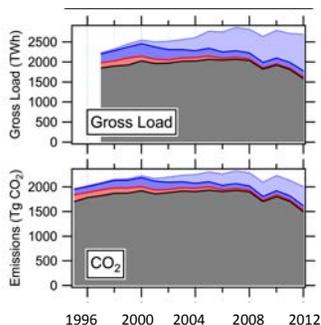


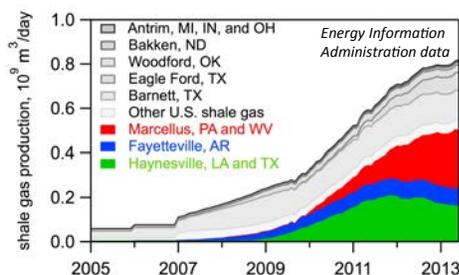
“Unconventional” gas production - a new CSD focus since our last review in 2008:

Advent of *horizontal drilling* and *high-pressure hydraulic fracturing* has led to major changes in the U.S. energy portfolio, with poorly known impacts on air quality & climate

CSD research results



Decreasing power plant CO₂ emissions...
de Gouw *et al.*, 2014



...from an increasing supply of natural gas
Peischl *et al.*, 2015



“Unconventional” gas production areas

AQ impacts: Increased CH₄ emissions. Summer *and* winter(!) O₃ formation.

CSD response:

- apply expertise in field measurements and atmospheric chemical modeling
- provide timely scientific information to industry, policymakers, and the public

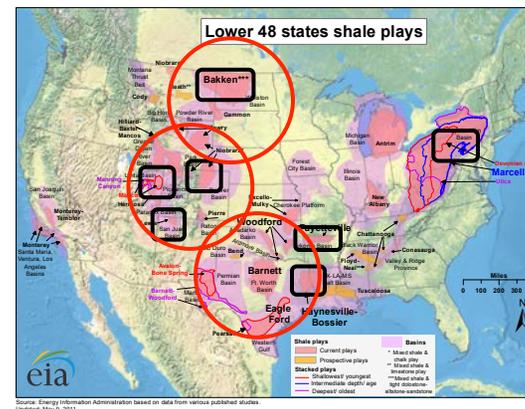


CH₄ emissions from energy development



CSD has led multiple field studies **quantifying CH₄ emissions** from oil & gas production regions

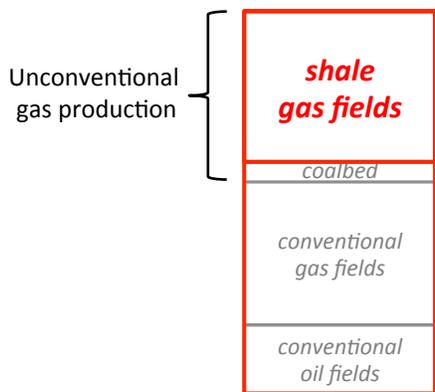
- 2010: California Research at the Nexus of Air Quality and Climate Change (CalNex)
- 2011: Nitrogen, Aerosol Composition, and Halogens on a Tall Tower (NACHTT)
- 2012–14: Uintah Basin Winter Ozone Studies (UBWOS) - *co-led with GMD*
- 2013: Southeast Nexus (SENEX)
- 2014: Twin Otter Projects Defining Oil/gas Well emissions (TOPDOWN) - *co-led with GMD*
- 2015: Shale Oil and Natural Gas Nexus (SONGNEX) ← *currently active*



Our work quantifies CH₄ emissions from regions accounting for 65% of unconventional shale gas production in the U.S.

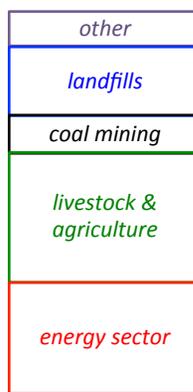
Talks by Trainer, 4-2; Ahmadov, 4-5

Leaks from U.S. **energy sector** natural gas production ...



EIA production data

... are a fraction of U.S. total CH₄ emissions



U.S. EPA inventory data

Keeping an eye on the big picture

CSD field projects have provided constraints on all major CH₄ source types in the U.S.

We collaborate with other agencies, academic researchers, and industry to better understand the total U.S. CH₄ emissions budget

This work addresses the President's Climate Action Plan goals for "improved understanding to reduce emissions"

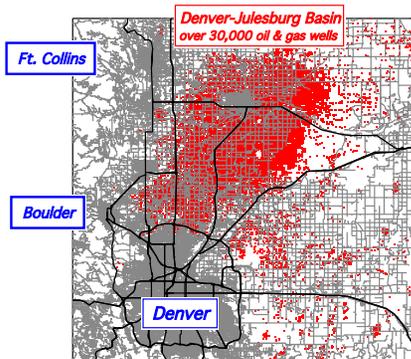


CSD has led multiple field studies assessing O₃ formation from oil & gas emissions

- 2011: Nitrogen, Aerosol Composition, and Halogens on a Tall Tower (**NACHTT**)
- 2012–14: Uintah Basin Winter Ozone Studies (**UBWOS**) - *co-led with GMD*
- 2013: Southeast Nexus (**SENEX**)
- 2014: Twin Otter Projects Defining Oil/gas Well emissionN (s) (**TOPDOWN**) - *co-led with GM*
- 2015: Shale Oil and Natural Gas Nexus (**SONGNEX**) ← *currently active*

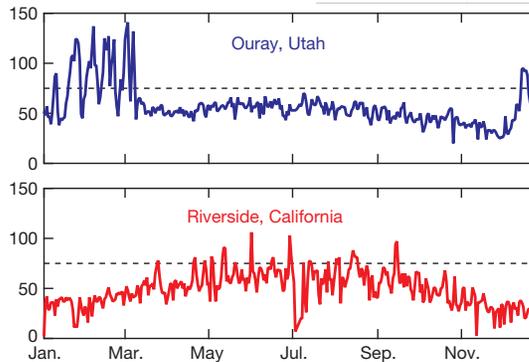
CSD research results

Summer: Oil & gas contributes about half of the initial VOC reactivity leading to O₃ formation in the Denver non-attainment area

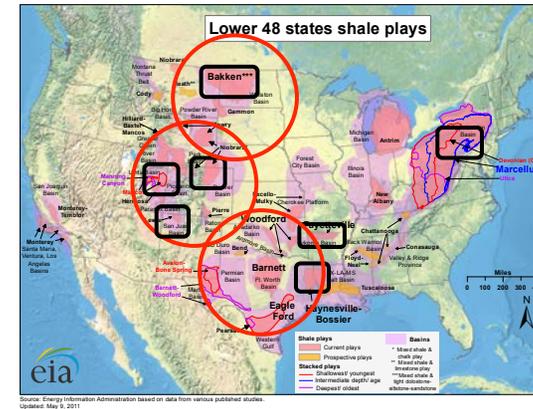


Gilman *et al.*, ES&T, 2013

Winter: Remarkably high O₃ values observed in oil & gas production regions in the rural western U.S.



Edwards *et al.*, Nature, 2014



See talks by
 Jessica Gilman, 4-2
 Jim Roberts, 4-3
 Christoph Senff, 4-4
 Ravan Ahmadov, 4-5

CSD research has quantified oil and gas emissions' impacts on both summer and winter O₃