Shale Petroleum Development: Air Emissions and Implications

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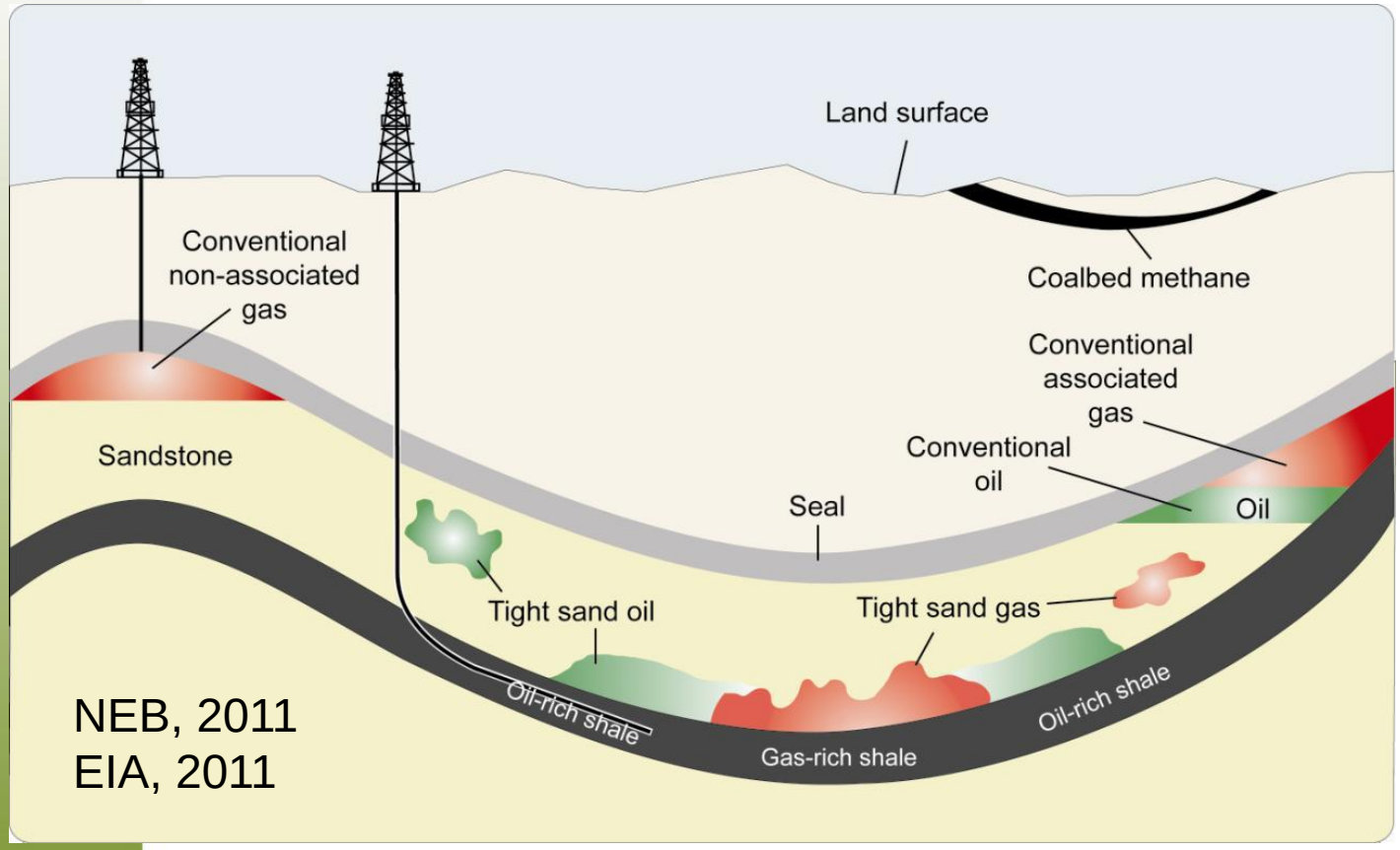
Shale Oil and Gas

NEB (2009)

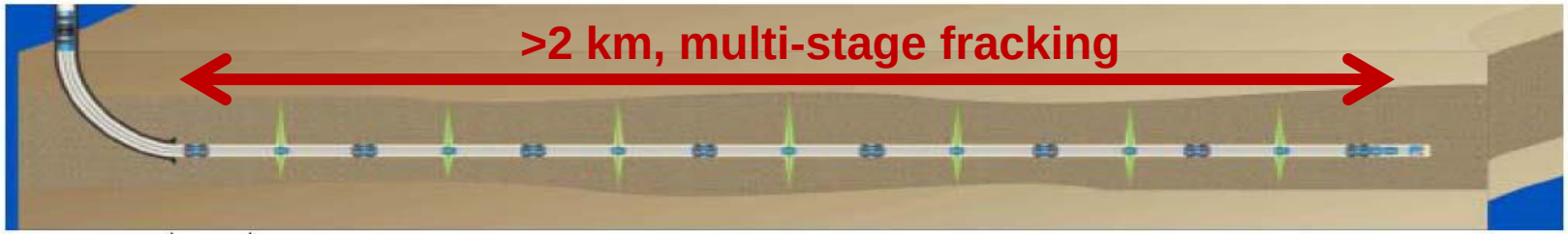
- Hydrocarbon trapped in impermeable or semi-impermeable, low porosity rock formations
  - **Shale** (claystone, mudstone, etc); once deposited as mud (clay and silt) and is a combination of clay, silica, carbonate
  - Organic materials from algae, plant, or plankton – biogenic and thermogenic gas and oil
  - Deep below the ground surface (1,500–6,100 m)

Hydraulic Fracturing (Fracking)



NEB, 2011
EIA, 2011

Per US EPA definition, ***hydraulic fracturing*** is a process to stimulate a gas/oil well to maximize extraction. The process includes the **acquisition of source water**, **well construction**, **well stimulation**, and **waste disposal**



Source: Packers Plus Energy Services Inc.

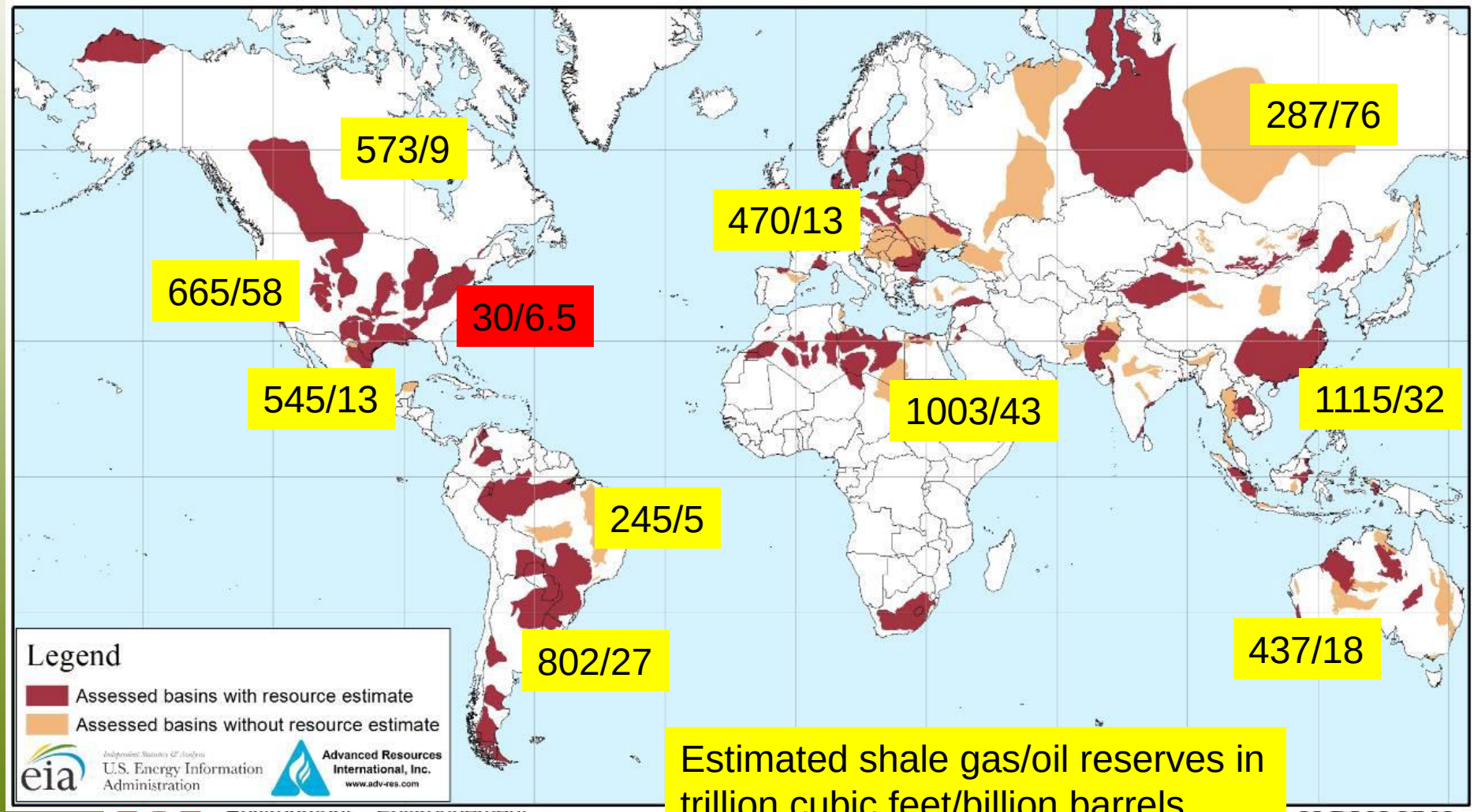
200 tonne frac in NE British Columbia

(Heffernan, CSUR)

