most recent EPA estimates (~1200 Gg).

The 957 Gg in emissions for completion flowbacks, pneumatics and equipment leaks, coupled with EPA national inventory estimates for other categories, leads to an estimated 2300 Gg of methane emissions from natural gas production (0.42% of gross gas production).

Comprehensive results at:
http://dept.ceer.utexas.edu/methane/study/index.cfm
http://www.engr.utexas.edu/news/releases/methanestudy

EDF Bottom-Up/Top-Down Field Campaigns in Colorado & Texas

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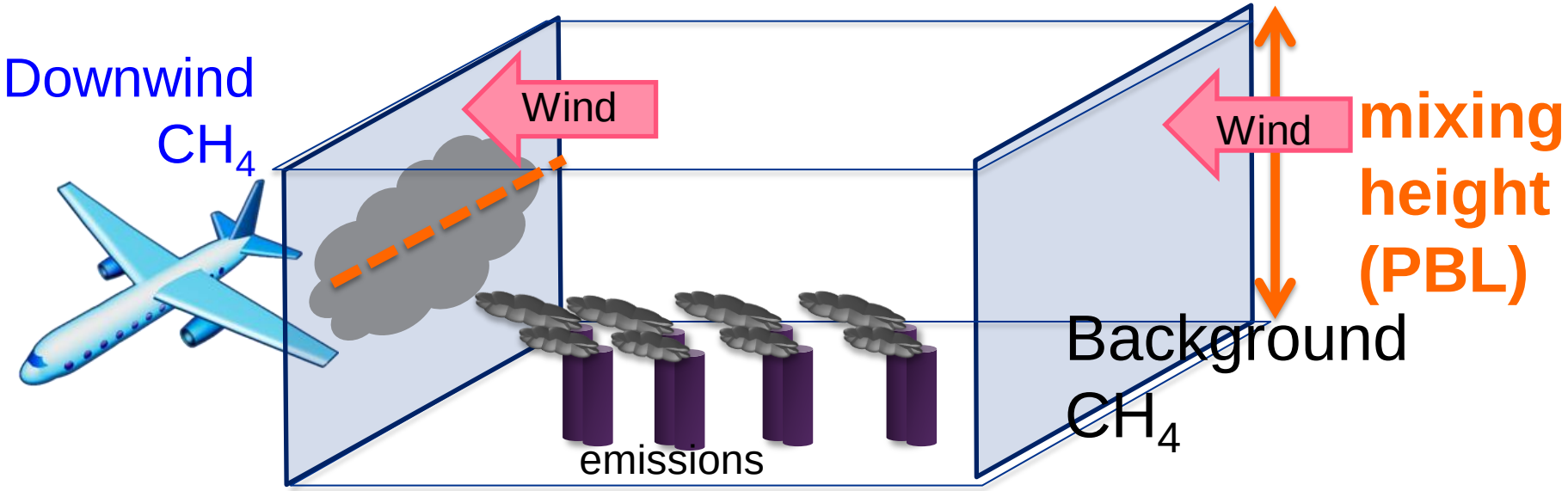
Top-Down Aircraft Mass Balance Method



CH_4 flux

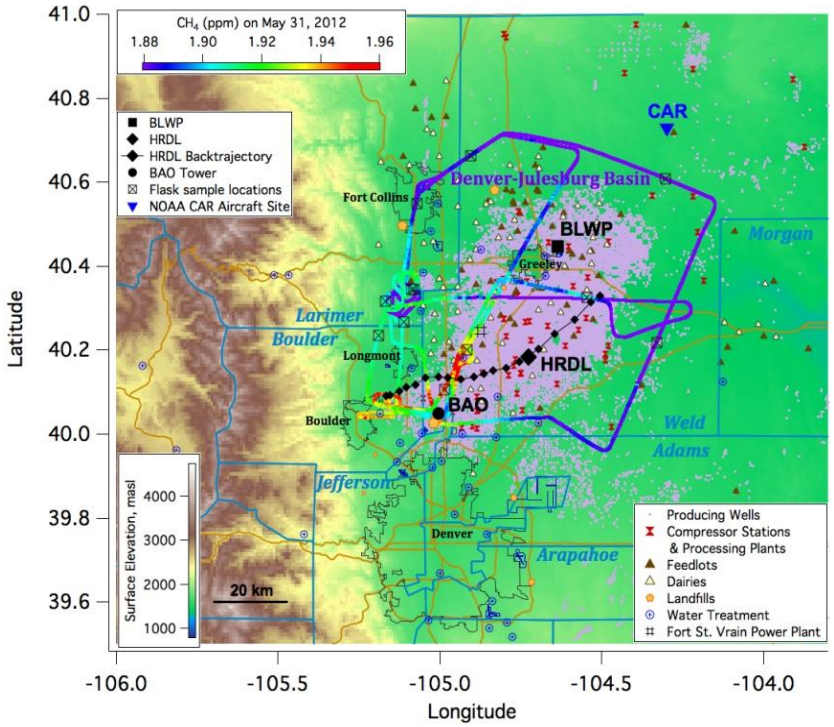
Molar CH_4 enhancement in PBL

$$\dot{n}_{CH_4} = V \cos\theta \int_{-b}^{+b} \Delta X_{CH_4} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air} dz \right) dx$$

Perpendicular wind speed in PBL

References: White et al., 1976; Ryerson et al., 2001; Mays et al., 2009

Denver-Julesburg Basin



Flux estimate	Total CH_4 source (tonnes/hr)	Relative 1-s Uncertainty in CH_4 source
May 29[a]	25.8±8.4	33%
May 31	26.2±10.7	41%
Average	26.0±6.8	26%

Petron et al., submitted

Denver-Julesburg Basin CH4 Emissions Budget

Source	May 29 (tonnes/hr)	May 31 (tonnes/hr)	Uncertainty (1-σ)
Total Emissions	**25.8**	**26.2**	**26%**
Enteric	5.15	5.15	18%
Livestock	0.97	0.97	100%
Landfill	1.44	0.66	100%
Waste treatment	0.47+0.47	0.47+0.47	15%+25%
Natural Seepage	0.1	0.1	100%
Remaining Emission	**17.3±8.6**	**18.5±10.8**	**54%**

