CSGM Panel Discussion: Effects and Impacts of Methane Leakage and Emissions

Kirk G. Osadetz[1],
[1]CMC Research Institutes Inc.,

Summary:

Methane (CH_4) in groundwater, soils and the atmosphere has variable impacts and effects, some of which are microbially mediated or indirect. The impacts are identical whether the source is anthropogenic or natural. Recent American studies spatially associate upstream petroleum activities with atmospheric CH_4 and heavier hydrocarbon anomalies, from which they infer the emissions source is primarily from upstream petroleum industry sources. In Alberta recent work has shown that there are clear indications of similar regional atmospheric CH_4 concentration anomalies that are likewise attributed to upstream petroleum activities. The impacts of anthropogenically facilitated CH_4 leakage and emissions can impact: safety, crop and plant Health, groundwater quality, climate and human health. These impacts are well understood and addressed, as they arise, by existing regulatory procedures and actions. The significance and costs of reducing upstream industry CH_4 leakage and emissions should be considered in comparison to natural, agricultural and other sources, some of which are not well characterized.

Introduction:

CH_4 impacts on groundwater, soils and the atmosphere are variable and commonly microbially mediated or indirect. The impacts are identical regardless of whether the source is anthropogenic or natural. Pipeline leakage safety issues after the change from a manufactured to a natural gas supply during the previous century identified and informed these impacts. CH_4 is a powerful greenhouse gas with a GWP_{100} = 28 (IPCC 5th Assessment Report, September 16th, 2016). It has a variety of natural, primarily biogenic, (~29%) and anthropogenic sources. Globally the largest anthropogenic emission sources are agriculture (33%), fossil fuels (19%) and anthropogenic wastes (11%). CH_4 is oxidized, primarily inorganically in the atmosphere where it forms carbon dioxide and water vapor primarily, or it is microbial consumed by methanotrophs in the oceans and the vadose zone of soils. CH_4 emissions from upstream petroleum facilities are a topic of considerable interest and recent policy initiatives, such Alberta plans to reduce upstream petroleum industry emission by 45% by 2025, at an estimated cost of about \$0.045/m^3 (\$1.06 USD/Mcf) CH_4 reduced (Pembina Institute, 2015).

Interest to reduce anthropogenic CH_4 emissions originate with concerns with historical increases in atmospheric CH_4 concentrations and climate impacts, as well as inferred differences between upstream petroleum industry equipment-based inventories of CH_4 emissions compared to monitored atmospheric CH4 concentrations in parts of the United States. Current atmospheric CH_4 levels are inferred to be the highest since ~650,000 years ago (Spahni et al., 2005). Atmospheric CH_4 increased almost 30% during the last 25 years at annualized rates of ~1% during the 1970's-80's, although rates declined recently to near zero (Simpson et al., 2002). Brandt and Petron (2015) estimated leakage from the US gas system using data from American agencies at 45.8 X 10^9 m^3/yr (1.615 Tcf/yr) from: production facilities including wells (10.4%), gas processing (36.5%), gas transportation (7.2%), and gas distribution (45.8%). Brandt and others (2014) showed that “top-down” atmospheric CH_4 concentration were higher than “bottom-up” estimates in petroleum producing regions, where they were also positively correlated with propane anomalies. They inferred that upstream petroleum activities were the source of the atmospheric CH_4 anomalies and that equipment-based upstream petroleum industry CH_4 inventories underestimated CH_4 emissions from those activities.

