CHARTERED PROFESSIONAL ACCOUNTANTS CANADA

The Time Value of Carbon

SMART STRATEGIES TO ACCELERATE EMISSION REDUCTIONS

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Cover photo: Mauna Loa photographed from Mauna Kea, Hawaii in January 2016. Mauna Loa is the location of the National Oceanic and Atmospheric Administration (NOAA) monitoring station that has measured CO_2 concentration in the atmosphere since the 1950s. Photo credit: Stephen Salter.

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Preface

The resolve to take action on climate change is growing in organizations across Canada and throughout the world, yet global greenhouse gas emissions continue to rise. At the same time, climate science shows that, to avoid potentially disastrous climate change, we must reduce emissions dramatically and in the very near term—i.e., within the next two decades. How can accounting professionals help concerned organizations focus their effort on the most meaningful actions now?

This report, which bridges the fields of climate science and accounting, aims to help concerned organizations examine actions they can take today—such as applying appropriate accounting practices—to accelerate their efforts to reduce greenhouse gas emissions. The report recommends ways for them to voluntarily report not only their near- and long-term impacts on climate, but also the actions they are taking to mitigate those impacts.

We offer this report at a time when securities regulators, in response to growing interest from investors, are providing publicly traded organizations with increased guidance for reporting their climate risks. These risks go beyond the impacts of a changing climate on organizations: they include the effects of organizations on the climate. We believe that providing concerned organizations with information and decision-making tools that facilitate meaningful action on climate change is consistent with our professional commitment to serving the public interest.

We welcome comments about this report. Please send feedback to:

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Executive Summary

Not all greenhouse gases are created equal. Some emissions of short-lived greenhouse gases, known as Near-Term Climate Forcers (NTCFs), contribute strongly to global warming within a few decades and can be reduced or eliminated through investments in cost-effective technologies.[1] Examples of NTCFs include methane and the hydrofluorocarbons used in air conditioning and refrigeration systems. This report explains the effects of this family of greenhouse gases on climate and proposes methods that accounting professionals can use to evaluate the costs and benefits of mitigating these gasses. While this report focuses on methane and the most common hydrofluorocarbon (HFC-134a), the approach described here may be applied to other NTCFs.

Climate scientists agree that reducing carbon emissions is urgent (Hansen et al. 2013). Climate science has proven that NTCFs strongly affect the *rate* of increase of global temperatures, while the total accumulation of carbon dioxide in the atmosphere affects the *total* increase of temperatures over the long term. Clearly, both effects are important. Unfortunately, however, current greenhouse gas reporting practices tend to understate the importance of NTCFs with respect to early climate change intervention. Over a 20-year time horizon, NTCFs contribute half of the Radiative Forcing (see **Glossary on page 53**) to climate change, and early action to reduce their emissions will bring early benefits.

The question of how best to account for the "time value of carbon" has become important to accounting professionals for several reasons:

- Global greenhouse gas emissions have continued to rise. In 2013, they were approximately 55% above 1990 levels. In Canada, greenhouse gas emissions increased approximately 20% between 1990 and 2013.

1 NTCFs are also referred to as Short-Lived Climate Forcers (SLCF), Short-Lived Climate Pollutants (SLCP), or Near-Term Greenhouse Gases (NTGG). This report uses the term NTCFs to be consistent with IPCC terminology.

- More and more organizations in both the public and private sectors want to make the most effective investments to reduce their greenhouse gas emissions.
- Regulators are providing publicly traded organizations with increased guidance for reporting their climate risks.
- Emissions of gases such as methane and hydrofluorocarbons represent either a direct economic loss (e.g., when natural gas is vented rather than sold) or a lost economic opportunity (e.g., when waste decomposes in a landfill site rather than being recovered to produce revenue). Avoiding losses or generating additional revenue can help offset the cost of reducing NTCF emissions.

This report draws on two bodies of knowledge: climate science and accounting. The climate science presented in this report is based on the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports, as well as the scientific research on which those reports are based. The accounting practices described in the report are based on both generally accepted accounting principles (GAAP) for external reporting and good practices for internal decision making. The report further refers to progressive, voluntary standards for sustainability and carbon reporting. The report includes five chapters:

> **Chapter 1** discusses the relationship between greenhouse gas emissions and climate change, introduces the time value of carbon concept, and discusses the relevance of this concept to the accounting profession. This chapter also discusses why NTCFs have become important, and the benefits of early action to reduce them. Interested readers will find a more detailed discussion of the climate science aspects of the report in **Appendix I** and **Appendix II**.
>
> **Chapter 2** explores how accounting professionals can help organizations quantify their NTCF emissions, evaluate the economic benefits of reducing emissions, and use decision-making frameworks to invest in initiatives to reduce their emissions.
>
> **Chapter 3** discusses cost-effective steps that can be taken to reduce NTCFs emissions at the international, national, municipal, and corporate levels. Interested readers will find further information on mitigation measures in **Appendix III**.

Chapter 4 offers potential starting points for organizations to address their NTCF emissions.

Chapter 5 recommends areas for further development related to the time value of carbon concept.

The report will be of special interest to accounting professionals and others involved in making investment decisions for projects aimed at reducing greenhouse gas emissions, providing guidance on the value of climate change prevention, and reporting on greenhouse gas emissions and sustainability.

The report concludes the following:

- Reducing emissions of CO_2 and NTCFs requires separate, distinct strategies. Reducing NTCFs can help organizations make more focused efforts to reduce their total greenhouse gas emissions.
- Organizations have an opportunity now to make significant and rapid contributions to addressing climate change, demonstrating leadership, and realizing the internal and external benefits of early action. Acting now can result in multiple environmental, social, and economic benefits.
- Accounting professionals have a vital role to play in helping organizations identify, quantify, and articulate the benefits of early action to address NTCFs; providing internal guidance on making investments in emission reductions; accounting for the economic, environmental, and social benefits of early action on a lifecycle basis; and highlighting the connections between external risks and the costs and benefits of early action to reduce NTCFs.
- There are no regulatory barriers to voluntarily reporting additional information on focused action on NTCFs. Accounting professionals can work with scientific, engineering, operational, and environmental personnel to frame such reports.

CHAPTER 1
Climate Change and the Time Value of Carbon

This chapter explains the intentions and limitations of this report, reviews the relationship between greenhouse gas emissions and climate change, and explains the contribution of NTCFs to global warming. The chapter concludes with a description of the unique opportunity that NTCFs can offer to climate change mitigation.

The Intentions and Limitations of the Report

The report is intended to offer accounting professionals and their colleagues new insights into the effects that one family of greenhouse gases, NTCFs, have on our climate. These gases are of special interest since they are responsible for approximately half of the global warming over a 20-year timeframe (i.e., in the near term), and early action to reduce NTCF emissions will bring early benefits. In addition, these gases have commercial value that can help offset the cost of investments to reduce their emissions. The fact that cost-effective measures are available to reduce NTCF emissions is particularly good news for large NTCF emitters in the agriculture, solid waste, and oil and gas sectors.

The approaches described in this report can complement existing greenhouse gas reporting and emission reduction initiatives. The ideas the report discusses are relevant to corporations as well as to municipal and regional governments involved in developing climate action plans. The authors hope accounting professionals reading the report will recognize the value of reducing NTCF emissions through early action (i.e., will recognize the "time value of carbon") and will work with their technical, operational, and environmental peers to:

- Evaluate the significance of their organizations' NTCF emissions.
- Review the NTCF mitigation measures available to their organizations.
- Provide guidance on the costs and benefits of NTCF mitigation measures.
- Measure and report the effectiveness of mitigation initiatives internally.
- Consider reporting the results of mitigation initiatives externally.

The report does not present new science, but synthesizes information published by the IPCC as well as the scientific research on which the IPCC's reports are based.[2] Further, the report does not present new accounting principles, but simply highlights ways in which knowledge about NTCFs can inform decision making by accounting professionals. This report considers accounting systems to be information systems that are based on our knowledge of the physical world and are designed to support decision making. When our understanding of the world changes as a result of new knowledge, accounting professionals have an opportunity to use this information to support better decisions.

Finally, the report is not intended to offer specific guidance to accounting professionals, to change existing greenhouse gas reporting protocols, or to change government policies on greenhouse gas reporting. Instead, the report is intended to stimulate a productive discussion among all interested professionals and the organizations they serve about the time value of carbon. It is hoped that this discussion will lead to further work as knowledge in this area evolves.

Greenhouse Gas Emissions and Climate Change

A pendulum at rest can be said to be in static equilibrium, while a pendulum in motion is in dynamic equilibrium. Similarly, the earth is in dynamic equilibrium, constantly rebalancing through physical and ecological processes that act on both human and geological time scales. Physical processes, such as sedimentation and erosion, create land and wear land away. Ecological processes, such as photosynthesis and natural carbon sequestration, balance the level of carbon in the atmosphere and enable life to exist. These processes, which have natural cycles that range from moments to millennia, maintain the earth's dynamic equilibrium.

2 The origin of the word science is scientia, Latin for knowledge.

Since the industrial revolution, however, humans have added a new and disruptive force to natural cycles: anthropogenic greenhouse gases. Combined with naturally occurring sources, these emissions stress the dynamic equilibrium that makes the earth habitable for life.

Just as the glass of a greenhouse allows sunlight to enter and prevents heat from escaping, before the industrial era naturally occurring greenhouse gases allowed the earth to hold just enough of the sun's energy to maintain a habitable environment. Emissions from human activities, however, are increasing the concentration of greenhouse gases in the atmosphere. This, in turn, is increasing the atmosphere's ability to trap heat. The resulting temperature change is often presented as an average global increase of a few degrees, but this tells only part of the story. For example, temperatures at the poles have increased faster than the average, flooding and drought are becoming more frequent and intense, and oceans are becoming more acidic as a result of increased absorption of carbon dioxide.

Further, certain climate feedback effects are accelerating climate change. For example, as the climate warms and the extent of sea ice declines, more of the sun's energy is absorbed by new expanses of open water, causing even more sea ice to melt. Rising temperatures also lead to warming-induced releases of CO_2 from the biosphere (Gillett & Mathews 2010) and methane from tundra and wetlands (Shindell et al. 2004), a phenomenon referred to as climate-carbon feedback or carbon-cycle feedback. The IPCC *Fifth Assessment Report* refers to this effect (IPCC 2013).

Humans further contribute to feedback effects, for example by running air conditioners during hotter summers. Air conditioning consumes more electricity and uses hydrofluorocarbons, both of which increase greenhouse gas emissions.

Climate science provides a well-researched understanding of cause and effect between emissions and climate change. It is clear that certain greenhouse gases are more detrimental because of their effectiveness in trapping heat. While greenhouse gases such as carbon dioxide last in the atmosphere for centuries, another group, the NTCFs, are the "sprinters" of global warming. While these gases last only a few decades in the atmosphere, they have a disproportionately detrimental effect during their lifetimes. For example, over a 20-year period, on a tonne-for-tonne basis, the commonly-used refrigerant HFC-134a is 3,700 times more effective in trapping heat than is carbon dioxide.

Climate scientists agree that reducing carbon emissions is urgent (Hansen et al. 2013), and there is an increasing awareness in society of the risks a changing climate presents. Securities regulators, in response to growing interest from investors, are providing publicly traded organizations with increased guidance for reporting their climate risks. Despite this growing awareness, greenhouse gas emissions continue to rise, and NTCF emissions are rising faster than the average. Data from the European Commission, for example, shows that, between 1990 and 2008, Canada's emissions of carbon dioxide increased by 21%, but emissions of methane increased by 39.8% (European Commission 2012).

Clearly, more effective strategies for reducing greenhouse gas emissions are needed.

The Issue and the Opportunity

IPCC Assessment Reports summarize current knowledge of the relationship between emissions of greenhouse gases and the changing climate.[3] The IPCC and the United Nations Framework Convention on Climate Change (UNFCCC) have also established common protocols for reporting greenhouse gas emissions. The protocols enable emitting organizations, communities, and nations to be accountable for their emissions and to understand emissions trends over time. Current protocols (i.e., those developed by the UNFCCC) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

To simplify emissions reporting by organizations and governments internationally, reporting protocols require that the warming effect of each non-CO_2 gas be equated with that of a reference gas (CO_2) over a 100-year time horizon. The ratio of these two effects is referred to as the Global Warming Potential (GWP). Total emissions reported by an organization or government are shown as CO_2e, or tonnes of CO_2 equivalents. Determining the total CO_2e emissions of a reporting entity then becomes a simple matter of multiplying the mass of emissions of each gas in a given year by its GWP value.

The strength of the GWP approach is that it enables changes in emissions to be compared over time and among different emitters. Without disputing the vital importance of internationally accepted reporting protocols, it is worth understanding some of the limitations of the current GWP approach. One weakness is that each greenhouse gas acts differently over time. Not only

3 The IPCC is a scientific body under the auspices of the United Nations.

can the effects on climate of non-CO_2 greenhouse gases (e.g., NTCFs) be significantly greater than the effects of CO_2, they also occur over markedly different time scales.[4] This makes "equivalence" imprecise and at times unhelpful in providing climate change mitigation guidance.

For example, 40% of the carbon dioxide emitted today will remain in the atmosphere after 100 years, and approximately 20% will remain after 1,000 years. On the other hand, NTCFs such as methane affect global warming significantly, but over relatively short time scales. Methane is removed from the atmosphere much more quickly than carbon dioxide, so that only 20% will remain after 20 years. The application of a 100-year time horizon to NTCFs tends to mask their very strong near-term effects on climate: over a 20-year timeframe, they account for approximately half of the energy all greenhouse gases contribute to global warming.

Climate scientists do not say that climate changes in the longer term have less value or are ultimately less important than those that take place in the near term. Climate scientists report that both the rate of temperature rise in the short term and the total temperature rise in the long term are important. Referring to reductions of NTCFs, the United Nations Environmental Programme (UNEP) has stated: "Because such reductions are likely to only make a modest contribution to *longer-term* climate goals, they must be viewed as a strategy that complements but does not replace carbon dioxide emission reductions" (UNEP 2014). Further, reducing emissions of carbon dioxide is necessary to mitigate its other effects, including ocean acidification. Clearly, early action on both CO_2 and non-CO_2 emissions (including NTCFs) is important (Shindell 2005).

Nor does this report propose delaying action to reduce CO_2 emissions until actions to reduce NTCFs are underway. Instead, this report suggests that it can be helpful for emitters to more clearly understand the effects of NTCFs today because these emissions are rising quickly, the strategies to reduce them are different from those for reducing CO_2, and reducing NTCF emissions can bring immediate economic benefits to emitters as well as benefits to human health and agriculture.

This report uses two NTCFs as examples: methane (CH_4) and a hydrofluorocarbon (HFC-134a). Methane was selected because it makes the second largest contribution to global warming after carbon dioxide, and because of its short

4 Consistent with the scientific literature, this report uses the term "effects on climate" to refer to greenhouse gas emissions, and the term "climate impacts" to refer to the impacts of a changing climate on humans and the environment.

lifetime of 12.4 years. HFC-134a was developed to replace ozone-depleting substances in refrigeration, air conditioning, aerosols, and in foam production, and is the most commonly used hydrofluorocarbon. It was included because of its very high GWP (3,700 over 20 years), its short lifetime of 13.4 years, and the recent rapid increase of its emissions (IPCC 2013).

Why Mitigating Near-Term Climate Forcers Is Important

Early Action Can Bring Early Climate Benefits

Climate science shows that NTCFs have a greater effect on the *rate* of increase of global temperatures while the total accumulation of carbon dioxide in the atmosphere has a greater effect on the *total* increase of temperatures over the long term.

Emissions of Near-Term Climate Forcers are Rising

Ozone depleting substances such as chlorofluorocarbons (CFCs) have been widely replaced by hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) in refrigeration and air conditioning equipment. Although HFCs have low or zero Ozone-Depletion Potentials (ODP ratings), they do have very high GWP values and, therefore, contribute strongly to global warming.[5]

Further, HFC emissions are rising at the rate of 10% to 15% per annum in the developing world (IGSD 2014). The atmospheric concentration of HFC-134a (i.e., tetrafluoroethane) — the most common hydrofluorocarbon — increased by more than 80% between 2005 and 2011 (IPCC 2013). HFC-134a is also the dominant contributor to Radiative Forcing of the HFCs. If emissions of HFCs continue to rise at current rates, the contribution of these gases to Radiative Forcing could increase by at least a factor of 20 (IPCC 2013 and Velders 2012).

Information from the European Commission, the IPCC, and the World Bank shows that global methane emissions are increasing faster than emissions of carbon dioxide. Data from the European Commission, for example, shows that, between 1990 and 2008, Canada's emissions of carbon dioxide increased by 21%, but emissions of methane increased by 39.8% (European Commission 2012). While Canada's profile for methane emissions differs somewhat from the global profile, it is worth noting that the top three sources are the same. Canada's sources of methane are summarized in Table 1.

5 The CFCs that have been phased out had even higher GWP values, and hence stronger warming effects on the climate than the HFCs that have replaced them.

TABLE 1. CANADA'S ANTHROPOGENIC METHANE EMISSIONS (EUROPEAN COMMISSION 2012)

Sector	Methane Emissions (tonnes of CH_4/year)	% of Total
Oil and Gas	1,983,000	38.6%
Waste Management	1,589,000	30.9%
Agriculture	1,368,000	26.7%
Manufacturing	112,000	2.2%
Residential Heating	57,000	1.1%
Forest and Grassland Fires	13,000	0.2%
Transportation	10,000	0.2%
Electricity Generation	4,000	0.1%
Total	**5,136,000**	

The source for the data in this table is the European Commission's Joint Research Centre's Environmental Assessment Agency Emission Database for Global Atmospheric Research (EDGAR) for the latest year available (2008). Note that the Forest and Grassland Fires category in the EDGAR database includes forest fires, agricultural waste burning, and grassland fires.

Emission Abatement Investments Bring Economic Returns

Emissions of NTCFs, such as methane and HFC-134a, represent either a direct economic loss or a lost economic opportunity. Avoiding losses or generating additional revenue can help offset the cost of investments to reduce emissions of these gases. For example:

- Reducing leakage of natural gas from drilling and transportation infrastructure will reduce the emitter's near-term effects on climate and also its economic losses.
- Diverting food waste away from disposal and into anaerobic digestion to produce compost and biomethane captures an otherwise lost economic opportunity.

