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 propane anomalies. In Canada and Alberta the situation is not obvious. Upstream activities are documented CH_4 sources, but there is no clear indication of regional atmospheric concentration anomalies. 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. 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 some policy initiatives, such Alberta plans to reduce upstream petroleum industry emission by 45% by 2030, 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.

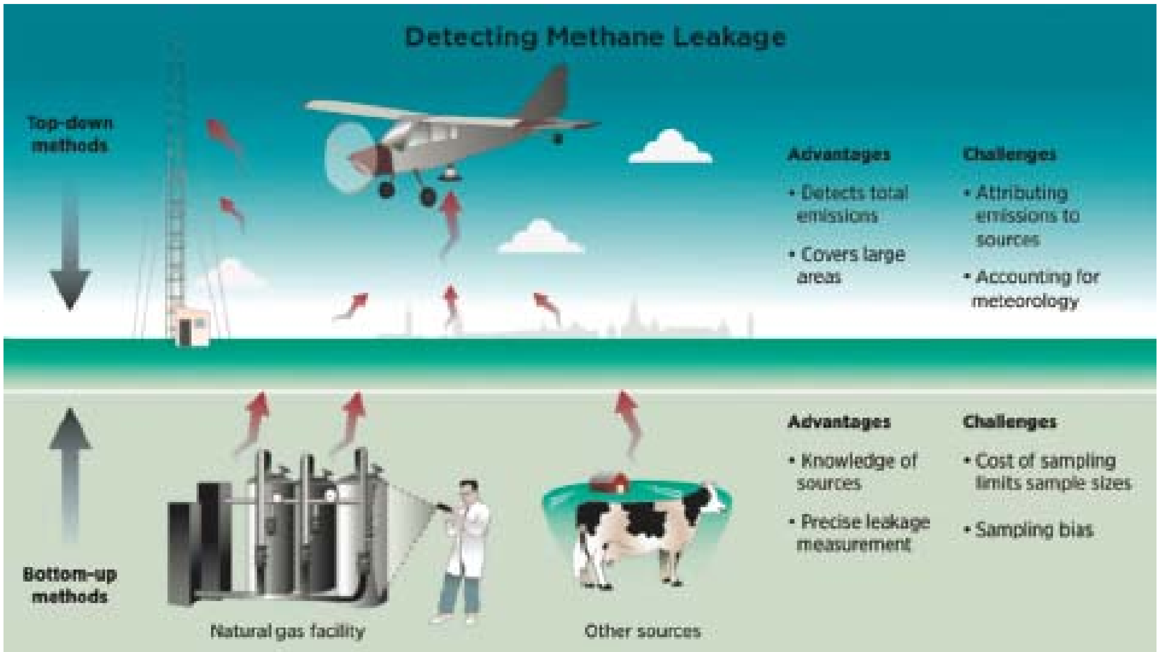

Figure 1: *Illustration of top-down and bottom-up methods for detecting CH_4 leakages. The advantages and disadvantages of the methods are complementary, suggesting important information to be gained from using both methods" (Figure and caption from Brandt and Petron, 2015, their Figure 2).*

Canadian wells and upstream facilities leak and emit methane, but unlike the United States, Alberta air quality surveys find atmospheric CH_4 concentrations (http://aep.alberta.ca/air/reports-data/air-quality-reports-and-surveys.aspx) like global averages (Dlugokencky et al., 2003). Bottenheim and Shepherd (1995) measured Canadian C_2-C_6 hydrocarbons over a single year (1991) and concluded that the major sources were anthropogenic. Their measurements showed seasonal and other trends, including weekday-weekend trends that correlated with CO observations suggesting that atmospheric C_2-C_6 hydrocarbons primarily had transportation sources.

Table 1: 2010 Alberta CH_4 emission inventory for upstream petroleum activities (AER, 2016b).

Methane Emissions by Sector and Source, 2010			
Sector	**Source**	**Total (kt/y)**	**% Share of Total**
Natural Gas Production	Unreported Venting	209.179	21.2%
Accidents and Equipment Failures	Surface Casing Vent Flow and Gas Migration	192.464	19.5%
Heavy Crude Oil Cold Production	Reported Venting	158.285	16.0%
Light/Medium Crude Oil Production	Unreported Venting	82.115	8.3%
Natural Gas Production	Fugitive Equipment Leaks	80.79	8.2%
Light/Medium Crude Oil Production	Reported Venting	52.829	5.3%
Light/Medium Crude Oil Production	Fugitive Equipment Leaks	34.648	3.5%
Gas Transportation	Fugitive Equipment Leaks	26.542	2.7%
Natural Gas Production	Fuel Combustion	22.479	2.3%
Heavy Crude Oil Cold Production	Fugitive Equipment Leaks	22.078	2.2%
TOTAL		**987.742**	**100%**

The 2010 Environment and Climate Change Canada (ECCC) upstream industry CH_4 emissions inventory (ECCC, 2014; AER 2016b; Table 1) is the baseline for upstream petroleum industry CH_4 emission reduction targets. The 2010 CH_4 emissions estimate attributed to "Accidents and Equipment Failures" comes predominantly from surface casing vents and gas migration, which was estimated at 192.464 kt CH_4, an increase from previous estimates. The observed and measured 2010 (AER, 2016a) SCVF and GM CH_4 emissions data was 95.1 X 10^6 m^3 (Table 3, Figure 9, from AER 2016a) or ~63.5 kt CH_4. It appears that the ECCC inventory overestimates some Alberta upstream industry CH_4 emissions categories which could impose higher CH_4 reduction targets than defined using AER data (AER, 2016b). The AER Climate Policy Assurance Team confirms this discrepancy and are working to resolve it.

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 (Smith et al., 2004; Steven et al., 2006). These include the vadose zone microbial vitality that are adversely affected by agriculture practice (Levine et al., 2001; Janzen et al., 2008).

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.

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 (Pembina Institute, 2015).

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 claims of surface occupants. 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. Although possibly significantly overstated 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. CH4 introduction to groundwater, soils and the atmosphere can have a number of variable impacts and effects.
2. The impacts of CH4 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 the situation is more complicated. While upstream petroleum industry activities are clear sources of CH4 there is no clear indication that they produce regionally identifiable atmospheric concentration anomalies.
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.

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