Fracking and Extraction

- Water acquisition – locally or transported
- Chemical mixing – chemicals transported
- Well construction – drilling
- Well stimulation – injection and fracturing
- Flowback and produced water management
  - Storage, recycling and re-use, transportation, disposal
- Gas/oil production
  - Gas/oil collection, treatment, separation
- Gas/oil transportation and distribution
- Re-fracturing

World Recoverable Shale Gas/Oil Reserves (EIA, May 2013)



Shale/Tight Oil and Gas Plays in North America

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Environmental Impacts of Fracking

- **Air –** CACs, GHGs, air toxics emissions
- **Water –** water acquisition and hydrological cycles, fracking fluid leakage, produced water management and disposal
- **Seismicity –** induced during fracking
- **Health impacts –** from exposure to air and water contaminants

Fracking Fluid and Produced Water

- 99.5% water and sand (proppant); water can be replaced by CO_2/propane/butane/N_2
- Chemical additives serving purposes of: friction reducers, biocides, corrosion inhibitors, gelling agent, and clay stabilizer
- Additives depending on the rock properties; chemical composition is proprietary information only partially publicly disclosed
- Naturally occurring radioactive materials (NORMs), salts, metals, and dissolved solids in produced water
- Disposal: well injection, waste water treatment plants, recycling

Air Emissions from Fracking

- **CAC emissions**
  - Transportation of water and chemicals: CACs and GHGs
  - Diesel or natural gas powered equipment (compressors, drilling rigs, pumps etc); CACs and GHGs
  - Flaring/venting: CACs/GHGs
  - Storage and processing facilities: VOC, CH_4
- **GHG emissions**
  - Natural gas byproducts: CO_2
  - CH_4 leakage rate ~2.4% (EPA, 2013), originating from wells, separators, compression stations, pipelines, gas returns to surface with flowbacks
  - Flaring/venting: CO_2, CH4, black carbon
- **Air toxics emissions**
  - from startup phase - fracking fluid storage, handling, and disposal
  - from production phase - storage, collection, processing, and distribution

Health Impacts of Fracking Fluid and Related Air Emissions (Colborn et al., 2011, in *Human and Ecological Risk Assessment*)

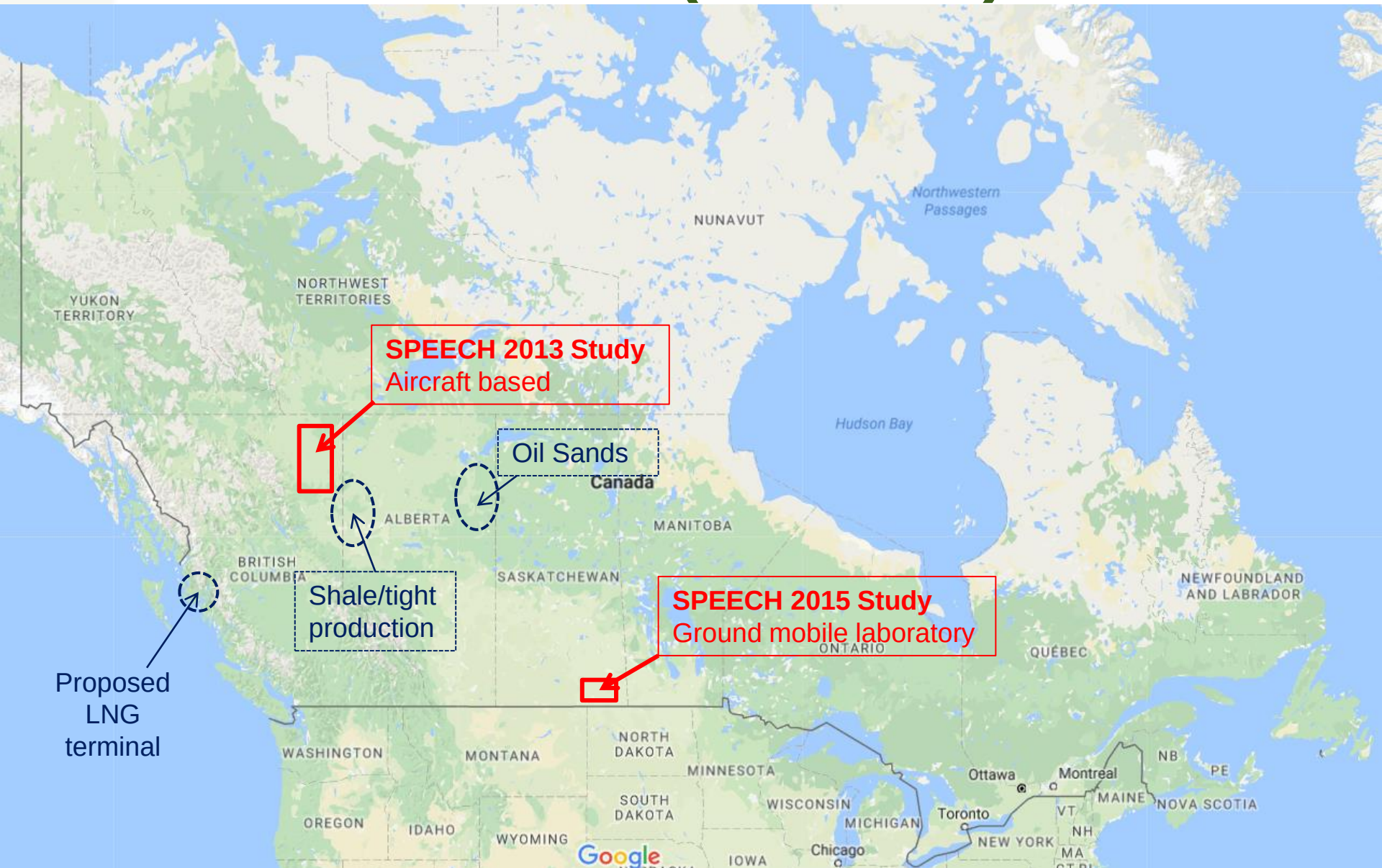
- HF fluid chemicals: 353 out of 994 fracking chemicals identified in fracking operations
  - >75% of the 353 chemicals affected the skin, eyes, and other sensory organs
  - 52% affected the nerve system
  - 40% affected the immune and kidney systems
  - 46% affected the cardiovascular system and blood

- Air emission health impacts
  - 35 chemicals affect the brain/nervous system; 33 liver/ metabolism; 30 endocrine system (reproductive and developmental effects); 28 immune system; 27 cardiovascular/blood; 25 sensory, and 25 respiratory systems

Shale Petroleum Extraction Emission CHaracterization (SPEECH) studies

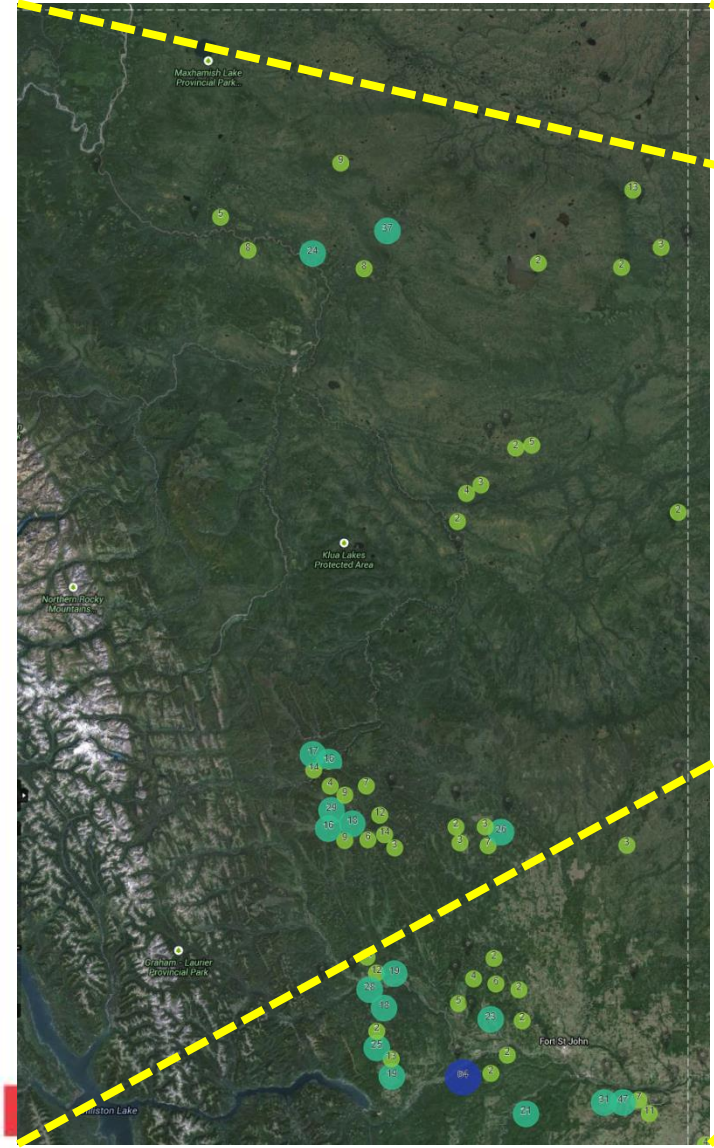
- **Objectives**
  - To survey regional air emissions from the shale petroleum extraction activities in the North Peace River region and the Horn River Basin in **northeastern British Columbia**
  - To survey the Bakken shale plays in **southeastern Saskatchewan**, to determine air pollutant emissions to the atmosphere
  - To determine the emission rates of CACs (VOCs), GHG/SLCP (CO_2, CH_4, black carbon), and air toxics (H_2S, aromatics) from these development activities
  - To provide data that can be used in emission inventory development and validation for policy making decisions