Organizations accounting for their own NTCF emissions will also recognize that HFC-134a has a commercial value of more than $3,000 per tonne and, at a price of $8.00 per GJ, lost natural gas (which consists mostly of methane) has a value of more than $400 per tonne.[6]

6 The methane content, energy content, and density of natural gas varies. This conversion was based on a density of natural gas of 0.7 $kg.m^{-3}$ and an energy content of 38 $MJ.m^{-3}$.

The external social and environmental values of reducing emissions of NTCFs have also been studied extensively, with researchers concluding: "Greenhouse gases other than CO_2 make a significant contribution to human-induced climate change and multi-gas mitigation strategies are cheaper to implement than those which limit CO_2 emissions alone" (Gillett & Mathews 2010).

The United States Environmental Protection Agency (US EPA) estimates that the first 12% reduction of emissions of non-CO2 gases would cost $0/tonne and that a modest carbon price of \$10/tCO_2e would result in a 20% reduction in emissions. This idea is explored further in Appendix III: Introduction to NTCF Mitigation Measures.

Emission Abatement Investments Bring Other Benefits

An organization's actions to reduce NTCF emissions can also reduce emissions of other greenhouse gases and pollutants (US EPA 2014 and UNEP 2014). For example:

- If an investment in energy efficiency or fuel switching reduces an organization's fossil fuel consumption, then CO_2, methane, N_2O, and black carbon emissions will all decrease. Chapter 11 ("Near-term Climate Change: Projections and Predictability") of the IPCC's *Fifth Assessment Report* states: "Emission reductions aimed at decreasing local air pollution could have a near-term impact on climate (high confidence)" (Kirtman et al. 2013).

- Diverting organic waste (e.g., food scraps) from landfills and diverting manure from storage lagoons to anaerobic digestion can reduce pollution of groundwater and surface water, recover the embodied nutrients in this waste, and recover renewable energy in the form of biomethane. This diversion can also reduce emissions of N_2O (IPCC 2006a).

- Methane contributes to ozone formation, which is harmful to human health and to crop yields: "We identified 14 measures targeting methane and BC (black carbon) emissions that reduce projected global mean warming ~0.5°C by 2050. This strategy avoids 0.7 to 4.7 million annual premature deaths from outdoor air pollution and increases annual crop yields by 30 to 135 million metric tons due to ozone reductions in 2030 and beyond. Benefits of methane emissions reductions are valued at US$700 to US$5,000 per metric ton, which is well above typical marginal abatement costs (less than $250)" (Shindell et al. 2012).

- West et al. (2006) estimated that, if methane emissions could be reduced by only 20% between 2010 and 2030, this could prevent 370,000 premature deaths. This study suggested that, if the value of a premature death is $1 million, the value of this methane reduction would be $240 per tonne of methane based on a GWP of 21 (West et al. 2006).

Emission Abatement Strategies Depend on the Gas

Differentiating among greenhouse gases can help organizations understand where the greatest benefit can be derived for a given investment in emission reductions. For example, strategies to reduce emissions of the refrigerant HFC-134a are very different from those required to reduce emissions of methane from the oil and gas industry, landfills, and agriculture. In addition, in Canada, most methane is emitted by a relatively small number of large sources. This fact can make investments in emission reductions practical and cost effective.

Emission Abatement Technologies Are Well-Established

The technologies for reducing methane and HFC-134a emissions are practical, mature, and well known in industry (US EPA 2013).

Society has Successfully Reduced Other Target Pollutants

The success of international treaties to address acid rain and the depletion of the ozone layer suggests that a similar, focused approach to reducing NTCF emissions could strengthen international efforts to address climate change. As the UNEP points out: "National efforts to reduce Short-Lived Climate Forcers can build upon existing institutions, policy and regulatory frameworks related to air quality management, and, where applicable, climate change" (UNEP 2014).

One Hundred Years Exceeds the Lifetime of Near-Term Climate Forcers

The term *lifetime* in climate science has a number of specific meanings, but in basic terms it can be understood as the time during which a greenhouse gas is most active in the atmosphere (IPCC 2013a). Since most NTCF effects are complete within 20 years, it makes sense to use a time horizon closer to this period for NTCFs.

One Hundred Years Lies Beyond Normal Planning Horizons

A 100-year time horizon is inconsistent with the normal time scale of human effort and business planning. Dynamic and progressive organizations do their business planning and financial reporting with the aim of providing accurate information and reliable guidance in a one- to five-year timeframe. If an organization recognizes that it can take meaningful action within a single year to reduce emissions of NTCFs, and that this reduction will have significant environmental benefits in a meaningful timeframe, the organization may be more likely to act quickly.

One Hundred Years Exceeds the Life of Mitigation Infrastructure

The infrastructure in which organizations are investing to reduce greenhouse gas emissions is likely to have a useful lifetime in the order of decades, a time scale over which NTCFs also have the greatest effects on climate. As a result, it makes sense to account for the environmental value of those reductions over a similar timeframe.

Uncertainty in GWP Values is Lower for a Short Time Horizon

Finally, the uncertainty inherent in NTCF GWP values is greater over a 100-year horizon than over 20 years (IPCC 2013). Appendix II: The Time Value of Carbon Model includes a brief discussion of the IPCC's evaluation of GWP uncertainty.

In summary, there are a number of compelling environmental, financial, and social reasons for increasing the focus on NTCFs as an adjunct to efforts to reduce all greenhouse gas emissions.

CHAPTER 2
Accounting for the Time Value of Carbon

This chapter explores how accounting professionals can help organizations quantify their NTCF emissions, recognize the economic benefits of reducing those emissions, and use decision-making frameworks to invest in projects aimed at emission reduction. The chapter also discusses options organizations can consider for voluntarily reporting their efforts to reduce NTCF emissions. Reporting on NTCF emissions is an emerging area for accountants and the organizations they work with. The ideas in this chapter are intended to encourage thinking about how accountants can best help their organizations address this new information need.

Framing the Issue

Organizations account for their greenhouse gas emissions to comply with regulatory requirements, to support internal decision making on emission-reduction initiatives, and to communicate their environmental impacts to external stakeholders. Current greenhouse gas reporting protocols require that the warming effect of each non-CO_2 gas be equated with that of a reference gas (CO_2) over a specific time horizon. The ratio of these two effects is referred to as the GWP. Organizations report their total emissions as CO_2e, or tonnes of CO_2 equivalents. Determining their total CO_2e emissions is a simple matter of multiplying the mass of emissions of each gas in a given year by its GWP value.

The GWP value for greenhouse gases can be assessed over any period of time, but current greenhouse gas reporting protocols rely on a time horizon of 100 years. The benefit of this approach is that it allows organizations to recognize that some greenhouse gases have a much greater effect on the climate than others, which in turn can help them set priorities for initiatives to reduce emissions. The challenge, however, is that the class of greenhouse gases known as NTCFs affects climate strongly within a few years of their release. These strong near-term effects are masked by the application of the 100-year time horizon to all greenhouse gases. As a consequence, it is more difficult for organizations to discern the near-term costs to the environment of NTCF emissions, as well as the near-term benefits of emission reductions.

Climate scientists warn that, to avoid disastrous climate change, near-term reductions of greenhouse gas emissions are vital, and that time is limited for society to achieve these reductions. This report frames this issue as "the time value of carbon" as a way of drawing a comparison with the time value of money.

Why Should Accounting Professionals Be Part of Addressing the Time Value of Carbon?

Accounting for carbon has not traditionally been seen as part of the accountant's role. The role of the accountant within an organization is, however, expanding into a number of new areas related to the provision of information to management and external parties. An organization's accounting function is considered to be an *information system*. Its key purpose is to provide relevant financial and related non-financial information about organizational activities that is useful to internal and external decision makers. To provide such information, accountants apply appropriate reporting standards, regulations, professional codes, frameworks, and models that are best suited to the type of organization involved and address the needs of decision makers. The significant public interest in the work of the accountancy profession puts it in a position of public trust.

To meet this responsibility, the profession is committed to providing professional services competently, with due care, and with the foremost obligation of serving the broader interest of the public at large (CPA Canada 2014).

The Key Roles of Professional Accountants in Business

The International Federation of Accountants (IFAC) publication *Competent and Versatile: How Professional Accountants in Business Drive Sustainable Organizational Success* outlines four key roles of professional accountants in business. IFAC defines each value role as:

> **Creators of value:** by taking leadership roles in the design and implementation of strategies, policies, plans, structures, and governance measures that set the course for delivering sustainable value creation.

Enablers of value: by informing and guiding managerial and operational decision making and strategy implementation for achieving sustainable value creation, as well as planning, monitoring, and improving supporting processes.

Preservers of value: by ensuring the protection of a sustainable value-creation strategy in the face of strategic, operational, and financial risks, and ensuring compliance with regulations, standards, and good practices.

Reporters of value: by enabling the transparent communication of the delivery of sustainable value to stakeholders.

Several key linkages exist between the above roles and the idea of helping organizations increase their focus on the effects of NTCFs on climate. Organizations may modify their accounting systems, tools, processes, and practices, as well as the resulting information provided for management decision making, as necessary for their particular circumstances.

Professional Codes of Practice

In addition to formalized accounting principles, such as GAAP and IFAC's Key Roles of Professional Accountants in Business, the work and professional judgment of accountants is also guided by formal codes of practice, ethical principles, and rules of conduct. These codes consistently identify the need for professional accountants to exemplify integrity, professionalism, and business expertise to serve and protect the interests of society (CPA Canada 2014).

Recognition of the accountant's role in supporting the needs of society (based on good practice and current scientific knowledge) should guide professional accountants when judging the materiality and relevance of information for an organization's internal and external decision makers and broader stakeholders. These considerations may extend to increasing their focus on the effects of NTCFs on the climate.

Canadian Generally Accepted Accounting Principles (GAAP)

GAAP informs the concepts and presentation methods used to prepare general purpose financial statements for decision makers external to the reporting organization (CPA Canada 2015). It has not been designed to provide information of a volumetric nature, such as a company's carbon emissions. To the extent that carbon emissions have financial consequences for a company, however, such as a liability to pay a carbon tax or under a cap-and-trade scheme, these consequences would be reflected in the financial statements. GAAP is set out in multiple handbooks containing relevant standards for different types of reporting entities. International Financial Reporting Standards (IFRS) are located in Part I of the *CPA Canada Handbook—Accounting* and apply to publicly accountable private-sector enterprises, while the standards for other private enterprises, not-for-profit organizations, and the public sector are prescribed elsewhere. IFRS is the body of accounting standards referred to in the remainder of this section unless otherwise noted.

Neither IFRS nor other segments of Canadian GAAP currently set out specific standards for companies reporting the financial consequences of their greenhouse gas emissions. The IFRS Interpretations Committee's *Emissions Rights* document, published in 2004, provided guidance on accounting for cap-and-trade emission schemes, but it was withdrawn in 2005 pending the conclusion of work on other relevant projects by the International Accounting Standards Board (IASB). In 2007, the IASB approved a research project to examine how to account for greenhouse gas transactions under IFRS (now named *Pollutant Pricing Mechanisms*), which remained in progress as of 2015.

While explicit accounting guidance remains unavailable, the underlying principles contained in the *IFRS Conceptual Framework* may be used to support financial accounting and reporting considerations related to greenhouse gas emissions. The framework's objective is to facilitate the consistent and logical formulation of standards and provide a basis for allowing accounting professionals to use judgment in resolving accounting issues.

Within the *IFRS Conceptual Framework*, concepts considered relevant to financial reporting of greenhouse gas emissions include:

- **Chapter 1:** Objective of Financial Reporting: Decision Usefulness
- **Chapter 3:** Fundamental Qualitative Characteristics of Useful Financial Information, including: Relevance, Materiality, and, in particular, Faithful Representation
- **Chapter 4:** Elements of Financial Statements, Recognition, and Measurement

Other areas of IFRS that accounting professionals may wish to review when accounting for the effects of an organization's NTCF emissions in financial statements include guidance on the recognition and measurement criteria for:

- Impairment of assets (International Accounting Standard 36)
- Provisions and contingent liabilities (International Accounting Standard 37)
- Intangible assets (International Accounting Standard 38)

Consideration may also be given to specific IFRS greenhouse-gas-intensive industry guidance, such as recognition and measurement criteria for the exploration and evaluation of mineral resources (IFRS 6), and guidance in the *Canadian Public Sector Accounting (PSA) Handbook*'s recognition and measurement criteria for contaminated sites (Section PS 3260, "Liability for Contaminated Sites").

In summary, GAAP provides accounting standards, based on defined economic transactions, to support materially consistent general-purpose financial reporting practices. Its intention is to provide external decision makers, including investors and lenders, with relevant information for making informed investment and lending decisions (CPA Canada 2015).

When coming to grips with NTCFs and their impact on the environment, professional accountants would, therefore, need to consider the relevant implications for their organizations' financial statements and the potential disclosures that might have to be made.

GAAP Concepts Useful For Reporting the Time Value of Carbon

Arguably, one of the most relevant concepts for this report is the qualitative characteristic of faithful representation. According to the *IFRS Conceptual Framework*, "financial reports represent economic phenomena in words and numbers. To be useful, financial information must not only represent relevant phenomena, but it must also faithfully represent the phenomena that it purports to represent." By analogy, reporting on carbon should faithfully represent the effect of carbon, including the time-related aspects.

A GAAP-based accounting concept that is highly relevant to an organization's acknowledgement and reporting of the effects of its NTCFs emissions on climate relates to the allocation of the cost of long-lived assets to different time periods, i.e., depreciation.

IAS 16 defines *Depreciation* as "the systematic allocation of the depreciable amount of an asset over its useful life" while it defines *useful life* as "the period over which an asset is expected to be available for use by an entity; or the number of production or similar units expected to be obtained from the asset by an entity." IAS 16 explains that the "useful life of an asset is defined in terms of the asset's expected utility to the entity…the useful life of an asset may be shorter than its economic life. The estimation of the useful life of the asset is a matter of judgment."

IAS 16 also says that the depreciation "method used shall reflect the pattern in which the asset's future economic benefits are expected to be consumed by the entity" and that "a variety of depreciation methods can be used to allocate the depreciable amount of an asset on a systematic basis over its useful life." Moreover, "the entity selects the method that most closely reflects the expected pattern of consumption of the future economic benefits embodied in the asset. That method is applied consistently from period to period unless there is a change in the expected pattern of consumption of those future economic benefits."

Acknowledging and reporting on the *near-term* effects of an organization's NTCF emissions on climate would reflect this concept. An analogy can be made between choosing an appropriate time horizon for measuring the effects of NTCFs on climate and choosing an appropriate timeframe for depreciation. In both cases, the timeframe should reflect a physical reality: in the case of an NCTF, its contribution to climate change over time and, in the case of an asset, its useful life. Current protocols assign a GWP based on a time horizon of 100 years and presume no variation in patterns of depletion, which is similar in concept to straight-line depreciation. On the other hand, the material effects of NTCFs on climate are initially very high but decline rapidly with time, and are largely complete within 20 years of their emission. This report, therefore, proposes the use of a time horizon, or life, that more closely matches the material effects of NTCFs and highlights the variations in an emission's pattern of depletion. This latter approach may more closely approximate a straight-line approach with a shorter useful life, or may be more analogous to the concepts used in the diminishing balance or units-of-production methods.

Potential Applications for Accounting Professionals

When an organization gets new information (e.g., due to changes in its external business environment or through evolving best practices for interpreting data), the organization and its professional accountants must consider how and when it is relevant to incorporate the new information into existing reporting and decision-support systems. Better information facilitates better decision making.

In a carbon-constrained world, taking meaningful action to reduce greenhouse gas emissions is increasingly critical. Informed businesses and society understand that what counts are the actual effects on climate, regardless of the accounting methods a particular protocol or regulation uses for reporting greenhouse gas emissions.

By using information that more accurately reflects the effects on climate of NTCFs, internal and external decision makers can make more informed decisions to focus scarce resources on the gases that cause the greatest harm. With emissions information that better reflects the true impact of an organization's operations, resource allocations, and investment choices, decision makers will be in a better position to understand the risks, opportunities, trade-offs, and returns of those decisions. Likewise, corporate leaders will have an opportunity to better understand the potential for improving their competitive advantage and mitigating business risks.

For illustration purposes, this report discusses two NTCFs: methane and HFC134a. Methane will be used as an example to discuss accounting concepts and applications. Table 2 shows how methane's contribution to climate change varies over a 100-year time horizon compared to the contribution of carbon dioxide. The table also shows the different rates at which these gases are removed from the atmosphere. The table includes the values for "Total Energy Added to the Climate System" to compare the contributions of both methane and carbon dioxide to climate change.