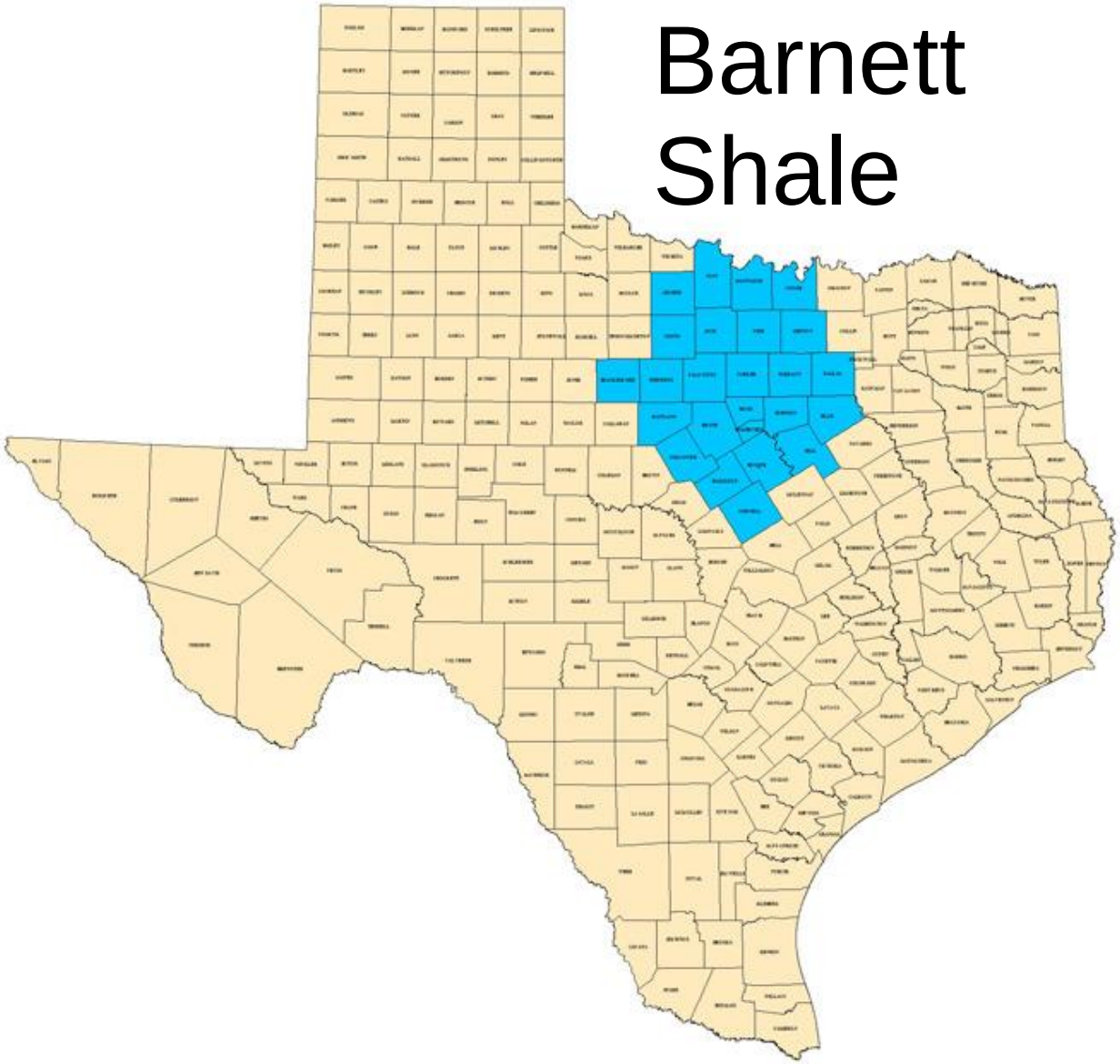
Average O&G production = 17.9±9.7 tonnes/hr

67% of total emissions

(assuming highest possible non O&G emissions)