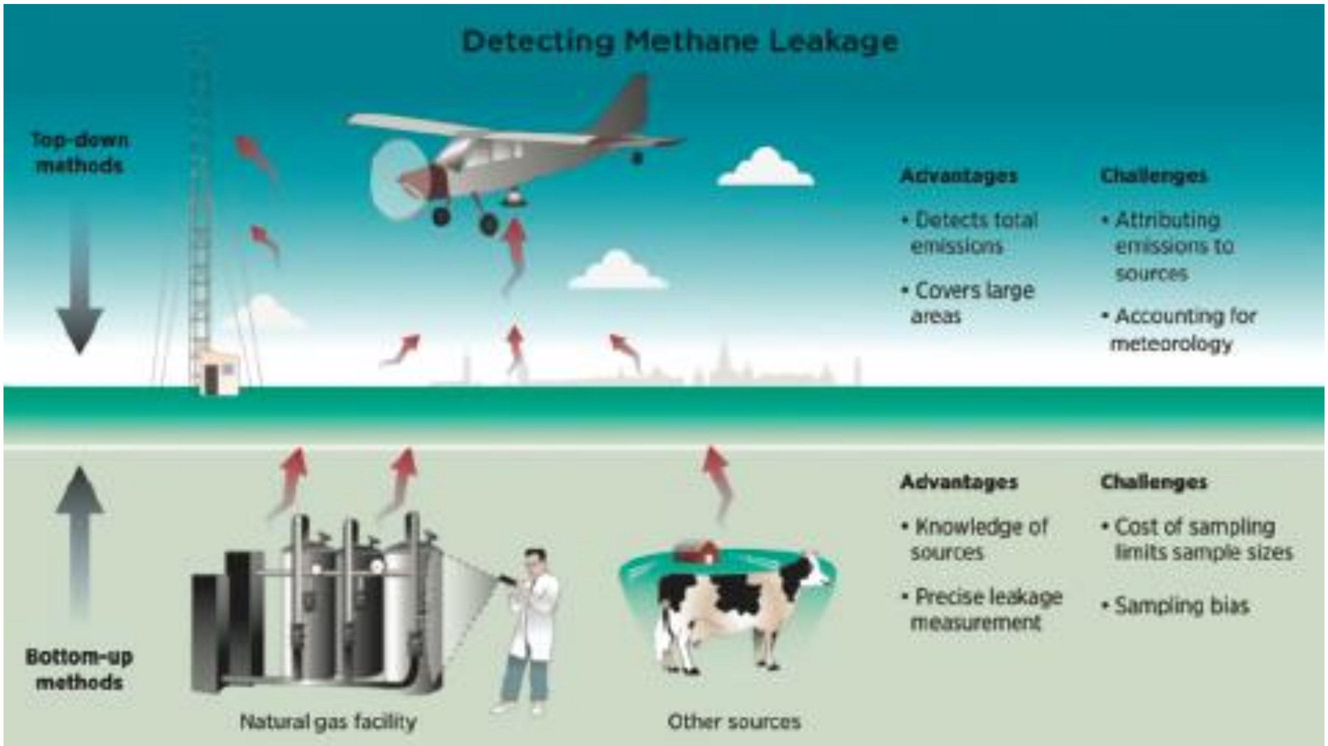

Figure 1: *Illustration of top-down and bottom-up methods for detecting CH_4 leakages. The advantages and disadvantages of the methods are complementary, suggesting important information to be gained from using both methods” (Figure and caption from Brandt and Petron, 2015, their Figure 2).*

Canadian wells and upstream facilities leak and emit methane also. Recently, like the United States, Alberta and B.C. trace gas atmospheric studies have found that find atmospheric CH_4 concentrations (http://aep.alberta.ca/air/reports-data/air-quality-reports-and-surveys.aspx) like global averages regionally (Dlugokencky et al., 2003) exhibit significant local to regional anomalies that suggest a significant upstream petroleum industry CH_4 emission, particularly in the areas where CHOPS production occurs (Johnson et al. 2017a; 2017b), although CH_4 leaks from upstream petroleum facilities appear to be common (Atherton et al., 2017). An interesting feature of these studies is the fact that they do not identify other expected sources of emissions such as water wells, landfills and natural background seepage, which should also be significant emission sources and which should be the topic of additional studies. This is a marked change from previous studies such as, Bottenheim and Shepherd (1995) measured

Canadian C_2-C_6 hydrocarbons over a single year (1991) and concluded that major anthropogenic sources had transportation sources.

