FASTER AND FURTHER:

Canada's Methane Strategy

September 2022

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Canada

Cat. No.: En4-491/2022E-PDF
ISBN: 978-0-660-45545-7
EC22117

Environment and Climate Change Canada
Public Inquiries Centre
12th Floor, Fontaine Building
200 Sacré-Coeur Boulevard
Gatineau QC K1A 0H3
Telephone: 819-938-3860
Toll Free: 1-800-668-6767 (in Canada only)
Email: enviroinfo@ec.gc.ca

Cover photo: © Getty images

Aussi disponible en français

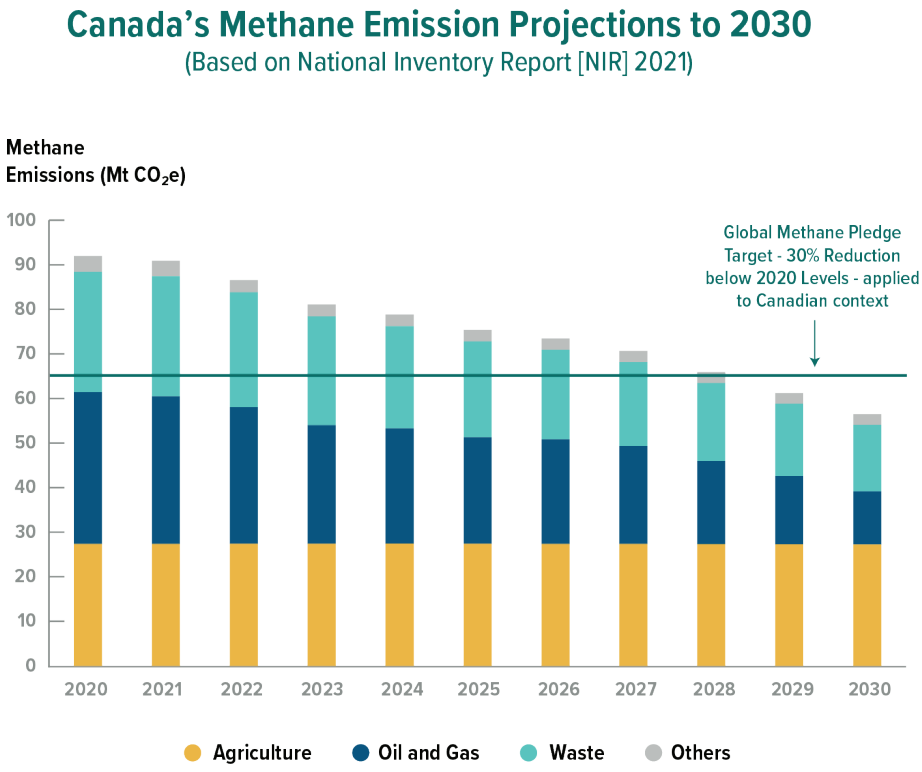
Table of contents

EXECUTIVE SUMMARY

Canada's 2030 Emissions Reduction Plan sets out an ambitious and achievable roadmap for Canada to reach its emissions reduction target of 40-45% below 2005 levels by 2030 and net-zero emissions by 2050. A key next step on this path is tackling methane emissions, which is one of the lowest cost opportunities to make important progress in the short-term on our climate goals.

Methane is a powerful greenhouse gas (GHG) that is responsible for roughly 30% of global warming since pre-industrial times. Lowering methane emissions is critical to limiting the rise of near-term global temperatures and the related impacts, such as increased wildfires, more severe storms and increased drought.

The good news is that significant progress has already been made to reduce methane emissions in Canada. This strategy builds on that progress with plans to further reduce methane in oil and gas, agriculture and at landfill sites. With the methane reduction measures and supporting programs outlined in this strategy – current and planned – we estimate that Canada will be able to reduce domestic methane emissions by more than 35% by 2030, compared to 2020.



Emissions Reduction Plan (ERP) Methane Projections by Economic Sector[1]

1 Canada's emissions pathway will change with future projections as emissions quantification is continuously improved. The ERP projections were based on the 2021 National Inventory Report (NIR); however, the 2022 NIR included significant revisions to historical methane emissions from the oil and gas sector, which will impact future projections.

Internationally, calls for action are increasing and Canada is proud to be one of those voices responding to that call. In November 2021, Canada joined over 100 countries in supporting the Global Methane Pledge (GMP). This pledge commits members to a collective goal of reducing human-caused methane emissions by 30% below 2020 levels by 2030. More recently, Canada joined as an inaugural member supporting the GMP Energy Pathway. As part of Canada's broader climate finance efforts, Canada has allocated $2 million over the next four years to support methane mitigation projects in developing countries. Canada was also the first country to commit to achieving at least a 75% reduction in methane emissions from its oil and gas sector from 2012 levels by 2030.

Although these methane reduction targets are ambitious, they are also doable. In many ways, Canada is already ahead of the game. We were one of the first countries in the world to introduce federal regulations in 2018 to reduce oil and gas methane. As well, Canadian clean technology companies have been very innovative at finding ways to detect, monitor, avoid and reduce methane emissions. This strategy aims to boost Canada's role as a first-mover on methane action. While this document focuses on federal efforts, ongoing complementary action by provinces, territories, municipalities, Indigenous groups, industry, the waste and agricultural sectors and others is critical to ensuring a successful reduction of methane emissions.

This strategy also looks at the science behind methane measurement and reporting. The accuracy and understanding of how much and where methane is emitted – and that it is reported properly – is critical to achieving methane targets. Canada will continue to develop and share innovations in methane science working with our domestic and global partners, including on improving detection methods and monitoring. As part of this work, Canada will establish a global centre of excellence on methane detection and elimination.

Canada's continued involvement in various international efforts to reduce methane is also an important part of this strategy. Canada will keep working with global partners – such as through the Globe Methane, Climate and Clean Air Forum – to encourage and support global methane reductions and prevention. This includes continuing to help developing countries, where there are often many opportunities for low-cost methane reductions.

The Government of Canada has a number of formal consultation processes underway and plans to work with partners, stakeholders and the public on regulations and other opportunities to reduce methane. Finding the most effective and efficient ways to implement measures and reduce emissions will help bring Canada closer to meeting its 2030 GHG target, while also building our clean technology expertise and taking a global leadership role in the low-carbon economy future.

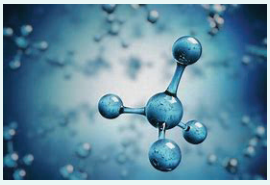
1. INTRODUCTION

Why Reduce Methane

Methane is a potent greenhouse gas (GHG) with at least 25 times the warming potential of carbon dioxide (CO_2) over a 100-year period. Methane is also classified as a short-lived climate pollutant meaning it stays in the atmosphere for a short time compared to other gases like CO_2. As a result, actions to cut methane emissions will quickly lower their atmospheric concentrations and lead to a relatively quick climate response. Methane also contributes to the formation of ground-level ozone, which negatively impacts air quality. This causes serious health problems like reduced lung function and asthma attacks, and is responsible for half a million premature deaths globally each year.

What is methane (CH_4)?

Methane is a colourless, odourless and highly flammable gas. It is the primary component of natural gas and it is also generated naturally during decomposition of organic materials, such as plant matter and animal wastes.



Momentum is growing internationally for urgent and immediate action to reduce methane. Scientists estimate that methane has contributed about 30% of observed global warming to date and that the level of atmospheric methane continues to rise (see Figure 1). Recent reports by the Intergovernmental Panel on Climate Change (IPCC), the Climate and Clean Air Coalition (CCAC) and the United Nations Environment Programme point to the need to significantly and urgently reduce global methane emissions this decade, alongside deep cuts in CO_2, in order to achieve the Paris Agreement temperature goal of limiting global warming to 1.5 degree Celsius. The International Energy Agency (IEA)'s Global Methane Tracker 2022 notes a rapid and sustained reduction of methane emissions is both achievable and essential to limit the rise in global average temperatures.

The Global Methane Assessment released in May 2021 estimates that human-caused methane emissions can be reduced by up to 45% this decade, and approximately 60% of methane reduction measures discussed in the report are considered to be low or negative in net costs, meaning companies could, in some cases, see an economic benefit from using or selling recovered natural gas. This is largely because methane is the main component in natural gas, and when captured, it can be used as a fuel. The IEA Global Methane Tracker 2022 highlights that the wasteful leakage of methane is all the more striking given today's backdrop of elevated natural gas prices. It states that the methane leaks in 2021 from fossil fuel operations, if captured and marketed, would have made an additional 180 billion cubic metres of gas available to the market, an amount similar to all the gas used in Europe's power sector.[i]

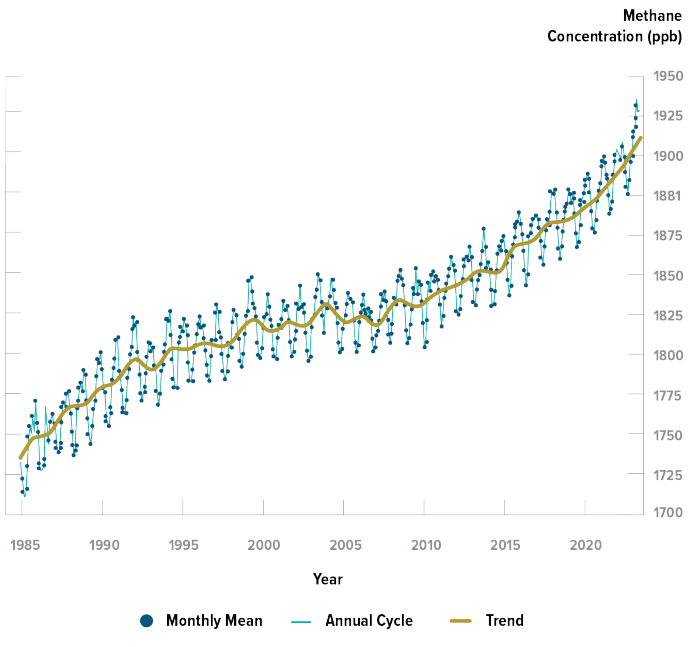


Figure 1: Methane Trend from Environment and Climate Change Canada's Laboratory in Alert, Nunavut

Taking Action

At the 26th annual United Nations Climate Change Conference of the Parties in November 2021 – known as COP26 – Canada and over 100 other countries joined the Global Methane Pledge. The Pledge aims to reduce global human-caused methane emissions across economic sectors by at least 30% from 2020 levels by 2030. Signatories include 15 of the top 30 global methane emitters and account for nearly 50% of global anthropogenic methane emissions. As part of this commitment, the Government of Canada is producing this methane strategy to demonstrate the significant progress made to date to address methane emissions from key sectors in Canada and highlight plans and opportunities for further action.

The Government of Canada has a suite of existing and forthcoming cross-sectoral regulations and programs in place that can contribute to reducing Canada's methane emissions, as well as other GHGs. A description of some of these various measures can be found in Annex 1. Of particular interest in the context of methane mitigation are the opportunities to generate credits under federal and provincial offset systems, which may create incentives and reduce mitigation costs. For example, Canada's Greenhouse Gas Offset Credit system provides a financial incentive to reduce methane emissions through activities such as landfill methane recovery and destruction, and livestock feed management.

Although Canada has continually worked to advance and improve our scientific knowledge and understanding of emissions and their impacts, our commitment to the Global Methane Pledge is a recognition that more can be done on methane to support Canada's efforts to reach our overall GHG emissions reduction targets. Further work includes building on existing efforts and exploring options to establish a global centre of excellence on methane detection and elimination in fulfillment of a previous commitment by the Government. Canada is continuing to collaborate in various international fora to encourage other countries to take action and share our clean technology advancements. In addition, the Government of Canada recognizes that provincial governments, municipalities, Indigenous peoples and the private sector play an important role in efforts to reduce Canada's methane emissions. While these efforts are also critical to achieving Canada's climate goals, they are not reflected in detail in this document, which focuses on federal actions.

2. MEASUREMENT, SCIENCE, INNOVATION AND REPORTING

2.1 Emissions Reporting

Canada's Methane Emissions

Each year, Canada submits a report on its official GHG emissions, including methane, to the United Nations Framework Convention on Climate Change (UNFCCC) in the *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada* (NIR). Canada also tracks emissions (including methane) from individual facilities through its Greenhouse Gas Reporting Program (GHGRP).[2]

Based on the latest NIR (published in April 2022), methane emissions in 2020 represented 14% of Canada's total GHG emissions (Figure 2). Over 95% of Canada's anthropogenic methane emissions are from three key sources: 1) oil and gas operations (38%); 2) agriculture (30%); and 3) waste/landfills (28%) (Figure 3). There were also smaller amounts of methane emissions from other sectors, such as transportation, residential buildings and coal mining.