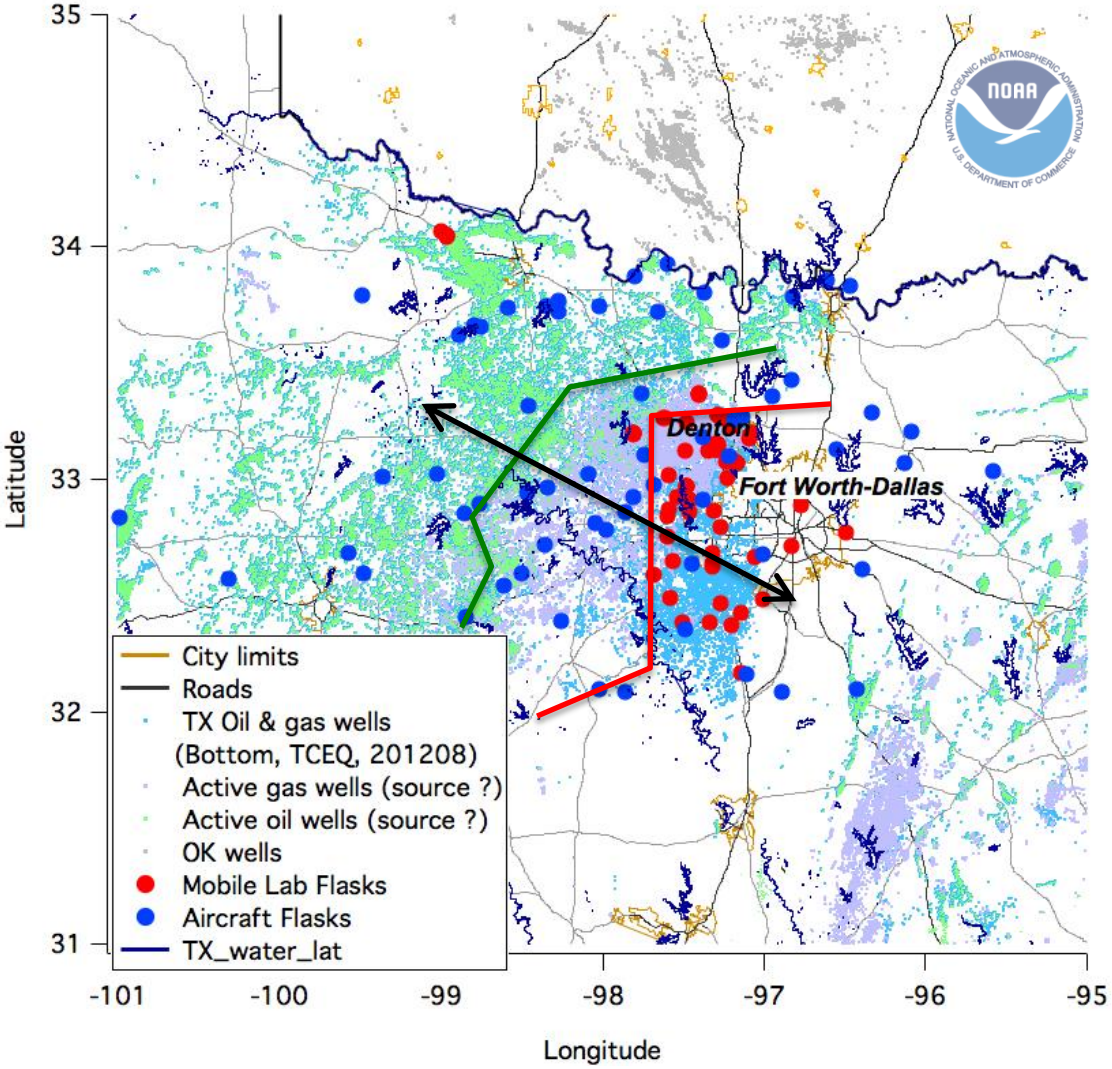
Petron et al., submitted

Barnett Shale

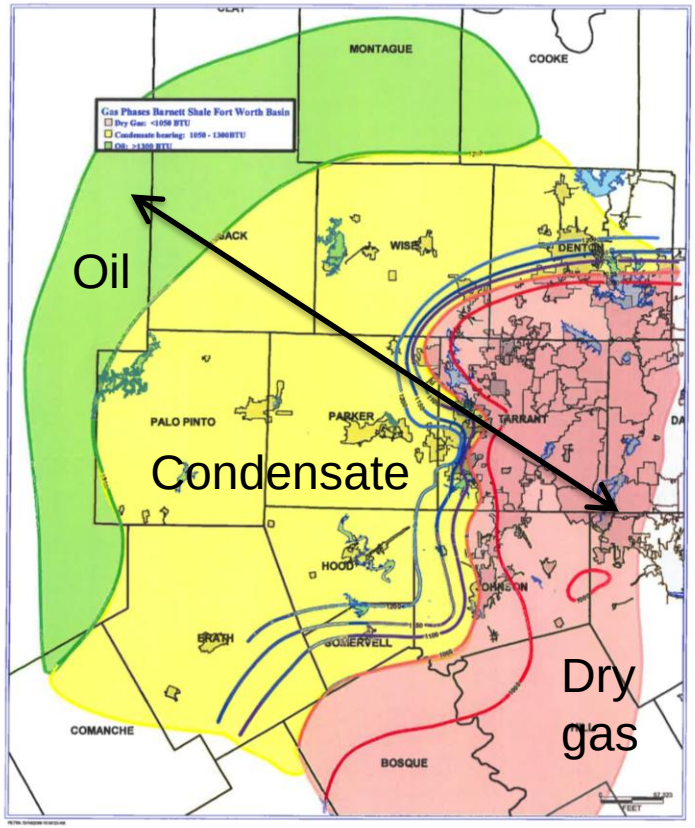


Texas Railroad Commission

Barnett Natural Gas, NGL's, & Oil

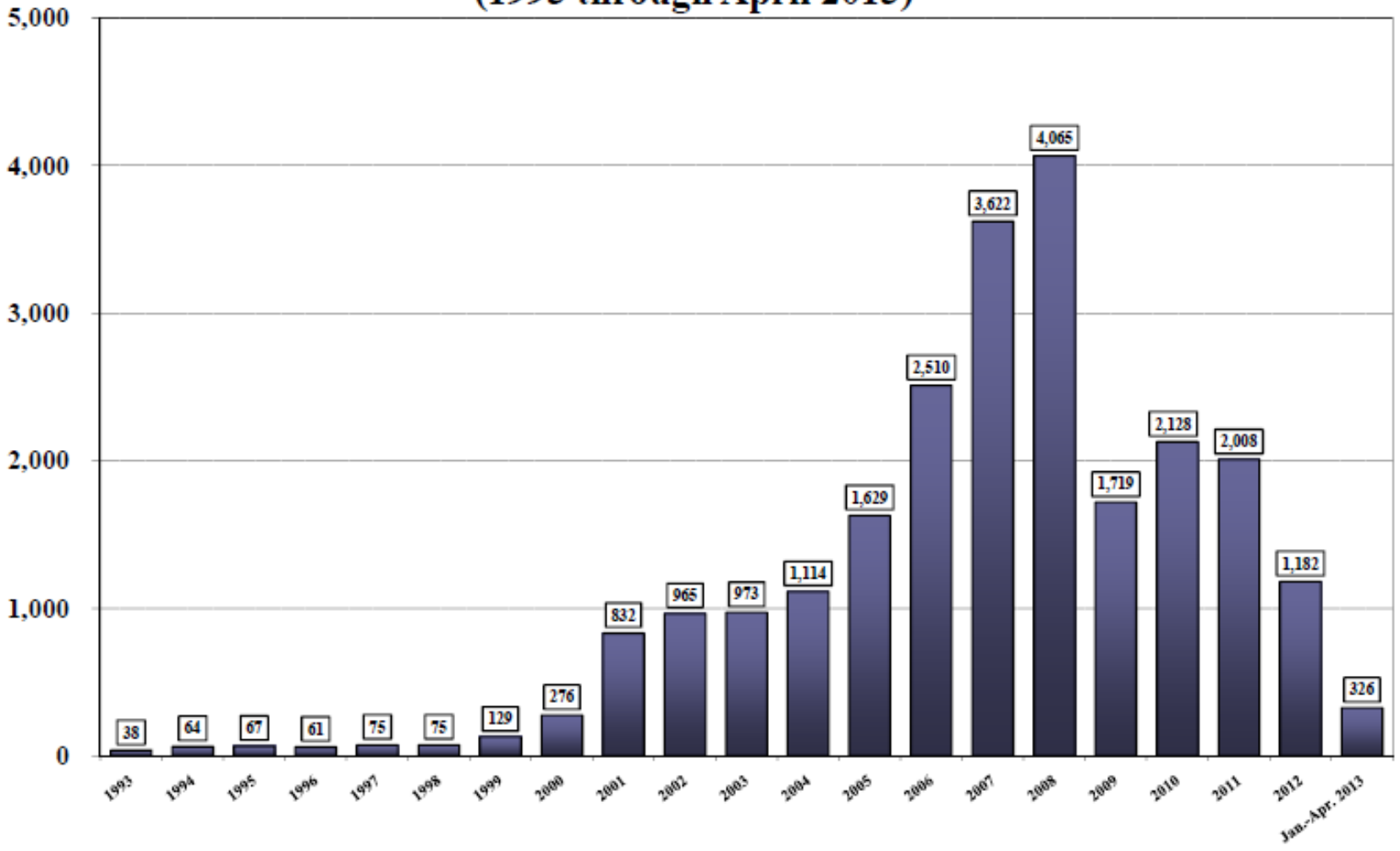


Production zones



The ratio of VOC to CH_4 will vary along the oil <--> dry gas gradient.