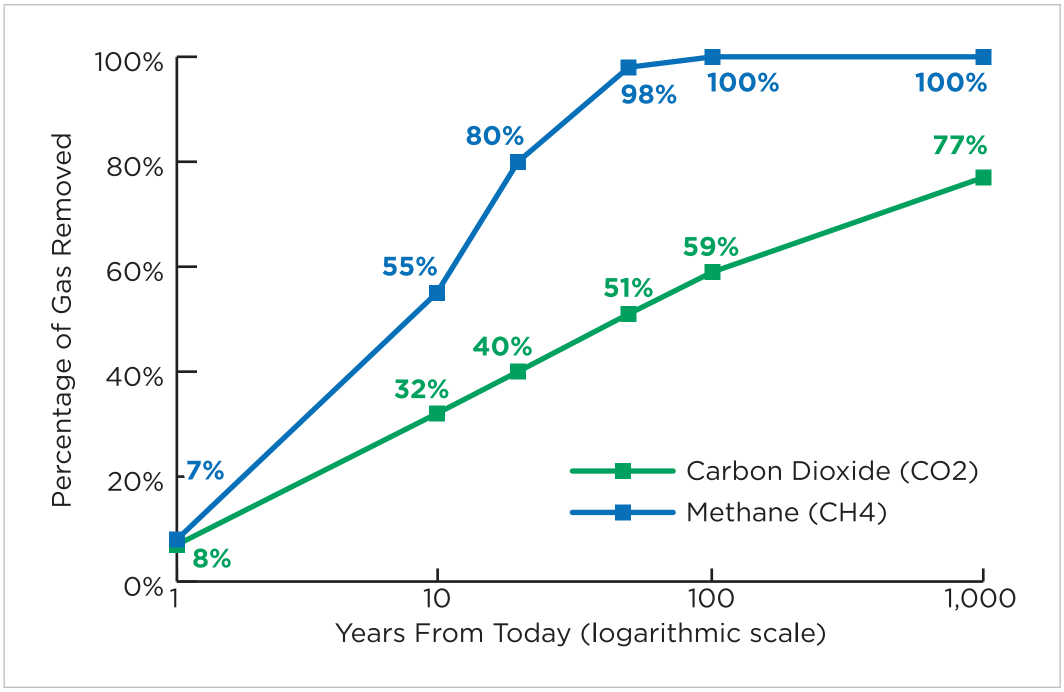
TABLE 2. METHANE'S GLOBAL WARMING CONTRIBUTIONS RELATIVE TO CARBON DIOXIDE OVER TIME

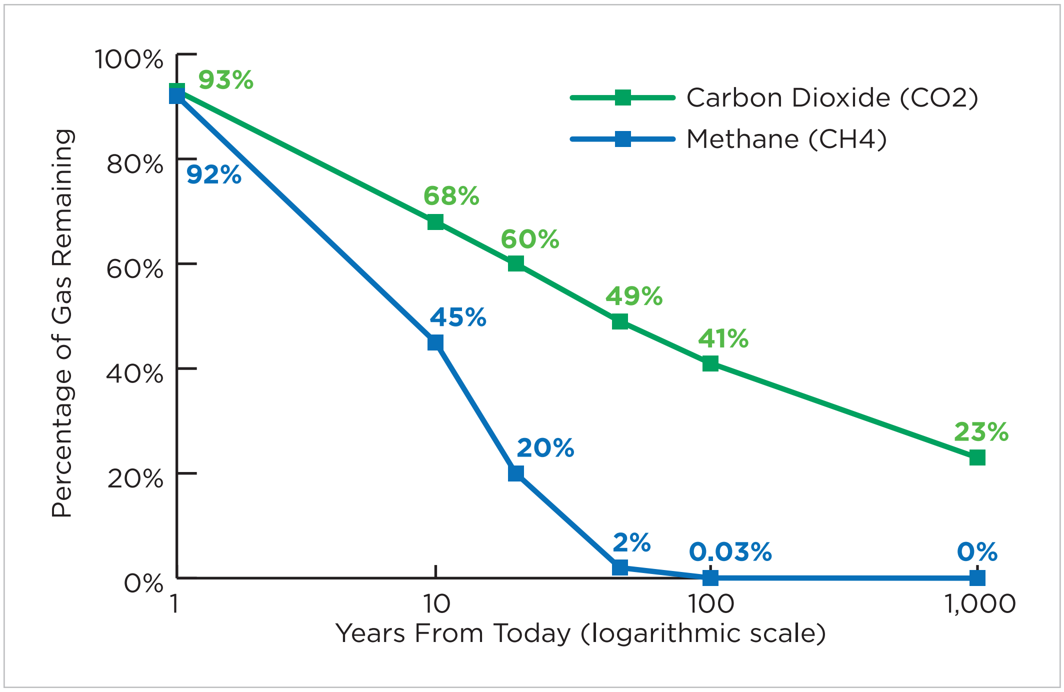
	Years From Today					
	1	10	20	50	100	1,000
Total Energy Added to the Climate System[7]						
(a) Methane ($W.m^{-2}.kg^{-1}.year \times 10^{-15}$)	204	1,456	2,106	2,583	2,629	2,630
(b) Carbon Dioxide ($W.m^{-2}.kg^{-1}.year \times 10^{-15}$)	1.6	14	25	53	92	545
GWP (a/b)	124	104	85	49	28	5
% of Gas Remaining *(Following an emission of 1 unit of gas at time 0)*						
Methane	92%	45%	20%	1.8%	0.03%	0%
Carbon Dioxide	93%	68%	60%	49%	41%	23%
Accumulated Removal Over 100 Years *(=1 - % of Gas Remaining)*						
Methane	8%	55%	80%	98.2%	99.97%	100%
Carbon Dioxide	7%	32%	40%	51%	59%	76%

7 Please see Appendix I for an explanation of the units of energy shown here.

Figure 1 presents the data contained in Table 2 for gas decomposition and gas remaining over time. As illustrated in Figure 1 and Table 2, most of methane's effects on climate occur within a few decades after its release, with 80% of its effects on climate complete after 20 years, and virtually all of the effects complete after 50 years. This contrasts with the impacts of the reference gas, carbon dioxide, which occur over a far longer time horizon and continue to contribute to global warming even beyond 1,000 years.

FIGURE 1. THE BEHAVIOUR OF METHANE AND CARBON DIOXIDE OVER TIME





The graphs in Figure 1 present the same data from opposite perspectives. The graph on the previous page shows how methane and carbon dioxide are removed from the atmosphere at different rates, while the graph above shows the proportion of each gas remaining in the atmosphere over time.

Current Reporting Practice and Its Challenges

Reporting requirements drive the practices for collecting, tracking, and using information. As the saying goes, *what gets measured gets managed*. While existing emission reporting protocols may address the intended purpose of the particular regulatory or reporting agent, they may also present challenges if an organization wishes to use this same information for risk management, internal decision making, or stakeholder accountability.

For example, based on current protocols, an organization that emits 1,000 tonnes of methane in the current year would report 28,000 tonnes of CO_2 equivalent for most emission-reporting and carbon-pricing purposes. If, however, the organization recognizes that the majority of the effects of its methane emissions on climate are complete within 20 years, it could apply a GWP_{20} factor of 85 to its emissions, meaning that it would recognize emissions of 85,000 tonnes of CO_2-equivalent.

In addition, after the current year, the protocols would no longer require the organization to track or report the ongoing effects of these emissions; greenhouse gas emissions are accounted for and reported only once (in the year of the original emission), even though the effects on climate of individual gases continue for decades or even millennia.

A number of concepts, however, are available to professional accountants for increasing an organization's focus on time value-related effects of NTCFs, including elements of depreciation methods, behaviour patterns of costs and volume, relevant information in decision analysis, and present value concepts.

The Concept of Allocating Costs to Different Periods (As Used For Depreciation)

GWP compares two gases that have very different removal patterns and lives. For example, methane generally stops having an effect on climate after 20 years and is 98% complete after 50 years. Conversely, the effect on climate of carbon dioxide is not materially complete even after 1,000 years. Methane and carbon dioxide have similar accumulated decomposition percentages at 20 years and 1,000 years respectively.

The Concept of Present Value

Using GWP values based on 100 years is, in some ways, similar to the concept of present value, since the effects on climate over 100 years are reported as an "equivalent" emission in Year 1. An alternative approach could be to report methane emissions using a 1-Year GWP value of 124 or a 20-year GWP value (GWP_{20}) of 85 rather than a 100-year GWP value (GWP_{100}) of 28. Accounting professionals could note that the Kyoto Accord allowed for the use of different time horizons: "In addition, for information purposes only, Parties may also use another time horizon, as provided in the Second Assessment Report" (UNFCCC 1997).

The Concept of Relevant Information

Because of the different lives of methane and carbon dioxide, the GWP calculation effectively uses a fixed value in the numerator and a variable value in the denominator after a certain point in time. For example, after 50 years, methane is almost completely removed from the atmosphere (or "depreciated"), meaning that the numerator in the GWP ratio reaches a fixed value, while carbon dioxide is only 50% removed by that time. Because current greenhouse gas reporting protocols use GWP values based on a 100-year timeframe, the resulting GWP value for methane is effectively diluted from a value of 85 based on a

20-year timeframe to a value of 28 based on a 100-year timeframe. This would be considered problematic for decision usefulness since relevant information is useful information.

Selecting the Relevant GWP Time Horizon and GWP Value

Accounting professionals may consider which GWP time horizon and value best reflects the effects on climate of their NTCF emissions, and the intended use of the resulting emissions information.

Focusing on methane, an organization could consider the following options:

- GWP_{100} of 25 based on the IPCC's *Fourth Assessment Report* of 2007 and to match most reporting protocols.
- GWP_{100} of 28 based on the IPCC's *Fifth Assessment Report* of 2013.
- GWP_{20} of 85 based on the IPCC's *Fifth Assessment Report* of 2013 and to match the more risk-relevant time horizon of 20 years.
- GWP_{1} of 124 to apply an opportunity-cost lens to the analysis.
- A GWP value representing either the useful life of the project or asset involved or the time horizon for an entity's long-range strategic planning cycle.
- An approximated GWP value using time value formulae (as discussed in Appendix II—The Time Value of Carbon Model).

Selecting any GWP value based on current scientific knowledge and a more risk-relevant time horizon could have a material effect on investment decisions and risk assessments. Adopting a 20-year time horizon, for example, would increase methane's CO_2-equivalent value by more than a factor of three relative to most existing protocols.

Benefits of Reducing NTCF Emissions

By reducing its NTCF emissions, not only could an organization reduce its immediate effects on climate and other global systems, it could potentially increase revenues or reduce costs. For example, if a natural gas company reduces fugitive emissions of methane, it will have more product available for sale. If a municipal government captures methane from its landfill, it can develop a new revenue source. In addition, regulatory agencies may alter their reporting requirements based on a better understanding of the effects on climate of NTCFs and the need for near-term action, which could create new incentives for organizations to reduce emissions of these gases and place additional regulatory risk on those that do not. Using the time value approach could lead to better organizational decision making, better government policies and incentives, and reduced environmental impacts that affect society at large.

A 2012 report by KPMG International provided a compelling analysis of the risks and opportunities from 10 "global sustainability mega-forces" they assert all businesses will face over the next 20 years (KPMG 2012). They identify climate change as the over-arching mega-force that will adversely affect all others if no meaningful action is taken. In addition, KPMG describes the business case for key industries such as oil and gas. Building on the risks and opportunities identified by KPMG International, the business case for reducing NTCF emissions can be summarized as follows:

- Seizing Opportunities and Demonstrating Authentic Leadership:
  - capturing opportunity costs (e.g., capturing previously vented methane to generate revenue);
  - investing in more sustainable product lines and products (e.g., less harmful refrigerant gases);
  - reducing social costs (e.g., litigation, social unrest (protests), and review process interventions);
  - capturing intangible benefits from demonstrated authentic leadership (e.g., boosting reputation, brand, employee and stakeholder support, and reducing divestment campaigns).
- Risk Mitigation:
  - reducing external risks (e.g., regulatory, reputation, and litigation risks);
  - reducing operational risks (e.g., supply-chain disruption, volatility of costs and infrastructure, and other disruptions to daily operations).

Applications for Accounting and Reporting

Current greenhouse gas reporting protocols vary by jurisdiction and reporting purpose. Regulatory filings typically involve applying a prescribed method for mandatory emissions reporting, while voluntary emission-reporting frameworks offer general guidelines and a selection of potential indicators. In general, these protocols use GWP values based on 100 years. This timeframe is applied even where the material effects on climate of selected NTCFs such as methane occur over a much shorter time.

Organizations have a wide range of potential applications for supplementary information on NTCF emissions. Emissions information currently reported to internal and external users could be modified, for example, to explicitly incorporate information about NTCF effects on climate over 20 years. Alternatively, organizations could provide emissions information through supplemental reports that disclose emissions and abatement efforts incorporated in their operations and use of products.

Internal Accounting and Reporting Options

Supplementary information on NTCF emissions could be voluntarily included in any component of an entity's internal strategic management framework (IFAC 2012). These components include an organization's:

- governance framework;
- strategic and operational plans;
- enterprise risk-management program;
- internal management accounting practices;
- greenhouse gas accounting systems;
- investment appraisal techniques or other decision-support tools;
- resource allocation and control systems;
- performance management and evaluation systems (including incentive frameworks).

According to the IFAC, using a systematic approach to considering such enhanced emissions information is often critical for making it part of business as usual:

> Improved social and environmental performance and transparency requires information flows to support the strategic and operational management of sustainability issues.... Reducing external environmental and social impacts... requires a systematic effort for data and information gathering, and the deployment of appropriate accounting, costing, and valuation methods. Organizations that take understanding their impacts and integrating sustainability issues into decision making seriously need to take a systematic and more formal approach to ensuring the availability of useful information to support decisions on how to (a) manage their social and environmental impacts, and (b) enhance their social and environmental value added (IFAC 2012).

In some organizations, modifying qualitative information (e.g., for investment appraisal techniques or within a balanced scorecard) might be sufficient to illustrate the opportunities and benefits of near-term decisions on NTCF reductions. Other organizations will require systematic approaches to improve long-standing practices.

External Reporting Options

The options for external reporting depend greatly on the purpose and nature of the reporting. Where reporting is voluntary, more options will exist for producing supplementary information on NTCF emissions. On the other hand, regulatory or standards-based reporting may require organizations to adhere to specific criteria, with possible considerations for narrative disclosure. External reporting options may include:

- Supplemental external reporting:
  - organizational web-based information;
  - protocol-based sustainability reports (two examples of global sustainability reporting frameworks include the Global Reporting Initiative (GRI) framework and the Carbon Disclosure Standards Board's Climate Disclosure Framework).

- Regulatory-based filings and related reporting guidance:
  - government and securities regulatory filings based on applicable authority and jurisdiction (e.g., the Toronto Stock Exchange for mandatory environmental information filings and the Province of British Columbia for carbon pricing);
  - related guidance for disclosures in periodic filings with securities regulators.

- GAAP-based financial statements:
  - recognition of financial impacts on the company in financial statements, using accounting principles for determining whether a transaction has occurred (CPA Canada 2015);
  - disclosure of financial impacts in accompanying notes (where an accounting professional refers to GAAP and conceptual framework components for direction on potential disclosure in the notes to the financial statements).

The discussion in this chapter leads to several conclusions:

- The 100-year time horizon currently used to report the "equivalent" effect of greenhouse gases on climate does not fully represent the material near-term effects of NTCF emissions.

- Organizations can increase their focus on NTCF emissions in several ways. Accounting for the financial effects of NTCF emissions may introduce new and intriguing substance-over-form examples for professional accountants to consider when applying professional judgment to GAAP-based financial reporting. This will take time to research and debate. Other options are more voluntary or internally-focused in nature and may be more feasible in the near term.

- The data used to make decisions should faithfully represent the issue, and should be relevant to the decisions. Faithful representation may include a sound estimate of how long emissions will affect climate and the pattern of the effect over that time period. Depreciation assumptions can be seen as a good analogy to that process. Faithful representation may also mean acknowledging that, until now at least, organizational concern about the effects of a given emission in a future year may have been less than concerns about the same effect in an earlier year. This is analogous to present value calculations that ascribe less value to cash flows in later years than to those in earlier years.

- Good decision-making frameworks support sound management decisions on investments in initiatives to reduce NTCF emissions. Accountants can contribute to these frameworks because of their training and education related to data quality and reporting, which are important to investment decisions.

- Accounting professionals can help organizations recognize the advantages of viewing the near-term effects of NTCFs on climate through the lens of current scientific knowledge. More appropriate time horizons could lead to better emission-reduction decisions and more effective action by stakeholders such as industry leaders, government regulators and policy developers, greenhouse gas reporting and standards-writing organizations, users of emissions-intensive products, local communities, and society at large.

CHAPTER 3
Mitigating Near-Term Climate Forcers

This chapter discusses how to reduce emissions of NTCFs at the international, national, municipal, and corporate levels.

Successful International Initiatives

While some countries, communities, and companies have individually struggled to reduce greenhouse gas emissions, it is possible to find promising examples where international cooperation has reduced emissions of other environmentally harmful gases such as sulphur dioxide (SO_2) and oxides of nitrogen (contributors to acid rain and smog), as well as CFCs (responsible for depletion of the ozone layer).

For example, under the UNEP's 1987 *Montreal Protocol on Substances that Deplete the Ozone Layer*, which has been signed by 191 countries, the production of 98% of ozone depleting substances has been eliminated. As a direct result of actions by parties to the treaty, the concentrations of ozone depleting substances in the atmosphere have declined from peak levels measured in the early 1990s (Velders et al. 2012).

As well, Canada has cooperated with the United States on initiatives to reduce emissions of SO_2 and NOx, which cause acid rain. Environment Canada reports that "the United States has reduced total SO_2 emissions from covered sources by 67 percent in 2010 from their 1990 levels while Canada's total SO_2 emissions have decreased by 57 percent in 2010 from 1990 emission levels" (Government of Canada 2012).

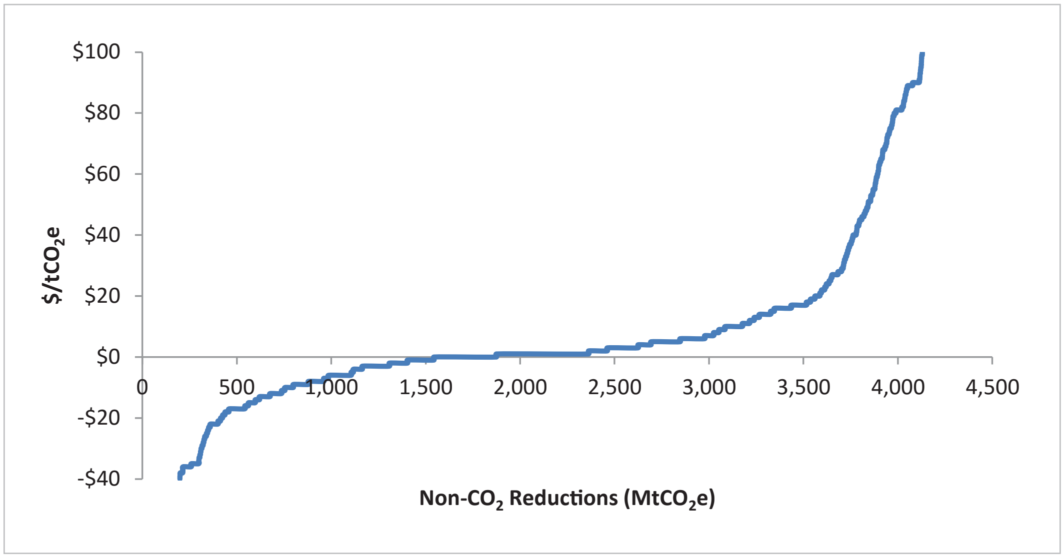
As for NTCFs, a number of international initiatives actively support the efforts of countries and corporations to reduce emissions. These initiatives include the Global Methane Initiative launched by the United States Environmental Protection Agency (US EPA), and the UNEP's Climate and Clean Air Coalition to Reduce Short Lived Climate Pollutants program, in which Canada is a participant.