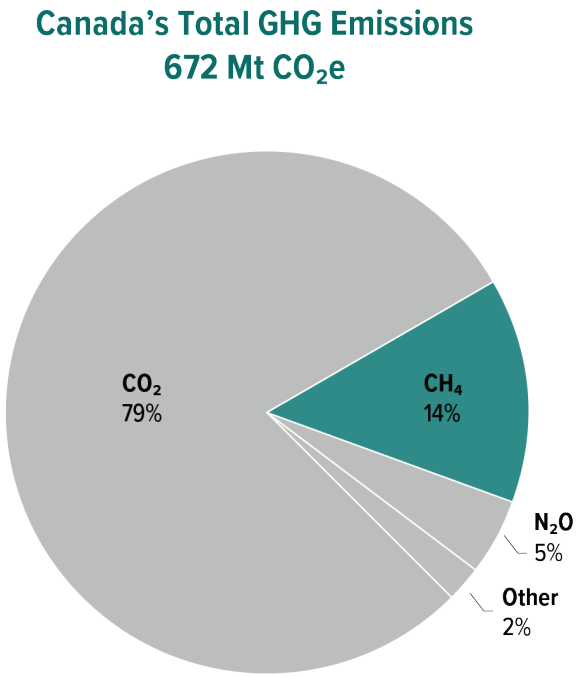


Figure 2: Canada's Total GHG Emissions (2020)

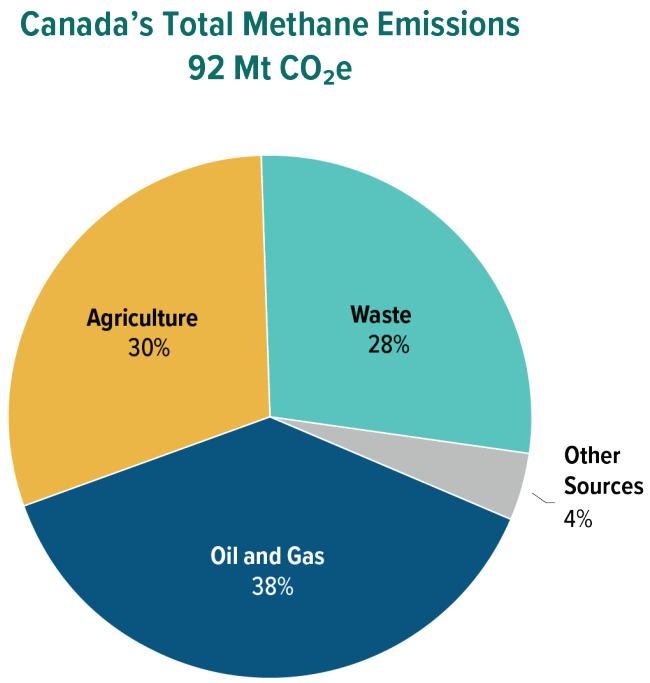


Figure 3: Canada's Total Methane Emissions by Sector (2020)

2 Facility-level reporting of methane emissions represents a small subset (16%) of national-level methane emissions reported in the NIR due to a 10 kilotonne CO_2 equivalent reporting threshold and the scope of emissions targeted (i.e., largely, industrial point sources).

The spatial distribution of Canadian methane emissions for the three major source sectors in 2018 are shown in Figure 4.[3] The vast majority of the oil and gas sector's methane emissions are from Alberta, Saskatchewan and northeastern British Columbia, whereas other sources of methane emissions like livestock and solid waste are spread across more regions of Canada, and methane emissions from solid waste appear to be particularly concentrated near major cities, particularly in southern Ontario and Quebec.

Canada's Anthropogenic Methane Emissions (2018)

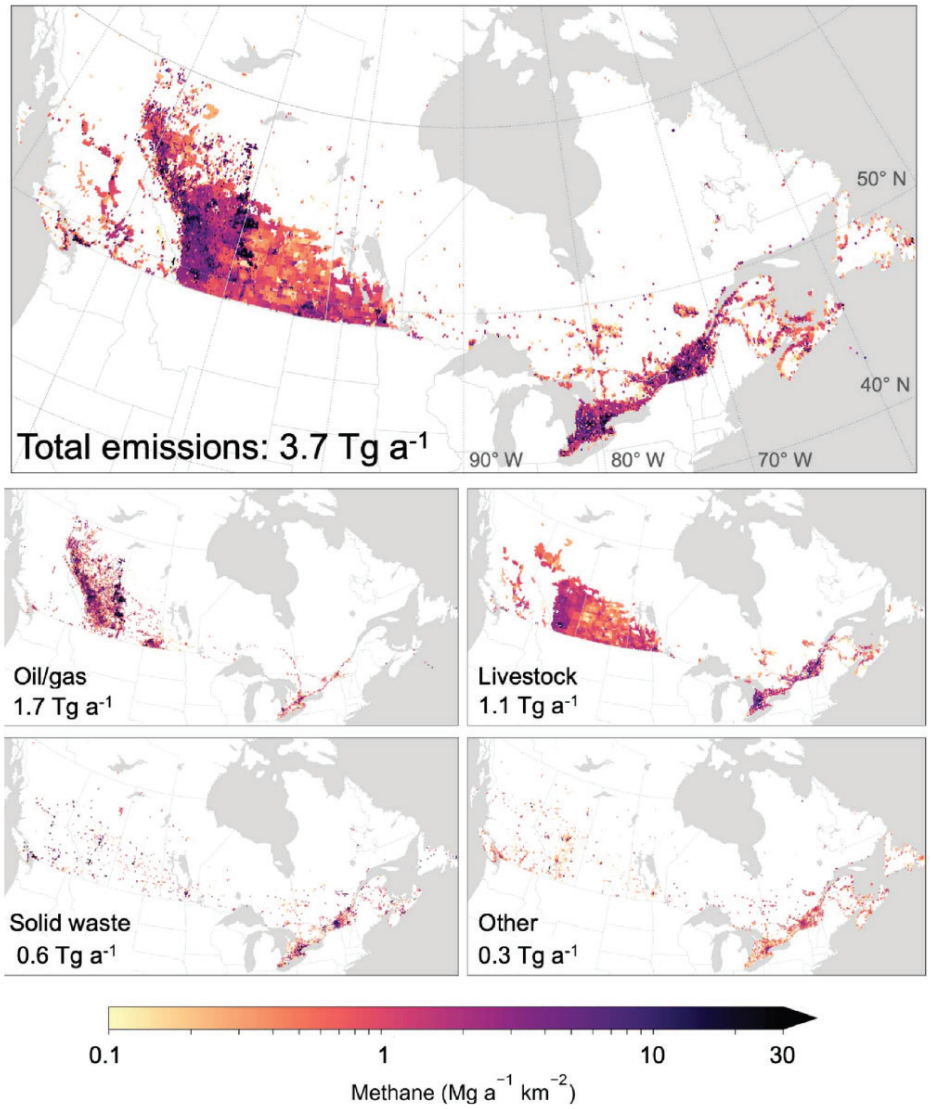


Figure 4: Anthropogenic methane emissions in Canada (2018)[ii]

3 This information is based on the 2020 NIR and was spatially allocated based on inventory information as well as country-specific geospatial data.

Planned and Potential Future Improvements

Continuous improvement is a key principle for the NIR. The 2021 edition included significant improvements to the estimation of methane emissions from landfills, and the 2022 edition included a new fugitive emission model to estimate methane emissions from components in the upstream oil and gas industry. The changes in the 2022 edition resulted in upward revisions to estimated methane emissions from the oil and gas sector of between 31% and 39% for the years 2010 to 2019 (Figure 5). This revision will impact Canada's next annual emissions projections, which use NIR information.

Future planned improvements to NIR methane estimates are being developed for the three main source sectors in Canada, specifically: 1) on-going work to continue to improve estimates of methane emissions from oil and gas sources; 2) leveraging facility reported emissions for the landfill sector; and 3) improving emission estimates from agricultural sources by using more complete data on production practices affecting enteric methane, as well as an improved understanding of factors controlling the formation of methane by microbes in stored manure. More information on NIR planned improvements can be found in Chapter 8 of the full report.

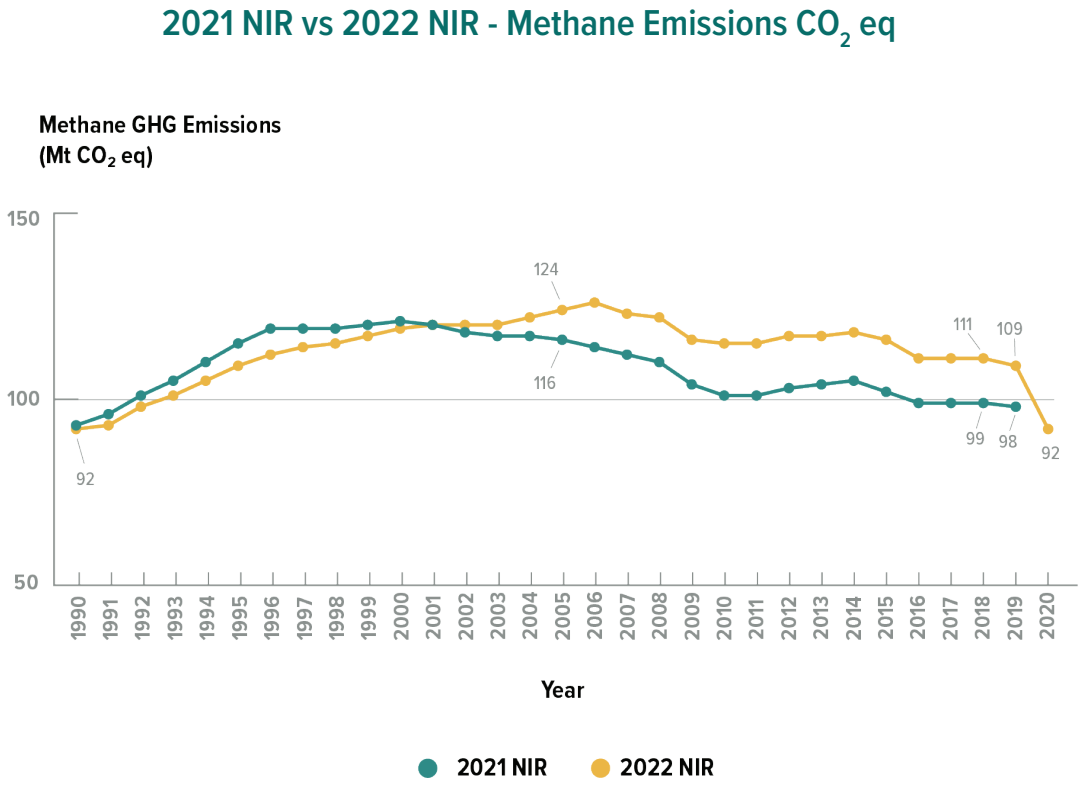


Figure 5: Methane Emissions Quantification Improvements

2.2 Methods for Measuring and Modelling Methane in the Atmosphere

There are several methods for measuring and modelling methane in the atmosphere. The diversity of sources and landscapes in Canada means that some measurement methods are better than others for measuring particular sources of atmospheric methane. Measurements of atmospheric methane are generally used for research purposes to improve the precision of detection technologies, but are also increasingly being used to support improved inventory reporting and the prediction of future atmospheric conditions.

Monitoring of Methane in the Atmosphere

Environment and Climate Change Canada (ECCC) has been measuring atmospheric GHG concentrations in Canada since 1975. Across Canada, a number of fixed monitoring sites are maintained long-term, while additional sites are project-based and thus short-term (Figure 6).

Figure 6: Long-term atmospheric monitoring sites in Canada that measure methane (ECCC)

Measuring atmospheric methane in a specific place (in-situ monitoring) relies on deploying instruments in areas that are representative of the methane source region(s) to be investigated. Recent studies have shown that long-term observations can be analyzed to estimate emissions from specific source regions.[iii]

In addition to fixed monitoring sites, mobile systems (e.g., aircraft) can also be utilized to undertake facility-scale emission monitoring or perform regional surveys that identify emission hot-spots and can also characterize methane plumes. Each of these different methodologies provide critical information by discovering unknown emission hotspots, and by supporting reported emissions through their validation (Figure 7).