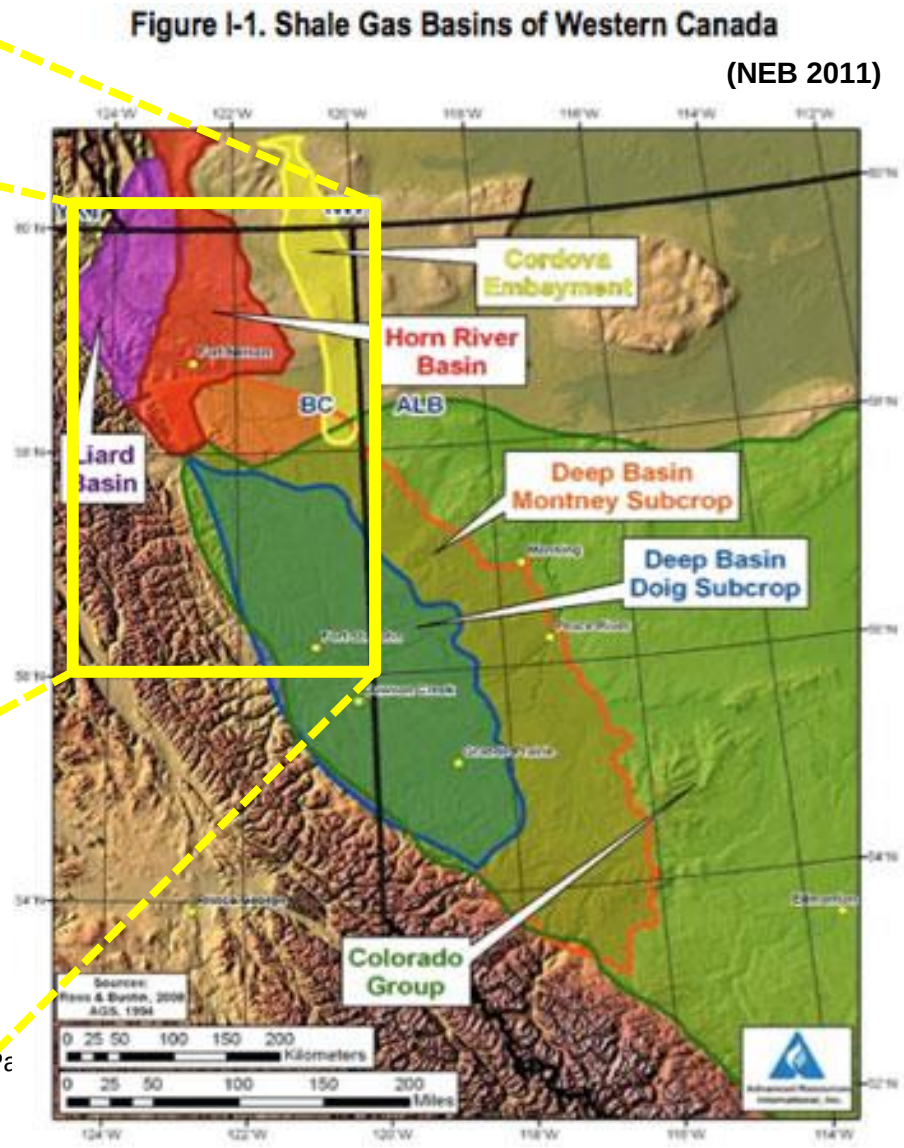
Shale Petroleum Extraction Emission Characterization (SPEECH) studies



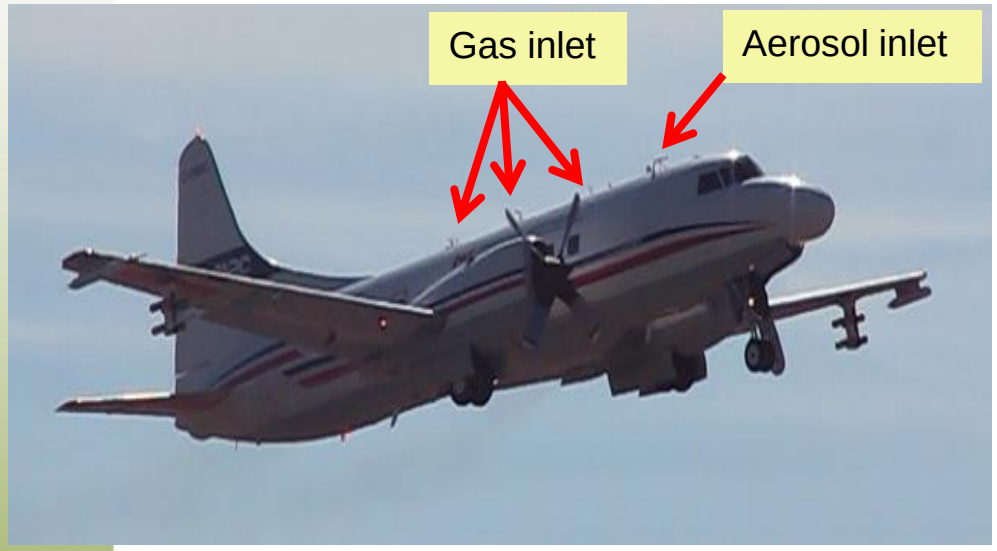
SPEECH 2013 Study, Northeast British Columbia

Fracking activities in northeastern BC (fracfocus.ca, accessed Nov 2014)





Airborne Measurements in NE BC



Gases – Continuous Measurements

O_3, NOy, NO, NO_2, SO_2 (TECO)	1 sec
VOCs (150 species canister GC/MS)	
VOCs (PTR-ToF-MS)	2 sec
Inorganic/organic acids (CIMS)	2 sec
CO, CO_2, CH_4, H_2O (CRDS)	1 sec
HCHO, NH_3 (QCL)	1 sec

Aerosol Particles – Continuous Measurements

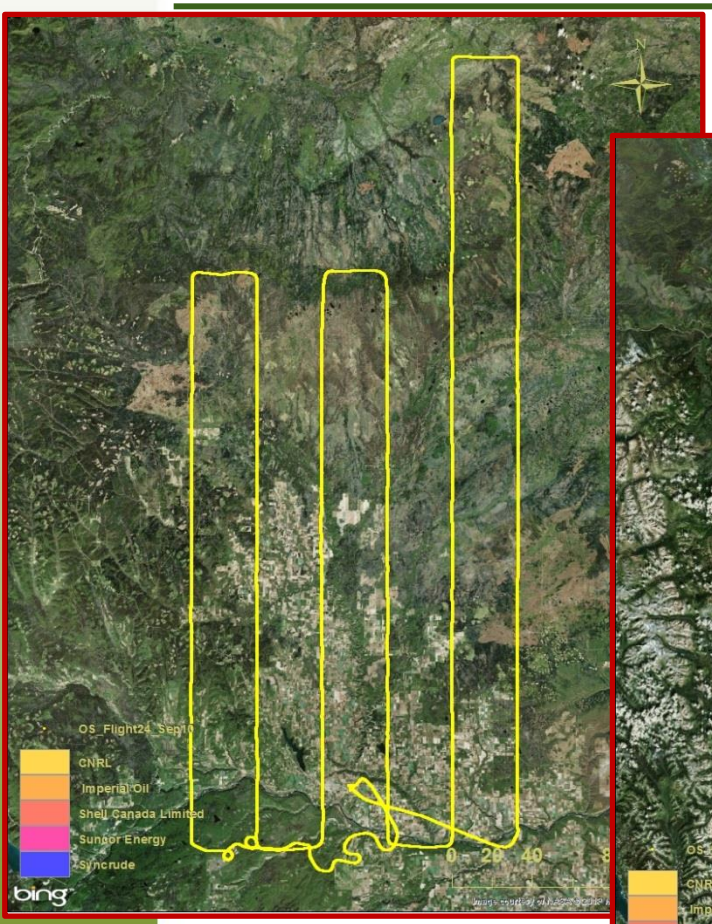
Black carbon (SP2)	<1 sec
Chemical composition (HR-ToF-MS)	10 sec
Number/volume/mass size distributions from 10 nm to 10 μm	1 sec

Meteorological State Parameters

Position and Altitude
Wind direction, wind speed, T, P

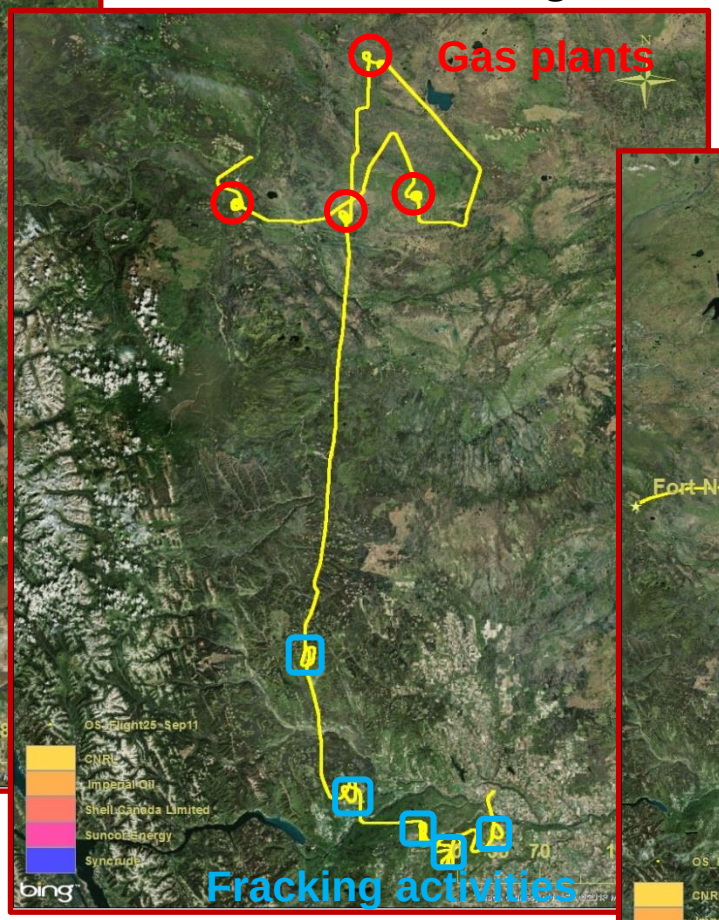
Three Flights on September 10-11, 2013, over the Fort St. John and Fort Nelson regions