The key result of these studies by what the AER would describe as “alternative” monitoring technologies is that they challenge the 2010 Environment and Climate Change Canada (ECCC) upstream industry CH_4 emissions inventory (ECCC, 2014; AER 2016b) which is the current baseline for upstream petroleum industry CH_4 emission reduction targets.

Method:

CH_4 introduction to groundwater, soils and the atmosphere can have variable impacts, the effects of which are identical regardless of the source. Neither does it matter if the source is natural or anthropogenic, irrespective of source category (petroleum wells, water wells, coal mines, municipal landfills, or agricultural activities). The impacts of CH_4 from among other sources, upstream petroleum activities, including SCVF and GM can effect: safety, crop and plant health, groundwater quality, climate and human health.

Examples:

Safety impacts occur because CH_4 is flammable and explosive (Harder et al., 1965). This uncommon impact is prevented currently by “setbacks” of upstream petroleum facilities from habited structures and repairs to gas pipeline leaks. Safety concerns are important where older pipeline systems constructed in urban areas originally distributed manufactured gas (Hamper, 2006) that were later switched to natural gas. Such pipeline leaks identified and characterized many of the impacts associated with subsurface, and near surface impacts on groundwater and plant health (Jackson et al., 2014; Phillips et al., 2013). Crop and plant health impacts are rarely due to CH_4 directly, but more commonly indirectly due to CH_4 microbial oxidation to CO_2 that stress or asphyxiate overlying agriculture or horticulture (Hoeks, 1972;). The effects of anthropogenic and natural CH_4 seepage on plants and crops are indistinguishable (Figure 2; Noomen et al., 2012). Neither has it been possible to attribute specific CH_4 leakage rates with given plants effects because of complicating factors in soils and agricultural practises (Smith et al., 2004; Steven et al., 2006). These include the vadose zone microbial vitality that are adversely affected by agriculture (Levine et al., 2001; Janzen et al., 2008).

Groundwater quality impacts result from reaction of CO_2 from microbial CH_4 oxidation in groundwater. These can change groundwater chemistry, releasing of metals and other compounds. The effects can be extensive and profound further effecting plants and groundwater quality and potablity, as illustrated by a gas well blowout in an uncased well (Kelly et al., 1985). Gas migration associated with well bore integrity issues more commonly have subtle and local impacts, including crop stress or plant mortality (Godwin et al., 1990; Van Stempvoort, 2005). Climate impacts occur because CH_4 is a powerful GHG, as discussed above. Although typically small individually, some estimate that petroleum system CH_4 leaks and emissions have significant economic value that should motivate companies to reduce emissions to “glean” revenues (Pembina Institute, 2015).

Figure 2: Typical pattern of plant impacts at the site of a seepage from Nooman et al. (2012, their Figure 4). In the centre of the seep vegetation is either absent or attenuated. This is surrounded by a halo of "green vegetation that gives way to "background" vegetation. The affected area has a radius of about 30 m, a person is shown scale on the left.

Some humans and all ruminants produce CH_4. There is no direct link to human or animal health for non-safety exposures to CH_4 itself. CH_4 is a common groundwater constituent in WCSB, from natural sources and human and agricultural pollution (Humez et al., 2016). Drinking water guidelines do not proscribe or mention CH_4 and human health impacts are not generally directly attributed to CH_4. Jackson et al (2011) concluded, "We found essentially no peer-reviewed research on [CH_4's] health effects at lower concentrations in water or air". Yet diverse sources indicate a common public concern associated with upstream petroleum activities some of which contribute to CH_4 leakage and emissions (Cherry et al., 2014). Several widely publicized claims of water well contamination attributed to petroleum wellbore integrity issues have been convincingly disproved, despite the persistent claims of surface occupants. In Alberta many water wells are completed in coaly successions and few domestic well owners realize that their production of potable or agricultural water is similar to the process of "coalbed" methane production. The effects of water well production are enhanced by the generally low permeability in the Upper Cretaceous succession due to its provenance and diagenetic history (but that is for a different talk). Drinking water CH_4 impacts are not the same as disinfection by-products impacts that are health hazards (Gopal et al., 2007). West et al. (2006) indicated that the reaction of CH_4 with NO_x's, primarily in urban settings contributes to tropospheric ozone. They proposed a 20% reduction of anthropogenic CH_4 to decrease surface ozone by 1 ppbv to prevent ~370,000 deaths over 20 years.