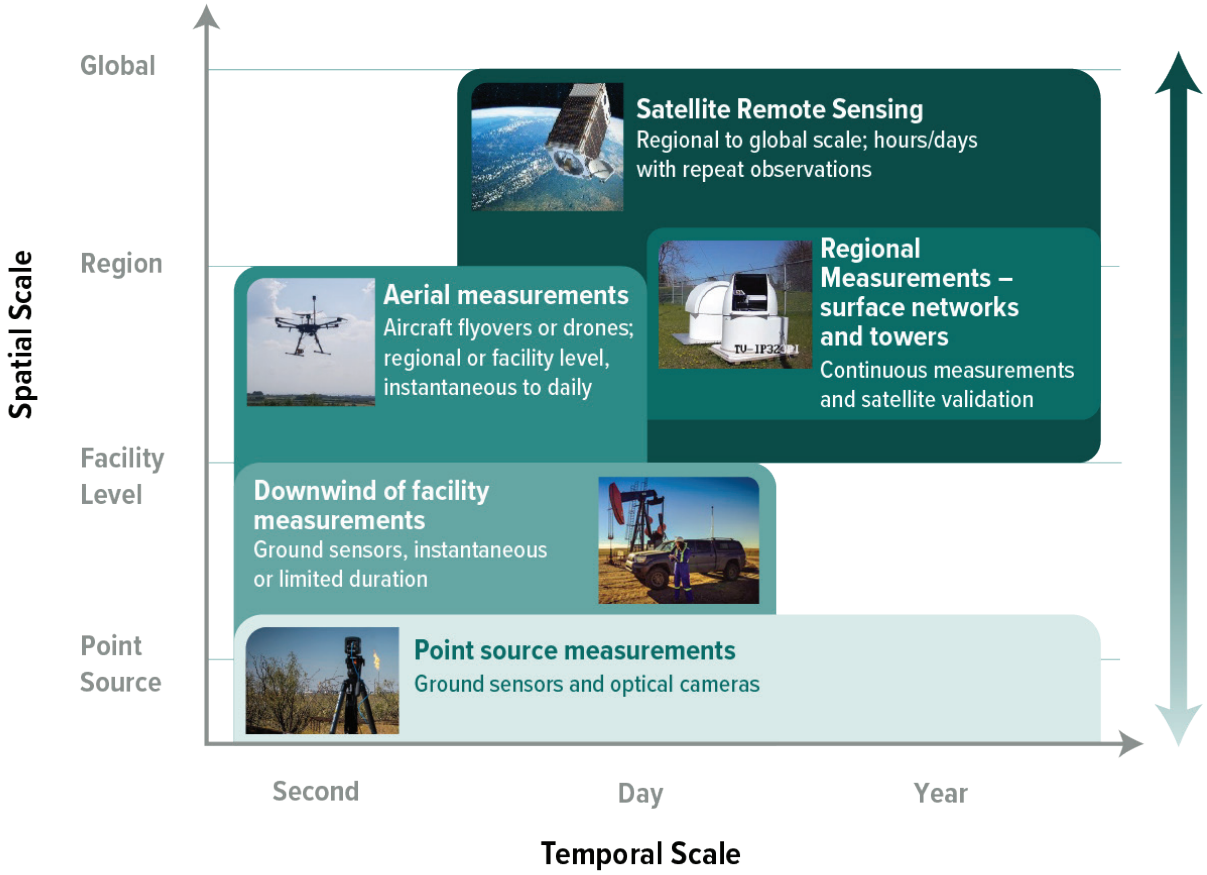


Figure 7: Emissions Measurement and Monitoring

Remote Sensing Methods

A growing area of research is the use of remote sensing methods to derive methane concentrations along a path (ground-based spectrometers, interferometers and light detection and ranging), or through a volume of air (aircraft or satellite-based), from which emissions can then be derived by using wind information (Figure 8). These approaches, in which the Canadian research community has proven to demonstrate global leadership, can now detect and quantify methane emissions on global and regional scales or urban/facility scales. Satellite Earth Observations are also an emerging area. Current sensors provide either global observations at coarse resolution, such as through Greenhouse Gases Observing satellites (GOSAT/GOSAT-2) or the Tropospheric Monitoring Instrument on board the Copernicus Sentinel-5 Precursor satellite, or at selected smaller targeted areas at higher resolution, such as observations conducted by GHGSat or the PRISMA hyperspectral satellite (Figure 9). These satellites offer the potential to identify large sources of methane under certain environmental conditions, but at present, there is insufficient data density. The many new instruments scheduled to launch over the next five years will greatly increase available data and will improve the ability to assess regional-scale methane emissions, complementing conventional monitoring methods.

Atmospheric Modelling of Methane

Atmospheric models exist that provide estimates of methane emissions for different domains in Canada, including local, regional, provincial, and national scale, based on atmospheric observations, meteorological data and locations of methane sources (anthropogenic and natural). It is now possible to use atmospheric models to estimate natural methane changes in Canada's sub-Arctic region, as well as Western Canada's anthropogenic oil and gas emissions. At smaller scales, modelling systems have allowed the analysis of methane emissions in the Greater Toronto Area and the quantification of emissions from individual facilities, such as landfills. Observation-based flux estimations enable greater understanding of Canada's natural methane source response to climate change, as well as the analysis of emission trends. Given that methane persists in the atmosphere for about 12 years, and has various anthropogenic and natural sources over land, sources can be challenging to differentiate using modelling tools alone. Observing and modelling multiple gases that are likely to be co-emitted with methane can help improve source identification (See Annex 2 for additional information on methods of measuring and modelling methane).

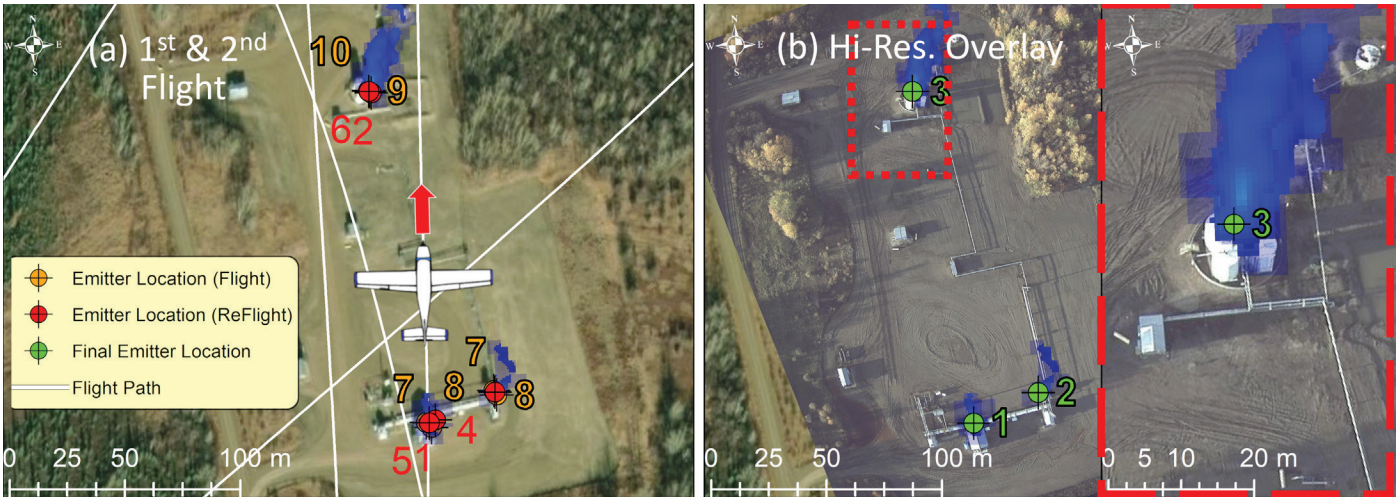


Figure 8: Airborne methane source detection by the Energy & Emissions Research Lab at Carleton University using Brigder Photonics LiDAR[iv]

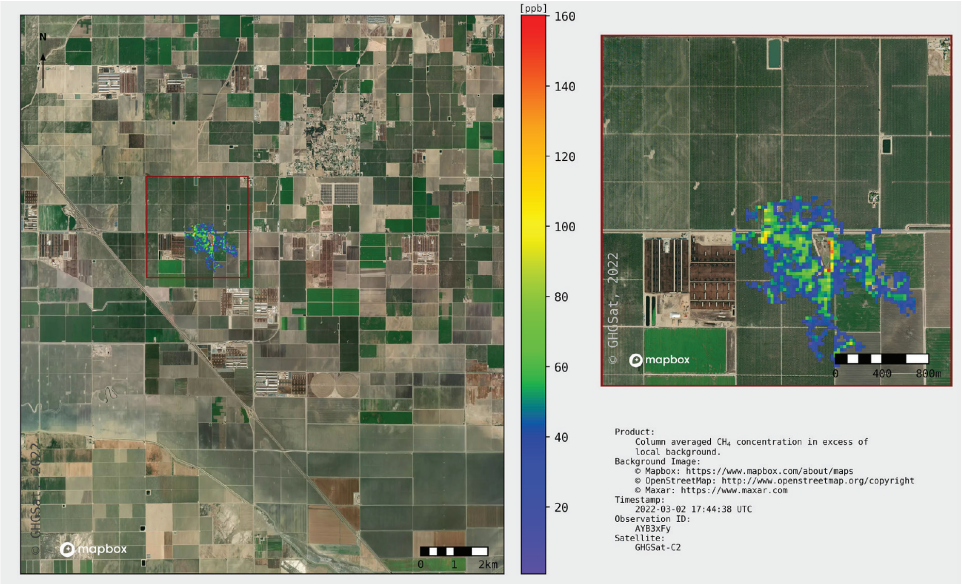


Figure 9: GHG Sat's high-resolution satellites capture methane emissions from a cattle feedlot in California's Joaquin Valley[v]

2.3 Tracking our Progress Using Emission Quantification Methods

Under the UNFCCC, the measurement, reporting and verification of GHG emissions will continue to be critical to track our progress. Both traditional emission reporting methods and estimates of emissions using atmospheric observations are now considered useful tools in determining emissions of methane, including their trends over time. The two approaches are generally referred to as:

- **Bottom-up** methods, which rely on the use of statistical approaches, typically developed from scientific studies and field measurements of individual sources that ascribe a unit of emissions to a specific source under given conditions. These parameters — generically called "emission factors" — are used with activity data to estimate emissions for sources and added up to provide a sector total.
- **Top-down** methods, which use atmospheric measurements of GHGs at a given time (i.e., during short-term field campaigns) and then apply inverse modelling and scaling to estimate sector emissions.

In Canada, recent top-down studies have demonstrated that bottom-up inventories under-estimate methane emissions from the oil and gas industry by between 25-90%.[vi, vii, viii, ix] These discrepancies have been shown to exist from the local (e.g., component, facility) to the national scale. For example, by temporarily expanding the national GHG monitoring network, researchers quantified a gap of +90% between observed and reported oil and gas methane emissions for Alberta and Saskatchewan. Airborne studies conducted in Canada have also revealed large discrepancies between reported and observed methane emissions for oil and gas production facilities and regions (both conventional and oil-sands), while mobile surveys in cities have highlighted the relevance of landfills and natural gas distribution infrastructure as methane sources.[x] Efforts are underway to reduce these discrepancies (e.g., conducting atmospheric studies, and collecting activity-data to support updated emission factors and using atmospheric models), including NIR improvements that resulted in recent upward revisions to estimated methane emissions from the oil and gas sector.

Top-down methods have also highlighted the significance of "super-emitters," where a small number of facilities contribute a disproportionately high percentage of total emissions due to abnormal or unforeseen processes. Regular observational surveys can help identify and eliminate emissions from these super-emitters.

At present, UNFCCC inventory guidelines require the reporting of source-specific estimates, which are obtained by the vast majority of countries, including Canada, using bottom-up methods alone. However, top-down methods are increasingly being used to improve the validity and robustness of emission estimates. The continued development of both bottom-up activity data and top-down methods is needed to continue to improve these estimates and reduce uncertainties. This would include regular, coordinated observational studies across multiple time and space scales and multiple source sectors, leveraging the broad range of expertise available in Canada. With targeted efforts and enhanced coordination, these studies will continue to increase confidence in our ability to accurately report on progress towards meeting our emission targets.

The Government of Canada recognizes that there are further opportunities to increase the integration of methane data and information from multiple sources (such as companies, association surveys, satellite providers, scientific studies and national inventories) and across various economic sectors and value chains. Integrating data into a coherent and policy relevant dataset would support a better understanding and quantification of emissions, informing clean technology innovation, evaluation and deployment, and mitigation efforts, including regulatory design and compliance. Building on Canada's expertise and global leadership in methane measurement and mitigation technology, we will continue to work with partners domestically and internationally to increase transparency, trust and the robustness of the measurement, monitoring and reporting of methane. For example, the Government of Canada is supporting multiple academic-federal collaborative research activities to advance the use of measurements and modelling to improve quantification of methane sources in a variety of contexts, such as working with Carleton University to advance aerial measurements in western Canada and with the private sector to investigate capability of satellite technology for the oil and gas sector.

In addition, ECCC continues its leadership to advance national climate change science through the implementation of Climate Science 2050: Advancing Science & Knowledge on Climate Change, Canada's first climate change science and knowledge plan. This plan is intended to focus investment and prioritize the research and knowledge mobilization to inform ongoing and ambitious efforts to achieve a net-zero, resilient Canada.

3. MITIGATION ACTION

3.1 Current 2030 Projections

The GHG emissions projections in the Government of Canada's 2030 Emissions Reduction Plan included mitigation measures and supporting programs underway and planned, as of March 2022. A breakdown of methane emissions by sector from the "bottom-up modelling approach" can be found in Table 1. Through this analysis, the estimated methane emission reductions in 2030 from 2020 levels for the three key emitting sectors are:

- Oil and gas: 65% reduction (which is equivalent to a 75% reduction from 2012 levels);
- Landfills/waste: 45% reduction; and,
- Agriculture: 1% reduction.[4]

The following sections describe these mitigation measures and programs, as well as pointing to opportunities for further action.