Survey Flight Tracks over NE BC

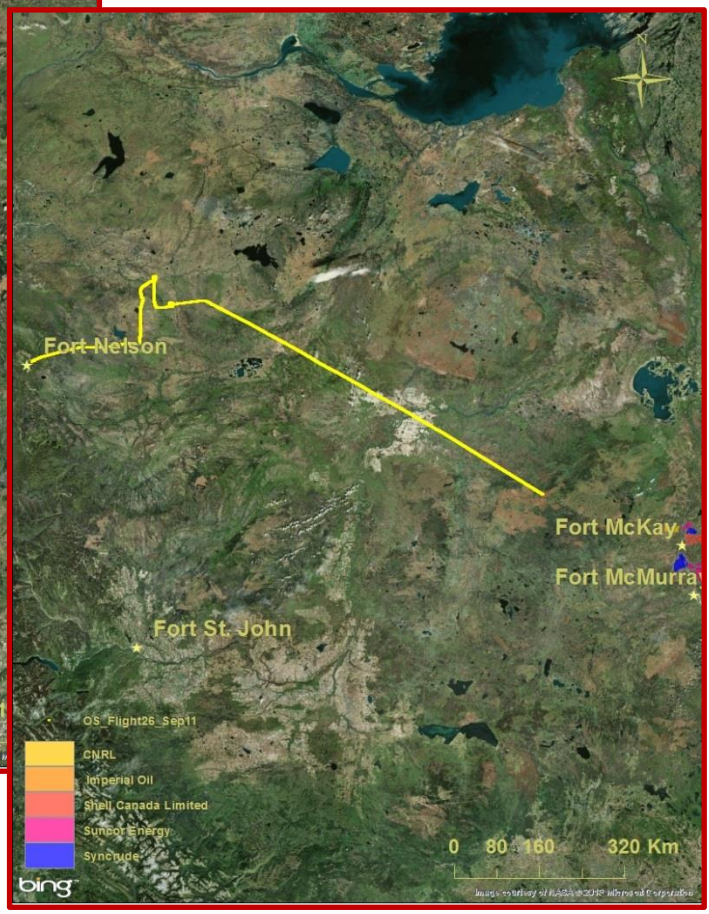


Flight 1

Flight 2



Flight 3



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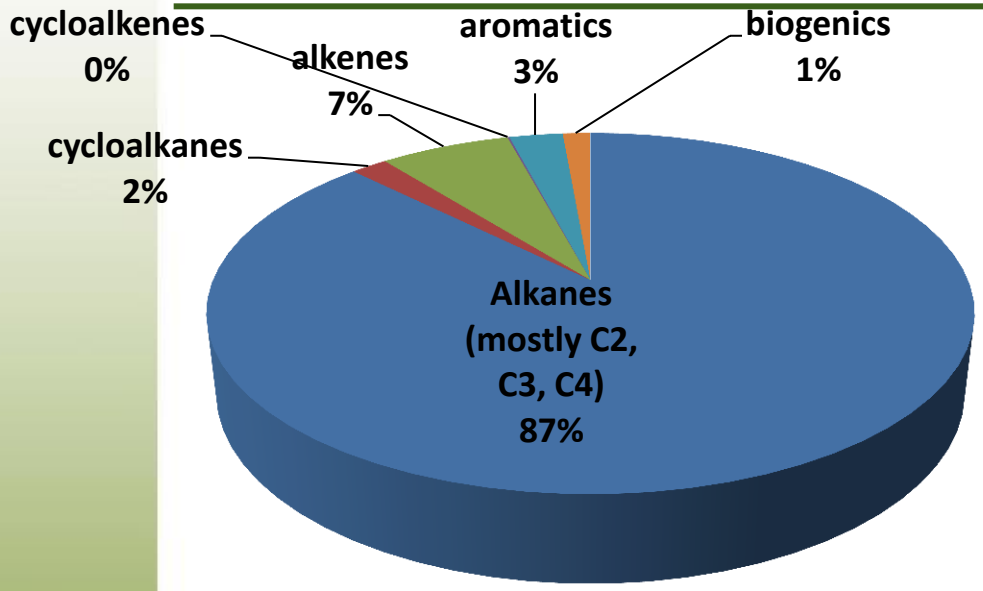
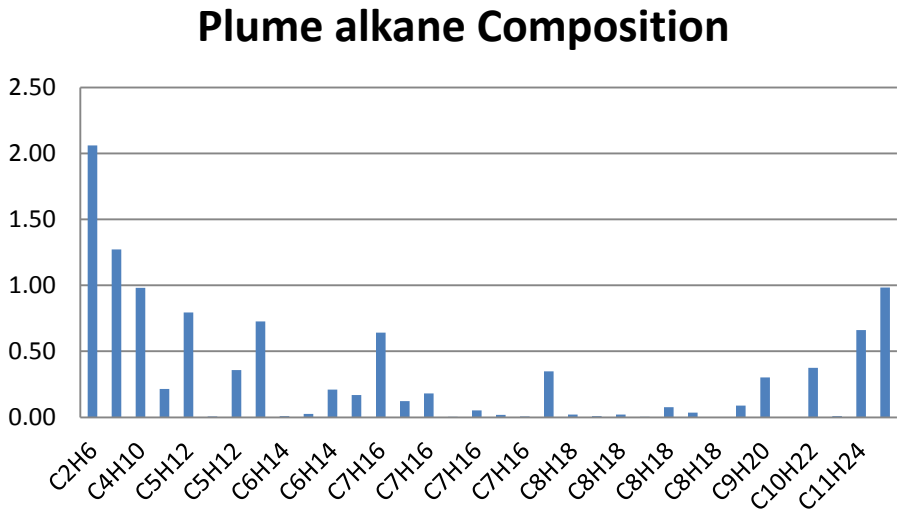
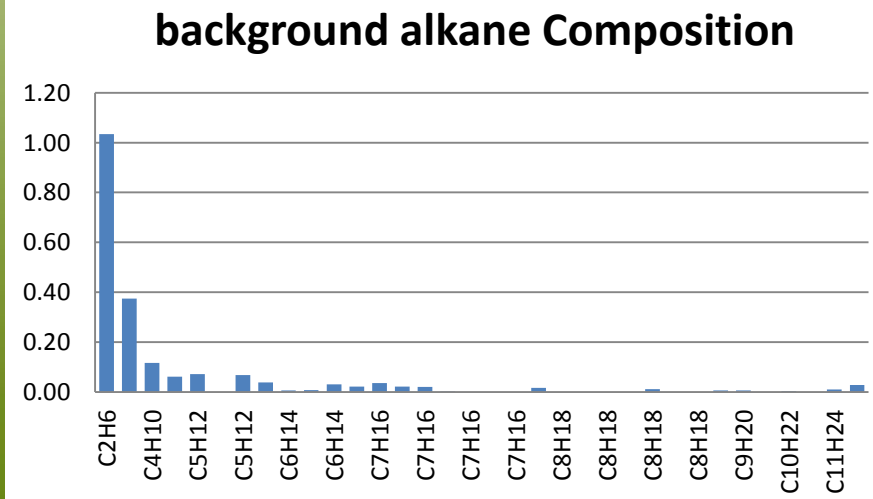
VOC composition in Fracking Plume / Background