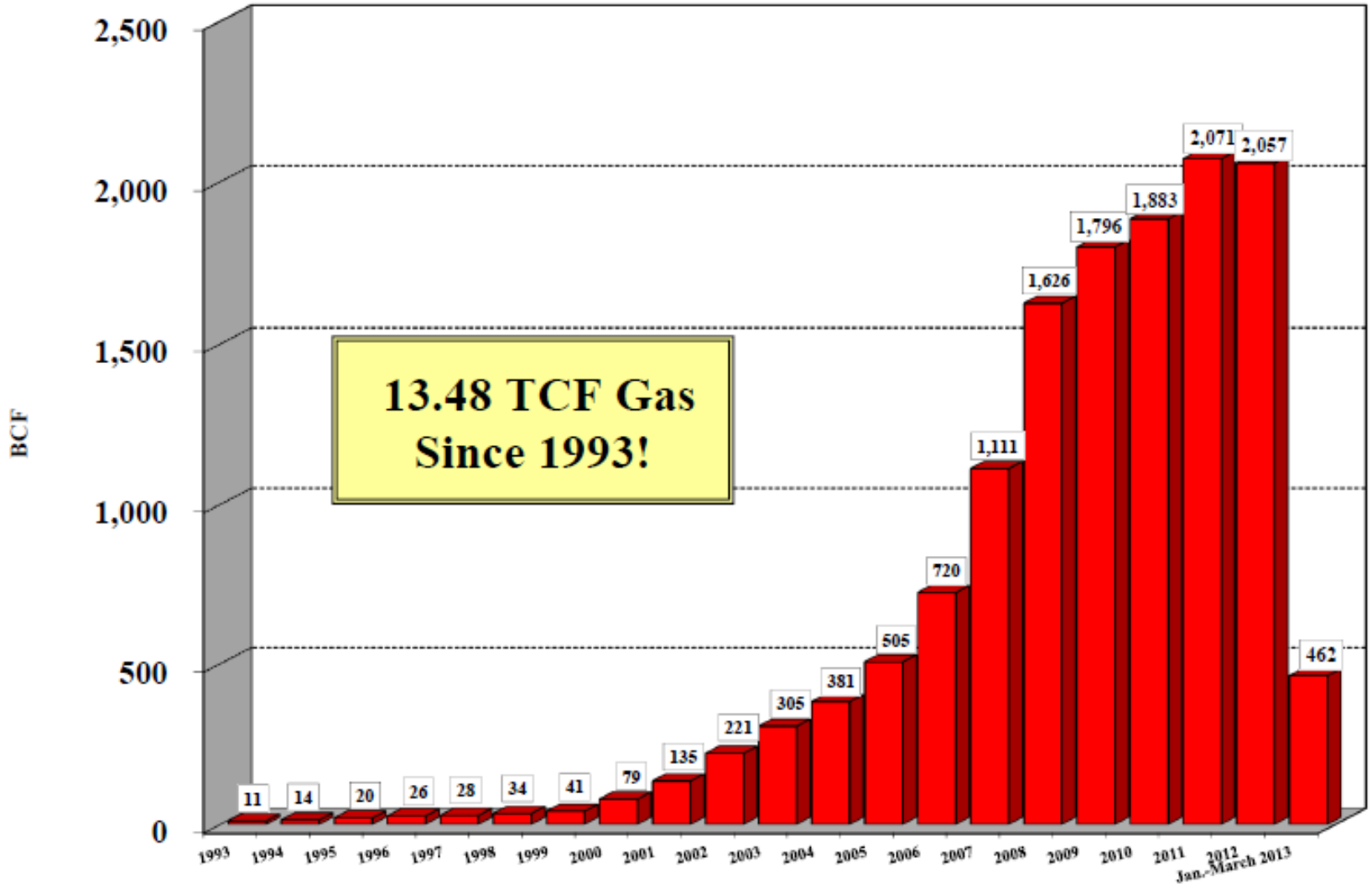
Newark, East (Barnett Shale)
Drilling Permits Issued
(1993 through April 2013)



Source: Texas Railroad Commission DrillingPermitQuery(Includes New Drill & ReEnter Permits)

05/02/2013

Newark, East (Barnett Shale)
Total Natural Gas Production
1993 through March 2013

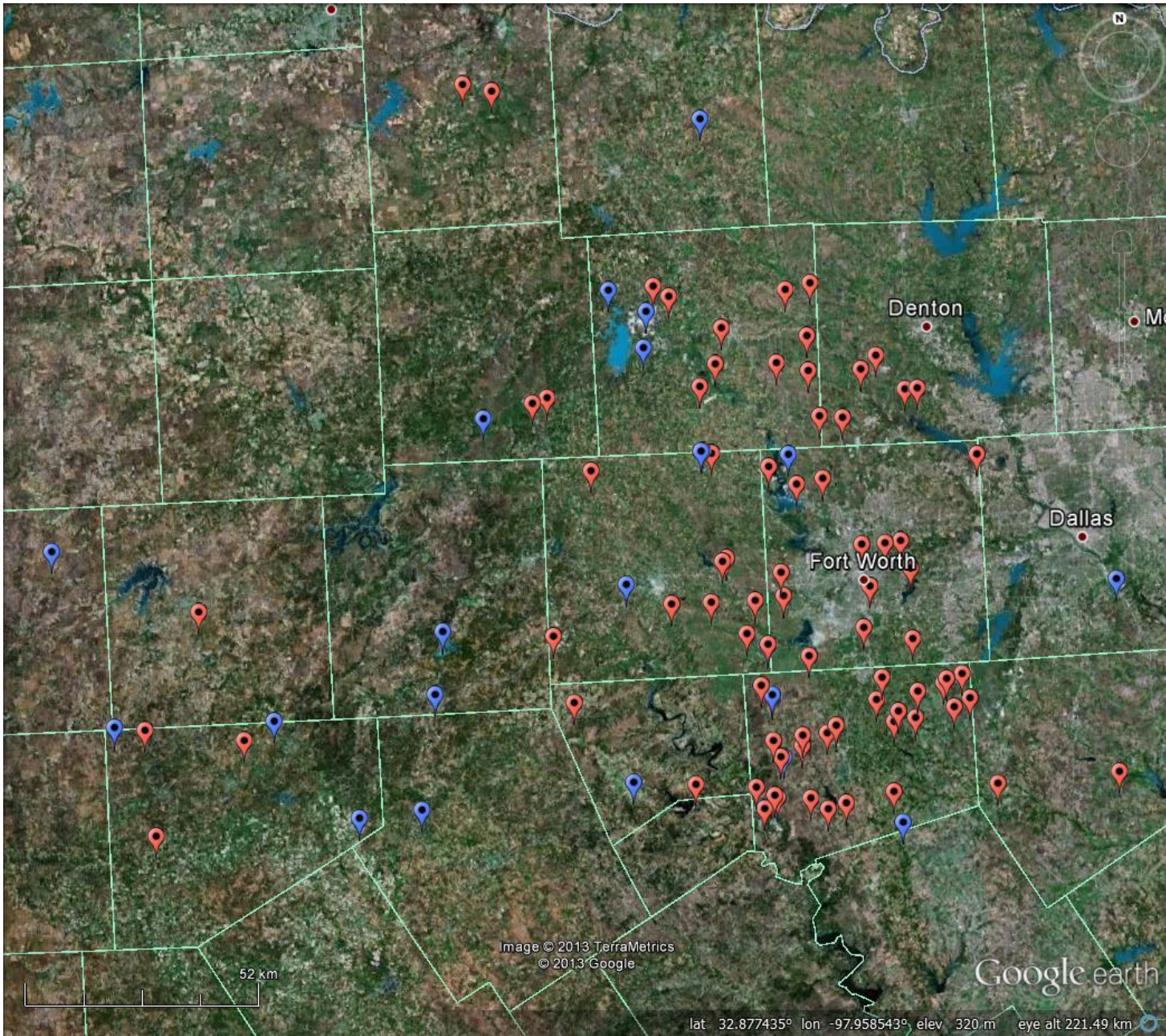


05/20/2013

Source: Texas Railroad Commission Production Data Query System (PDQ)