Table 1. 2030 Emissions Reduction Plan Methane Results by Economic Sector (in megatonnes of CO_2e)[5]

Sector/Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Agriculture	27.37	27.36	27.38	27.40	27.41	27.39	27.37	27.34	27.33	27.29	27.22
Buildings	1.30	1.28	1.24	1.20	1.16	1.12	1.08	1.05	1.01	0.97	0.94
Electricity & Steam	0.17	0.19	0.24	0.23	0.25	0.24	0.26	0.23	0.20	0.19	0.18
Heavy industry	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20
Oil and Gas	34.06	33.10	30.67	26.61	25.87	23.87	23.43	21.99	18.64	15.30	11.94
Others	1.34	1.26	0.47	0.46	0.42	0.40	0.40	0.39	0.40	0.40	0.41
Transportation	0.59	0.61	0.62	0.63	0.66	0.66	0.66	0.66	0.67	0.68	0.68
Waste	26.98	26.95	25.76	24.39	22.92	21.54	20.10	18.82	17.49	16.22	14.90
Grand Total	**91.99**	**90.93**	**86.57**	**81.11**	**78.89**	**75.41**	**73.50**	**70.68**	**65.93**	**61.26**	**56.46**

4 Agricultural methane emissions have already decreased by 20% since 2005, due to several factors including increased productivity per animal resulting from improved genetics, management, and nutrition. The figure does not account for recent programming which has an estimated additional 0.25 Mt reduction in methane emissions from agriculture. These numbers will be revised further with updated production information and as new technologies and practices become available. For example, further enteric methane reductions could be achieved through the use of feed additives and grazing strategies, however, the former requires regulatory approval in Canada while the latter requires further research to determine the most effective methods and methodologies to. measure changes. Additional emissions reductions associated with manure management can require costly infrastructure and operational modifications. These topics are discussed further in Section 3.4.

5 This analysis uses the 2021 NIR and does not reflect the recent revisions to historical methane emissions from the oil and gas sector, which will affect future modelling predictions. As well, this analysis does not reflect any potential mitigation efforts in the agriculture sector, including through advances in clean technology, adoption of methane-reducing beneficial management practices and existing technologies, or participation in carbon markets by Canada's livestock producers.

3.2 Oil and Gas

Key Mitigation Actions

- Federal methane regulations were published in 2018 to reduce oil and gas methane emissions from 2012 levels by 40-45% by 2025.
- An Emissions Reduction Fund was created to invest in green technologies to lower or eliminate methane and other GHG emissions from the oil and gas sector.
- Strengthened methane regulations are being developed to achieve at least a 75% reduction of oil and gas methane emissions by 2030 from 2012 levels. Proposed regulations will be published in 2023.

Methane Emission Sources

As a major economic contributor to the country and Canada's largest source of GHG emissions, the oil and gas sector has a critical role to play in meeting Canada's climate objectives. The oil and gas sector is the largest emitter of methane in Canada, responsible for about 38% of Canada's methane emissions in 2020, as reported in Canada's 2022 NIR. Many oil and gas industry activities emit methane, including exploration, drilling, production, field processing, gas gathering, refining, and transmission and distribution. However, most of the methane emissions from this sector are from upstream activities: the production and field processing of light and heavy crude oils, bitumen, natural gas and natural gas liquids (Figure 10). The types of production facilities and their future levels of production activity can have a significant impact on future methane emissions. Methane emissions can vary significantly by production activity and from one site to another, depending on a variety of factors (e.g., gas composition, access to gas gathering infrastructure, equipment types, operating conditions/practices).

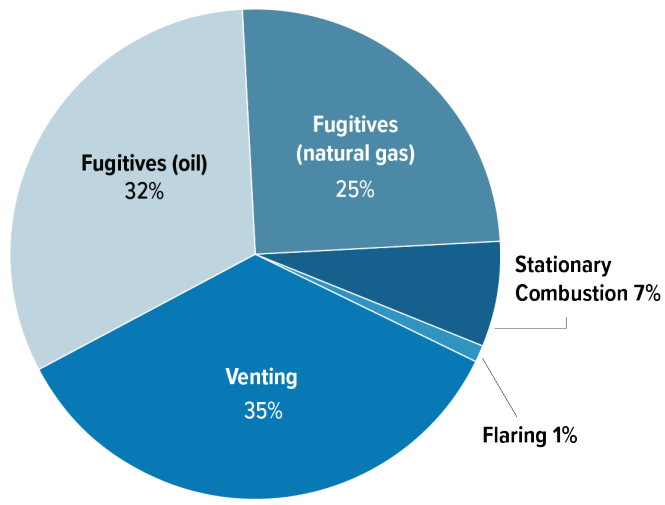


Figure 10: Canada's Oil and Gas Sector Methane Emissions (2020)

Methane emissions in the oil and gas sector are often categorized according to how they are released:

- **Venting:** Intentional equipment venting for operational or safety reasons occurs when natural gas is used to operate controllers and pumps. Compressors increase gas pressure to transport it, but typically vent small volumes. Tanks and other systems not designed for high pressure are directly vented, or incorporate safety systems that may vent gas to ensure the equipment does not fail due to pressure changes. At oil production facilities, when infrastructure to deliver gas off-site is not available and there is no immediate need for the gas on site as fuel, produced gas is typically flared or vented.
- **Fugitives:** Emissions from unintentional leaks or equipment failures may result from deterioration of equipment, especially seals and fittings, or improper installation or operation of equipment. Such emissions occur at all stages of production, processing and transmission, across all equipment and facility types. Area sources are also fugitive emissions, present at oil sands production and processing operations in Canada, where methane is emitted during surface mining activities and from tailing ponds.

- **Stationary Combustion:** Combustion of natural gas as a fuel or disposal in flaring systems can result in methane emissions where combustion is incomplete – that is light hydrocarbons 'slip' through the flame as methane rather than being converted to CO_2).

Challenges and Opportunities

Globally, reducing methane emissions from the oil and gas sector is one of the lowest-cost GHG reduction opportunities, partly because methane gas that is conserved is a marketable product and can be sold as fuel (natural gas). Methane emission control measures in the oil and gas sector can have substantial co-benefits for other air pollutants, including reducing volatile organic compounds and black carbon.

Oil and gas methane emissions can be continuous, intermittent or temporary, and this variability creates challenges to reduce emissions. Where methane emissions are continuous and significant, measures to capture and use or manage methane are generally clearly identifiable and can be relatively low-cost. Where emission sources or releases are temporary, intermittent, low volume, diffuse or unexpected, mitigation can be more challenging.

Reducing methane emissions to meet Canada's objectives for 2030 will require current technology to be deployed on a much greater scale than currently underway, along with developing new solutions that may be at an earlier stage of technical readiness. Achieving deeper reductions of at least 75% by 2030 will also require actions that go beyond the lower-cost opportunities. New and enhanced technologies, including a number of made-in-Canada technologies, have been developed that reduce methane emissions through electrification, fuel switching, efficiency improvement, and mitigating fugitive emissions. Adding gas gathering and processing infrastructure would accommodate gas conservation measures.

In March 2022, the Oil and Gas Climate Initiative, comprised of major international oil and gas companies, announced a target of near-zero methane emissions from oil and gas production by 2030. This is in recognition of alignment in the sector to drastically cut these emissions. It also reflects the achievable nature of reductions in the sector in the short-term. This ambitious commitment will help inform the Government's approach to achieving its 2030 methane target.

Cost-Effective Mitigation Approaches

A number of cost-effective technologies and measures are available to reduce methane emissions from oil and gas operations. Many pieces of equipment in the oil and natural gas value chains emit natural gas (which is composed primarily of methane) in the regular course of operation, including valves, and gas-driven pneumatic controllers and pumps. Retrofitting these devices or replacing them with lower-emitting versions can reduce emissions.[xi] Canada's 2018 methane regulations were estimated to reduce methane emissions at an average cost of $17 per tonne of GHGs ($CO_2$ equivalent), even without accounting for the additional benefits of spurring clean technology development. Some of the most cost-effective mitigation approaches include:

- **Leak Detection and Repair:** regular inspection and repair of sites using instruments to detect leaks and emissions due to improper operations;
- **Gas Capture Technologies:** devices such as vapour recovery units and plungers can be installed to capture gas and pair it to an end use that is less harmful than direct release to the atmosphere;
- **Pneumatic Devices and Engines:** replace gas-powered pneumatic devices and gasoline or diesel engines with electric-powered equipment or with compressed air or other gases; and
- **Compressors:** replace compressor seals or rod to limit venting; replace pressurized gas pumps and controllers with electric or air systems.

Federal Actions

Table 2 below highlights Canada's federal existing and upcoming measures targeting oil and gas methane.

Table 2. Action to Reduce Methane Emissions from the Oil and Gas Sector

Methane Measure	Target
Current Regulatory Requirements	
• In 2018, Canada published the *Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector)*. • The regulations cover key fugitive and venting emission sources in the upstream oil and gas sector, including leaks, general facility production venting, venting from pneumatic devices, venting from compressors, and venting from well completions involving hydraulic fracturing. The first requirements came into force in January 2020, with the rest coming into force by 2023. • By 2020, the Government of Canada entered into Equivalency Agreements with the Governments of British Columbia, Alberta and Saskatchewan, each of which have provincial methane regulations in place that will achieve the same or better reductions than the federal regulations. These agreements enable regionally-tailored approaches to methane mitigation in their respective oil and gas sectors. • In December 2021, a federal review of Canada's oil and gas methane regulations concluded that Canada is on track to meet its 2025 target.	40 to 45% reduction of methane emissions by 2025 of 2012 levels
New Regulatory Requirements Under Development	

• In March 2022, ECCC launched public consultations through a discussion paper to inform the development of more stringent regulations to achieve further methane emission reductions in the oil and gas sector.
  ○ The paper sought comments on two regulatory design options:
  ▪ Building on the current regulatory approach, expanding fugitive emissions management and other requirements in order to reach the target of at least 75% reductions; and
  ▪ Shifting to a new performance-based approach, such as facility-level emissions intensity standards.
  ○ The availability of standardized monitoring technologies will influence the design of the regulations. ECCC is also exploring options for addressing super emitters.
• ECCC will continue to engage Indigenous organizations, industry, research organizations and civil society on regulatory options and complementary measures.
• ECCC plans to publish proposed regulations will be introduced in the first half of 2023 and final regulations in 2024.
	At least 75% reduction of methane emissions by 2030 of 2012 levels

Emissions Reduction Fund	

Methane Measure	Target
• Launched in the fall of 2020 as a COVID-19 response measure, the Emissions Reduction Fund (ERF) includes a $675 million Onshore Program for eligible oil and gas companies to invest in green technologies to lower or eliminate methane and other GHG emissions from regulated sources, with funding available until March 31, 2023. • As of March 2022, ERF Onshore Program had funded 93 projects across Alberta, Saskatchewan, British Columbia and Manitoba. • Applications are currently being reviewed under the program's third intake period.	Under the third intake, only projects that fully eliminate methane emissions – exceeding regulatory requirements – will be considered for funding
Support for Clean Technology Innovation	

• The Government of Canada has made a number of investments to support clean technology development related to methane mitigation in the oil and gas sector. Examples include:
  ○ Clean Resource Innovation Network (CRIN) – The Government's Strategic Innovation Fund provided $100 million to CRIN's Technology Development and Deployment Program, which includes methane emissions as a focus area of projects.
  ○ The Canadian Emissions Reduction Innovation Network (CERIN) – A collaborative initiative jointly funded by the federal and Alberta governments that brings together academia, governments and industry and provides testing platforms in industrial field and laboratory settings to accelerate the development, validation and deployment of technologies that reduce oil and gas sector emissions, including methane.
	Advancing oil and gas methane emissions measurement and mitigation technology development and deployment

3.3 Landfills/ Waste

Key Mitigation Actions

- Developing new regulations to increase recovery and destruction of methane from large municipal solid waste landfills by about 50% by 2030 from 2019 levels.
- Working with provinces and territories to support and accelerate resource and energy recovery efforts for biodegradable waste, which would contribute to additional GHG reductions over the longer term.

Methane Emission Sources

In 2020, Canada's waste sector was responsible for about 28% of Canada's total methane emissions. The majority of these emissions were from municipal solid waste landfills (Figure 11). Landfill methane emissions in 2020 were about the same as they were 20 years ago, meaning mitigation efforts by provinces, territories, municipalities and the private sector to reduce emissions have only managed to keep pace with Canada's growing population (up 23% during this time) and the associated increase in waste generated (up 16% between 2002 to 2018). By 2030, approximately 40% of the methane that will be generated will be created by biodegradable waste that was disposed before 2020. In 2019, the 270 largest landfills in Canada received almost 90% of the total quantity of waste disposed. Those landfills were responsible for over 85% of Canada's annual landfill methane emissions.