The US EPA's comprehensive report, *Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030*, includes estimates of the costs and benefits of reducing emissions of non-CO_2 greenhouse gases, including NTCFs (US EPA 2013). The US EPA report states that: "Without a price signal (i.e., at \$0/tCO_2e), the global mitigation potential is greater than 1,800 million metric tons of CO_2 equivalent (MtCO_2e), or 12% of the baseline emissions. As the break-even price rises, the mitigation potential grows. Significant mitigation opportunities could be realized in the lower range of break-even prices. The global mitigation potential at a price of \$10/tCO_2e is greater than 3,000 MtCO_2e, or 20% of the baseline emissions" (US EPA 2013). This result from the EPA report is shown in Figure 2.

Expressed another way, based on global baseline methane emissions of 714 million tonnes per year (approximately 15 billion tonnes per year of CO_2e based on the GWP_{100} value of 21), the US EPA concludes that the first 12% reduction in global methane emissions would be self-financing and that a modest greenhouse gas price of \$10/tonne of CO_2e would result in a 20% reduction in emissions.

Note that the US EPA report is based on a 100-year GWP of 21 for methane, which is consistent with the IPCC *First Assessment Report*, but which is lower than the value of 28 from the IPCC *Fifth Assessment Report* and considerably lower than the value of 85 when using a 20-year time horizon. It would be interesting, in a further stage of research, to model the Marginal Abatement Cost on updated IPCC GWP values, especially on the effects of NTCFs over a 20-year time horizon.

FIGURE 2. GLOBAL AGGREGATE MARGINAL ABATEMENT COSTS (US EPA 2013)



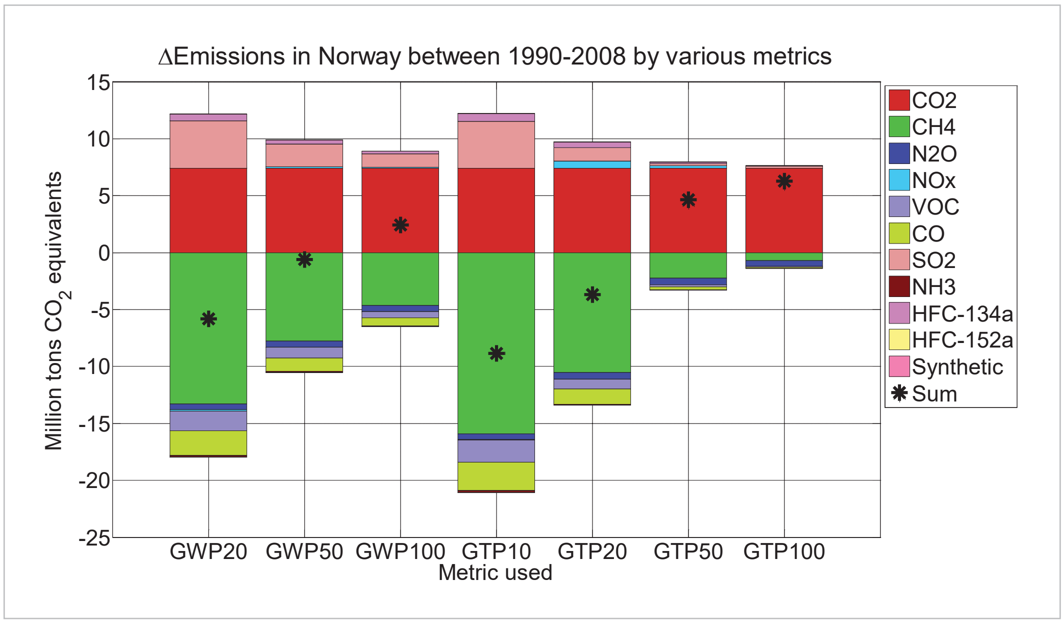
In June 2014, Environment Canada introduced the *Multi-sector Air Pollutants Regulations*, with the goal of reducing NOx emissions by 2,065,000 tonnes and SO_2 emissions by 96,000 tonnes before 2035. Environment Canada's *Regulatory Impact Analysis Statement* for these regulations includes a cost and benefit analysis. The analysis shows that, based on a combined reduction of 2,161,000 tonnes of SO_2 and NOx, Canada would realize a total net benefit of $9.1 billion, giving these reductions a value of approximately $4,200 per tonne. Environment Canada also expects "3.4 million tonnes of greenhouse gas reductions between 2013 and 2035, as a cobenefit to these regulations" (Government of Canada 2014a).

When considering the cost of abatement of greenhouse gas emissions in general, it is interesting that the *Regulatory Impact Analysis Statement* prepared for the *Multi-sector Air Pollutants Regulations* discusses a social cost of carbon of between $29.06 and $115.18 per tonne of CO_2 in 2013 and states that the "Social cost of carbon values increase over time to reflect the increasing marginal damages of climate change as projected greenhouse gas concentrations increase" (Government of Canada 2014a). At the invitation of Canada's Minister of Environment, the National Round Table on the Environment and the Economy (NRTEE) prepared a report that included estimates of the abatement costs of greenhouse gas emissions required to meet Canada's 2010 Copenhagen Accord reduction target of 607 million tonnes of CO_2e by 2020. The report identified a gap between projected emissions and Canada's target of an estimated 90 million tonnes of CO_2e per year. The report also estimated that part of this gap could be addressed through carbon capture and storage at costs ranging from $50 to $150 per tonne of CO_2e, with an average cost of $100 per tonne of CO_2e (NRTEE 2012).

Leadership from Norway

Norway has demonstrated that a focus on methane emissions can result in significant net greenhouse gas reductions on a national level. A study for the Norwegian Climate and Pollution Agency reported that Norway's greenhouse gas emissions rose by approximately 2% between 1990 and 2008, assuming conventional 100-year GWP values for NTCFs. Based on 20-year GWP values for NTCFs, however, Norway's greenhouse gas emissions fell by approximately 6% in the same period. Figure 3 taken from the study, illustrates this result.

FIGURE 3. REDUCTION OF GREENHOUSE GAS EMISSIONS IN NORWAY BETWEEN 1990 AND 2008 (AAMAAS ET AL. 2012)



The authors of the study discuss the results as follows: "The (figure shows the) change in Norwegian emissions between 1990 and 2008 using alternative metrics. There has been a relatively small increase in CO_2 emissions, but a large reduction in CH_4. For more than half of the examples presented here, the cooling from reducing CH_4 emissions outweighs the warming from increasing CO_2 emissions" (Aamaas et al. 2012). The alternative metrics are

GWP and Global Temperature Change Potential (GTP) for 10-, 20-, 50-, and 100-year time horizons. "Sum" in Figure 3 is the total CO_2 equivalents of all emissions (Aamaas et al. 2012).[8]

Mining, quarrying, and oil and gas extraction are a significant source of methane emissions. Norway's emission reductions took place despite the fact that these industries account for approximately 23% of Norway's GDP. Canada is in a good position to replicate Norway's results, as these industries comprise approximately 8% of Canada's GDP.

Opportunities for Cities

Cities occupy only 2% of the earth's land but consume 75% of the earth's resources and produce a similar proportion of all wastes. The environmental impacts of cities include upstream effects of resource extraction, downstream effects of waste disposal, and emissions of greenhouse gases. The environmental effects of cities reach far beyond their political boundaries; it has been estimated that London, England requires 125 times more land than its own area to meet its resource needs (Pearce 2006).

Fifty-four percent of the world's population lives in urban areas, a figure that is projected to climb to more than 60% by 2050, representing an additional 2.5 billion people (United Nations 2014). Expanding urban areas will continue to require massive infrastructure investments that, depending on the investment approaches, will either impede or enhance society's ability to reduce greenhouse gas emissions.

Municipalities have opportunities to reduce upstream effects on climate in the supply chain that may not be obvious. For example, if a new urban greenfield is planned and developed using business-as-usual methods, fossil fuel consumption for vehicles and buildings will rise. The increased consumption will require expansion of the energy supply chain, with an attendant increase in emissions of greenhouse gases; in consumption of land for fossil fuel extraction and oil and natural gas processing; in oil and natural gas transportation via pipelines and railways; and in the use of tankers. This expansion of upstream infrastructure caused by downstream demand has been termed *energy sprawl*. This term refers to the consumption of land that occurs when the energy supply chain expands to meet demand (Bronin 2010). Such upstream impacts lie

8 Global Temperature Change Potential (GTP) is an alternative metric to GWP.

beyond the political boundaries of cities, but they can be reduced by urban planning that facilitates:

- energy conservation in buildings;
- sustainable energy sources for buildings (e.g., passive solar heating and solar photovoltaics);
- the design of compact and mixed-use communities to reduce fossil fuel use for conventional transportation;
- industrial ecology solutions to recover energy from waste sources for use in local energy systems.

Municipalities also have direct control over NTCF emissions from solid waste management (e.g., methane from landfills) and liquid waste management (e.g., methane from wastewater treatment facilities). In the case of solid waste management, the traditional greenhouse gas mitigation approach has been to capture landfill gases (methane) resulting from the breakdown of organic materials, but this can still result in significant releases of methane (Spokas et al. 2006). For liquid waste, new treatment processes may be implemented without fully considering greenhouse gas mitigation potential (Rosso & Stenstrom 2008).

A stronger focus on NTCFs can help to reframe the decision-making context and encourage a paradigm shift from business-as-usual to innovative solutions. For example, an Integrated Resource Recovery approach substantially reduces methane emissions while reframing waste as a resource from which energy can be captured and revenues generated, a win-win solution (Province of British Columbia 2009). Currently, there are insufficient regulatory incentives to consider novel solutions such as resource recovery, but by placing more weight on the near-term benefits of methane reductions, it is possible for municipalities to favour novel solutions, with their ancillary benefits, over the status quo.

Finally, municipalities have not included land-use change and agricultural practices in their climate change plans. A better understanding of NTCFs emissions caused by these sources could, however, help uncover cost-effective opportunities to reduce their emissions. Efforts by cities to reduce NTCFs emissions can bring other social benefits. For example, since methane contributes to ozone formation, which is harmful to human health, reducing methane emissions mitigates this harm.

Opportunities for Corporations

The proportion of greenhouse gas emissions consisting of NTCFs will vary significantly among Canadian businesses depending on the nature of an organization and its sector. It is possible to generalize, however, by saying that NTCFs will comprise relatively significant proportions of greenhouse gas emissions from oil and gas drilling, natural gas transmission, solid waste management, and agriculture. On the other hand, NTCFs will comprise relatively smaller proportions of emissions from the combustion of fossil fuels and biofuels for electricity generation, transportation, and heating of buildings.

Fugitive emissions from natural gas pipelines and related infrastructure are a significant source of methane (Phillips et al. 2013). The United States Energy Information Administration (US EIA) reports that known natural gas losses amounted to 198 billion cubic feet in 2013, and that a further 237 billion cubic feet of natural gas were unaccounted for, representing 1.7% of all natural gas consumed in the United States (US EIA 2013). If known losses and unaccounted volumes were both released to the atmosphere, 8.5 million tonnes of methane would have been emitted each year. Using a GWP_{100} value for methane of 28, these losses would amount to 240 million tonnes of CO_2e, equivalent to the greenhouse gas emissions from approximately 48 million cars. At a value of US$8.00/GJ of natural gas, these emissions also represent an economic loss of US$3.7 billion per year. Note that these estimates do not include extraction losses associated with well drilling and hydraulic fracturing. These findings show that what can appear to be a small loss on a percentage basis can, in fact, represent a significant environmental and economic opportunity.

While a few academic studies have investigated fugitive natural gas emissions in specific cities, these emissions are not on the agenda of most municipalities. Understanding the effects of these emissions on climate over a 20-year time horizon, as well as the scale their economic loss to utilities, could motivate municipalities to investigate and mitigate fugitive emissions (Shindell et al. 2012 and West et al. 2006).

At the level of individual organizations, it is possible to find examples of firms that have significantly reduced their greenhouse gas emissions, while simultaneously reducing their costs:

> In 1994, DuPont committed to cutting its (greenhouse) gas emissions by 40% by the year 2000 from its 1990 levels. By 2000 the company had met its original target and set an even more ambitious one—a 65% reduction

> by 2010. But the gains have been so dramatic that DuPont has already hit that goal too. It also uses 7% less energy than it did in 1990, despite producing 30% more goods. That has saved $2 billion (*Business Week* 2005).
>
> and;
>
> Across Canada, Sobeys has taken the lead in implementing CO_2 transcritical refrigeration, having a total of 34 installations, with 22 more approved for 2013. CO_2 is a core part of Sobeys' goal to reduce greenhouse gas emissions by 15% by the end of 2013 (Shecco 2013).[9]

Avoiding Infrastructure Lock-In

"Lock-in" or path dependence occurs when corporations and municipalities continue to implement old technologies or practices despite the availability of new, better technologies (Liebowitz & Margolis 2009). Lock-in results in investing in old technologies (no matter how ineffective they are in reducing greenhouse gas emissions) or avoiding new technologies, regardless of their effectiveness (Kemp-Benedict 2014). These investments are the result of postponing adopting more effective solutions for as long as possible because of concerns over sunk costs. Lock-in has important implications for corporate and urban planning when it negates proper accounting of the environmental, social, and economic lifecycle costs and benefits of long-lived municipal infrastructure.

Optimal use of resources by corporations and municipalities is critical to efforts to reduce greenhouse gas emissions, as is maximizing emission reductions per unit of investment. Decisions about solid waste, wastewater treatment, road planning and construction, land-use policy, and other areas have financial, energy, and greenhouse gas consequences that will last for 50 to 100 years: "Infrastructure decisions are critical in determining long-term emissions and abatement costs because they can enhance or restrict the number and type of future options. Infrastructure decisions determine development patterns in transportation, urban settlement, and land use and influence energy system development and deforestation patterns" (IPCC 1996).

Methane emissions from industrial and municipal landfills, and from incinerating garbage, represent significant sources of greenhouse gases within the direct control of municipalities and corporations. The International Energy Agency (IEA) estimates that approximately two-thirds of methane emissions from landfills could be eliminated if greenhouse gases were taxed at CDN$30/

9 In this example, conventional refrigerants such as HFC-134a are being replaced with carbon dioxide.

tonne of CO_2e (IEA 2003).[10] If a new landfill or incinerator is constructed and a subsequent mandate for greenhouse gas emissions reductions requires an alternative approach to waste management, not only will a city absorb the significant additional cost of implementing an alternative solution in the future, but it may also find itself with a stranded asset.

In summary, the success of international treaties in reducing emissions of other gases such as ozone depleting substances and sulphur dioxide suggests that a similar effort could help reduce emissions of NTCFs. At the national level, Norway has demonstrated how a focus on one NTCF, methane, can significantly reduce the country's total greenhouse gas emissions. Finally, organizations have an opportunity to recognize the economic value of NTCFs as they consider investments in mitigation measures.

Appendix III: Introduction to NTCF Mitigation Measures includes a summary of reduction strategies that can be applied to various sources of NTCF emissions.

10 Values from Table 6.3 in the IEA report have been adjusted from US$ in the year 2000 to CDN$ in the year 2015.

CHAPTER 4

Potential Starting Points

Organizations willing to increase their focus on NTCFs may do so in four stages:

1. **Evaluation.** As an internal exercise, an organization could first evaluate its near-term effects on climate by asking two questions:

    a. Based on our current reporting methods and using 100-year GWP values, what proportion of our total emissions (tonnes/year of CO_2e) do NTCFs represent?

    b. If we recalculate our greenhouse gas emissions based on 20-year GWP values, what proportion of our total emissions (tonnes/year of CO_2e) do NTCFs now represent?

2. **Comparing Options.** After asking the above questions, the organization could research the options available for reducing its NTCF emissions. Accounting professionals could work with the organization's technical and operations personnel to ask: What strategies are available to reduce NTCF emissions? What investments would those strategies require, and what are the projected economic returns of those investments? What other benefits could these investments bring, for example to health, safety, operating efficiency, and reputation? The following resources are available to support this work:

    a. Environment Canada's Multi-sector Air Pollutants Regulations and Regulatory Impact Analysis Statement (Government of Canada 2014a).

    b. The US EPA's Global Methane Initiative, which can provide emission-reduction ideas as well as marginal abatement cost information (US EPA 2013).

    c. The UNEP Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (UNEP 2014).

3. **Taking Action.** Accounting professionals can ensure investments in emission-reduction strategies are incorporated into the organization's business plans by:

    a. Clearly defining the internal costs and benefits of emission-reduction strategies. In particular, accounting professionals can help ensure that all costs and benefits are included in this analysis, including the value of avoided losses of product (e.g., reducing natural gas leaks), improved operating efficiencies, new sources of revenue from recovered resources (e.g., an anaerobic digester for manure or food waste), and revenues from the sale of emission offsets.

    b. Working with the organization's sustainability personnel to articulate the external benefits of emission reductions, including benefits to climate, air quality, human health, and the organization's reputation.

4. **Considering Reporting Progress.** After making investments to reduce NTCF emissions, the organization could consider sharing its results on a voluntary basis. This information would be supplementary to existing greenhouse gas and sustainability reports, and could include:

    a. the organization's reasons for focusing on NTCFs;

    b. the proportion of the organization's greenhouse gases that NTCFs initially represented, based on 20-year GWP values;

    c. the investments and initiatives the organization completed to reduce emissions;

    d. the emission reductions and other benefits that resulted from these initiatives and investments;

    e. the organization's plans for further emission reductions.

Resources available to support the communications stage include the Carbon Disclosure Project (CDP) and the Science Based Targets initiative developed by the CDP, the World Resources Institute, and the World Wildlife Fund (Science Based Targets 2015).

While organizations would continue to report their supplementary information on greenhouse gas emissions based on existing protocols, they could voluntarily add an indicator for NTCFs. This supplementary information could take the form shown in Table 3.

TABLE 3. GREENHOUSE GAS REPORTING CALCULATION WITH SUPPLEMENTARY INFORMATION

Greenhouse Gas	Emissions in 2015 (tonnes/year)	GWP_{100}	CO_2e = Emission × GWP (CO_2e tonnes/year)
Carbon Dioxide (CO_2)	10,000	1	10,000
Methane (CH_4)	100	28	2,800
Nitrous Oxide (N_2O)	1	265	265
HFC-134a	0.1	1,300	130
Total: (Per Existing Protocols)			**13,195**
Supplementary Information: Action to Address Near-Term Climate Forcers			
Greenhouse Gas	**Emissions (tonnes/year)**	**GWP_{20}**	**CO_2e = Emission × GWP (CO_2e tonnes/year)**
Methane (CH_4) in 2013	200	85	17,000
Methane (CH_4) in 2016	100	85	8,500

Notes:
1. The organization's methane emissions have decreased by 50% since 2013.
2. Further investments in emission reduction initiatives are planned for Fiscal Year 2016.