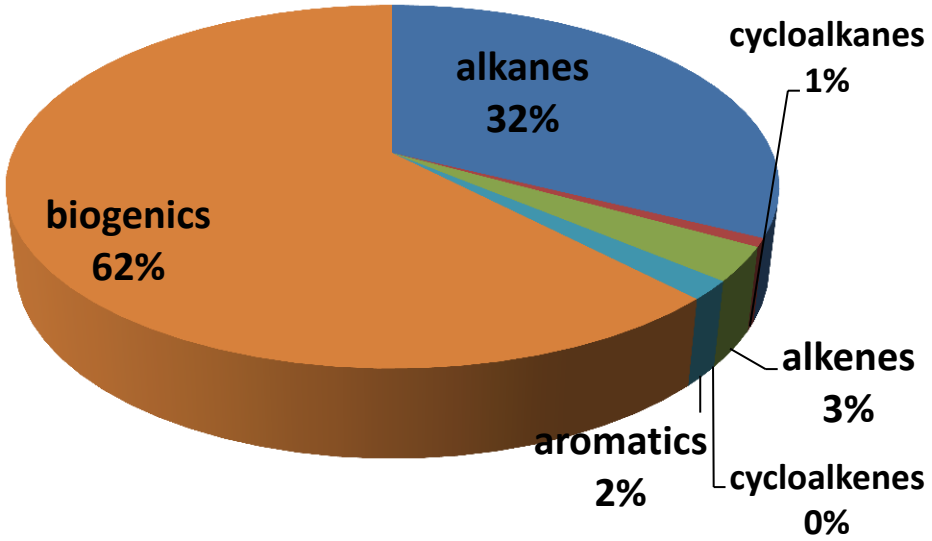


VOC in Fracking Plume, total VOC = 12 ug/m3



Background near Fracking, total VOC = 6 ug/m3





Partial List of Compounds Identified in Fracking Plume from CIMS/PTR-ToF-MS

CIMS

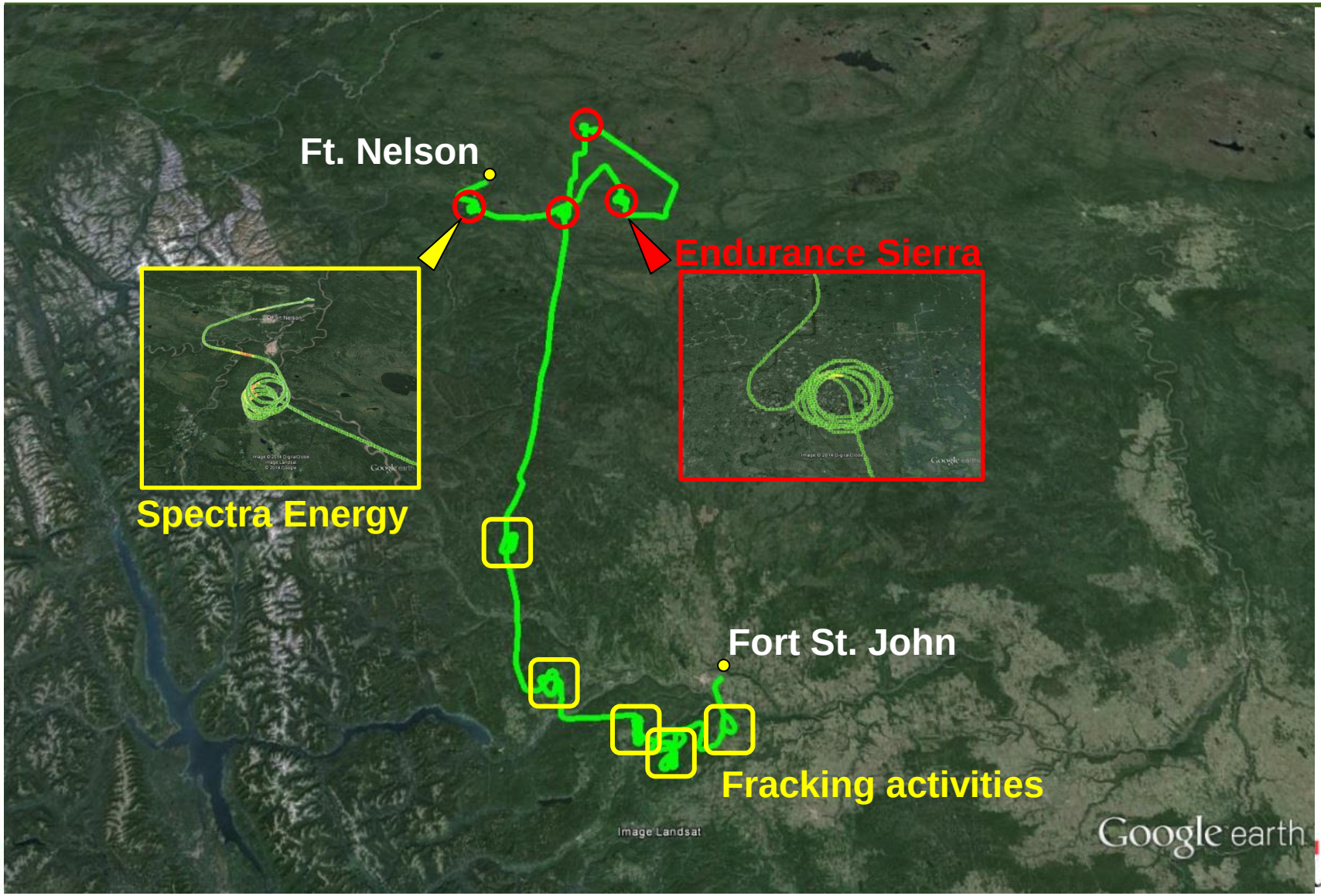
Compounds related to fracking fluid (ie: correlated with HCl)	Compound Name
HCl	HYDROCHLORIC ACID
HNCO	ISOCYANIC ACID
CH2O2	FORMIC ACID
CH4S	METHANETHIOL?
C2H2O2	GLYOXAL?
C2H2O3	GLYOXYLIC ACID
C2H4O3	GLYCOLIC ACID
C2H2O4	OXALIC ACID
C4H6O4	SUCCINIC ACID
C6H6OSO3	BENZENESULFONIC ACID

Compounds related to combustion during fracking (ie: correlated with SO_2 or HNO_3)	Name
HNO3	NITRIC ACID
SO2	SULFUR DIOXIDE
C4H5O	?
C3H4O2	ACRYLIC ACID
C5H5O	?
C5H7O	?
C4H6O2	METHACRYLIC ACID
C3H4O3	PYRUVIC ACID (sometimes)
C6H6O	PHENOL
C6H8O	?
C5H6O2	PENTADIENEOIC ACID
C5H8O2	2-PENTENEOIC ACID
C4H6O3	2-OXO-BUTANOIC ACID
C5H10O2	VALERIC ACID
C5H4O3	FURANOIC ACID
C6H12O2	HEXANOIC ACID
C7H6O2	BENZOIC ACID
C7H8O2	METHYLBENZENEDIOL
C6H6O2	BENZENEDIOL
C6H5NO3	NITROPHENOL
C7H8O3	HYDROXYBENZYL ALCOHOL
C9H12O2	??
C9H12O3	??

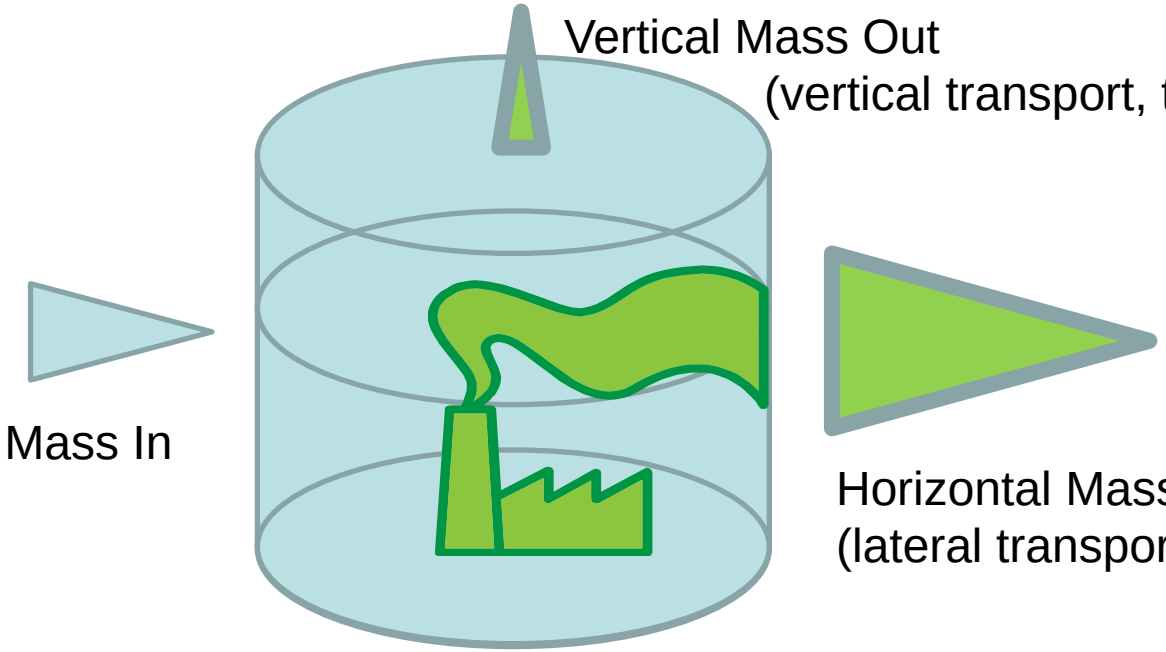
PTR-ToF-MS

CH3OH	methanol
CH3COCH3	acetone
C6H6	benzene
C6H5CH3	toluene
C6H5C2H5	xylenes/ethylbenzene
HCHO	formaldehyde

Flight over gas plants



Mass Balance in A Cylinder



$$\text{Emission Rate} = \text{Mass Out Rate - Mass In Rate}$$

$$= \oiint_{\theta} \overrightarrow{F}(z,\theta) \bullet r \bullet d\theta dz + \iint \vec{F}(r,\theta) \bullet r \bullet dr d\theta$$

$$= \oiint_{\theta} \rho_{air}(r,\theta,z) \bullet \chi(r,\theta,z) \bullet u_{\perp} r \bullet d\theta dz + \iint \rho_{air}(r,\theta,z_T) \bullet \chi(r,\theta,z_T) \bullet v \bullet r \bullet dr d\theta$$

ρ_{air} – air density; χ – mixing ratio; $u_{\perp}$ – horizontal wind speed normal to the wall; $r \bullet d\theta$ – track distance increment; z – height of plume; v – vertical wind speed