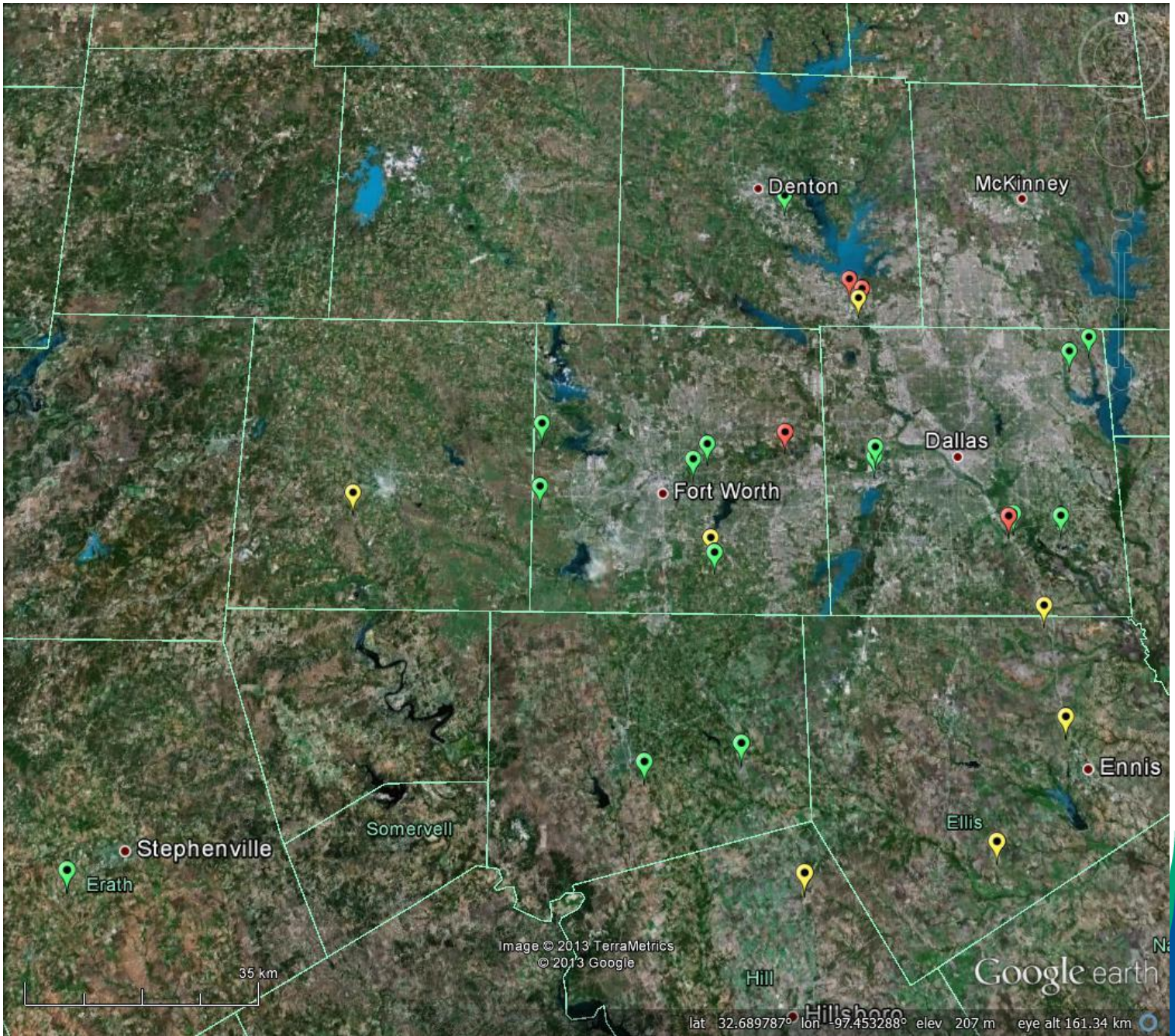
Midstream O&G Facilities

- 83 compressor stations & 21 processing plants in 2011 NEI
- 400 midstream facilities in TCEQ 2009 special EI
- 40 compressor stations & 23 processing plants with 12.5 Gg CH_4 emissions in 2011 GHGRP



Landfills

- 23 landfills with 88.5 Gg CH_4 emissions in 2011 GHGRP
- ~60 smaller landfills



CH4 (Mg)

- 0 to 5,000
- 5,000 to 10,000
- 10,000 to 16,405

Barnett Methane Experiment

- Phase I: March 2013
  - University of Colorado
  - NOAA/ESRL (GMD, CSD)
  - Picarro
  - Shell / Sanders Geophysics
  - Aerodyne
  - Penn State
- Phase II: October 2013
  - Purdue
  - University of Michigan
  - University of Cincinnati
  - UC Irvine
  - University of Houston
  - West Virginia University
  - Duke
  - Princeton & UT Dallas