When reporting supplementary information about its near-term effects on climate, an organization should clarify that non-CO_2 gas emissions are not counted twice.

CHAPTER 5

Areas for Further Development

The authors of this report would like to recommend the following areas related to the time value of carbon for future research and development:

- Although the approach described in this report has been limited to an analysis of methane and HFC-134a, the analysis can also be applied to other NTCFs.

- To date, estimates of methane abatement costs have been based on a GWP_{100} value of 21. It would be interesting to model the marginal abatement cost based on current IPCC GWP values over a 20-year time horizon.

- This report has touched on the economic, environmental, and social benefits of reducing NTCF emissions. Future work could use Lifecycle Analysis to further develop these connections, especially with respect to energy consumption and greenhouse gas emissions from agriculture, fertilizer production and application, water management, liquid waste management, and solid waste management, all of which are interrelated elements of our food supply chain.

- Although GWP has been widely adopted as a useful indicator of the effects of greenhouse gases other than CO_2, its limitations are also recognized in scientific literature (Shine 2005). GTP is an alternative metric to GWP, which models the temperature change in a given year after a pulse emission of a greenhouse gas in relation to the temperature change that would result from a pulse emission of a reference gas (CO_2). As with GWP, the choice of time horizon is important (Peters 2011). It would be interesting to apply the approach developed in this report to the Global Temperature Change Potentials of greenhouse gases.

- Regarding carbon pricing, organizations could explore the question of whether it is appropriate to modify an existing greenhouse gas price based on a particular emission's relevant time horizon of material impact (i.e., when the emission class has done the most harm).

- The accountancy profession could consider these questions:

  — If a regulatory framework relies on outdated science and if the scientific community offers compelling evidence that alters an event's economic substance (giving rise to GAAP-based reporting), would the professional accountant be bound to comply with the *form* of regulation or the underlying *substance* of emissions and their effects on climate?

  — Would it be appropriate for organizations to incorporate Scope 3 emissions into reporting (particularly the emissions from the organization's carbon-intensive products) in addition to the near-term effects on climate discussed in this report? Conversely, in a carbon-constrained world, is it inappropriate (i.e., ethically, legally, morally, and professionally) for industries supplying carbon-intensive products to avoid reporting Scope 3 emissions?[11]

11 Scope 3 emissions are all indirect emissions that occur in the value chain of a reporting organization, including both upstream and downstream emissions (World Resources Institute 2004).

Conclusions

While the relationships among greenhouse gases, their effect on climate, and efforts to address climate change may be complex, the message of this report is simple.

- Carbon emissions, like money, have a time value.
- Since 1990, greenhouse gas reporting has become common practice, but global emissions continue to rise and NTCF emissions are rising more quickly than emissions of carbon dioxide.
- Reducing the risk of potentially disastrous climate change requires urgent action.
- Not all greenhouse gases affect the climate in the same way. While the total increase of temperatures over the long term is closely related to the total emissions of CO_2, the rate of increase of global temperatures in the nearer term is affected by emissions of NTCFs.
- Reducing CO_2 emissions requires different strategies than reducing NTCF emissions. Understanding this can help organizations make more focused efforts to reduce their greenhouse gas emissions.
- To understand the significance of NTCFs, organizations can choose GWP values based on 20 years, a period which more closely matches the timeframe over which NTCFs make their greatest contributions to global warming.

- Organizations have an opportunity now to make significant and rapid contributions to addressing climate change, to demonstrate leadership, and to realize the internal and external benefits of early action. Acting now will bring multiple benefits, such as:
  - reducing the organization's effects on climate;
  - reducing the harm NTCFs cause to human health and crops;
  - reducing risks to the organization (including the risk of increased regulatory focus on NTCFs);
  - the economic value of investments to reduce emissions.

- Accounting professionals have a vital role in:
  - helping organizations identify, quantify, and articulate the benefits of early action to address NTCFs;
  - providing internal guidance on emission-reduction investments and accounting for the economic, environmental, and social benefits of early action on a lifecycle basis;
  - highlighting the connections among external risks, costs, and benefits of early actions to address climate change, specifically with NTCFs.

- Accounting professionals provide insight into effective ways to mitigate risk in general. Identifying risks associated with climate change is consistent with the roles and responsibilities of professional accountants in society.

- There are no regulatory barriers to voluntarily reporting supplementary information on focused action on NTCFs, and accounting professionals can help frame this communication.

- The more all professionals understand how human activities affect climate change and how different strategies can reduce emissions, the more effective we can be in fulfilling our broadest responsibilities to society.

Glossary

Term	Explanation	Source
AGWP	Absolute Global Warming Potential is the integration/summation of Radiative Forcing at a given time horizon, with units of $W.m^{-2}.kg^{-1}.year$.	IPCC 2013a
AGTP	Absolute Global Temperature Change Potential is the change in global surface temperature at a given time after emissions.	IPCC 2013a
BC	Black carbon, also referred to as soot. This aerosol is formed when fossil fuels or biofuels are burned inefficiently and without adequate pollution controls. Black carbon contributes to climate change by increasing the absorption of sunlight.	IPCC 2013a
Carbon	The term "carbon" is used in this report as a common term to refer to all greenhouse gases. An area of confusion within greenhouse gas emissions reporting concerns units of measure. While the universal unit is tonnes of CO_2e (Equivalent Carbon Dioxide Emission), some organizations report tonnes of CO_2, while others report tonnes of "C" (i.e., carbon). One tonne of CO_2 equals one tonne of CO_2e, but one tonne of "C" equals 3.66 tonnes of CO_2 (based on the ratio of molecular weights of carbon and carbon dioxide).	
CH_4	Methane, which is the main component of natural gas, is also produced when organic matter decomposes in the absence of oxygen (e.g., in landfills).	
CO_2e	Equivalent Carbon Dioxide Emission (CO_2e) is the amount of carbon dioxide emissions that would cause the same integrated Radiative Forcing, over a given time horizon, as an emitted amount of a well-mixed greenhouse gas or a mixture of well-mixed greenhouse gases.	IPCC 2013a
Climate Change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.	IPCC 2013a

Term	Explanation	Source
Climate Impacts	Consequences of climate change on natural and human systems. In this report, the effects of human activities (e.g., greenhouse gas emissions) on climate are referred to as "effects on climate."	IPCC 2001
Greenhouse Gas	Greenhouse gases include any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).	UNFCCC 2015
GTP	Global Temperature Change Potential is the ratio of change in global mean surface temperature at a chosen point in time caused by the emissions of a greenhouse gas relative to the change in global mean surface temperature caused by CO_2. GTP also involves the choice of a specific time horizon.	IPCC 2013a
GWP	Global Warming Potential is an index, based on radiative properties of well-mixed greenhouse gases, measuring the Radiative Forcing of a unit mass of a given well-mixed greenhouse gas in the present day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. For example, GWP_{100} refers to a GWP based on a 100-year time horizon while GWP_{20} refers to a GWP based on a 20-year time horizon.	IPCC 2013a
Halogens	While the scientific definition of a halogen is a salt forming group of elements (e.g., chlorine or fluorine), the term *halogen* is used in greenhouse gas reporting to refer to Hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs).	
HFCs and HCFCs	Hydrofluorocarbons and Hydrochlorofluorocarbons are used in refrigeration and air conditioning equipment and as aerosol propellants. HFCs have low or zero Ozone-Depletion Potential (ODP), but have high GWPs and contribute significantly to global warming. The most commonly-used hydrofluorocarbon is HFC-134a (chemical formula CH_2FCF_3, also known as tetrafluoroethane).	Environment Canada 1996
IPCC	The Intergovernmental Panel on Climate Change is a scientific intergovernmental body which operates under the auspices of UNEP and the United Nations' World Meteorological Organization (WMO).	
IRF	Impulse Response Function represents the time-dependent abundance of gas caused by the additional emission of one kilogram of gas at time zero.	Joos 2013
Lifetime	Lifetime is a general term used to characterize the rate of processes affecting the concentration of trace gases. In general terms, the lifetimes of NTCFs are in the order of years or decades. A complete definition of lifetimes can be found in the IPCC 2007 Annex I Glossary.	IPCC 2013a
MAC	The Marginal Abatement Cost is the cost of eliminating an increment of pollution.	US EPA 2013
Mt CO_2e	Million tonnes of CO_2e.	

Term	Explanation	Source
N_2O	Nitrous oxide, one of the six greenhouse gases to be mitigated under the Kyoto Protocol. The main anthropogenic source of nitrous oxide is agriculture (soil and animal manure management), but important contributions also come from sewage treatment, combustion of fossil fuel, and chemical industrial processes. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests.	IPCC 2013a
NOx	NOx or NO_x refers to nitric oxide (NO) and nitrogen dioxide (NO_2). NOx is formed during the combustion and decomposition of organic matter. NOx leads to ozone formation, and both NOx and ozone are harmful to human health.	IPCC 2006
NTCFs	Near-Term Climate Forcers (NTCFs) refer to compounds whose impact on climate occurs primarily within the first decade after their emission. NTCFs are also referred to as Short-Lived Climate Forcers (SLCF), Short-Lived Climate Pollutants (SLCP), or Near-Term Greenhouse Gases (NTGG). This report uses the term NTCFs to be consistent with IPCC terminology.	IPCC 2013a
ppm	Parts per million. In the context of climate science, this is a measure of the concentration of a gas in the atmosphere.	
ppt	Parts per trillion. In the context of climate science, this is a measure of the concentration of a gas in the atmosphere.	
Radiative Efficiency	Radiative Efficiency is the Radiative Forcing per unit increase in atmospheric burden of gas, and has units of $W{\cdot}m^{-2}{\cdot}kg^{-1}$. The Radiative Efficiency of methane, for example, is approximately 70 times greater than that of carbon dioxide, while the radiative efficiency of HFC-134a is 5,000 times greater than that of carbon dioxide.	Joos 2013
Radiative Forcing	Radiative Forcing is the change in the net (i.e., downward minus upward) radiative flux (expressed in $W.m^{-2}$) at the tropopause or top of atmosphere due to a change in an external driver of climate change (e.g., a change in the concentration of carbon dioxide or the output of the sun).	IPCC 2013a
SCC	The estimated value of damages avoided through greenhouse gas reductions is based on the climate change damages avoided at the global level. These damages are usually referred to as the Social Cost Of Carbon (SCC).	Government of Canada 2014a
UNEP	United Nations Environmental Programme.	
UNFCCC	United Nations Framework Convention on Climate Change.	
WCI	The Western Climate Initiative is a coalition of Arizona, California, Montana, New Mexico, Oregon, Utah, Washington, British Columbia, Manitoba, Ontario, and Quebec that works to develop programs to measure and reduce greenhouse gas emissions.	

APPENDIX I

The Climate Science of Near-Term Climate Forcers

Climate science provides a well-researched understanding of cause and effect between emissions and climate change. It is clear that certain greenhouse gases are more detrimental because of their effectiveness in trapping heat. While greenhouse gases such as carbon dioxide last in the atmosphere for centuries, another group, called NTCFs, are the “sprinters” of global warming. These gases last only for a few decades in the atmosphere, but have a disproportionately detrimental effect during their lifetimes. For example, over a 20-year period, HFC-134a, a commonly-used refrigerant, is 3,700 times more effective in trapping heat than carbon dioxide on a tonne-for-tonne basis.

FIGURE 4. RELATIONSHIPS BETWEEN EMISSIONS AND CLIMATE CHANGE

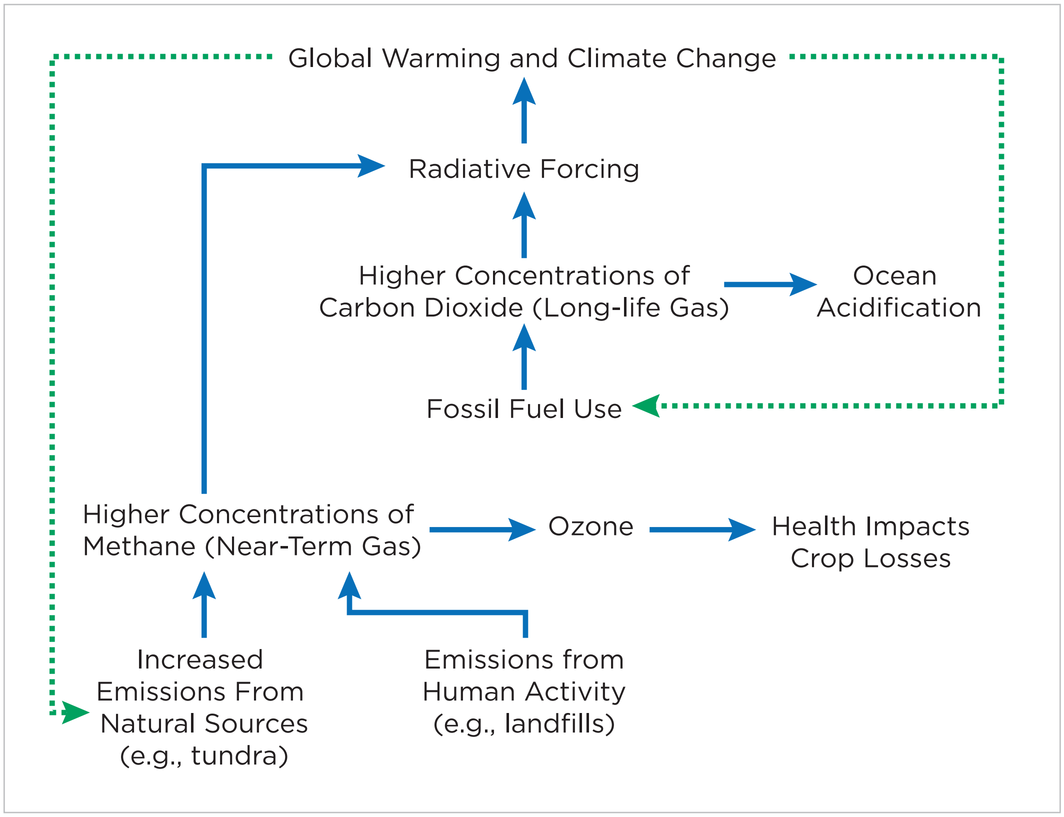


Figure 4 shows a highly simplified illustration of the relationship between emissions and climate change. In the figure, feedbacks are shown as dotted lines. In summary:

- Burning fossil fuels releases CO_2, a gas with long-term effects on climate.
- Industrial activities and solid-waste management release methane, a NTCF with near-term effects on climate.
- Both classes of greenhouse gas increase the atmosphere's ability to retain heat from sunlight, a mechanism referred to as "Radiative Forcing."
- Each greenhouse gas's contribution to Radiative Forcing depends on its chemistry and its concentration in the atmosphere.
- Radiative Forcing, in turn, causes rising temperatures.
- Rising temperatures, in turn, cause ice to melt and wind and ocean currents to change, which results in other changes such as the geographic distribution of precipitation.

Current Greenhouse Gas Reporting

IPCC Assessment Reports summarize current knowledge about the relationship between emissions of greenhouse gases and the changing climate.[12] The IPCC and the UNFCCC have also established common protocols for reporting greenhouse gas emissions. The protocols enable emitting organizations, communities, and nations to be accountable for their emissions and to understand emissions trends over time. Current protocols (i.e., those developed by the UNFCCC) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

To simplify emissions reporting by organizations and governments internationally, reporting protocols require that the warming effect of each non-CO_2 gas be equated with that of a reference gas (CO_2) over a 100-year time horizon. The ratio of these two effects is referred to as the GWP. Total emissions reported by an organization or government are shown as CO_2e, or tonnes of CO_2 equivalents. Determining the total CO_2e emissions of a reporting entity then becomes a simple matter of multiplying the mass of emissions of each gas in a given year by its GWP value. The IPCC defines GWP as follows: "A direct interpretation is that the Global Warming Potential is an index of the total energy added to the climate system by a component in question relative to that added by CO_2" (Myhre et al. 2013).

Table 4 shows an example of how CO_2 equivalents are calculated for four greenhouse gases.

TABLE 4. SIMPLIFIED GREENHOUSE GAS REPORTING CALCULATION

Greenhouse Gas	Emission of Each Gas (tonnes/year)	GWP_{100}	CO_2e = Emission × GWP (CO_2e tonnes/year)
Carbon Dioxide (CO_2)	10,000	1	10,000
Methane (CH_4)	100	28	2,800
Nitrous Oxide (N_2O)	1	265	265
HFC-134a	0.1	1,300	130
		Total	**13,195**

The strength of this approach is that it enables changes in emissions to be compared over time and amongst different emitters. Without disputing the vital importance of internationally accepted reporting protocols, it is worth understanding some of the limitations of the current GWP approach. As noted

12 The IPCC is a scientific body under the auspices of the United Nations.

above, current greenhouse gas reporting protocols require emitters to equate the effects of non-CO_2 gases to the equivalent effect of CO_2. A weakness of the GWP approach is that each greenhouse gas acts differently over time. Not only can the effects on climate of non-CO_2 greenhouse gases be significantly greater than the effects of CO_2, they also occur over markedly different time scales.[13] This makes "equivalence" imprecise and at times unhelpful in providing climate change mitigation guidance.