NE British Columbia Horn River Basin Shale Play Survey Results

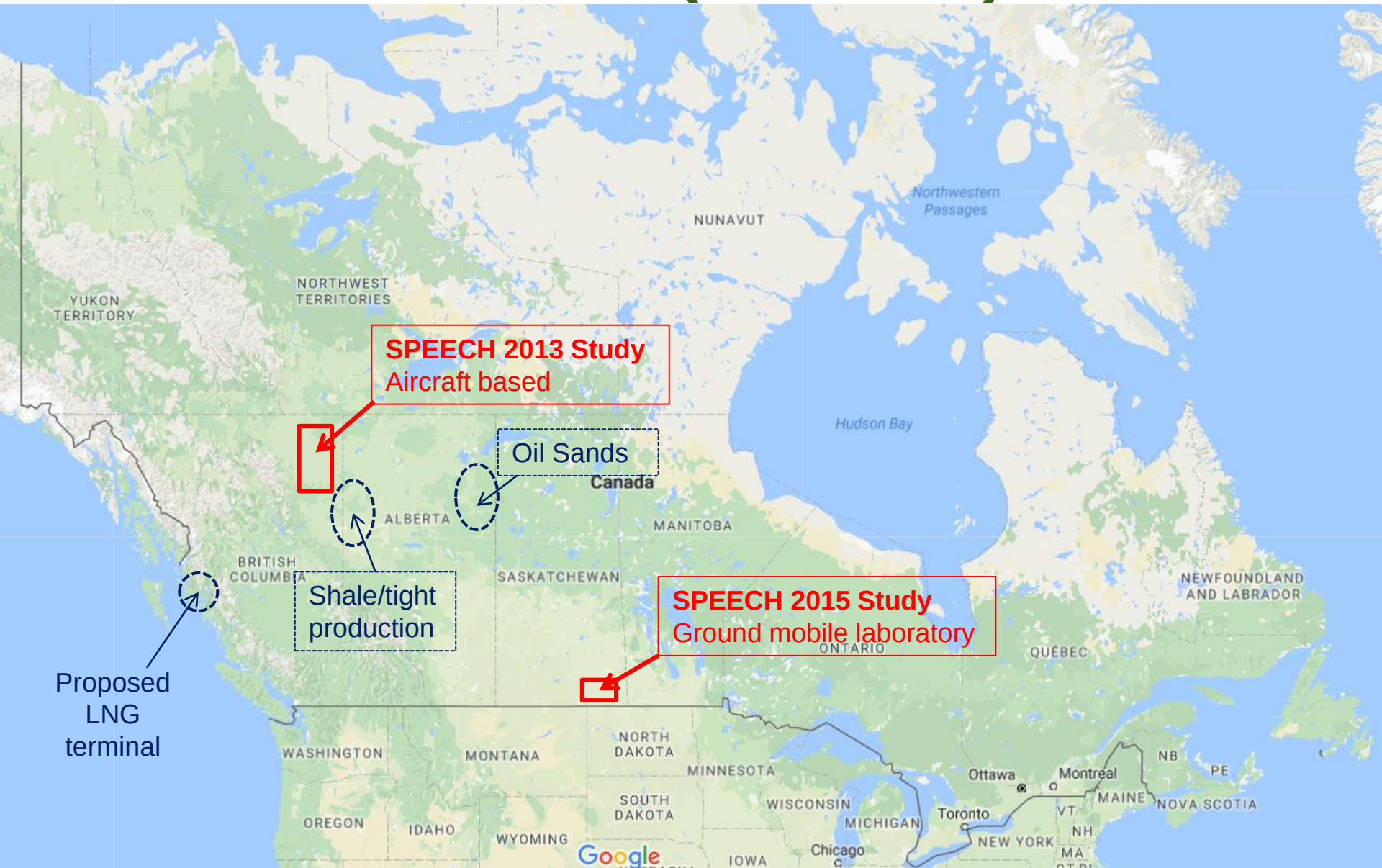
- Data on CACs and GHGs emissions were obtained from the survey of air emissions from shale fracking activities in northeast British Columbia

- High emissions of CO_2 and CH_4 were found in gas plant emissions, along with many CACs
  - Higher emission rates for CO_2 compared to company reports

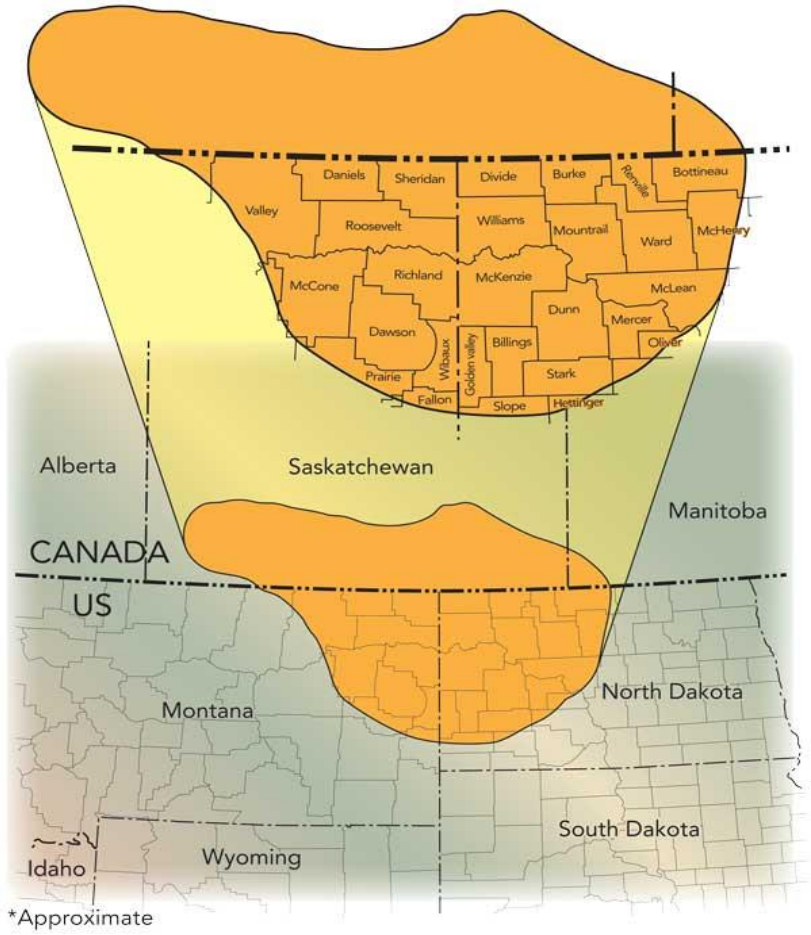
- Detailed speciation of hydrocarbons and other CACs were obtained for shale fracking and gas processing emissions

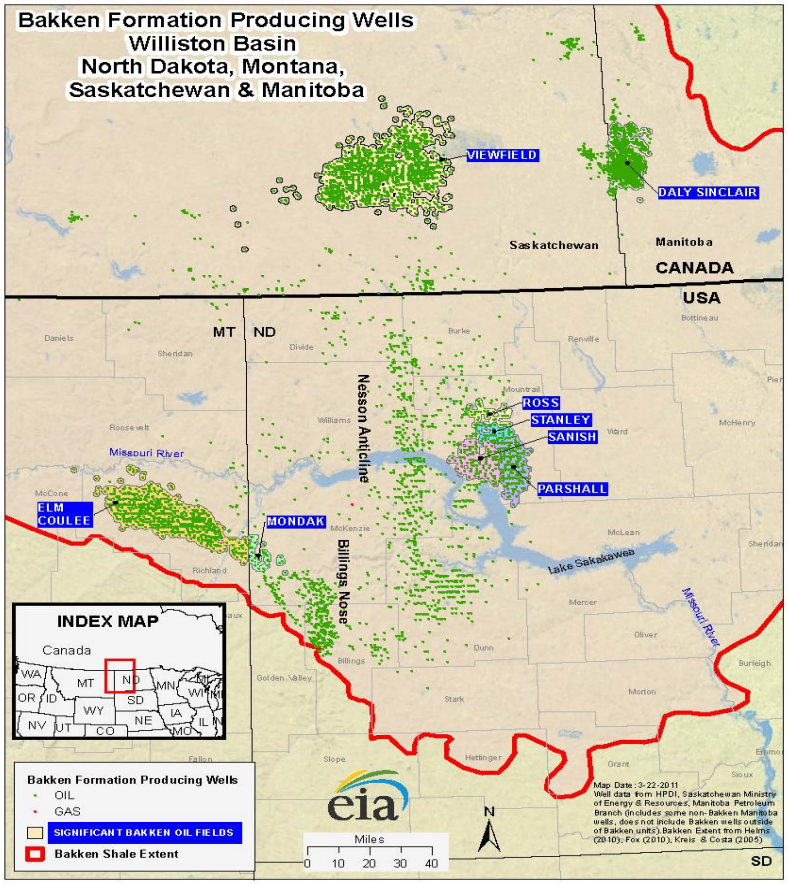
SPEECH 2015 Study, Bakken Shale, southeast Saskatchewan

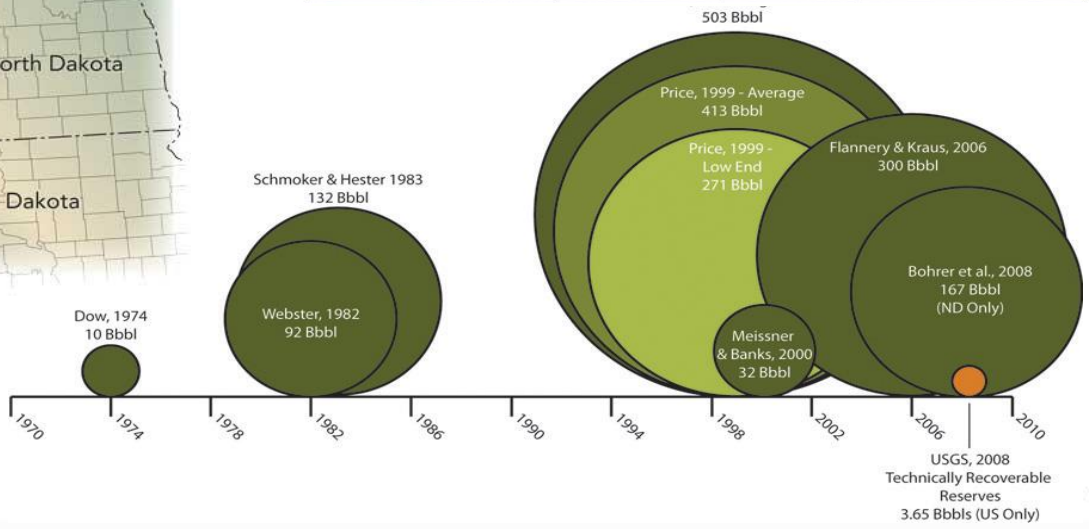
Shale Petroleum Extraction Emission Characterization (SPEECH) studies