Biodegradable waste, including food, yard waste, paper, wood and others, makes up over 60% of the waste disposed in Canada. In 2018, about 16 million tonnes of biodegradable waste were landfilled (about 85% of the quantity generated).

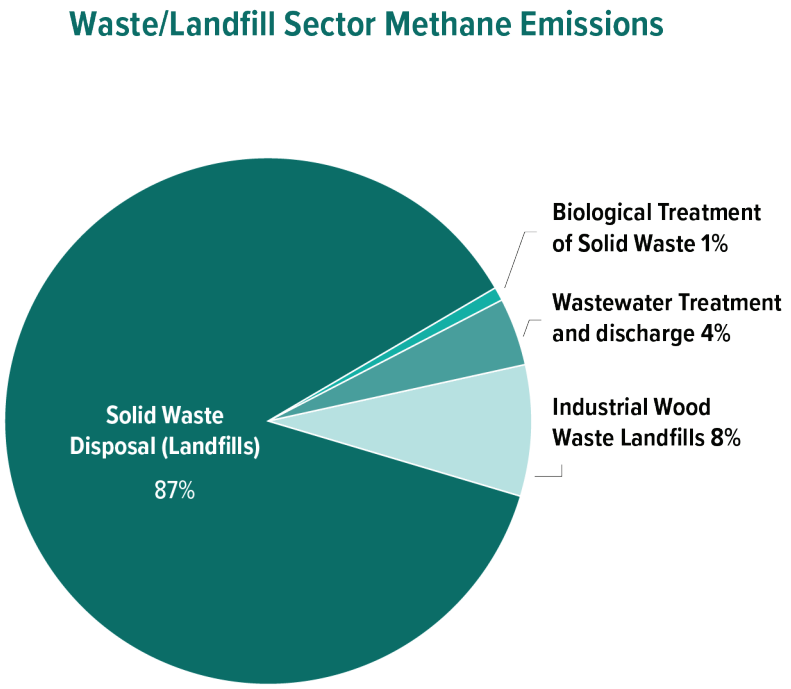


Figure 11: Canada's Waste/Landfill Sector Methane Emissions (2020)

Challenges and Opportunities

Capturing Methane – The Government of Canada recognizes that several provinces have implemented requirements to capture methane emissions from landfills. However, these requirements are inconsistent across jurisdictions and are generally less stringent than what is technically and economically feasible with modern capture, measurement and monitoring approaches. Increasing the number of landfills that capture methane and improving existing capture systems can reduce annual landfill methane emissions by about 50% by 2030 from the 2019 level.

Using Methane – Although 112 large landfills across Canada already have methane recovery systems, only about half of the recovered methane was utilized as a renewable energy source in 2019. Key challenges include access to capital and/or financial incentives, accessibility of end-markets/users, and limited opportunities for smaller landfills

that lack the scale to make projects viable. In 2019, the Government announced up to $1.5 million in funding to help the Region of Waterloo increase gas collection efficiency and use at the Waterloo Landfill facility.

Diversion of Biodegradable Waste – Composting, anaerobic digestion, recycling (paper, wood, natural fiber textiles), mechanical biological treatment and thermal treatment are alternative approaches that avoid landfill methane generation, and can achieve additional GHG reductions through resource and energy recovery. Where municipal organics diversion programs are in place across Canada, the garbage stream still contains 31% food waste and other compostable organics (such as soiled paper) that could have been diverted.

Non-Residential Sectors – Where there are no policies requiring Canada's industrial, commercial, institutional, and construction and demolition sectors to divert their organic waste, they have defaulted to the lower cost and more convenient option of landfilling. Recently, Québec, Ontario and British Columbia announced organic waste diversion targets that apply to both residential and key non-residential sectors. Achieving these targets will keep significant additional tonnage of organic waste out of landfills and recycle this waste into beneficial end-products, such as compost, digestate and biogas.

Cost-Effective Mitigation Approaches

The infrastructure needed to recover methane from large landfills is cost-effective, with an average estimated cost of less than $50 per tonne of CO_2 equivalent reduced. There are also opportunities for larger landfills to generate revenue from using captured landfill gas for heat/energy, renewable natural gas, etc. For smaller landfills, active methane recovery may also be cost-effective at certain sites, and experience in implementing other approaches, such as passive methane oxidation (e.g., biocovers) is increasing, albeit limited. Diverting biodegradable waste to alternative management approaches can also be cost effective, particularly at larger scale, with estimated costs ranging from $50 to > $100 per tonne of CO_2 equivalent reduced.

Planned Federal Regulations and Other Measures

Building on the actions taken by some provinces to incent projects that divert organic waste and mitigate landfill methane emissions, the federal government is developing regulations to ensure consistency and stringency across the country. Table 3 highlights key existing and upcoming measures targeting methane reductions from the waste sector.

Table 3. Action to Reduce Methane Emissions from the Waste Sector

Methane Measure	Target
Federal Landfill Methane Regulations	
• The Government of Canada is developing new regulations to increase recovery and destruction of methane from municipal solid waste landfills. • A discussion paper was published in January 2022, seeking public input on the design and scope of the regulations, including which landfills should be regulated and how to ensure that regulated landfills maximize methane recovery, whether the regulations should also require or stimulate diversion of organic waste from landfills, and whether they should require or encourage the utilization of recovered methane to produce low-carbon fuels (e.g., biogas and renewable natural gas) and energy. • Consultation with a Technical Working Group in fall 2022 will support the development of a Proposed Regulatory Framework, which will be published early in 2023 for public comment. • Draft regulations are planned for 2024, with final regulations anticipated to be in force in 2025.	Reduction of about 50% per year by 2030, from the 2019 level

Methane Measure	Target
Market-Based Measures	
• *Clean Fuel Regulations* and *Canada's Greenhouse Gas Offset Credit System Regulations* will create incentives for the recovery and destruction of methane from municipal solid waste landfills. • The federal *Landfill Methane Recovery and Destruction* offset protocol provides an incentive to reduce landfill methane from non-regulated small to medium-sized landfills, and from non-regulated large landfills before the proposed federal landfill regulations are finalized. Projects can generate federal offset credits, which can be used by facilities covered by the federal Output-based Pricing System to compensate for excess emissions. • The *Clean Fuel Regulations* may increase demand for biogas. Biogas and renewable natural gas derived from landfill gas are eligible to create credits under the regulations. Methane reductions from landfill gas management could also reduce the carbon intensity of the biogas and renewable natural gas, resulting in more credits.	Additional emission reductions by 2030 and beyond
Canadian Council of Ministers of the Environment Aspirational Waste Reduction Goals	
• Provinces, territories and municipalities have in place regulations, extended producer responsibility requirements and/or funding programs to encourage or require the diversion of biodegradable waste from landfills. • Some have or are considering landfill disposal bans for certain biodegradable materials. • Numerous municipalities, representing a majority of the country's population, have implemented residential diversion programs for food and kitchen organic waste and/or leaf and yard waste.	30% reduction in waste disposal by 2030 and 50% reduction by 2040
Food Waste Reduction Challenge (Government of Canada)	
• Launched in 2020, the Food Waste Reduction Challenge is a $20 million initiative to incentivize development and deployment of innovative solutions for reducing food waste across the food supply chain. • The federal government is working with provinces and territories to support and accelerate resource and energy recovery efforts for biodegradable waste. • The federal government will continue to assess the need for additional federal measures to ensure these reductions are realized.	Additional methane emission reductions from diversion activities by 2030
Support for Infrastructure and Technology Development	
Federal examples: • Investing in Canada Infrastructure Program • Low-Carbon Economy Challenge Fund • Canada Community Building Fund • Clean Fuels Fund • Energy Innovation Program Provincial examples: • British Columbia, Quebec and Manitoba are investing in organic waste diversion infrastructure and programs. • British Columbia and Quebec have targets and programs for renewable natural gas. • Ontario has a voluntary program to encourage use of renewable natural gas. Municipal (via GoC investment) examples: • City of Winnipeg – $1.3 million to expand its landfill gas capture system • City of Peterborough – $6 million to support the development of a centralized composting facility • Town of Petawawa – $2.7 million to upgrade its wastewater treatment digesters to divert food waste from landfills and generate more clean energy	Enhance waste and recycling infrastructure to reduce GHGs

3.4 Agriculture

Key Mitigation Actions

- The On-Farm Climate Action Fund (OFCAF), as part of the Agricultural Climate Solutions program, will provide $670 million to support immediate on-farm action to tackle climate change, including through actions to reduce methane emissions.
- The Agricultural Clean Technology Program (ACT) is a $495.7 million program that aims to support the development and adoption of clean technologies in agriculture.
- Livestock Feed Management protocol is being developed for use in Canada's Greenhouse Gas Offset Credit System, while protocols for Livestock Manure Management and Anaerobic Digestion are planned for subsequent development.

Methane Emission Sources

Agriculture is responsible for 30% of Canada's total methane emissions, with 71% of that being attributed to beef production. Enteric fermentation, resulting from the digestive process in ruminants, such as cattle, goats, and sheep, accounts for 86% of Canada's agricultural methane emissions, while manure emissions account for the remaining 14% (Figure 12).

Agricultural methane emissions have decreased by 20% since 2005 primarily due to a reduction in the number of beef and dairy animals in Canada, and an overall increase in productivity per animal resulting from improvements in nutrition, genetics, and management.

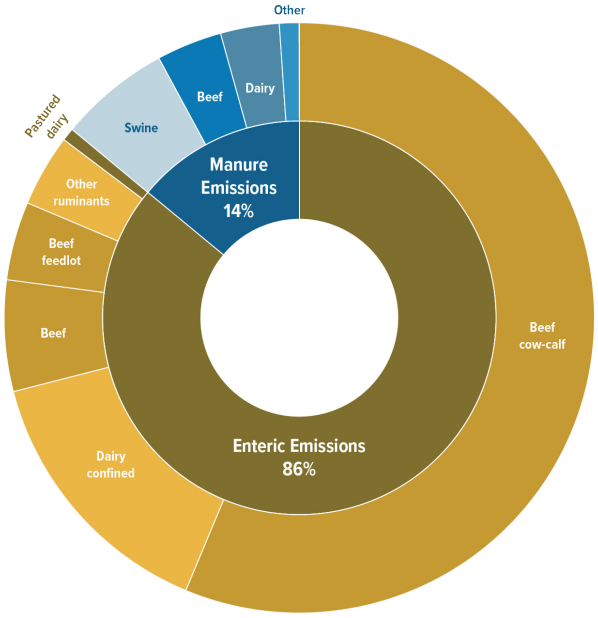


Figure 12: Canada's Agriculture Sector Methane Emissions (2020)

Challenges and Opportunities

Estimating and Quantifying Agricultural Methane Emissions

The diversity of production practices – regional climatic conditions and varying soil types across 189,874 farms in Canada (2021 Census of Agriculture) (including more than 70,000 Canadian cattle operations) – means there is no "one size fits all" solution for reducing methane emissions. Beef cattle, which account for the largest share of cattle in Canada, spend a significant portion of their lives grazing on pasture, and are often dispersed over a wide area, with minimal intervention, making methane emissions challenging to measure. Methane emission estimates must also account for Canadian-specific types of feed, pasture type and composition, use of feed additives, seasonal considerations, and, in the case of manure emissions, treatment and storage practices and local temperature.

To date, the sector's ability to reduce emissions has come from improvements in production efficiency, as well as feeding and breeding practices. Enhancements to agricultural methane modelling will require estimates of the impact of mitigation measures, which in turn will require improved on-farm activity data on use and adoption of practices and technologies on farms. Due to the complex interactions of biological processes that produce agricultural GHGs, these models would also benefit from better integration with models for other GHGs.

GHG Emissions Reductions and Ecological Trade-offs

While livestock are a significant source of methane emissions, they provide an important source of protein for consumption and can positively contribute to environmental objectives related to carbon sequestration, biodiversity and water quality. Portions of Canada's native grasslands, one of the world's most endangered ecosystems, can be conserved or even improved when appropriately grazed by livestock and well-managed grazing can contribute to soil carbon sequestration. Conversely, reductions in cattle populations[xii] can correlate with reduced grasslands, pastures and forage production in Canada, leading to an overall loss of sequestered carbon due to land use changes.[6] Grazing cattle can also help regulate the flow and quality of water, protect fragile soils from erosion, recycle nutrient content, and help maintain habitat for wildlife and plants (including threatened and endangered species).

Sector Interest in Reducing Emissions and Greater Environmental Sustainability

A variety of livestock producer and industry groups are already setting voluntary targets and goals to reduce GHG emissions, building momentum for the abatement of emissions from the sector. For example, the Canadian Beef Advisors has a 2030 goal of reducing GHG emission intensity from primary beef production by 33%, while the Dairy Farmers of Canada have set a goal to reach net-zero by 2050.