Possible Actions:

Safety, environmental and economic impacts of SCVF and GM are well documented and addressed, as they arise, by existing regulatory procedures and mitigating and remediating actions. SCVF and GM emissions are a significant part (19.5%) of the ECCC emissions inventory. These emissions are a significant CH_4 volume that needs to be considered and addressed when setting emissions reduction targets. As a result of industrial and regulatory attention to this issue significantly prior current policy initiatives, the emissions from SCVF and GM have declined progressively from 104.3 X 10^6 m^3 in 2008 to an estimated 84.4 X 10^6 m^3 in 2016 (AER, 2016a) mostly from reductions at serious wells. Reliable anecdotal evidence suggests that CH_4 emissions could be reduced further by a comprehensive survey of older non-serious wells, as many as 20% of which may have “died out”. This might reduce emissions by an additional ~11.8 X 10^6 m^3 /yr. Improved well construction techniques and materials have also contributed to a reduction in the average CH_4 emissions from non-serious wells by 40% since 2000. A practical limit for reducing well integrity issues as the average emissions rates from both serious and non-serous wells have “leveled-off” since 2012. Flaring and abandonment are potential, but more costly, strategies to further reduce SCVF emissions from non-serious wells. To what extent and cost additional SCVF and GM emissions reductions should be sought should be informed by a study of cost and benefits that consider all natural and anthropogenic methane emission sources. Questions of groundwater contamination, now commonly primarily addressed by gas isotopic compositional methods should be addressed in more comprehensively, but considering also the impact of water wells and coal mines that also penetrate the aquifer and bedrock successions, possibly using geochemical tracers and fluid flow modelling. Natural fluxes and their seasonal variability should also be better characterized.

Conclusions:

1. CH_4 introduction to groundwater, soils and the atmosphere can have a number of variable impacts and effects.
2. The impacts of CH_4 migration into groundwater, soils and the atmosphere are identical regardless of the source, whether anthropogenic or natural.
3. American studies identify upstream petroleum industry emissions as the source of CH4 concentration anomalies that are correlated with propane anomalies in regions with significant upstream petroleum industry activities
4. In Canada and Alberta particularly new data suggest that there are significant issues with the equipment based inventory of methane emissions and that much larger than anticipated emissions occur regionally, particularly associated with CHOPS production sites.
5. The impacts of anthropogenically facilitated CH4 can have unintended and undesirable effects on: Safety, Crop and Plant Health, Groundwater Resource Quality, Climate and Human Health.
6. These impacts are well documented and addressed, as they arise, by existing regulatory procedures and actions.

References

Alberta Energy Regulator. 2016a. Surface Casing Vent Flow and Gas Migration—Natural Gas Emissions Rates (Draft Copy), June 2016, 10 p.

Alberta Energy Regulator. 2016b. Climate Policy Assurance Team –Backgrounder: Compressors & Dehydrators, Surface-Casing Vent Flows & Gas Migration, and Production Casing (CHOPs) & Tank Venting (Upstream, All Sources) July 20, 2016 (Draft Copy), 11 p.

Alberta Energy Regulator. 2016c. What We Heard: CPAT Technical Focus Group: DRAFT, (Attachment to Personal Communication), 28 p.