Bakken fracked wells on both sides of the border







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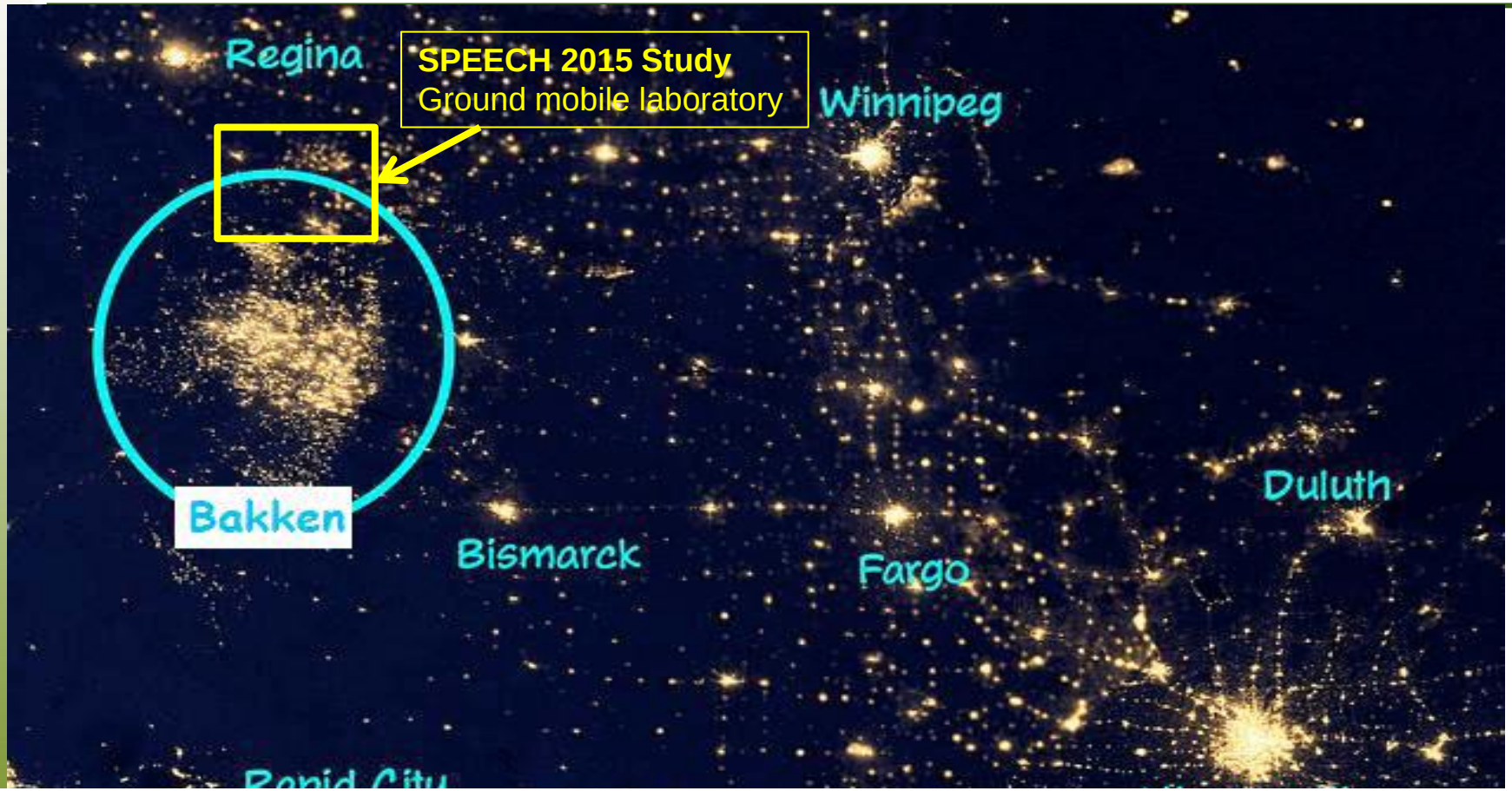
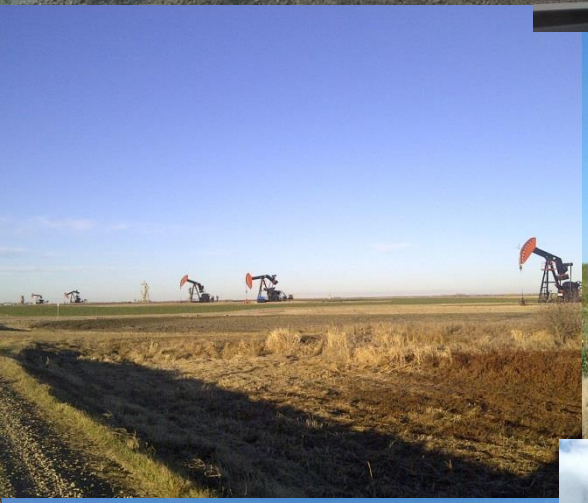
Bakken Flares Detected from Space



Oil from Bakken is shipped via a new Enbridge pipeline north to Canada then to the US Midwest, and by rail cars to the east coast. In ND alone, gas is flared, from 100 to 266 million CF/day from 2010-2012, emitting CO_2 equivalent to 100 million cars.






Measurements during SPEECH 2015

- **CH_4, CO_2, CO, CH_4/CO_2 carbon isotope**
- **NO, NO_2, SO_2, H_2S**
- **VOCs** in canisters (**~150 VOCs**)
- **OVOCs + BTEX**
- **Acids** (organic and inorganic)
- **Black carbon**, **$PM_{2.5}$** and particle number size distribution
- **Met** parameters (T, P, RH, 3-d wind speeds, wind direction, turbulence)