Most Effective Mitigation Approaches

Canada's farmers and ranchers have already been leading the adoption of climate-friendly practices, innovating to reduce GHG emissions and build resilience to the impacts of climate change. Recognizing that producers will need to invest time, equipment and training to transition to new practices, achieving methane emission reductions will be dependent on the right support and other incentives to drive adoption levels, especially given there are typically minimal private benefits (e.g., productivity gains) associated with methane inhibiting practices. Furthermore, many of the potential measures to reduce methane emissions from the sector are at early stages of development, requiring scientific validation and in some cases regulatory approval. These challenges, as well as the biological nature of methane emissions in agriculture, are why a number of countries are focusing on improving the measurement of methane emissions and overcoming obstacles to the adoption of emission-reducing practices as part of their methane strategies.[xiii, xiv]

Interventions addressing concentrated methane emissions may offer the greatest opportunity for mitigation efforts. For example, methane reducing feed additives, such as seaweed or enzyme inhibitors, are most easily delivered in beef feedlot and dairy settings, where animals are confined and diets are highly controlled. While novel methane reducing feed additives could offer considerable potential for reducing enteric methane emissions from cattle, these will need to undergo regulatory assessment before they can be commercially available. Within the context of the agricultural sector and food production, human health and consumer acceptance are also critical pieces to consider regarding interventions involving methane-reducing feed additives and, as such, market opportunities and barriers need to be considered.

Methane reducing manure management approaches, such as liquid manure acidification, liquid-solid separation techniques, manure tank or lagoon covers, and anaerobic digestion, are most feasible for confined livestock operations employing liquid manure management, including dairy and swine operations.

Considerable opportunity exists in Canada to produce biogas from manure through the use of anaerobic digesters. Anaerobic digesters are enclosed structures used to process manure and other organic materials in the absence of oxygen a process known as anaerobic digestion. Anaerobic digestion converts this organic matter into biogas, a renewable energy carrier, and recovers nutrients from the feedstock that can be returned to agricultural soils. Currently, less than 1% of Canada's livestock manure undergoes anaerobic treatment, mainly to produce renewable electricity. The greatest potential to produce biomethane is in large intensive livestock operations, such as feedlots,

6 Between 1981 to 2011, there was a reduction in the area of hayland and tame pasture from Ontario eastward (Statistics Canada 2022), and a corresponding increase in the area of annual crops which resulted in an overall loss of soil organic carbon over the same timeframe (Agriculture Agri-Food Canada 2018).

or where there are several livestock farms in close proximity, and the biogas energy can be used directly to produce power/heat or be upgraded to renewable natural gas. However, improvements in accessibility and affordability of these technologies are needed to support greater adoption.

Beyond confined livestock, low methane pastures, which involve increasing legumes and high tannin plants in pastures, can also lead to a reduction in methane emissions in grazing cattle. Achieving additional reductions to methane emissions would be a longer-term effort.

Federal Actions

Building on voluntary, sector-led efforts to reduce emissions, the federal government continues to provide further support to enhance momentum for the abatement of methane and other GHG emissions. Table 4 highlights key existing and upcoming measures targeting methane reductions from the agriculture sector.

Table 4. Action to Reduce Methane Emissions from the Agriculture Sector

Methane Measure
Agricultural Climate Solutions
• Agricultural Climate Solutions Living Labs will provide $185 million to accelerate co-development, testing, adoption, dissemination, and monitoring of technologies and practices that sequester carbon and/or mitigate GHG emissions. • Agricultural Climate Solutions On-Farm Climate Action Fund will provide $670 million to support immediate on-farm action to tackle climate change, including through actions to reduce methane emissions.
Agricultural Clean Technology Program
• Agricultural Clean Technology Program will provide $495.7 million to create an enabling environment for the development and adoption of clean technologies. • Priority areas include precision agriculture, improved feed strategies considering additives, and manure storage and treatment; on-farm energy efficiency to support better management of energy intensive processes and technologies; and green energy and bioeconomy including biofuels and farm-scale biodigesters. • The Research and Innovation stream of the program will be used to incent innovative methane-reduction technologies.
Sustainable Canadian Agricultural Partnership
• Federal and provincial/territorial cost-shared funded programs to raise producers' awareness of environmental risks and support the adoption of beneficial management practices, including those which reduce methane emissions. • AgriScience Clusters programs for research and development in collaboration with the sector, including the beef and dairy sectors, to provide innovative solutions for effective methane mitigation. • The new Sustainable Canadian Agricultural Partnership will replace the existing partnership as of April 1, 2023, and seeks, among other priority areas, a 3-5 Mt reduction in greenhouse gas emissions over the lifespan of the framework.
Green Agriculture Plan
• The Green Agriculture Plan is being developed to bring together priority environmental issues in the agriculture sector, including methane emissions, into a coordinated plan for long-term action, focusing on sector sustainability, competitiveness, and vitality. • Agriculture and Agri-Food Canada (AAFC)'s consultative process will target various stakeholders in the agriculture and agri-food sector, aiming to integrate feedback on issues such as mitigation, adaptation, soil health, water quality and quantity, and biodiversity to inform policies and approaches to advance key agri-environmental outcomes.

Methane Measure
Canada's Greenhouse Gas Offset Credit System
• Protocol for Livestock Feed Management is being developed, which will credit methane reductions from livestock produced through enteric fermentation. • Protocols for Livestock Manure Management and Anaerobic Digestion are also planned for subsequent development.
Other Federal Measures
• Emissions Reduction Plan announced an investment of $100 million in transformative science to support fundamental and applied research, knowledge transfer, and the development of metrics. • AAFC continues to leverage its longstanding collaboration with the livestock sector to increase resiliency and sustainability, while maintaining the sector's economic prosperity and Canada's food supply.

AAFC will continue working with key stakeholders and partners, including through upcoming engagement processes to support the development of a Green Agriculture Plan, to better understand barriers and opportunities related to the reduction of methane emissions in the agriculture sector. As stewards of the land, farmers and ranchers are on the front lines of climate change, and ensuring their views and expertise are taken into consideration is a key priority of the Federal Government.

Given the alignment between the federal government's climate policy and the agricultural sector's climate ambitions as stated above, the Government of Canada will continue to work with the agriculture community to evaluate, develop and implement additional policies and measures. The Government is committed to supporting the sector in achieving these goals.

3.5 Other Sources of Anthropogenic Methane

Although the oil and gas, agriculture, and waste sectors are responsible for the vast majority of Canada's methane emissions, there are some other smaller sources responsible for about 4% of Canada's total methane emissions. The largest of these remaining methane sources are coal mining, residential buildings, and transportation (Figure 13).

Coal Mining

Coal mining is responsible for 1.2% of Canada's total methane emissions. Methane is formed during the geological process of coal formation, and this methane (known as coal bed methane) can be released during and after mining. The amount of methane released varies greatly from mine to mine depending on coal type and the geological conditions. Canada is working to address emissions in the sector by:

- Phasing out unabated coal-fired electricity in Canada by 2030;
- Leading a global effort to phase-out coal-powered electricity, which will reduce the mining of thermal coal; and
- Banning thermal coal exports from Canada by 2030.

Other Sources of Methane Emissions

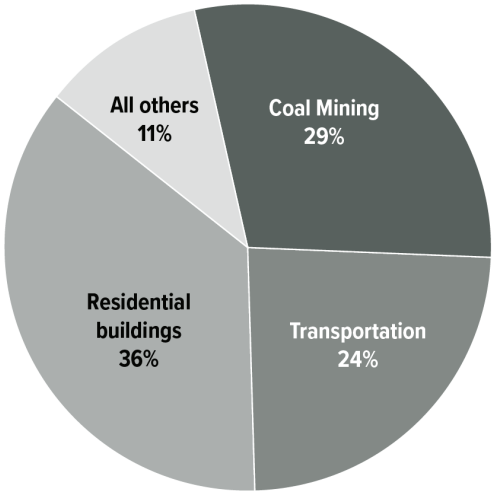


Figure 13: Other Sources of Methane Emissions (2020)

Residential Buildings

Residential buildings are responsible for about 1.5% of Canada's methane emissions, as many residential buildings in Canada use natural gas for home heating or for cooking. As discussed earlier, methane is the main component of natural gas, so natural gas that leaks or is not fully combusted contributes to methane emissions. Replacing gas furnaces and gas-burning stoves with electric alternatives, such as electric heat pumps or electric stoves, can help to reduce methane emissions from residential buildings. The Government of Canada has already made investments in decarbonizing buildings through:

- the Canada Greener Homes Grant
- the Energy Efficient Buildings program
- the Green Municipal Fund
- the Green and Inclusive Community Buildings program
- the Low Carbon Economy Fund

Canada is also working to develop a Canada Green Buildings Strategy to achieve net-zero emissions from buildings by 2050, which will set the standard for greener and more efficient homes and buildings. This includes a transition away from fossil-fuel home heating systems.

Transportation

Transportation is responsible for about 1% of Canada's methane emissions, and these emissions are from a mix of sources including off-road transportation and road transportation. The Government of Canada has numerous policies and programs in place and is developing further measures to accelerate the transition to zero-emission vehicles, including:

- regulations to reduce GHG emissions from light-duty and heavy-duty on-road vehicles;
- purchase incentives to support the adoption of Zero Emission Vehicles; and,
- investments in electric vehicle charging infrastructure, such as the Zero Emission Vehicle Infrastructure Program.

4. ECONOMIC OPPORTUNITIES

Quantifying and Capturing the Opportunity for Canadian Businesses in a Changing Global Market

The methane technology sector is poised to grow rapidly over the next few years as countries meet targets under the Global Methane Pledge and other methane initiatives. The Global Commission on the Economy and Climate found that bold climate action could yield direct economic gains of US $26 trillion globally.[xv] Methane technologies and solutions could make up an important share of this and support Canada's clean technology sector, which is expected to grow by almost 50% by 2030.[xvi] In the past few years, new players, such as venture capitalists, accelerators, and hubs, have joined the Canadian clean technology landscape. There are currently several hundred companies across the country involved in the early stage development and manufacturing of technologies to improve methane monitoring, reduce oil and gas leaks, capture and manage emissions from landfills and abate agricultural methane[xvii] – making us a global leader in developing and implementing innovative technologies to address methane emissions.

Spotlight on Canadian Clean Tech firms

A growing number of Canadian clean technology companies are specializing in methane monitoring and methane abatement from oil and gas, agriculture and landfills. Over the past few years, Canada's methane sector has developed an important global competitive advantage and become a hub of global excellence in methane emissions detection and reduction. This combination of technology, innovation and collaboration can help provinces and all of Canada meet their climate goals. Notable examples of Canadian methane tech firms include:

Oil and Gas

- **GHGSat** (Montreal, QC): A global leader in high-resolution methane and greenhouse gas monitoring from space through satellites and sensor-equipped aircraft and one of 13 Canadian firms named under the 2022 Global Cleantech 100.
- **Westgen Technologies** (Calgary, AB): The company's solar-hybrid remote power generation system provides an economic solution to eliminating methane venting from pneumatic devices.
- **NEXT Compression Corporation** (Calgary, AB): Provides a flare gas reduction and vapor recovery compression technology to reduce or eliminate fugitive methane emissions.

Waste and Landfills

- **CHAR Technology** (North York, ON): The company's system can purify biogas generated in landfills and transform the byproducts into a valuable sulfur-rich agricultural fertilizer to benefit crop yields.
- **Sysgaz Inc** (Montreal, QC): Developed a RNG Technology Platform integrating landfill gas management enabling profitable RNG project development from landfill gas.
- **Integrated Gas Recovery Services** (Ottawa, ON): Offers complete design, build, own and operate solutions for all landfill gas utilization, control and emission reduction projects.

Agriculture

- **Bio-En Power Inc** (Elmira, ON): Designs, builds, and operates large-scale biogas plants and anaerobic digesters to turn manure into energy.
- **Viresco Solutions Inc** (Edmonton, AB): A pioneer in quantifying agricultural emissions reduction, the company participates in agricultural methane emission reduction solutions including over 30 on-farm trials for feed additives under Project Clean Cow.

Still, there is a growing national clean tech ecosystem looking to deploy even more methane solutions (e.g., Petroleum Technology Alliance Canada, CRIN, Zone Agtech, Ecofuel Accelerator, etc.) and accelerate methane technology development in order to capitalize on the green energy jobs of the future. A study conducted for Calgary Economic Development found that the energy transition could create 170,000 jobs in the clean tech sector in Alberta and contribute $61 billion to GDP by 2050.[xviii] Canada's energy sector is particularly well positioned to advance its world-class expertise on methane technologies with established solutions and projects. Table 4 below summarizes the key methane mitigation technologies and practices, technological gaps and areas for further innovation to drive deeper reductions. These technologies and practices are generally sector-specific, given the differences between sources of methane from the different sectors.