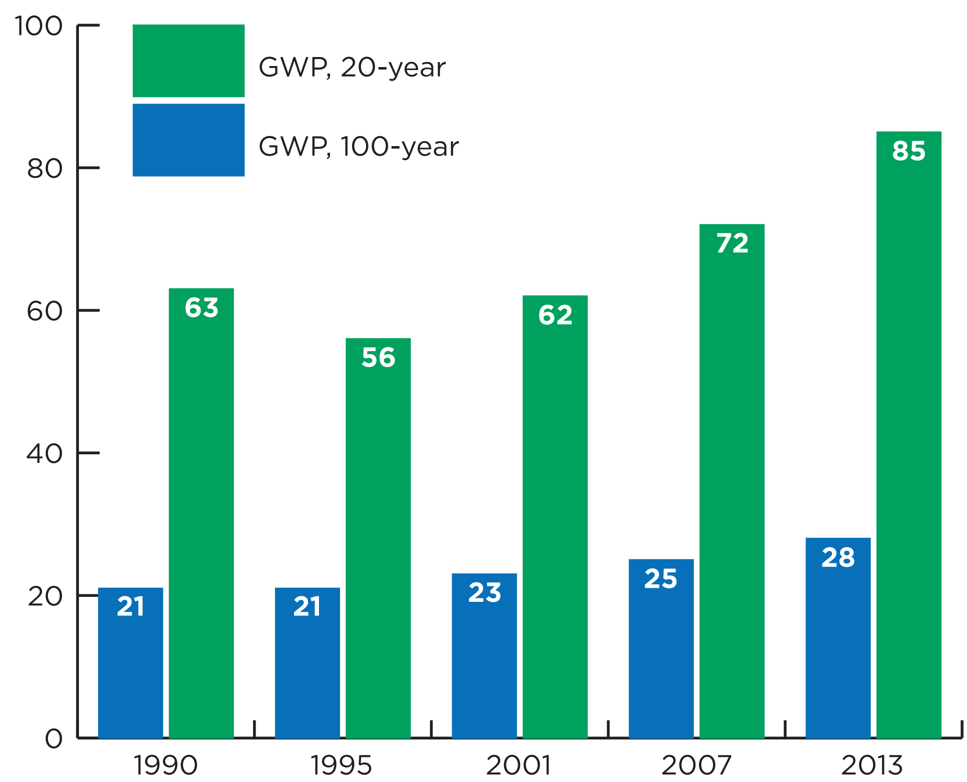
Carbon dioxide is removed from the atmosphere through slow geological processes so that 40% of the CO_2 emitted today will remain after 100 years, and approximately 20% will remain after 1,000 years. On the other hand, NTCFs such as methane affect global warming significantly, but over relatively short time scales. Methane is removed from the atmosphere much more quickly than CO_2, through reactions with other atmospheric chemicals and through metabolism by soil bacteria, so that only 20% will remain after 20 years.

Further, the IPCC's *Fifth Assessment Report* explains that the increase in GWP values for individual greenhouse gases since 1990 reflects both the degraded ability of the atmosphere and biosphere to neutralize methane and new scientific knowledge about the behaviour of greenhouse gases in the atmosphere (IPCC 2013). The atmosphere's degraded capacity to neutralize methane is caused, in part, by increasing methane emissions.

Figure 5 shows how the GWP_{20} and GWP_{100} values for methane reported by the IPCC have changed over time.

13 Consistent with the scientific literature, this report uses the term "effects on climate" to refer to greenhouse gas emissions, and the term "climate impacts" to refer to the impacts of a changing climate on humans and the environment.

FIGURE 5. CHANGES TO THE GLOBAL WARMING POTENTIAL OF METHANE SINCE 1990 (IPCC 2013)



The GWP values commonly used for reporting greenhouse gas are derived from the IPCC's *First Assessment Report*, which was based on scientific research carried out in the early 1990s. GWP values, however, have not been revised upwards in reporting protocols in step with successive IPCC Assessment Reports issued since 1990. For example, the 100-year GWP value for methane of 21 from the IPCC's *First Assessment Report* is still widely cited, although the IPCC's *Fifth Assessment Report* (released in 2013) included a 100-year GWP value of 28 without climate feedbacks, and a value of 34 with climate feedbacks taken into account.

While the 100-year values for the GWP of methane shown in Figure 5 increased by 33% between 1995 and 2013, the 20-year values increased by more than 50%. These changes are not the focus of this report, but they do highlight one aspect of the need to update and improve the reporting of the effects of NTCFs.

The Near-Term Challenge and Opportunity

Climate scientists do not say that climate changes over the longer term have less value or are ultimately less important than those that take place in the near term. Climate scientists report that both the rate of temperature rise in the short term and the total temperature rise in the long term are important. Referring to reductions of NTCFs, the UNEP has stated: "Because such reductions are likely to only make a modest contribution to *longer-term* climate goals, they must be viewed as a strategy that complements but does not replace carbon dioxide emission reductions" (UNEP 2014). Further, reducing emissions of carbon dioxide is necessary to mitigate its other effects, including ocean acidification. Clearly, early action on both CO_2 and non-CO_2 emissions (including NTCFs) is important (Shindell 2005).

Nor does this report propose delaying action to reduce CO_2 emissions until actions to reduce NTCFs are underway. Instead, this report suggests that it can be helpful for emitters to more clearly understand the effects of NTCFs today because these emissions are increasing quickly, the strategies to reduce them are different from those for reducing CO_2, and reducing NTCF emissions can bring immediate economic benefits to emitters as well as benefits to human health and agriculture.

This report uses two NTCFs as examples: methane (CH_4) and a hydrofluorocarbon (HFC-134a). Methane was selected because it makes the second largest contribution to global warming after carbon dioxide, and because of its short lifetime of 12.4 years. HFC-134a was developed to replace ozone-depleting substances in refrigeration, air conditioning, aerosols, and in foam production and is the most commonly used hydrofluorocarbon. It was included because of its very high GWP (3,700 over 20 years), its short lifetime of 13.4 years, and the recent rapid increase of its emissions (IPCC 2013).

The Relevance of Time Horizons

Since 1990, climate scientists providing information to the IPCC have pointed out that the choice of a 100-year time horizon for GWPs has limitations: "For the GWP used by the UNFCCC and in the Kyoto Protocol, a time horizon of 100 years is applied, though this choice lacks a scientific basis" (Joos et al. 2013) and "There is no scientific argument for selecting 100 years compared with other choices. The choice of time horizon is a value judgment because it depends on relative weights assigned to effects at different times" (IPCC 2013, based on Fuglestvedt et al. 2003, and Shine et al. 2009).

When it comes to the question of value, climate scientists observe that "Rapid emissions reduction is required to restore Earth's energy balance and avoid ocean heat uptake that would practically guarantee irreversible effects" (Hansen et al. 2013).

Carbon emissions, like investments, have a time value. One can think about this time-related value in several ways:

- Reducing greenhouse gas emissions by 50% between the years 2015 and 2020 clearly has more value than doing nothing until 2115, and then reducing emissions by 50%. Carbon has a time value.
- Early investments to reduce emissions will bring earlier economic returns. Money has a time value.
- It can be challenging for people to invest resources and effort today in initiatives having long-term benefits that can appear to be less intangible (e.g., investing today to avoid the worst impacts of climate change in the future). This bias was originally and famously explained by Daniel Kahneman and Amos Tversky in their development of aversion theory and prospect theory (Kahneman and Tversky 1979). Human choice has a time value.

This report looks at the connections among these three elements of value in an effort to show that early action to reduce emissions of NTCFs is practical, affordable, and desirable.

The GWP values calculated for greenhouse gases are greatly affected by the choice of time horizon over which the calculation is done. As noted above, current reporting practices assume that the effects of all greenhouse gases occur over 100 years, a choice of time horizon that originated with administrators responsible for the development of the Kyoto Protocol. *Decision 2/CP.3. Methodological issues related to the Kyoto Protocol* reads: "Reaffirms that global warming potentials used by Parties should be those provided by the Intergovernmental Panel on Climate Change in its *Second Assessment Report* ("1995 IPCC GWP values") based on the effects of the greenhouse gases over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in global warming potential estimates. In addition, for information purposes only, Parties may also use another time horizon, as provided in the *Second Assessment Report*" (UNFCCC 1997).

If the authors of the Kyoto protocol considered "complicated uncertainties" as one reason for choosing a 100-year time horizon, it is interesting to note that the IPCC's *Fifth Assessment Report* points out the uncertainty in GWP values for a 20-year time horizon is actually lower than the uncertainty for a 100-year horizon (IPCC 2013).

AGWP represents the total amount of Radiative Forcing caused by a quantity of a greenhouse gas over a given time horizon, which is an indication of its contribution to global warming. The GWP of a greenhouse gas is simply the ratio of its AGWP to the AGWP of CO_2 summed over a specific time horizon. Appendix II: The Time Value of Carbon Model includes a detailed explanation of AGWP. Table 5 shows how methane and carbon dioxide contributions to global warming change over five different time horizons.

TABLE 5. HOW THE CHOICE OF TIME HORIZON AFFECTS GWP FOR METHANE

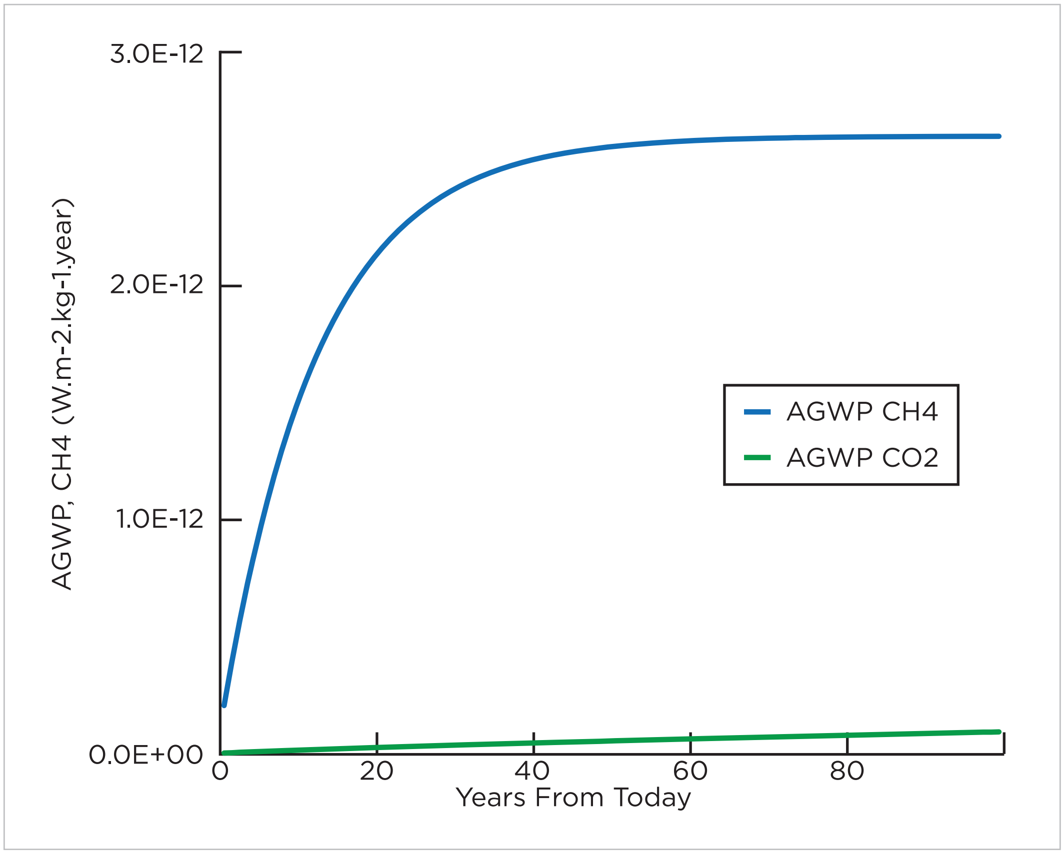
Time Horizon	1	10	20	50	100
AGWP, CH_4 ($x10^{15}$) ($W.m^{-2}.kg^{-1}.year$)	204	1,456	2,106	2,583	2,629
AGWP, CO_2 ($x10^{15}$) ($W.m^{-2}.kg^{-1}.year$)	1.6	14	25	53	92
% of 100-year Impact, CH_4	8%	55%	80%	98%	100%
GWP (AGWP, CH_4 / AGWP, CO_2)	124	104	85	49	28

The table shows that, while the energy contribution to global warming of one unit of methane is far higher than the contribution of one unit of carbon dioxide, the energy contribution of CO_2 continues to rise over time. Carbon dioxide remains in the atmosphere for centuries, where it continues to induce climate change. On the other hand, methane makes 80% of its total contribution within the 20 years following its release (and, on a tonne-for-tonne basis, a more significant contribution).

It is simple to see that, after Year 20, the decrease in methane's GWP values is due more to the ongoing but smaller effects of CO_2, and much less to the effects of methane. In other words, the remaining 80 years in the calculation of methane's 100-year GWP arithmetically dilute its GWP value and, therefore, mask methane's near-term effects on climate. This simple analysis illustrates how using a 100-year time horizon for a gas that is most active over 20 years also masks the value of early mitigation action.

Figure 6 shows the difference between the global warming effects of methane (CH_4) and carbon dioxide (CO_2) over time, illustrating the important time value effects of NTCFs.

FIGURE 6. ABSOLUTE GLOBAL WARMING POTENTIAL (AGWP) FOR METHANE AND CARBON DIOXIDE OVER TIME



To further emphasize the idea that different greenhouse gases contribute to global warming in dramatically different ways, one could say that a tonne of methane contributes the same amount of energy to global warming in the six months after its release as a tonne of carbon dioxide contributes over 100 years. Similarly, it would take 100 years for one tonne of CO_2 to contribute the same total energy to global warming as one tonne of HFC-134a can contribute in the four days following its release.[14]

Seen another way, one could say that to use a 100-year GWP is to assume that the effects on climate of all non-CO_2 gases (including NTCFs) can be mathematically averaged over 100 years, and that these effects are discounted at

14 The comparison for methane is based on the fact that the AGWP for carbon dioxide over 100 hundred years, for methane over six months, and the AGWP for HFC-134a over four days are all approximately equal to 9E-14 $W.m^{-2}.kg^{-1}.year$ based on data in the IPCC's *Fifth Assessment Report* (see **Appendix II: The Time Value of Carbon Model** for a more detailed explanation of AGWP). The comparison is only offered to show the magnitude of the difference between the impacts of methane and carbon dioxide. In practice, the ratio of the climate forcing effects of the three gases would change over time as a result of factors such as changes to the atmospheric concentrations of the gases, changes to their respective radiative efficiencies, and so on.

a rate of 0% up to 100 years and then at a rate of 100% thereafter.[15] For long-life gases like nitrous oxide (N_2O) (121 year lifetime) and sulphur hexafluoride (50,000 year lifetime), a 100-year GWP cannot account for the very long-term effects of the gas on climate. For NTCFs like methane (12.4 year lifetime) or HFC-134a (13.4 year lifetime), the effect is reversed since the 100-year GWP value does not represent the very near-term effects of the gas on climate in a way that is most relevant for decision making today.

In summary, current greenhouse gas reporting methods do not take into account the very different timeframes over which NTCFs, such as methane, and longer-term gases, such as carbon dioxide, contribute to the greenhouse effect. This fact has consequences in a number of important areas that will be discussed in the next section.

Greenhouse Gas Reporting by Municipalities

Different philosophies can frame a city's approach to reporting greenhouse gas emissions (Keirstead, Jennings, & Sivakumar 2012). The "geographic" approach seeks to account for all emissions within the physical boundary of a city. The "geographic plus supply chain" approach accounts for specified upstream emissions. A "consumption-based" inventory accounts for emissions associated with all of the goods and services consumed by the residents of a city. The predominant approach is the "geographic plus" method, which generally includes upstream emissions as a result of electricity consumption, but does not include upstream emissions associated with other goods and services.

In addition to varying philosophical approaches, different cities use different reporting frameworks specific to a region or country. As a result of these varying approaches, there are significant data gaps in most existing city-level inventories (Sovacool & Brown 2010), and inventories from different cities are not comparable (Seto et al. 2014). A coalition of organizations, including the World Resources Institute, United Nations Habitat, and ICLEI-Local Governments for Sustainability, issued the Greenhouse Gas Protocol for cities at the 2014 United Nations Climate Change Conference in Lima. The Protocol represents a global standard for reporting emissions at the municipal level, consistent with the UNFCCC national inventories approach. Achieving a consensus on a standard approach addresses one of the major sources of uncertainty around community-scale greenhouse gas emissions (Seto et al. 2014). The Greenhouse Gas Protocol, which requires that seven

15 The authors are indebted to Dr. Nathan Gillett of the Canadian Centre for Climate Modelling and Analysis for this analogy.

greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC, SF_6, and NF_3) be individually tracked, provides guidance on GWPs using the latest values from the IPCC *Fifth Assessment Report* (Fong et al. 2014).

Of the Canadian provinces, British Columbia has adopted the most comprehensive greenhouse-gas-emissions reporting and reduction strategy. A 2008 provincial law, Bill 27, required municipalities in BC to adopt greenhouse-gas emission-reduction targets. The targets are set out in municipal by-laws, often within the Official Community Plan (Government of BC 2008). To identify actions to meet those targets, many municipalities have hired consultants to model future emissions scenarios and develop climate action plans. The province supports a working group of modelers and provides guidance on assumptions and methods (Sustainability Solutions Group 2013). Municipalities are able to track their progress in reducing emissions using the Community Energy and Emissions Inventories (CEEI). The CEEI is a standardized greenhouse gas emissions inventory completed every two years by the BC Ministry of Environment for each municipality and regional government using a combination of data from energy utilities and data from other sources. The CEEI, however, only lists carbon dioxide equivalents rather than reporting specific greenhouse gases.

In Canada, the typical powers of a municipality vary by jurisdiction. They are flexible (Hargraves 2012), but standard services include regulating land-use, providing transportation infrastructure, and managing solid and liquid waste (Senbel, Fergusson, & Stevens 2013). As a result, the emissions categories that municipalities typically track include private and commercial vehicles, private dwellings, commercial buildings, and solid waste. In some cases, emissions from industry, liquid waste, agriculture, forestry, and land-use change are also included. In the future, the Greenhouse Gas Protocol will include these sectors.