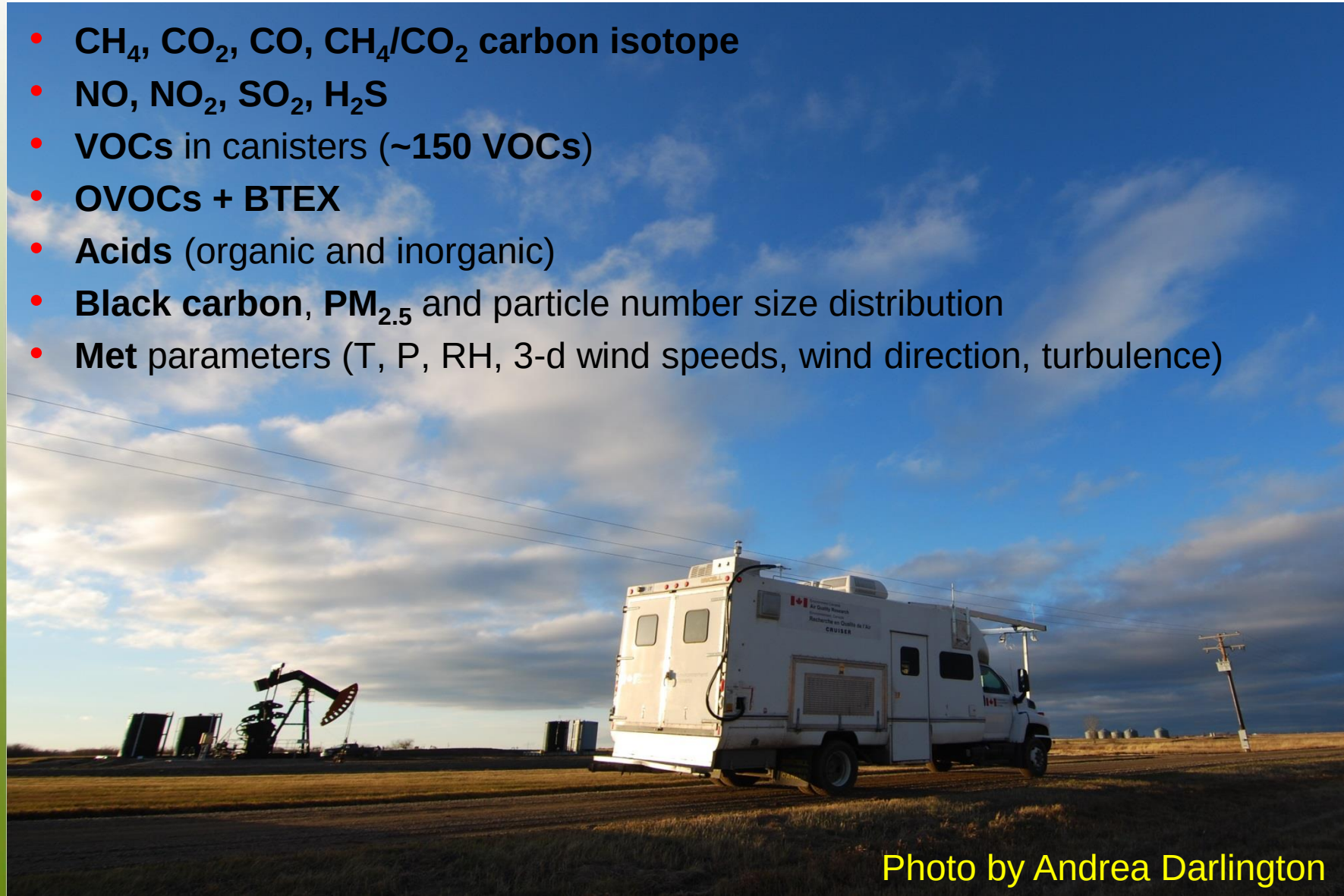
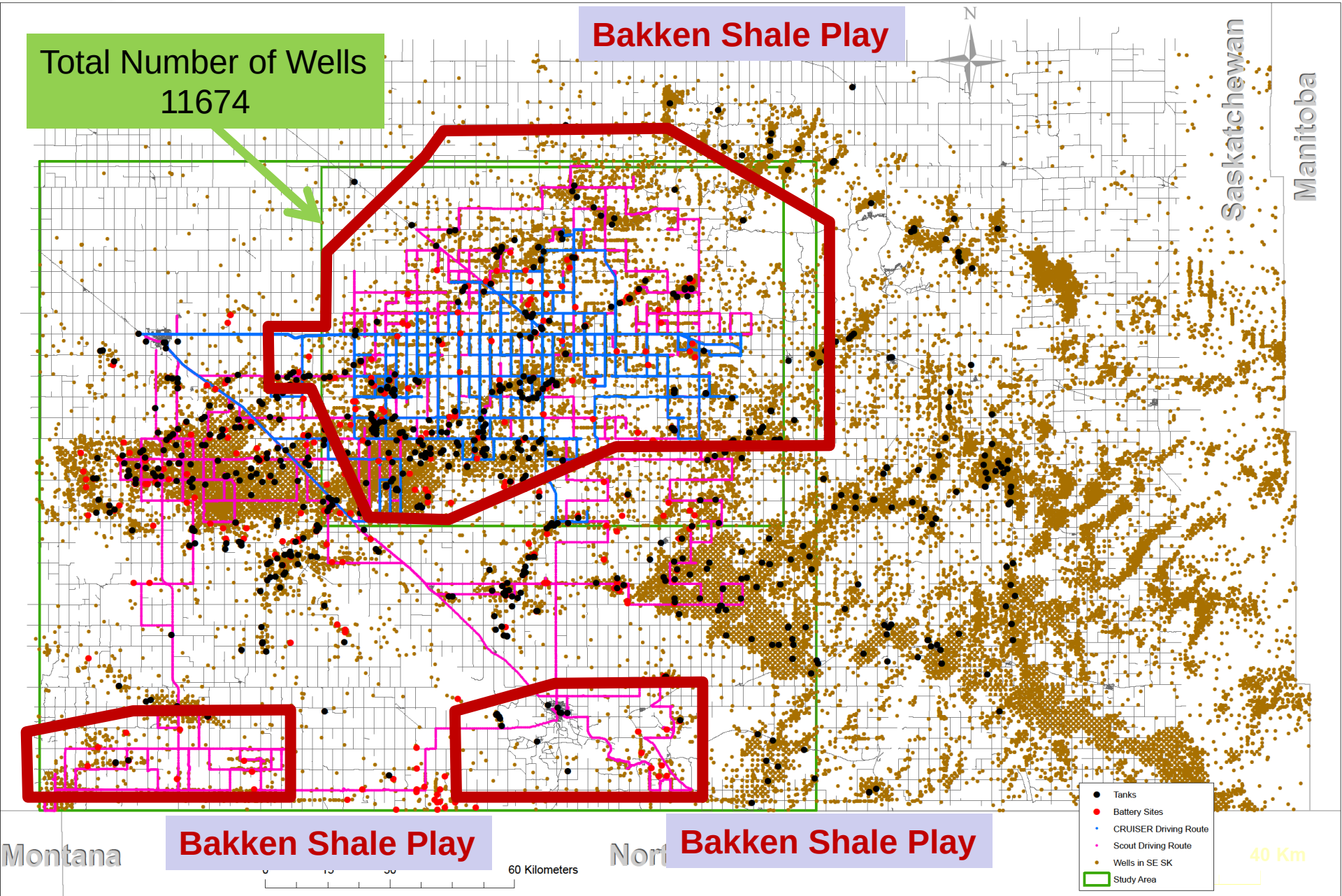
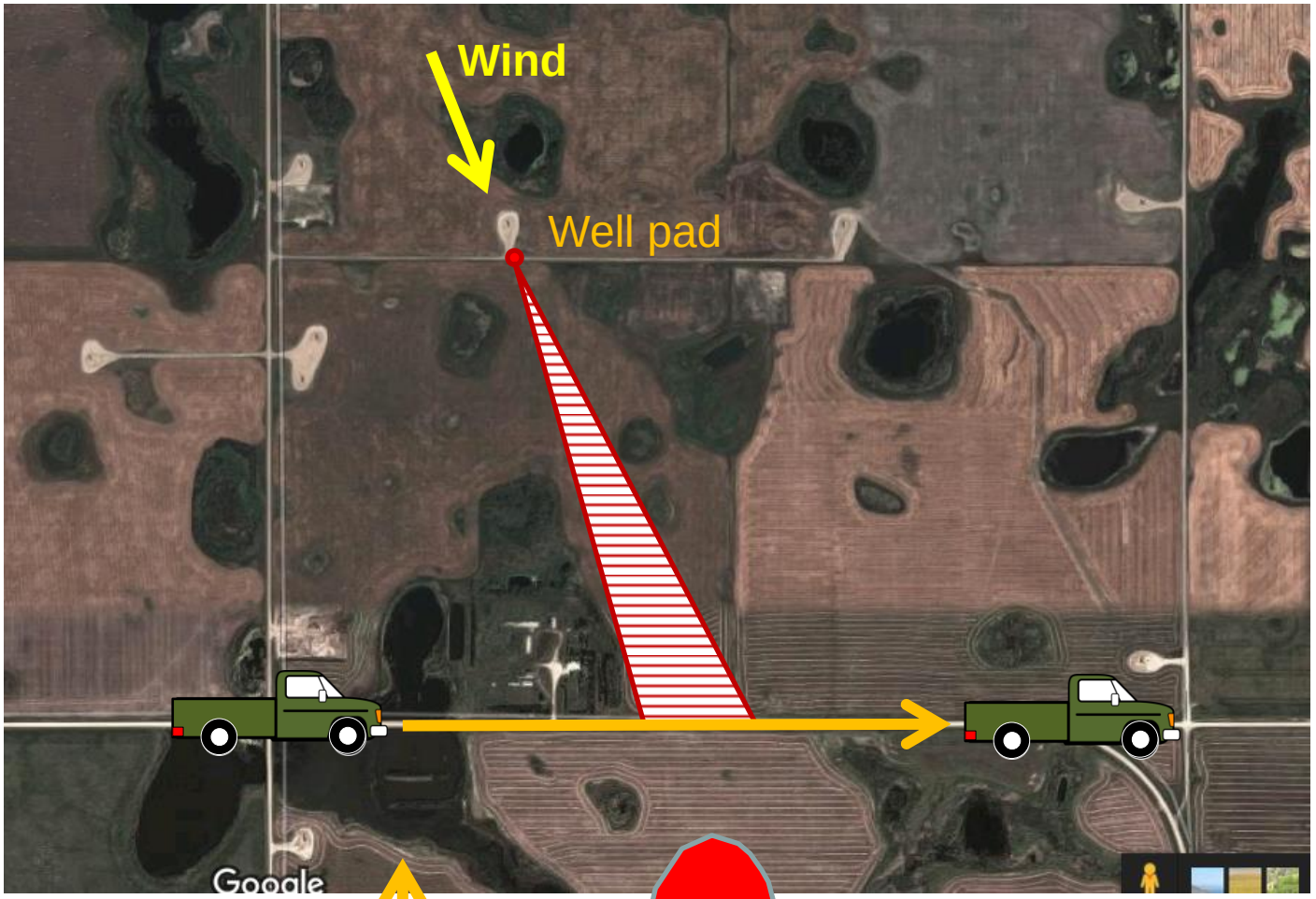


Photo by Andrea Darlington

Well Map and SPEECH Survey Routes



Tracer Release Experiment Design



Summary

- Many chemicals in fracking fluid can be emitted into the air during fracking, thus potentially leading to respiratory exposure risks

- Emissions from continued oil and gas productions from fracked wells can be significant. In gas plants, large amounts of waste gas (e.g., CO_2) are discharged into the atmosphere

- A significant portion of fracked wells has CH_4 emissions from leaks; but a small number of facilities dominate regional CH_4 emissions from these facilities

Contributors to the SPEECH studies

SPEECH 2013 Participants

Katherine Hayden, John Liggio, Julie Narayan, Samar Moussa, Ralf Staebler, Peter Liu, Jason Obrien, Richard Mittermeir, Danny Wang, Paul Makar, Andrea Darlington, Amy Leithead, Stewart Cober, Patrick Thompson, Ka Sung, NRC Aircraft Team

SPEECH 2015 Participants

Ralf Staebler, Julie Narayan, Andrea Darlington, Kathy Hayden, John Liggio, Amy Leithead, Peter Liu, Jeremy Wentzell, Patrick Lee, Richard Mittermeier, Andrew Sheppard, Raymond Atienza, Rajananth Santhaneswaran, Doug Worthy, Morgan Lopez, Bob Kessler, Larry Giroux