Alberta Environment, 2016, http://aep.alberta.ca/air/reports-data/air-quality-reports-and-surveys.aspx

Atherton, E., Risk, D., Fougère, C., Lavoie, M., Marshall, A., Werring, J., Williams, J. P., and Minions, C.: Mobile measurement of methane emissions from natural gas developments in northeastern British Columbia, Canada, Atmos. Chem. Phys., 17, 12405-12420, https://doi.org/10.5194/acp-17-12405-2017, 2017.

Bottenheim, Jan W., Marjorie F. Shepherd, 1995, C2-C6 hydrocarbon measurements at four rural locations across Canada, Atmospheric Environment, Volume 29, Issue 6, Pages 647-664

Brandt, A. R. and Petron, G., 2015. Fugitive Emissions and Air Quality Impacts of US Natural Gas Systems. The Bridge, v. 45/2, p. 22-31.

Brandt, A.R., G. A. Heath, E. A. Kort, F. O'Sullivan4, G. Pétron, S. M. Jordaan, P. Tans, J. Wilcox, A. M. Gopstein, D. Arent, S. Wofsy, N. J. Brown, R. Bradley, G. D. Stucky, D. Eardley, R. Harriss and others, 2014. Methane Leaks from North American natural gas systems. Science, v. 343, p. 733-735 and supplemental material retrieved from: http://science.sciencemag.org/content/sci/suppl/2014/02/12/343.6172.733.DC1/1247045.Brandt.SM.revision2.pdf.

Brigmon, R. L., T. A. Anderson and C. B. Fliermans. 1999. Methanotrophic Bacteria in the Rhizosphere of Trichloroethylene-Degrading Plants. International Journal of Phytoremediation: Vol. 1, No. 3, pp. 241–253.

Cherry, J. and others (2014). Environmental impacts of shale gas extraction in Canada. Ottawa (ON): The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction, Council of Canadian Academies. Council of Canadian Academies.Retrieved from: http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/shale%20gas/shalegas_fullreporten.pdf .

Dlugokencky, E.J., Houweling, S., Bruhwiler, L., Masarie, K.A., Lang, P.M., Miller, J.B. and Tans, P.P. 2003. Atmospheric methane levels off: Temporary pause or a new steady-state? Geophysical Research Letters 30: 10.1029/2003GL018126.

Godwin, R., Abouguendia, Z., Thorpe, J., 1990. Lloydminster Area Operators Gas Migration Team Response of Soils and Plants to Natural Gas Migration from Two Wells in the Lloydminster Area, Saskatchewan Research Council, E-2510-3-E-90, 85 p.

Gopal, K., Tripathy, S., Bersillon, J.-L., Dubey, S. P., 2007. Chlorination byproducts, their toxicodynamics and removal from drinking water, Journal of Hazardous Materials, Volume 140, Issues 1–2, 9 February 2007, Pages 1-6, ISSN 0304-3894, http://dx.doi.org/10.1016/j.jhazmat.2006.10.063.

Hamper Martin J. (2006) Manufactured Gas History and Processes. Environmental Forensics, 7:1, 55-64, DOI: 10.1080/15275920500506790, retrieved from: http://www.tandfonline.com/doi/pdf/10.1080/15275920500506790

Hanson, T. E. and Hanson, R. S., 1996, Methanotrophic Bacteria. MICROBIOLOGICAL REVIEWS, June 1996, p. 439–471 Vol. 60, No. 2

Harder, A.H., Whitman, H.M., and Rogers, S.M., 1965, Methane in the freshwater aquifers of southwestern Louisiana and theoretical explosion hazards: Department of Conservation, Louisiana Geological Survey, and Louisiana Department of Public Works Water Resources Pamphlet no. 14, 22 p.

Hoeks, J., Changes in composition in soil air near leaks in natural gas mains. Soil Science, v. 113, p. 46-54.