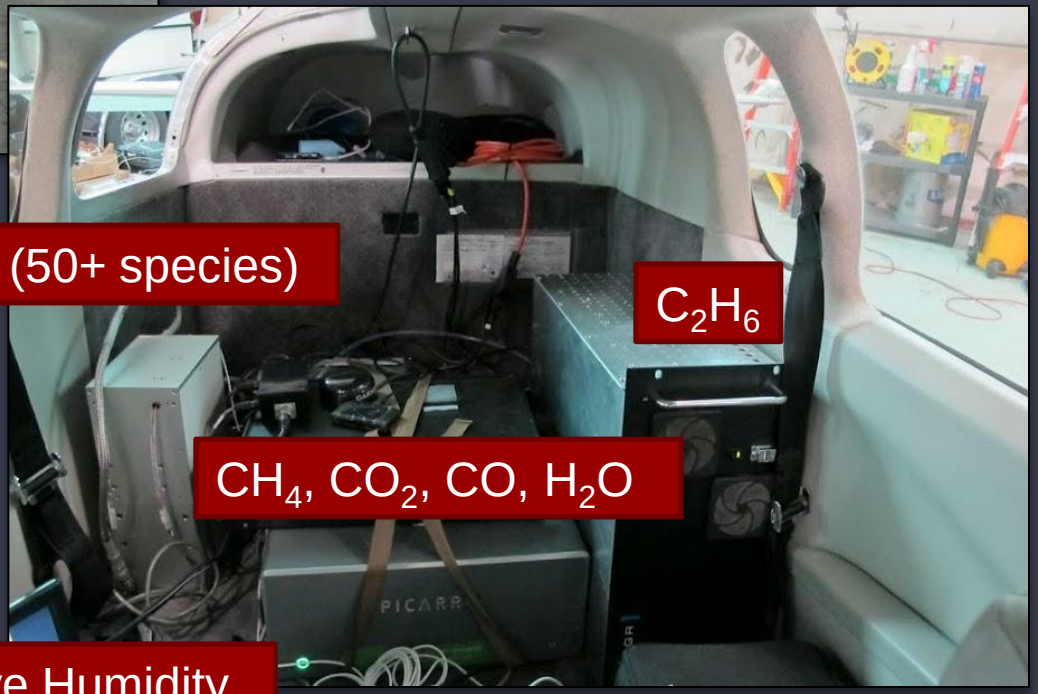
Barnett II Methane Experiment: Aircraft

Purdue Duchess

Scientific Aviation Mooney

Aircraft Instrumentation

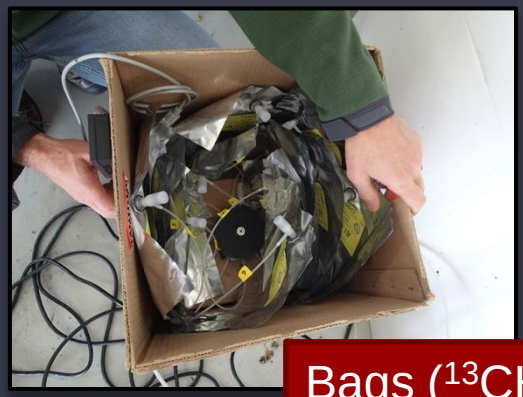
Measurement of additional species (such as ethane and $^{13}CH_4$) help with attribution of methane to an oil and gas source.



Flasks (50+ species)