The Importance of Near-Term Climate Forcers

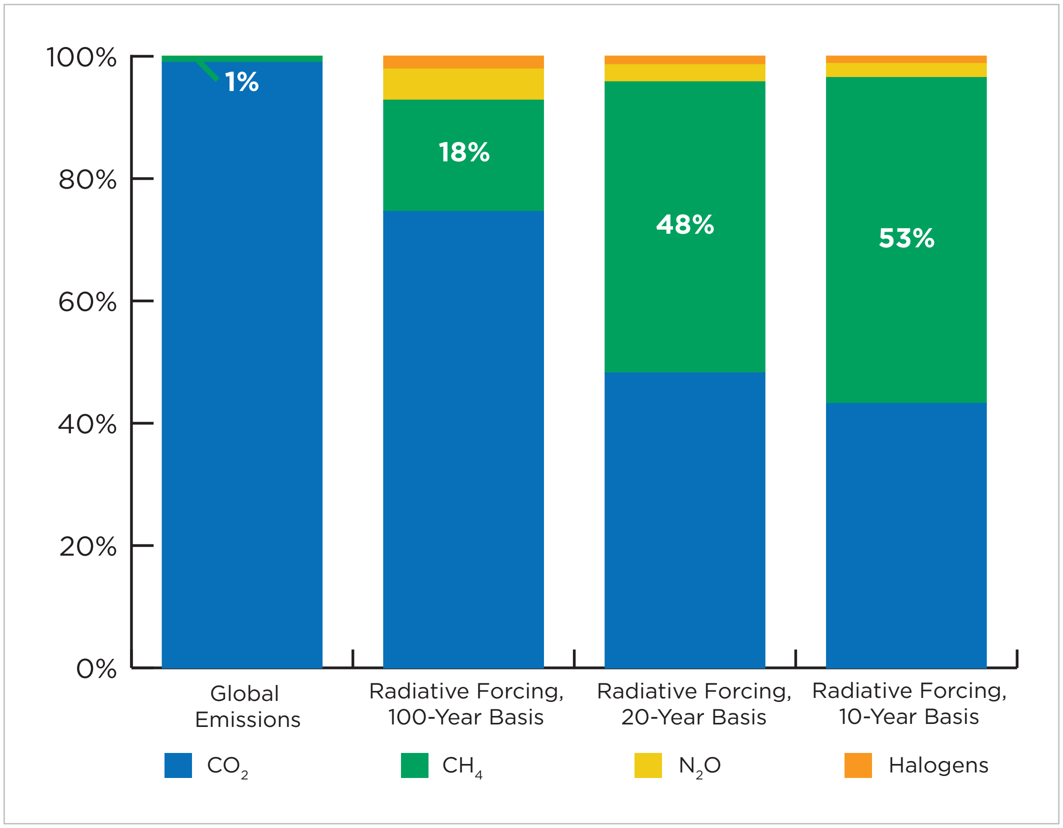
Climate science shows that NTCFs have a greater effect on the *rate* of increase of global temperatures while the total accumulation of carbon dioxide in the atmosphere has a greater effect on the *total* increase of temperatures over the long term:

> This analytic analysis shows that the measures substantially reduce the global mean temperature increase over the next few decades by reducing tropospheric ozone, CH_4, and BC (Fig. 1). The short atmospheric lifetime of these species allows a rapid climate response to emissions reductions. In contrast, CO_2 has a very long atmospheric lifetime (hence, growing

> CO_2 emissions will affect climate for centuries), so that the CO_2 emissions reductions analyzed here hardly affect temperatures before 2040. The combination of CH_4 and BC (black carbon) measures along with substantial CO_2 emissions reductions [a 450 parts per million (ppm) scenario] has a high probability of limiting global mean warming to <2°C during the next 60 years, something that neither set of emissions reductions achieves on its own (Shindell et al. 2012).
>
> and;
>
> Furthermore, delays in the abatement of short lived forcing agents imply greater heat storage in the deep ocean and greater sea level rise; thus, the utility of the peak trimming is affected by when it is implemented as well as by how much. Peak trimming can also reduce the rate of warming, with attendant benefits for the ability of human and natural systems to adapt (Solomon et al. 2011).
>
> and;
>
> Greater benefits in peak trimming are obtained the sooner the emissions are abated (see Held et al., 2010). However...the long term climate...is determined largely by the cumulative carbon emitted (Solomon et al. 2011).

Another way to appreciate the effects of methane relative to CO_2 is to compare the energy contributions that each gas makes over different time horizons. While methane comprises only 1% of global greenhouse gas emissions by mass, based on a 100-year GWP value of 21, it is responsible for 18% of global emissions on a CO_2e basis. Taking this comparison a step further, Figure 7 shows the relative contributions to Radiative Forcing of carbon dioxide, methane, nitrous oxide, and halogens (which includes hydrofluorocarbons such as HFC-134a) over two additional time horizons. The results are based on the 100-year GWP value of 21, as well as 20-year and 10-year GWP values based on the IPCC's *Fifth Assessment Report* (85 and 104 respectively for methane).

FIGURE 7. Radiative Forcing Caused by Methane Emissions Relative to Other Greenhouse Gases



The figure shows that, through a lens of 10- and 20-year GWPs, methane is responsible for 48% of Radiative Forcing on a 20-year basis, and for over 50% of Radiative Forcing on a 10-year basis, an effect that has been reported in scientific literature (Shindell et al. 2005). Furthermore, climate scientists report that the global warming effects of methane are actually underestimated because methane emissions also cause warming-induced CO_2 emissions (Gillett & Mathews 2010).

In Table 6, the second column shows the proportion of total global annual emissions of each gas on a mass basis, while the remaining three columns show the relative impacts of each gas based on GWP values for 100 years, 20 years, and 10 years.

TABLE 6. RADIATIVE FORCING CAUSED BY METHANE EMISSIONS RELATIVE TO OTHER GREENHOUSE GASES

Greenhouse Gas	Global Emissions (by mass)	% of Radiative Forcing Based on GWP_{100}	% of Radiative Forcing Based on GWP_{20}	% of Radiative Forcing Based on GWP_{10}
CO_2	~99%	74.6%	48.2%	43.2%
CH_4	~1%	18.2%	47.7%	53.3%
N_2O	0.022%	5.1%	2.8%	2.3%
Halogens[16]	0.002%	2.1%	1.4%	1.2%

16 In greenhouse gas reports, the term "halogen" is used to refer to hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs).

APPENDIX II

The Time Value of Carbon Model

The time value of carbon analysis developed in this appendix relies on the IPCC Assessment Reports as well as on the independent studies on which the IPCC reports are based. The relationships for GWP and AGWP used in this report are based on Shine et al. (2005), Joos et al. (2013), and IPCC (2013).

GWP is the ratio of the AGWP as follows:

EQUATION 1. GWP AS A FUNCTION OF TIME HORIZON

$$GWP_i(H) = \frac{[\mathrm{AGWP}_i\,(H)]}{[\mathrm{AGWP}_{CO_2}(H)]} = \frac{\int_0^H \mathrm{RF}_i(t)dt}{\int_0^H \mathrm{RF}_{CO_2}(t)dt}$$

Where:

$GWP_i(H)$ is the Global Warming Potential for a given gas i at time horizon H

$AGWP_i(H)$ is the Absolute Global Warming Potential for a given gas i at time horizon H

$AGWP_{CO2}(H)$ is the Absolute Global Warming Potential for CO_2 at time horizon H

H is the time horizon in years from the time of release of the given gas

RF is Radiative Forcing

Absolute Global Warming Potential (AGWP) is the integration of Radiative Forcing at a given time horizon, with units of $W.m^{-2}.kg^{-1}.year$ (Shine et al. 2005). The AGWP for the reference gas (CO_2) at time horizon H is as follows:

EQUATION 2. ABSOLUTE GWP FOR CARBON DIOXIDE (SHINE ET AL. 2005)

$$AGWP_{CO_2}(H) = A_{CO_2}\left[a_0 H + \sum_{i=1}^{I} a\tau_i \left(1\text{-exp}\left(-\frac{H}{\tau_i}\right)\right)\right]$$

Where:

A_{CO2} is the Radiative Efficiency for CO_2

a_i are weighting factors for each perturbation period

τ_i are perturbation periods for three timescales for the redistribution of CO_2 within the atmosphere, ocean, and land biosphere

The definitions of Radiative Forcing and Radiative Efficiency are provided by Joos et al. (2013): "The Radiative Forcing, RF_X, of gas x can be written as the product of its radiative efficiency, A_X, and the perturbation in its abundance or burden, IRF_X. A_X is defined as the Radiative Forcing per kg increase in atmospheric burden of gas x."

For CO_2, the values of the variables are based on the IPCC's *Fifth Assessment Report* and Joos et al. (2013):

TABLE 7. COMPONENTS OF THE AGWP CALCULATION FOR CARBON DIOXIDE

Factor	Value	Units	Explanation
RF_{CO2}	5.35	$W.m^{-2}$	Radiative Forcing attributable to CO_2.
A_{CO2}	1.759E-15	$W.m^{-2}.kg^{-1}$	Radiative Forcing per increase in abundance.
a_0	0.2173	—	Dimensionless coefficients which are weighting factors for the effect of each perturbation timescale, τ_n. The sum of a_0, a_1, a_2, a_3 is unity.
a_1	0.2240	—	
a_2	0.2824	—	
a_3	0.2763	—	
τ_1	394.4	years	Perturbation timescales for three modes of redistribution of CO_2 following release.
τ_2	36.54	years	
τ_3	4.304	years	

Source: Joos et al. 2013 (Supplementary Information, Table S1, Multi-Model Mean)

Methane is removed from the atmosphere through three processes. Approximately 88% is removed through reactions with hydroxyl radicals in the troposphere, 7% is destroyed in the stratosphere, and 5% is removed by bacteria in the soil (Fuglestvedt et al. 2010, IPCC 2001, and Boucher et al. 2009). The increase in GWP values since the IPCC's *First Assessment Report* in 1990 reflects the degraded ability of the atmosphere and biosphere to chemically and biologically neutralize methane and also reflects new scientific knowledge. The IPCC's *Fifth Assessment Report* states: "The chemical coupling between OH and CH_4 leads to a significant amplification of an emission impact; that is, increasing CH_4 emissions decreases tropospheric OH which in turn increases the CH_4 lifetime and therefore its burden" (IPCC 2013). As a result of ongoing changes to factors, such as the concentration of individual greenhouse gases in the atmosphere, and changes to the atmosphere's capacity to neutralize these gases, the reference parameters for the AGWP (and, therefore, GWP) relationships will continue to change over time.

The AGWP for a given gas, such as methane, at time horizon H is the time integrated Radiative Forcing from the time of release to year H, given by:

EQUATION 3. ABSOLUTE GWP FOR METHANE (SHINE ET AL. 2005)

$$AGWP_{CH_4}(H) = \int_0^H RF(t)dt = (1 + f_1 + f_2)A_{CH_4}\int_0^H \exp\left(-\frac{H}{\tau}\right)dt$$

Integrating:

$$AGWP_{CH_4}(H) = (1 + f_1 + f_2)A_{CH_4}\,\tau\left(1-\exp\left(-\frac{H}{\tau}\right)\right)$$

For methane, the values of the variables based on the IPCC's *Fifth Assessment Report* are as follows:

TABLE 8. COMPONENTS OF THE AGWP CALCULATION FOR METHANE

Factor	Value	Units	Explanation	Source
(f_1+f_2)	0.65	—	Scaling factors to include the effects of methane on ozone and stratospheric H_2O, where f1 relates to effects on ozone and f2 relates to effects on stratospheric H_2O. The sum of f_1+f_2 is 0.65.	IPCC *Fifth Assessment Report*, Chapter 8 Joos et al. 2013
A_{CH4}	1.285E-13	$W.m^{-2}.kg^{-1}$	Instantaneous Radiative Forcing per increase in atmospheric abundance.	
τ	12.4	years	Perturbation Period.	
H	Variable	years	Time Horizon.	

Values for instantaneous Radiative Forcing (A_i) for CO_2, HFC-134a, and CH_4 are derived as follows:

TABLE 9. DERIVATION OF VALUES FOR RADIATIVE FORCING (A_i)

	CO_2	CH_4	HFC-134a	Units	Source
Current Gas Concentration (Mole Fraction)	3.91E+02	1.803E+00	6.27E-05	ppm	IPCC *Fifth Assessment Report*, Chapter 8 Joos et al. 2013
Radiative Efficiency	1.368E-05	3.63E-04	1.60E-01	$W.m^{-2}.ppb^{-1}$	IPCC *Fifth Assessment Report*, Chapter 8 Table 8.A-1 Joos et al. 2013
Converting ppb to kg of CO_2	2.12E+12	2.12E+12	2.12E+12	$kg\text{-}C.ppm^{-1}$	Joos et al. 2013
Molecular Weight	44.01	16	102.03	$kg.kmol^{-1}$	
A_i (RF per increase in abundance)	1.759E-15	1.285E-13	8.855E-12	$W.m^{-2}.kg^{-1}$	

Table 10 gives a summary of the revised GWP values for methane, along with a summary of the rate of increase of methane emissions, the resulting changes to the concentration of methane in the atmosphere, and the associated increase in Radiative Forcing.

TABLE 10. TRENDS IN EMISSIONS AND EFFECTS ON CLIMATE METHANE SINCE 1990

IPCC Report Cycle	Year	20 Year GWP	100 Year GWP	Lifetime (Years)	Atmospheric Concentration (ppb)	Emission Change (%)
First Assessment Report	1990	63	21	10.0	1,710	0%
Second Assessment Report	1995	56	21	12.2	1,745	—
Third Assessment Report	2001	62	23	12.0	1,775	-2%
Fourth Assessment Report	2007	72	25	12.0	1,780	15%
Fifth Assessment Report	2013	85	28	12.4	1,810	18%

Source : *IPCC Assessment Reports*, World Bank 2010

Uncertainty in GWP Values

The uncertainty about the radiative efficiency of CO_2 in the near term is lower than the uncertainty over 100 years, which reflects uncertainty in the rate of CO_2 removal over time: “Based on a multi-model study, Joos et al. (2013) estimate uncertainty ranges for the time-integrated IRF for CO_2 to be ±15% and ±25% (5 - 95% uncertainty range) for 20- and 100-year time horizons, respectively” (IPCC 2013).

Alternatives to GWP_{100}

A challenge of the GWP approach is that warming inputs may not directly correspond to temperature rises that result from the emission of the greenhouse gas. An alternative to the GWP, the GTP, models the temperature change at the end of a given time horizon that would be caused by a pulse emission of a greenhouse gas (Shine et al. 2005). GWP and GTP are both sensitive to the choice of time horizon. For NTCFs, the values provided by shorter time horizon GTPs correlate reasonably well with those provided by shorter time horizon GWPs (Aamaas et al. 2012).

Global Damage Potential (GDP) uses a cost-benefit framework to model the marginal social costs of emissions (Aamaas 2012).

For a comprehensive discussion of alternatives to GWP, see Fuglestvedt et al. (2000); Shine et al. (2005); Peters et al. (2011); and Aamaas, Peters, and Fuglestvedt (2013). Since GWP is embedded in current reporting protocols, it has been chosen as the basis for this report. Future work could apply a time value analysis to alternative metrics such as Global Temperature Change Potential.

Modelling the Effects of Near-Term Climate Forcers

The following section develops the idea that a time series could represent the GWP of a given gas on an annual basis. Although the AGWP values used in this section are based on current climate science, the idea of a time series is offered here only as a suggested starting point for further discussion.

One challenge in developing a time series to represent the effects of NTCFs on a year-by-year basis lies in the fact that GWP values represent the ratio of the impacts of these gases to the ratio of the impacts of CO_2 over the same time period. Yet the rate of change of each NTCF's impact is very different from the rate of change for CO_2. The rates of change of these two AGWP values over time are very different, as shown earlier in Figure 6. This graph illustrates the important time value effects of NTCFs, such as methane, where the AGWP effects occur rapidly over the first 20 years following release.

The question is, given that the GWP of NTCFs such as methane depends on the time horizon, how can organizations model the effects on climate of a pulse emission of a gas such as methane? This report considered several options for recognizing NTCF effects:

1. Use the 20-year GWP value of 85 as published in the IPCC *Fifth Assessment Report*.
2. Calculate a 10-year GWP value of 104 based on the methods used in the IPCC *Fifth Assessment Report*.
3. Calculate a 1-year GWP value of 124, based on the methods used in the IPCC *Fifth Assessment Report*.
4. Calculate a time series which estimates annual GWP values from the year of release to 100 years.

The first option is the simplest and does show that the effects on climate of a release of methane in comparison with CO_2 are approximately three times larger than they are over 100 years.

The fourth option offers the potential to show that the effects on climate of NTCFs decline relatively quickly over time. The challenge in developing a time series for GWP lies in the fact that the GWP for a given time horizon depends not only on the AGWP of the NTCF but also on the AGWP for CO_2 over the same time horizon. Any method to derive a time series to approximate the climate effect of NTCFs on an annual basis would need to account for this difference and would also need to provide its result in units of CO_2e, which is currently the common denominator for comparing greenhouse gas emissions.

A time series (the "Effective Annual GWP") was derived for this report, based on the AGWP values for the reference gas (CO_2) and for the gas of interest (e.g., methane) for each year (n) after release. Although the Effective Annual GWP is derived mathematically from AGWP values based on the methods used by the IPCC, this term is not part of IPCC nomenclature and is offered here as a starting point for discussion. The time series is based on the idea that, by using the difference in AGWP values between successive years, the sum of all annual values of Effective Annual GWP will not be greater than the GWP value for a time horizon of one year. The equation developed in this report for methane is shown here:

EQUATION 4. EFFECTIVE ANNUAL GWP FOR METHANE

$$\text{Effective Annual GWP}_n = \frac{[\text{AGWP}_{(n)} - \text{AGWP}_{(n-1)}]_{CH4}}{[\text{AGWP}_{(n)}]_{CO2}} - \frac{[\text{AGWP}_{(n+1)} - \text{AGWP}_{(n)}]_{CH4}}{[\text{AGWP}_{(n+1)}]_{CO2}}$$

Based on input variables for AGWP from the IPCC *Fifth Assessment Report*, the time series values were calculated and are shown in Table 13 (for methane) and Table 14 (for HFC-134a) at the end of this appendix.

This approach can address two questions:

1. How can an organization report the effects on climate of the NTCFs it emits?
2. How can an organization estimate the economic value of reducing its emissions of these gases?