Jackson R.B., B Rainey Pearson, SG Osborn, NR Warner, A Vengosh. 2011. Research and policy recommendations for hydraulic fracturing and shale-gas extraction. Center on Global Change, Duke University, Durham, NC. p. retrieved from: https://nicholas.duke.edu/cgc/HydraulicFracturingWhitepaper2011.pdf

Humez, P., Mayer, B., Ing, J., Nightingale, M., Becker, V., Kingston A., Akbilgic, O., Taylor, S., 2016. Occurrence and origin of methane in groundwater in Alberta (Canada): Gas geochemical and isotopic approaches. Science of the Total Environment, v. 541, p. 1253-1258.

Jackson, R. B., Down, A., Phillips, N. G., Ackley, R. C., Cook, C. W., Plata, D. L., Zhao, Z., 2014. Natural gas pipeline leaks across Washington D.C., Environmental Science and Technology. v. 48/3, p. 2051–2058, DOI: 10.1021/es404474x.

Johnson, M.R., Tyner, D.R., Conley, S., Schwietzke, S. and Zavala-Araiza, D., 2017a. Comparisons of Airborne Measurements and Inventory Estimates of Methane Emissions in the Alberta Upstream Oil and Gas Sector. Environmental Science & Technology 2017 51 (21), 13008-13017, DOI: 10.1021/acs.est.7b03525

Johnson, M.R., Tyner, D.R., Conley, S., Schwietzke, S. and Zavala-Araiza, D., 2017b. Supporting Information, Comparisons of Airborne Measurements and Inventory Estimates of Methane Emissions in the Alberta Upstream Oil and Gas Sector. Environmental Science & Technology 2017 51 (21), p. S1-S12.

Levine, U. Y., Tracy K Teal, G. Philip Robertson, Thomas M Schmidt. 2011. Agriculture's impact on microbial diversity and associated fluxes of carbon dioxide and methane. The International Society for Microbial Ecology Journal. v. 5, p. 1683–1691

Noomen, M. F., Harald M.A. van der Werff, Freek D. van der Meer. 2012. Spectral and spatial indicators of botanical changes caused by long-term hydrocarbon seepage Ecological Informatics v.8, p. 55–64

Pembina Instiute, 2015, Economic Analysis of Methane Emission Reduction Opportunities in the Canadian Oil and Natural Gas Industries, a report prepared for the Environmental Defense Fund, Calgary and New York, 117p. https://www.pembina.org/reports/edf-icf-methane-opportunities.pdf.

Phillips, N. G., Robert Ackley, Eric R. Crosson, Adrian Down, Lucy R. Hutyra, Max Brondfield, Jonathan D. Karr, Kaiguang Zhao, Robert B. Jackson, 2013. Mapping urban pipeline leaks: Methane leaks across Boston, Environmental Pollution, Volume 173, , Pages 1-4, ISSN 0269-7491, http://dx.doi.org/10.1016/j.envpol.2012.11.003.

Simpson, I.J., Blake, D.R. and Rowland, F.S. 2002. Implications of the recent fluctuations in the growth rate of tropospheric methane. Geophysical Research Letters 29: 10.1029/2001GL014521

Smith, K. L., Colls, J. J., and Steven, M. D., 2005. A facility to investigate effects of elevated soil gas concentration on vegetation. Water, Air and Soil Pollution, v. 161, p. 75-96.

Steven, M. D., Smith, K. L., Beardsley, M. D., and Colls, J. J., 2006, Oxygen and methane depletion in soil affected by leakage of natural gas. European Journal of Soil Science. V. 57, p. 800-807.

Van Stempvoort, D., Maathuis, H., Jaworski, E., Mayer, B., Rich, K., 2005. Oxidation of Fugitive Methane in Ground Water Linked to Bacterial Sulfate Reduction. Groundwater. V. 43/2, p. 187–199.

West, J.J., Fiore, A.M., Horowitz, L.W., Mauzerall, D.L., 2006. Global health benefits of mitigating ozone pollution with methane emission controls. Proceedings of the National Academy of Sciences U.S.A. 103, 3988e3993.