C_2H_6

CH_4, CO_2, CO, H_2O

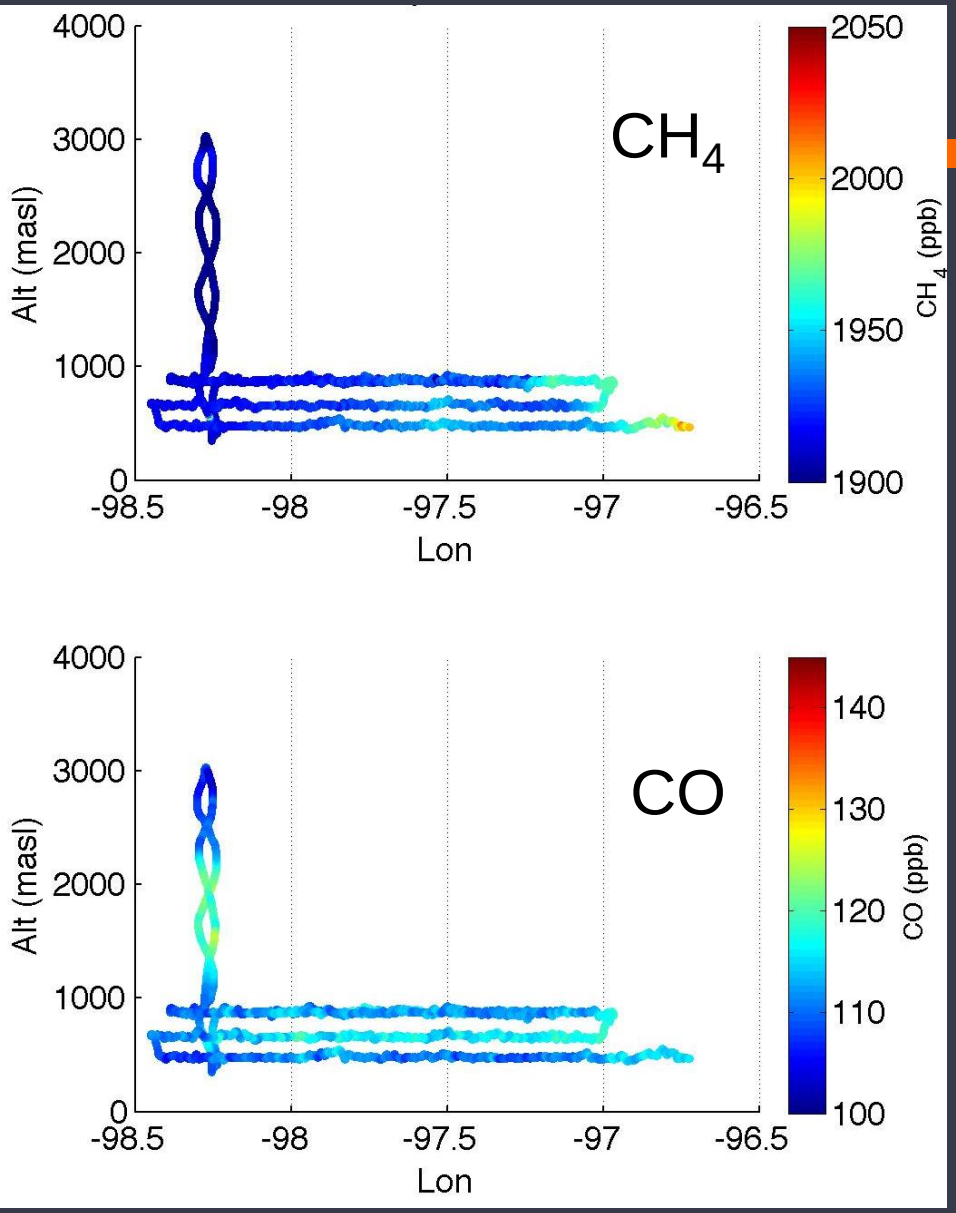


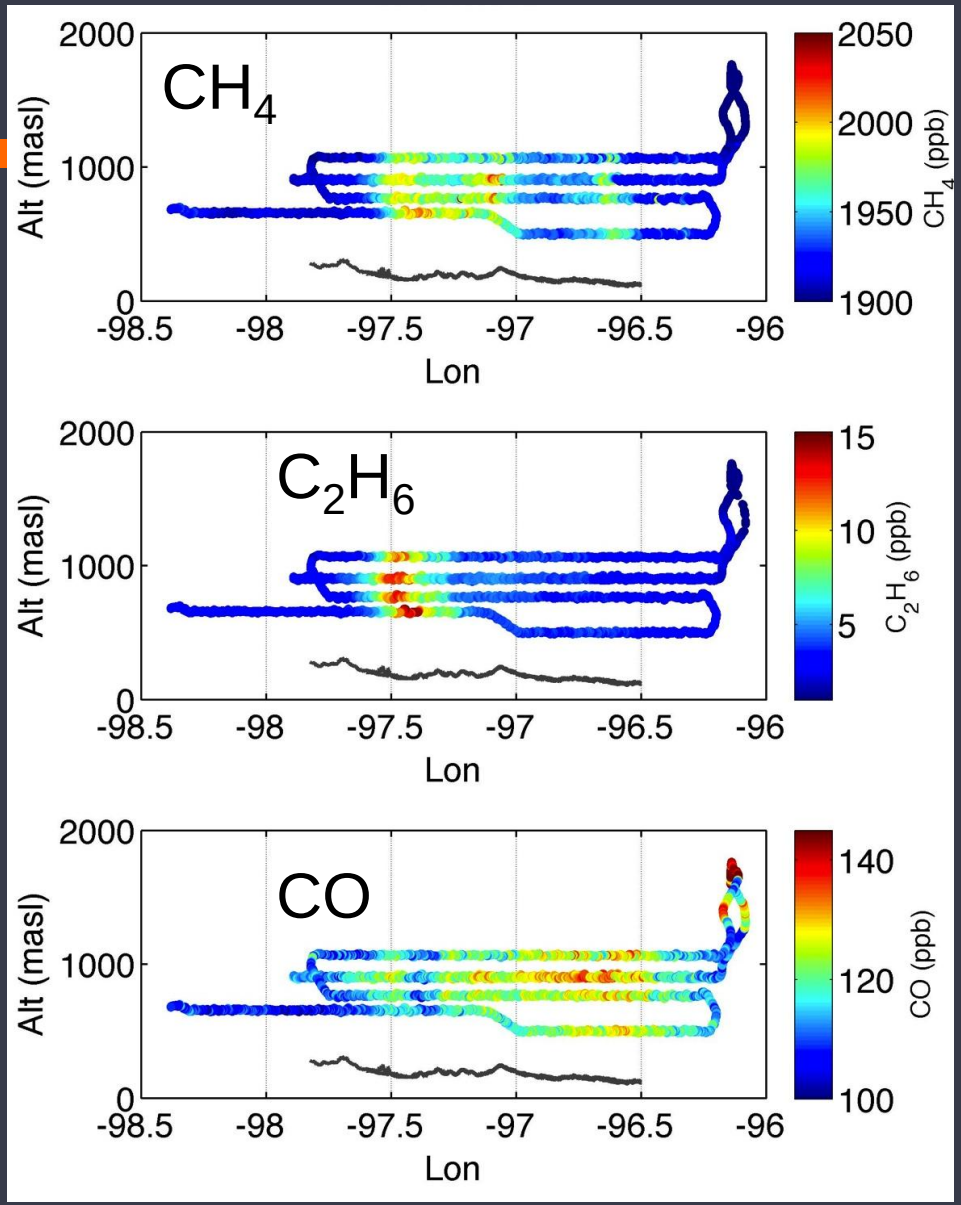
Bags ($^{13}CH_4$)

Also: Wind, GPS, Temperature, Relative Humidity

Upwind (Duchess)

Downwind (Mooney)