Table 5. Summary of Key Methane Abatement Solutions and Opportunities for Further Innovation

Focus Area/ Sector	Methane Detection and Abatement Technologies & Practices	Technology Gaps & Opportunities for Further Innovation
Monitoring, Reporting, and Verification (MRV)	**In-situ and Remote Sensing** can detect methane at various ranges of spatial and temporal resolution • Ground Based Sensors for leak detection: including handheld instruments and fixed cameras, or surface mobile sensors. • Ground Based Sensors for diffuse sources: including flux tower and open-path lasers. • Aerial Sensors: drones or small planes to detect plumes. • Satellites: can provide frequent, low-cost measurements over large areas. They can be used to identify superemitters and monitor facilities over time.	• Development of technologies for the accurate detection, quantification, and localization of methane emissions. • Need to improve the integration of data across space and time. • Need lower-cost continuous monitoring technologies for point sources. • Develop networks of methane emission measurement sites to support improved quantification. • Standardize methods for collection and reporting of emissions data.
Oil and Gas	**Leak Detection and Repair:** regular inspection and repair of sites using instruments to detect leaks and emissions due to improper operations.	• Existing technologies can achieve a 75% reduction by 2030; however, will require greater deployment of zero-bleed devices, zero-flaring, methane abatement from pipe blowdowns, engine exhaust and distribution pipelines.
	Pneumatic Devices and Engines: replace gas-powered pneumatic devices and gasoline or diesel engines with electric-powered equipment.	
	Compressors: Replace Compressor Seals or Rod to Limit Venting: replace pressurized gas pumps and controllers with electric or air systems.	
	Glycol Dehydration: New technologies reduce venting or use alternative dessicants to remove water from natural gas.	
	Combustion/Power Generation: Improved efficiency and reduced venting from boilers and combustion equipment.	

Focus Area/ Sector	Methane Detection and Abatement Technologies & Practices	Technology Gaps & Opportunities for Further Innovation
Waste	**Diverting Biodegradable Waste/Alternative Waste Management Practices will Reduce Landfilling of Waste** • Anaerobic digestion (process waste under no oxygen to produce biogas). • Composting (breakdown of waste, which reduce methane). • Mechanical-biological treatment and thermal treatment.	• Higher rates of methane capture and an expansion in the number of landfills deploying gas capture technologies. • Innovation opportunities include: better conversion of waste to renewable natural gas; emerging approaches - such as biocovers and biovents to treat very low levels of methane emissions; and circular economy approaches and reduced food waste.
	Landfill Gas Capture • Electricity or Heat: captured gas can be combusted directly in a landfill gas flare, a boiler or an electrical generator, or • Renewable Natural Gas: captured methane can be upgraded to remove impurities, which allow use as renewable natural gas or compressed renewable natural gas. Captured methane also offers a source of revenue which companies can sell to heat homes and power turbines at power plants or industrial facilities.	
Agriculture	**Reduce Enteric Fermentation** • Feed Additives or Improvements: improving quality of feed, increasing legumes in pastures, or using novel feed additives, such as seaweed and chemicals (when commercially available), could reduce methane emissions. • Selective Breeding: animal breeding can selectively exploit natural variation in methane to permanently decrease enteric emissions.	• Innovation opportunities include: novel feed additives, the development of slow-release methane inhibitors or antimethanogen vaccines for pastured livestock, genetic engineering to reduce enteric fermentation; cellular agriculture; methane capture from livestock facilities; and improved bioreactors for manure management at various scales.
	Livestock Manure Management • Anaerobic Digesters: process animal waste under anaerobic conditions (no oxygen) to produce biogas. • Liquid Manure Acidification: addition of concentrated acid to manure tanks to reduce production of methane. • Covered Lagoons: covers on the surface of the manure reduce the transfer of GHGs to the atmosphere. • Composting: breakdown of waste through aerobic decomposition to reduce production of methane.	

5. INTERNATIONAL ENGAGEMENT

Early, ambitious and sustained international action is needed to rapidly reduce global methane emissions and meet the Global Methane Pledge target. Accessible and cost effective solutions exist to achieve this goal, and, as a signatory to the Pledge, Canada is committed to implementing and advocating for these solutions. Canada can leverage its vast technical expertise and regulatory experience in order to support other countries in slashing methane emissions. Action in other countries also helps slow near-term warming here in Canada, since methane reductions anywhere in the world will have impacts domestically, particularly in the North, which is warming at three times the rate of the rest of the planet.

Energy Security

As the world grapples with volatile energy markets exacerbated by Russia's illegal, unprovoked, and unjustifiable invasion of Ukraine, capturing and utilizing methane from across sectors, and in particular oil and gas sector, present cost-effective near-term opportunities to improve energy security and advance clean energy development. That is why, at the Major Economies Forum, Canada was proud to join the Global Methane Pledge Energy Pathway, which aims to:

- Accelerate action to eliminate routine flaring;
- Capture the full extent of zero-cost methane abatement potential through leak detection and repair and eliminating venting; and
- Expand clean energy deployment to offset natural gas consumption.

Canada is taking a multi-pronged approach to international engagement on methane, with a focus on climate, air quality, and economic objectives. As the Government of Canada engages with international partners through fora such as the Climate and Clean Air Coalition (CCAC), the Arctic Council, and the Global Methane Initiative, it will continue to demonstrate leadership by:

- **Supporting Cost-Effective Global Reductions:** Providing technical expertise and funding to developing countries as well as international initiatives to implement reductions in methane, many of which can be achieved at low or zero net cost.[7]
  - Between 2015-2021, Canada provided $20 million to help 20 countries move toward the implementation of their Paris Agreement Nationally Determined Contributions (NDCs). This included funding for Mexico and Colombia, among many other countries.
  - At COP26, Canada announced an additional contribution of $10 million to the CCAC to promote climate action in developing countries by mitigating emissions of short-lived climate pollutants (SLCPs), including methane.
  - Canada is also providing $2 million over the next four years for bilateral projects in developing countries to help reduce methane emissions, with expert support from the Global Methane Initiative.
  - Through various fora, Canada continues to promote knowledge sharing, technical expertise, strengthened ambition and implementation.
- **Seizing Market Opportunities:** Promoting and delivering ready-to-deploy solutions to the international market.
  - Promotion of Canadian clean technology – such as solutions to address methane emissions from oil and gas, which are also applicable to agriculture, waste management, hydroelectricity, biomass, and thermal generation among others – at trade fairs, high-profile events, and bilateral/regional engagement.
  - Canada's export support services and Trade Commissioner Service are helping Canadian businesses reach new international market opportunities.

7 The International Energy Agency assessed that a significant fraction of current global methane emissions from oil and gas can be eliminated at low or no net cost.

  - Canada is investing $20 million in the satellite company GHGSat through Sustainable Development Technology Canada in order to expand its fleet of high-tech satellites and provide methane data to the International Methane Emissions Observatory (IMEO). GHGSat has received constant support from the Trade Commissioner Service to foster growth in international markets, including funding through the CanExport program.
  - Canada participates in the Net-Zero Producers Forum, a platform for oil and gas-producing countries to discuss how the sector can support the goal of achieving net-zero emissions by 2050. For example, Canada is working collaboratively with Qatar to explore methane reductions from their oil and gas sector.

- **Advancing International Science, Research and Development:** Supporting knowledge-sharing and implementation in the rapidly evolving fields of methane monitoring, reporting and verification technologies, which are critical to reducing global methane emissions. Canadian innovators and researchers are actively contributing to this work at a global scale.
  - Canada has a long track record of international collaboration on improving global emissions inventories, including with the U.S. and the Intergovernmental Panel on Climate Change (IPCC) Task Force on Inventories.
  - Canada is an active member of the Arctic Council's Arctic Monitoring and Assessment Programme and the Global Research Alliance on Agricultural Greenhouse Gases, both of which include work on methane.
  - Canada is committed to establishing a global centre for excellence on methane detection and elimination.

- **Encouraging Global Action:** Working with international partners to raise ambition and deliver on commitments to reduce methane.
  - Canada and the U.S. established a Roadmap for a Renewed U.S.-Canada Partnership and a High Level Ministerial Dialogue on Climate Ambition, which include joint commitments to reduce methane in the oil and gas sector.
  - Canada is driving ambition under the Global Methane Pledge by encouraging other signatories to publish their own methane strategies and urging additional countries to support the Pledge.
  - Canada is an active participant in the Arctic Council[8] and will contribute to developing an ambitious collective methane reduction goal.

8 Arctic Council activities are currently on pause due to Russia's invasion of Ukraine. Russia holds the rotating chair of the Arctic Council from 2021 to 2023.

Actions by Peer Jurisdictions

In addition to Canada's early action to reduce methane emissions, Canada is closely monitoring measures being implemented by peer jurisdictions, such as the U.S. and European Union, and will continue to consider these actions as it develops further domestic policies and regulations.

U.S.

- In November 2021, the U.S. published a plan to reduce domestic methane emissions from oil and gas, landfills, agriculture and abandoned coal mines. For the oil and gas sector, the U.S. Environmental Protection Agency (EPA) published a proposal for methane regulations that would build upon existing regulations for new and modified sources, including the elimination of gas venting and expanded leak detection and repair requirements, as well as consider first time requirements for existing sources. The EPA plans to issue a supplemental proposal in October 2022 and publish a final rule in May 2023.
- Recently, the U.S. passed into law the *Inflation Reduction Act*, which includes a Methane Emissions Reduction Program to lower methane from oil and gas by providing funds to reduce leaks from production and distribution. The Act also establishes a methane emissions charge that applies to methane emissions from specific types of facilities that are required to report their GHG emissions to EPA's Greenhouse Gas Emissions Reporting Program. The charge starts at $900 per tonne of methane in 2024, increasing to $1,500 after two years (2026), which equates to $36 and $60 per tonne of CO_2e, respectively.

European Union (EU)

- The EU published a strategy in 2020 to reduce methane emissions across sectors, including oil and gas, agriculture, and waste and wastewater. The strategy also notes that the EU will consider options for emission reduction targets, standards, or incentives on energy consumed and imported in the EU.
- In December 2021, the EU Commission published a proposal to regulate methane emissions reductions in the EU energy sector. The proposal includes improved measurement, reporting and verification, mandatory leak detection and repair, and a ban on venting and flaring.

6. NATURAL SOURCES AND SINKS

Although global commitments are currently focused on reducing human-caused methane emissions, the role of natural sources and sinks of GHGs, including methane, are also of concern as the climate warms. Wetlands and terrestrial and offshore Arctic permafrost are of particular concern as they store huge amounts of organic carbon and can be both natural sinks and sources of greenhouse gases. Emissions of methane from permafrost and from the abundant number of wetlands, lakes, and rivers located in boreal and arctic regions are expected to substantially increase this century due to rapid climate warming and associated permafrost thaw, changing moisture regimes, wildland fire frequency and severity, successional changes and ecozone boundary shifts. As the Canadian Arctic is currently warming at a pace that is three times the global average, there is concern for a positive climate change feedback, thereby diminishing existing abatement efforts.

Substantial knowledge gaps and uncertainties exist around the present state and the trajectories of wetlands, permafrost thaw, and the associated methane emissions. Difficulties with estimating natural sources include that they are dispersed over vast areas and can be challenging to identify by remote sensing due to vegetation cover or small size. Notably, current global GHG modelling and reporting do not fully consider permafrost or natural methane system feedbacks. Compounding effects of human activity on wetlands and permafrost may increase as a function of economic growth and development, but it is difficult to foresee where these activities will take place. The risk of irreversible climatic tipping points are difficult to predict, but thawing permafrost is a looming challenge that could greatly accelerate climate change.[xix] Scientific research is underway, but further observations, modelling and analysis will be required to address these knowledge gaps.

Federal Actions

Protecting and Conserving Marine and Coastal Areas – To preserve and protect our oceans and preserve our coastal communities, the Government of Canada has committed to conserving 25% of Canada's oceans and 25% of its land and freshwater by 2025, working towards 30% by 2030. Grounded in science, Indigenous knowledge and local perspectives, we are advancing collaborative approaches to work with provincial, territorial, and Indigenous governments on these collective aims.

Ramsar Convention on Wetlands – Canada is a member of this international treaty that provides the framework for the conservation and wise use of wetlands and their resources. Through impact assessments, the Government of Canada takes actions to limit industrial disturbance of new projects on wetlands by proposing mitigation measures to minimize or offset negative environmental impacts (e.g., GHG emissions, biodiversity loss).

Nature Smart Climate Solutions Fund – To enhance the potential for the natural environment to store carbon and reduce GHG emissions, the Government of Canada's Budget 2022 provided $780 million to expand this existing fund. This additional funding builds on a 10-year $631 million funding commitment to support projects that conserve, restore and enhance wetlands, peatlands, and grasslands to capture and store carbon.

7. LOOKING AHEAD

This strategy highlights the multiple federal actions underway across the broader Canadian economy to reduce methane emissions. With the methane reduction measures and supporting programs – planned and underway – we estimate that Canada will be able to reduce domestic methane emissions by more than 35% by 2030, compared to 2020. In particular, the new target for the oil and gas sector to reduce emissions by at least 75% by 2030 will drive significant reductions. These methane reductions put Canada in the forefront as a global leader and support the Global Methane Pledge efforts to achieve a global 30% reduction by 2030.