For internal reporting, an emitter could also choose to apply a time series to reflect the changing value of the Effective Annual GWP of each NTCF, for example, as follows:

TABLE 11. EXAMPLE OF THE IMPACTS OF METHANE OVER TIME

Year (n)	1	2	3	4	5	6	7	8	9	10
Emissions of CH_4 (tonnes)	1,000	800	500	300	100	—	—	—	—	—
Effective Annual GWP, CH_4	62.8	21.0	10.5	6.3	4.2	2.9	2.2	1.7	1.3	1.1
Tonnes CO_2e from Year 1	62,800	21,000	10,500	6,300	4,200	2,900	2,200	1,700	1,300	1,100
Tonnes CO_2e from Year 2		50,300	16,800	8,400	5,000	3,300	2,400	1,700	1,300	1,100
Tonnes CO_2e from Year 3			31,400	10,500	5,200	3,100	2,100	1,500	1,100	800
Tonnes CO_2e from Year 4				18,900	6,300	3,100	1,900	1,200	900	700
Tonnes CO_2e from Year 5					6,300	2,100	1,000	600	400	300
Total (tonnes of CO_2e)	62,800	71,200	58,700	44,000	27,000	14,600	9,500	6,800	5,000	3,900

Table 11 illustrates an example in which an organization gradually reduces its emissions of methane from 1,000 tonnes in Year 1 to zero in Year 6. The new methane emissions from each year are multiplied by the Effective Annual GWP, which changes over time. The time series approach illustrates the fact that the organization's methane emissions continue to have effects on climate (albeit at a diminishing rate over time) in the years following the emission. For illustration purposes, the time series shown in the table ends at Year 10, but in practice could continue until residual values are negligible. The values in Table 11 were calculated as follows:

$$\text{Tonnes of } CO_2e_n = \sum_1^n (\text{Mass of } CH_4 \text{ Emitted in Year 1}) * (\text{Effective Annual GWP}_n)$$

An alternative approach would be to simply multiply the current year's emissions of the NTCF by the GWP with a one-year horizon (124 for methane and 5,000 for HFC-134a). If time series is extended to 100 years (rather than the 10 years shown in the table above), the tonnes of CO_2e reported over time will be the same in each case.

Estimating the Time Value of Near-Term Climate Forcers

To estimate the time value of investments or other initiatives to reduce emissions of NTCFs, an organization could use the time series (shown for methane in Table 13 and for HFC-134a in Table 14), a price of greenhouse gas emissions (shown here as $/tonne of CO_2e), and the discount rate used for comparable investment decisions within the organization. The price of greenhouse gases could either be the value established by regulation ($30/tonne of CO_2e in British Columbia, for example), or a value estimated by the emitting organization based on its understanding and evaluation of the environmental and social costs of greenhouse gases.

Table 12 shows the Effective Annual GWP in the years following an emission of one tonne of methane in Year 1. Multiplying the GWP value by one gives the tonnes of CO_2e associated with the release of methane for each year. A price of $30/tonne of CO_2e and a discount rate of 0% have been applied to the values for CO_2e to give the value of the release over time.

TABLE 12. SAMPLE TIME VALUE CALCULATION FOR ONE TONNE OF METHANE EMITTED IN YEAR ONE

Year	1	2	3	4	5	6	7	8	9	10
Effective Annual GWP, CH_4	62.8	21.0	10.5	6.3	4.2	2.9	2.2	1.7	1.3	1.1
Annual Tonnes of CO_2e	62.8	21.0	10.5	6.3	4.2	2.9	2.2	1.7	1.3	1.1
Value, Undiscounted	$1,885	$629	$314	$188	$125	$88	$66	$50	$40	$32
Present Value ($/t of CH_4)	$3,417									

Based on this approach, an organization emitting methane could estimate that the value of mitigating further releases is approximately $3,400 per tonne of methane.

The values in the table below are derived from Equation 4. Effective Annual GWP for methane.

TABLE 13. EFFECTIVE ANNUAL GWP VALUES FOR METHANE

Year (n)	AGWP (n) CO_2 ($W.m^{-2}.kg^{-1}.year$)	AGWP (n) CH_4 ($W.m^{-2}.kg^{-1}.year$)	Effective Annual GWP
1	1.70E-15	2.04E-13	62.8
2	3.29E-15	3.92E-13	21.0
3	4.81E-15	5.65E-13	10.5
4	6.25E-15	7.25E-13	6.3
5	7.63E-15	8.73E-13	4.2
6	8.96E-15	1.01E-12	2.9
7	1.03E-14	1.13E-12	2.2
8	1.15E-14	1.25E-12	1.7
9	1.27E-14	1.36E-12	1.3
10	1.39E-14	1.46E-12	1.1
20	2.51E-14	2.11E-12	0.2
50	5.32E-14	2.58E-12	0.007
100	9.21E-14	2.63E-12	0.001

The values in the table below are derived from Equation 4, but substituting AGWP values for HFC-134a.

TABLE 14. EFFECTIVE ANNUAL GWP VALUES FOR HFC-134A

Year (n)	AGWP (n) CO_2 ($W.m^{-2}.kg^{-1}.year$)	AGWP (n) HFC 134a ($W.m^{-2}.kg^{-1}.year$)	Effective Annual GWP
1	1.70E-15	8.53E-12	2,617
2	3.29E-15	1.65E-11	874
3	4.81E-15	2.38E-11	437
4	6.25E-15	3.06E-11	262
5	7.63E-15	3.70E-11	174
6	8.96E-15	4.28E-11	124
7	1.03E-14	4.83E-11	92
8	1.15E-14	5.33E-11	71
9	1.27E-14	5.80E-11	56
10	1.39E-14	6.24E-11	45
11	1.51E-14	6.64E-11	37
12	1.63E-14	7.02E-11	31
13	1.74E-14	7.37E-11	26
14	1.86E-14	7.69E-11	22
15	1.97E-14	7.99E-11	18
16	2.08E-14	8.27E-11	16
17	2.19E-14	8.53E-11	14
18	2.29E-14	8.77E-11	12
19	2.40E-14	8.99E-11	10
20	2.51E-14	9.20E-11	9
30	3.51E-14	1.06E-10	3
50	5.32E-14	1.16E-10	0.4
100	9.21E-14	1.19E-10	0.1

APPENDIX III

Introduction to NTCF Mitigation Measures

The information in this appendix is offered as an introduction to measures to reduce NTCF emissions. Readers could refer to the 2013 US EPA report, *Global Mitigation of Non-*CO_2 *Greenhouse Gases: 2010-2030*, for a detailed analysis of the costs and benefits of initiatives to reduce NTCF emissions such as methane, and to the 2013 Shecco report, *Natural Refrigerants Market Growth for North America*, for a detailed analysis of the costs and benefits of initiatives to reduce HFC emissions.

Table 15 gives an overview of the kinds of initiatives companies can consider to reduce their NTCF emissions.

TABLE 15. POTENTIAL NTCF ABATEMENT MEASURES

Sector	Activity	Source	Relative Impact	Potential Abate ment Measures	Notes and Co Benefits
Agriculture	Beef and milk production	Methane from enteric bacteria	High 29% of global methane emissions 21% of Canada's methane emissions	Changes to feed management and to pasture management. (EPA 2013)	Co-benefits can include reduced N_2O emissions.

Sector	Activity	Source	Relative Impact	Potential Abate ment Measures	Notes and Co Benefits
Fossil energy	Oil and natural gas extraction, processing, transportation	Leakage from natural gas wells Leakage and venting from transmission and distribution pipelines	High 23% of global methane emissions 39% of Canada's methane emissions	Reduced Emissions Completion (REC) practices. Improvements to maintenance practices for compressor stations, pipelines, and gate stations. When required for maintenance reasons, gas can be flared rather than vented from pipelines. (EPA 2013)	Co-benefits include savings from reduced losses of product (natural gas).
Waste management	Industrial and municipal landfills	Methane which bypasses Landfill Gas Capture systems	High 11% of global methane emissions 26% of Canada's methane emissions	Diverting organics to anaerobic digestion to produce biomethane and compost. Smart urban planning to incorporate industrial ecology to find better uses for wasted materials, water, and energy. Landfill gas capture efficiency for existing landfills can be improved. (EPA 2013)	Typical landfill gas capture systems capture less than 50% of methane produced from decomposing organic material. Diverting solid waste reduces N_2O emissions and groundwater pollution by leachate, generates new revenues from biomethane and compost, reduces upstream impacts of fossil fuel extraction, and increases employment in the recycling and bioenergy sectors. When the values of all recovered resources are considered, diversion can also be more cost-effective than Landfill Gas Capture systems.
Fossil energy	The mining and burning of coal	Methane from mining, combustion	Moderate 8% of global methane emissions	Methane capture systems can be implemented. (EPA 2013)	Reduced risk of methane explosions in coal mines.

Sector	Activity	Source	Relative Impact	Potential Abate ment Measures	Notes and Co Benefits
Agriculture	Rice Cultivation	Methane emissions from artificial wetlands	Moderate 6% of global methane emissions	Changes can be made to manage-ment regimes for water, nutrients, and waste. (EPA 2013)	Reduced N_2O emissions, reduced water consumption.
Refrigeration Electronics manufacturing (solvents) Aerosol propellants Fire suppression Solid foam manufacturing	HFC use	Losses from manufacturing Losses from premature failure, maintenance Losses at end of life	Moderate 356 MT of CO_2e/year (EPA 2013)	Building designers can: Use less conven-tional chilling through energy efficiency measures. Use different cool-ing methods such as water cooling, natural cooling cells, adsorption chillers, absorption chillers, or thermo-electric magnetic chillers. Manufacturers can substitute working fluids such as CO_2 (also called R744 in the refrigeration industry). Regulators can expand Extended Producer Respon-sibility (EPR) regulations for recovery of refrigerants during servicing and at the end of equipment life.	Reduced energy consumption, and potential reduc-tions in emissions of HFCs (Shecco 2013).

Sector	Activity	Source	Relative Impact	Potential Abate ment Measures	Notes and Co Benefits
Waste management	Industrial and municipal wastewater treatment	Methane from anaerobic processes in wastewater treatment, and from sludge management	Moderate 4% of global methane emissions 4% of Canada's methane emissions	Municipalities can reduce water consumption through metering, rate structures, and price incentives. The design and operation of wastewater treatment facilities can be improved, and can also incorporate technologies designed to recover resources such as energy and fertilizer. Larger wastewater treatment facilities already digest sludge anaerobically to produce biomethane. Smaller facilities could use Integrated Resource Recovery principles to improve the economics of digestion by co-digesting community organics with sludge. (EPA 2013)	The economic value of recovered energy, fertilizer, and potentially reclaimed water for non-potable uses.
Agriculture	Beef and milk production	Methane from conventional manure management	Moderate 3% of global methane emissions 4% of Canada's methane emissions	Manure can be processed by anaerobic digestion to produce biomethane (which, in turn, can be used to generate electricity and heat, or used as vehicle fuel), compost, and bedding. (EPA 2013)	Reduced odours (which can improve community good will), recovery of compost (which reduces the cost of artificial fertilizers), recovery of animal bedding, and recovery of energy (which reduces the cost of conventional energy inputs such as electricity and heat).

Sector	Activity	Source	Relative Impact	Potential Abate ment Measures	Notes and Co Benefits
Waste management	Waste-to-energy (incineration)	Methane from burning of plastics and organic matter	Low[17]	Solid waste can be separated at the source into recycling and biological treatment (e.g., anaerobic digestion) to recover embodied materials, nutrients, and energy. (EPA 2013)	In Canada, emissions of methane and CO_2 from incineration are a relatively small fraction of total emissions, reflecting the small number of Canadian incinerators (EC 2012). Diverting plastics (which are oil derivatives) to recycling reduces fossil CO_2 emissions, N_2O emissions, air pollution, and increases employment in the recycling sector.
Waste management	Composting	Methane from anaerobic bacteria	Low	Organics can be diverted to anaerobic digestion to produce both biomethane and compost.	Diversion to anaerobic digestion reduces N_2O emissions and generates revenues from biofuels, compost, and potentially carbon offsets.
Forestry development	Open burning of wood residues	Methane from inefficient combustion	Low	Wood residues can be diverted to higher-value uses such as composite materials or district energy. Municipal and regional governments can implement bylaws to limit open burning of wood waste.	Reduced air pollution, reduced black carbon emissions, reduced N_2O emissions, and the economic benefits of higher-value uses for wood residues.
Bioenergy	Anaerobic digestion	Fugitive methane emissions	Low	Fugitive methane emissions can be minimized by design.	Higher yield of biomethane and reduced odours.

17 Burning or landfilling one tonne of mixed garbage (that is, including carbon dioxide, methane, and nitrous oxide) can result in similar greenhouse gas emissions (IPCC 2006a).

Sector	Activity	Source	Relative Impact	Potential Abatement Measures	Notes and Co Benefits
Bioenergy	Biomass combustion	Methane from combustion	Low	Fuel moisture content and chip size can be optimized to improve combustion efficiency.	Reduced air pollution, reduced black carbon emissions, reduced N_2O emissions, lower fuel consumption, and lower operating costs.
Building heating	Fossil fuel combustion	Methane from combustion	Low	Smarter urban planning facilitates and encourages building energy efficiency, district energy systems, and fuel switching. Municipalities can include enhanced energy conservation requirements in local building codes and bylaws. Building owners can invest in efficiency measures and fuel switching.	Reduced air pollution, reduced N_2O emissions, reduced fossil CO_2 emissions, reduced black carbon emissions, and potentially lower life cycle costs of building ownership.
Transportation	Fossil fuel combustion	Methane from combustion	Low	Smarter urban planning develops and encourages the use of mass transit. Vehicle owners can invest in efficiency measures and fuel switching.	Reduced air pollution, reduced black carbon emissions, reduced N_2O emissions, reduced fossil CO_2 emissions, and potentially lower life cycle costs of transportation.

Acknowledgments

The authors of this report gratefully acknowledge the financial support of the Chartered Professional Accountants of Canada (CPA Canada).

The materials in this report discussing accounting practices are adapted from the original work of Deborah Rasnick, CPA, CGA.

The authors would like to thank the members of the CPA Canada Sustainability Advisory Board for their guidance and suggestions and, specifically, Gordon Beal, CPA, CA; Todd Scaletta, FCPA, FCMA; Monica Sood, CPA, CA; Sarah Keyes, CPA, CA; Susan Todd, CPA, CA; Elaine Wong, CPA, CA; Alexandra Wilson; and Mark Walsh, FCPA, FCA for their thoughtful and helpful feedback.

The authors would also like to thank external reviewers Dr. Nathan Gillett; Dr. Scott Harrison; Chris Kellman, CPA, CGA; and Nick Kootnikoff, CPA, CMA for their invaluable insights and suggestions.

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Additional Resources

The resources listed below were not used as references for the report, but are offered for the benefit of readers interested in further reading.

Accounting for Sustainability (A4S) website: **www.accountingforsustainability.org**

Association of Chartered Certified Accountants (ACCA) and Carbon Tracker. *Carbon avoidance: Accounting for the emissions hidden in reserves*, 2014.

CPA Canada. *Executive briefing: Climate change and related disclosures.* Toronto: CPA Canada, 2008.

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Sustainability Accounting Standards Board (SASB) website, **www.sasb.org**

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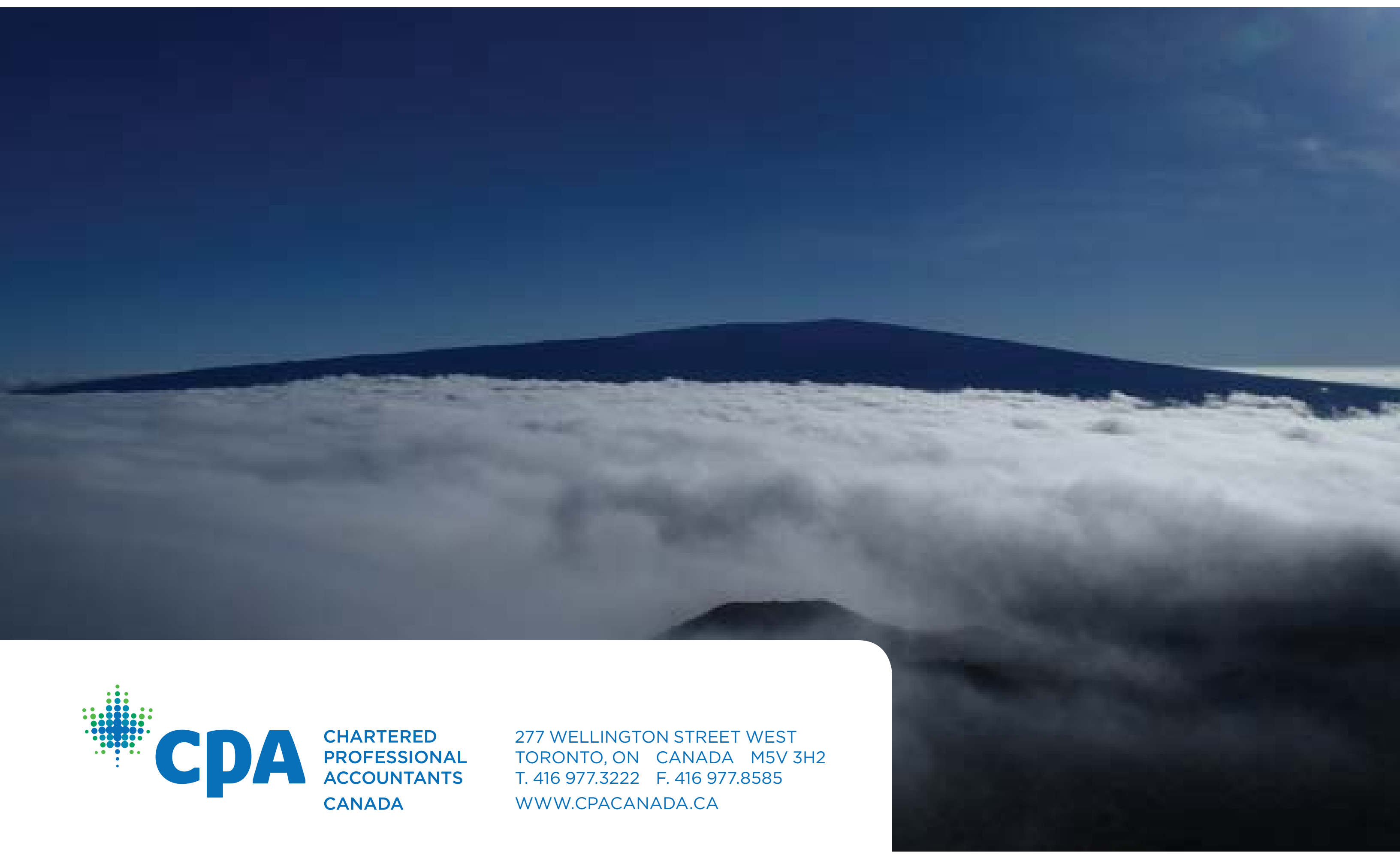

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