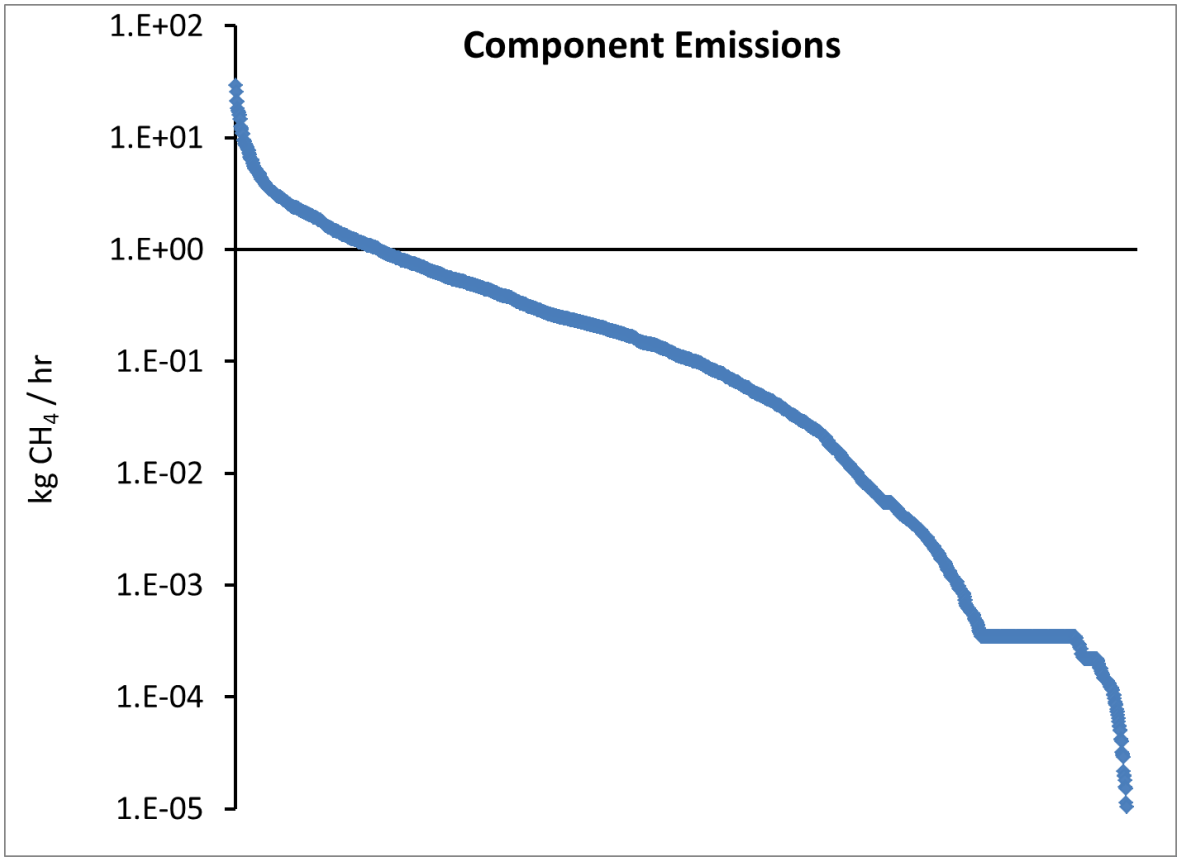




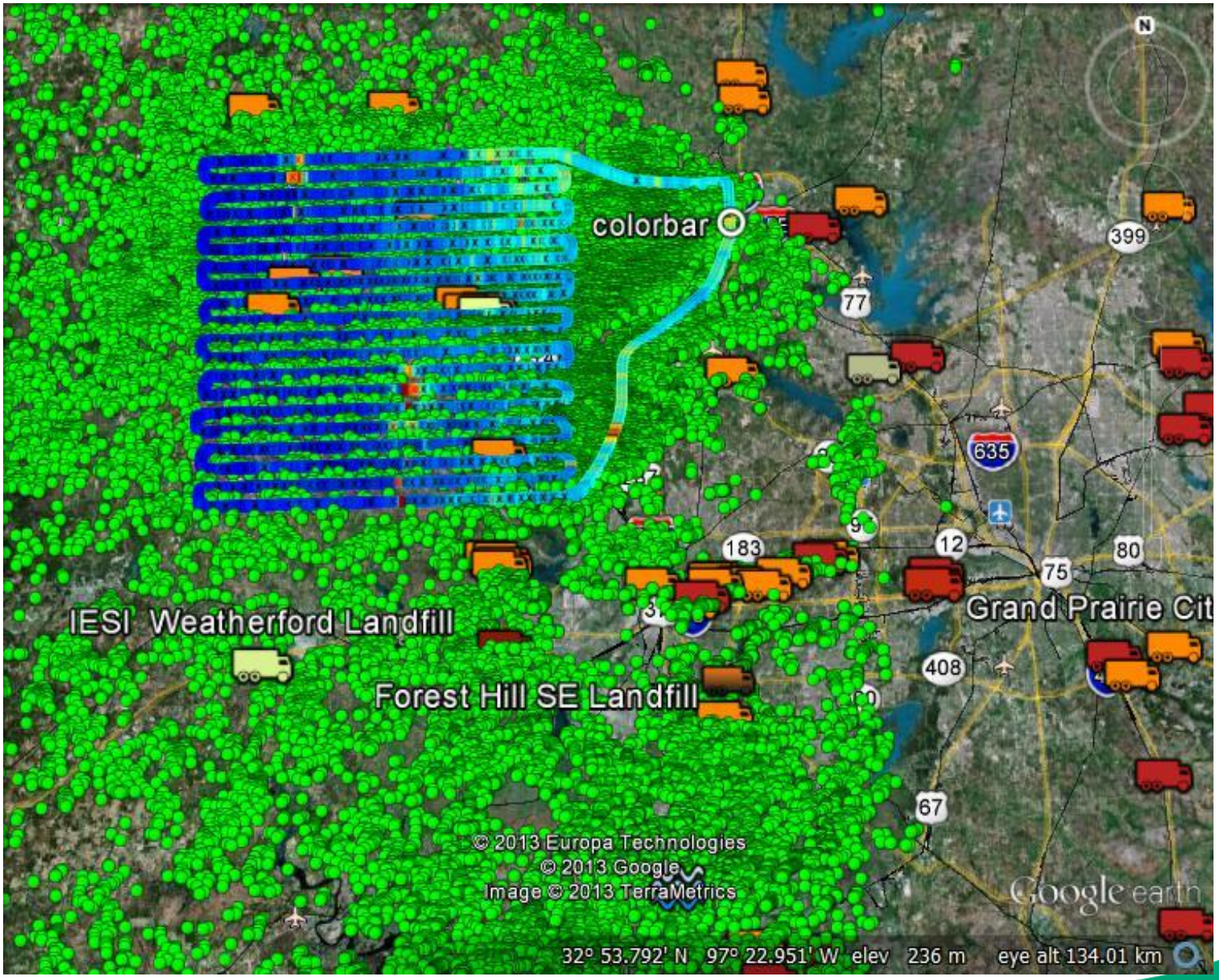
Fort Worth Air Quality Study

- 388 sites surveyed with infrared camera for leaks
- CH_4 emissions measured from 2,126 components
- 68% of emissions from 10% of components

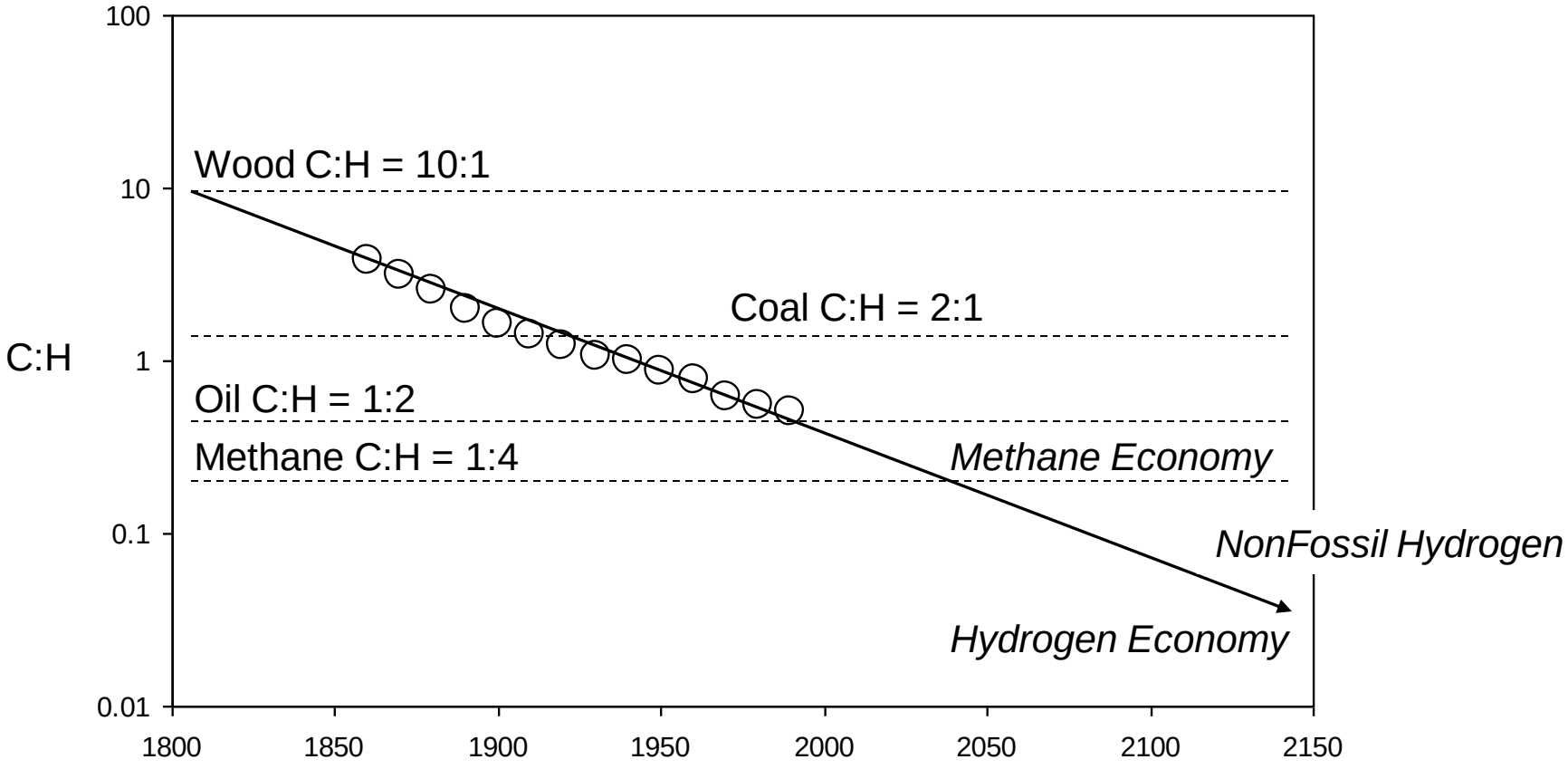
	kg/hr CH4
Minimum	0
25%	0.004
Mean	0.67
Median	0.11
75%	0.52
90%	1.6
99%	9.1
Maximum	29.5



Sanders Geophysical & Shell: Low altitude CH_4 mapping



Decarbonization
Evolution of C:H Ratio in Global Fuel Mix



Source: Ausubel 2007, after Ausubel, 1996 and Marchetti, 1985

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