While this document focuses primarily on federal actions underway across the broader Canadian economy to reduce methane emissions, ongoing complementary action by provinces, territories, municipalities, Indigenous groups, industry, the waste and agricultural sectors and others is critical to ensuring successful reduction of methane emissions. We will continue to work with these partners to find the most effective and efficient ways to reduce methane emissions, while also building our expertise in clean technologies and leading on the global stage.

Increasing coordination and collaboration amongst various experts from different fields and sectors can help resolve differences in approaches and create pathways to share new knowledge and innovations. As Canada expands its leadership in methane detection and mitigation, the data, technology, expertise, and lessons learned can be better shared across sectors domestically, and abroad. This is why the Government of Canada has committed to establishing a global centre of excellence on methane detection and elimination. This new centre will create a focal point linking Canadian methane leadership to the world and, ultimately, positioning Canadian businesses for success in the net-zero economy of the future. The Government of Canada is engaging key stakeholders and Canadians on options for this centre, with an intention to launch in 2023.

The work we do at the international level on methane is important to support global progress on reducing emissions. The Government of Canada will continue to work with our international partners to support the development of methane policies and the use of clean technologies that result in cleaner air, more sustainable and resilient farming, and improved human health conditions around the world. We encourage other countries to develop their own methane reduction strategies and plans specific to their circumstances and context. Reducing methane globally is an important tool to help limit near-term global temperature rise and improve air quality for communities around the world.

Finally, the Government of Canada is committed to sharing developments on our methane plan in order to be as transparent as possible. We will report on our methane progress at the annual Global Methane Pledge meetings, as well through the *Canadian Net-Zero Emissions Accountability Act*. This Act holds the Government of Canada accountable by requiring the Minister of Environment and Climate Change to report to Parliament with respect to its emissions reduction targets.

ANNEX 1: CROSS-SECTORAL MEASURES

The Government of Canada has a suite of existing and forthcoming cross-sectoral regulations and programs in place that can contribute to reducing Canada's methane emissions, as well as other GHGs. These regulations and programs will play an integral part in Canada reducing its GHG emissions by 40-45% below 2005 levels by 2030, and the goal of net-zero by 2050.

Clean Fuel Regulations

The *Clean Fuel Regulations* (CFR), under the *Canadian Environmental Protection Act, 1999,* requires gasoline and diesel primary suppliers to reduce the lifecycle carbon-intensity of the gasoline and diesel they produce or import for use in Canada. The Regulations also establish a credit market whereby the annual carbon intensity reduction requirement could be met via three main categories of credit-creating actions: (1) actions that reduce the carbon intensity of the fossil fuel throughout its lifecycle, (2) supplying low-carbon intensity fuels, and (3) supplying fuel and energy in advanced vehicle technologies. The CFR incentivizes methane reduction projects, such as methane conservation at crude oil and liquid fossil fuel production facilities, provided they meet the eligibility criteria under the CFR. The CFR also provides credits for methane emissions avoided by the production of biogas or renewable natural gas from landfill gas and livestock manure.

Pricing Carbon Pollution

Since 2019, every jurisdiction in Canada has had a price on carbon pollution. Provinces and territories have the flexibility to design their own carbon pricing system tailored to local needs. The federal government sets minimum stringency criteria (the benchmark) that all systems must meet to ensure they are comparable and effective. In remaining jurisdictions, the federal pricing system applies. The federal carbon pricing system has two parts: a regulatory charge on fossil fuels like gasoline and natural gas (the fuel charge) and a performance-based emissions trading system for industry, the Output-Based Pricing System (OBPS). Although the benchmark does not require systems to cover methane, some carbon pricing systems across Canada cover methane emissions to some degree, creating a financial incentive to reduce methane emissions. The minimum price on carbon pollution for explicit pricing systems is $50/tonne in 2022. Under the updated benchmark criteria for the 2023-2030 period, this will increase by $15 per year to $170/tonne in 2030.

Canada's Greenhouse Gas Offset Credit System

The *Canadian Greenhouse Gas Offset Credit System Regulations* established under the *Greenhouse Gas Pollution Pricing Act* (GGPPA) establishes Canada's GHG Offset Credit System (Offset System). The Offset System encourages cost-effective, voluntary GHG emissions reductions and removals from activities that are not covered by carbon pollution pricing and that go beyond legal requirements and common practice by allowing the generation of federal offset credits. Thus, it will expand the financial incentives to reduce carbon pollution across the economy. Facilities covered by the Federal Output-Based Pricing System can use federal offset credits as a compliance option, while other groups, including businesses, individuals and governments, can use federal offset credits to meet other climate objectives.

The initial set of protocols will create a financial incentive to reduce methane emissions from activities such as landfill methane recovery and destruction, and livestock feed management. *The Landfill Methane Recovery and Destruction* protocol provides incentive to reduce landfill methane from non-regulated small to medium-sized landfills, and non-regulated large landfills prior to proposed federal landfill regulations. *The Livestock Feed Management* protocol is still under development, and will help reduce the methane enteric emissions released from livestock (particularly cows) as a result of digestion of feed in the rumen and reduced time to market. GHG reductions will be achieved through alterations in livestock feeding strategies and other technologies. Moving forward ECCC will continue to develop protocols for activities in the agriculture, forestry and waste sectors, which may include protocols for anaerobic digestion and manure management, as well as technology-based CO_2 removal and sequestration projects, such as Direct Air CO_2 Capture and Sequestration.

Strategic Innovation Fund - Net Zero Accelerator

The Strategic Innovation Fund - Net Zero Accelerator (SIF-NZA), led by Innovation, Science and Economic Development Canada (ISED), holds much potential for contributing to the federal government's efforts to tackle methane emissions. Announced in the 2020 Healthy Environment and Healthy Economy plan, this $8 billion initiative is expediting decarbonization projects with large emitters, scaling up clean technology and accelerating Canada's industrial transformation across all sectors. With a flexible investment framework and a new dedicated multi-departmental team - the Industrial Decarbonization Team - designed to facilitate enhanced collaboration with industry, the SIF-NZA is well positioned to leverage and build on the learnings, experiences, and results from programs that have been supporting methane abatement, most notably the Emissions Reductions Fund, with large scale investments in sector-wide transformative projects.

Clean Growth Hub

The Clean Growth Hub was introduced through Budget 2017, and renewed through Budget 2021, as the federal focal point for clean technology. Co-led by ISED and Natural Resources Canada (NRCan), the Hub is a unique service model that brings together 17 member departments and agencies to help clean tech developers and users navigate federal programs, enhance program coordination, and track the outcomes of federal investments in clean technology. The Hub has a client base of over 2,300 clean technology stakeholders and has assisted clients of all sizes and across various sectors of activity in accessing federal programs to support their projects. Clients range from young clean tech innovators with high potential for disruption to large adopters in high-emitting industries facing growing pressures to decarbonize.

Sustainable Development Technology Canada

Sustainable Development Technology Canada (SDTC) is a federal foundation that assists Canadian companies to develop and deploy clean technology solutions that address climate change, clean air, clean water and clean soil. Through funding and by utilizing their knowledge ecosystem, SDTC helps move technologies from demonstration closer to commercialization while growing the Canadian economy. Since 2001, SDTC has invested $1.4B in 539 small-medium enterprises and is an additional resource for companies seeking to develop methane detection, reduction and abatement technologies.

The Energy Innovation Program

The Energy Innovation Program (EIP) advances clean energy technologies that will help Canada meet its climate change targets, while supporting the transition to a low-carbon economy. It funds research, development and demonstration projects, and other related scientific activities, including support for methane detection, reduction and abatement technologies.

ANNEX 2: ADDITIONAL INFORMATION ABOUT METHODS FOR MEASURING AND MODELLING METHANE

Many new instruments for methane monitoring are scheduled to launch over the next five years, which will greatly increase available data and will span a wide range of resolution, coverage, and precision through a combination of government, non-profit, and commercial installations. This will improve the ability to assess regional scale methane emissions, detect sources, and provide more frequent monitoring of specific facilities. Although various remote sensing methods have limitations (e.g., clouds, sunlight, surface reflectivity), ground-based, aerial and satellite remote sensing are expected to make contributions to the UNFCCC global stock take effort in 2028 and beyond, and are complementary to conventional monitoring methods. Remote sensing methods are anticipated to contribute to monitoring intensive livestock agricultural operations such as feedlots, but the dispersed nature of agricultural emissions pose a challenge.

Mobile systems for monitoring methane (e.g. aircrafts) are typically not deployed on a regular basis, but rely on individual field measurement campaigns that are undertaken by a variety of research groups in Canada, including government, academia, industry and non-government organizations. These studies require stable wind and weather conditions to obtain reliable methane emission estimates. Close to point sources, handheld sensors such as optical gas imaging cameras can be used to identify methane emissions from individual components or processes but this is time consuming, labour intensive and requires access to all components.

Atmospheric modelling systems that estimate anthropogenic emissions, require specification of natural methane emissions (from wetlands and peatlands), as well since atmospheric methane concentrations are the result of both natural and anthropogenic emissions. A significant part of the uncertainty in these atmospheric modelling systems is related to the quality and spatial resolution of underlying natural methane emissions which are specified on the basis of best possible data from inventories. However, natural methane emissions, which are mostly emitted by wetland ecosystems, require their own modelling and in particular depend on the local hydrology. Decomposition of organic matter in wet anaerobic conditions emits methane while decomposition in dry aerobic conditions emits CO_2. Another challenge is the potential for wetland methane emissions to increase in magnitude due to permafrost thaw and the lengthening of the emissions season as temperatures continue to increase. A comprehensive modelling system that takes into account the dynamic nature of both natural and anthropogenic methane emissions requires improved integration of knowledge across different disciplines and realms.

ENDNOTES

[i] International Energy Agency. (2022). Global Methane Tracker 2022 - Overview.

[ii] Il Scarpelli, T.R., Jacob, D.J., Moran, M., Reuland, F., and Gordon, D. (2021). A gridded inventory of Canada's anthropogenic methane emissions. Environmental Research Letters, Volume 17, Number 1.

[iii] Chan, E., Worth, D.E.J., Chan, D., Ishizawa, M., Moran, M.D., Delcloo, A., and Vogel, F. (2020). Eight-year estimates of methane emissions from oil and gas operations in western Canada are nearly twice those reported in inventories. Environ. Sci. Technol., 54(23): 14899-14909.

[iv] Johnson, M.R., Tyner, D.R., and Szekeres, A.J. (2021). Blinded evaluation of airborne methane source detection using Bridger Photonics LiDAR. Remote Sensing of Environment, Volume 259.

[v] CNN. (2022). Planet-warming emissions from cow burps have been seen from space.

[vi] Chan, E., Worth, D.E.J., Chan, D., Ishizawa, M., Moran, M.D., Delcloo, A., and Vogel, F. (2020). Eight-year estimates of methane emissions from oil and gas operations in western Canada are nearly twice those reported in inventories. Environ. Sci. Technol., 54(23): 14899-14909.

[vii] Johnson MR, Tyner DR, Conley S, Schwietzke S, Zavala-Araiza D. (2017). Comparisons of airborne measurements and inventory estimates of methane emissions in Alberta upstream oil and gas sector. Environ. Sci. Technol., 51(21):13008-13017.

[viii] MacKay, K., Lavoie, M., Bourlon, E., Atherton, E., O'Connell, E., Baillie, J., Fougère, C., and Risk, D. (2021). Methane emissions from upstream oil and gas production in Canada are underestimated. Sci. Rep., 11: 8041.

[ix] Tyner, D.R., and Johnson, M.R. (2021). Where the Methane Is—Insights from Novel Airborne LiDAR Measurements Combined with Ground Survey Data. Environ. Sci. Technol., 55(14): 9773-9783.

[x] Ars, S., Vogel, F., Arrowsmith, S.H., Knuckey, E., Lavoie, J., Lee, C., Pak, N.M., Phillips, J.L., and Wunch, D. (2020). Investigation of the Spatial Distribution of Methane Sources in the Greater Toronto Area Using Mobile Gas Monitoring Systems. Environ. Sci. Technol., 54, 15671-15679.

[xi] International Energy Agency. (2020). Methane Tracker 2020 - Methane abatement options.

[xii] Statistics Canada. (2022). Table 32-10-0130-01 Number of cattle, by class and farm type (x 1,000).

[xiii] White House Office of Domestic Climate Policy. (2021). U.S. Methane Emissions Reduction Action Plan.

[xiv] European Commission. (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU strategy to reduce methane emissions.

[xv] Global Commission on the Economy and Climate. (2018). Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action in Urgent Times.

[xvi] Clean Energy Canada. (2020). The New Reality.

[xvii] Methane Emissions Leadership Alliance. (2017). Methane Jobs Analysis.

[xviii] Calgary Economic Development. (2021). Alberta Energy Transition Study | A $61B Job Opportunity.

[xix] Fewster, R.E., Morris, P.J., Ivanovic, R.F., Swindles, G.T., Peregon, A.M., and Smith, C.J. (2022). Imminent loss of climate space for permafrost peatlands in Europe and Western Siberia. Nat. Clim. Chang. 12, 373–379.