

STANDARDS RESEARCH

Climate Change Adaptation for Natural Gas and Propane Installations

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Executive Summary

Canada's climate is changing. As the impacts of climate change continue to intensify, they may affect the performance and condition of gas infrastructure. The risk of damage and service disruption — and the potential consequences for human health and safety — may worsen over time. However, if these risks can be identified early and better understood, then measures can be taken to help address them.

Codes and standards help to ensure that engineered systems are safely planned, designed, developed, and operated. Codes and standards must also support the appropriate management of risks that could arise, or worsen, because of the changing climate.

The codes and standards community is already taking action to help address such risks. For example, standards systems in Europe, North America, and other regions have led programs and developed guidance to help standards developers incorporate climate change considerations into codes and standards. In Canada, many codes and standards have been updated and others have been developed specifically to facilitate the use of climate change risk management measures.

This report further contributes to this work by presenting the findings of research on advancing climate resilience through the following Canadian gas sector codes:

- CSA B149.1, *Natural gas and propane installation code;*
- CSA B149.2, *Propane storage and handling code;* and
- CSA B149.3, *Code for the field approval of fuel-burning appliances and equipment.*

Through a comprehensive literature review, interviews with stakeholders from the Canadian gas sector, and a series of focus group discussions with the Project Advisory Panel, the following hazards were identified as those of the greatest concern for natural gas and propane installations in Canada:

- Floods;
- Wildfires;
- Heavy snow and ice events; and
- Extreme temperature conditions.

A review of the role that codes, standards, and related solutions play in advancing natural gas and propane infrastructure's resilience to climate change showed that effectively addressing climate change risks requires rethinking how systems are managed to identify opportunities for risk reduction or greater efficiency. To ensure codes and standards remain relevant and continue to serve their purpose despite the effects of climate change, the climate information used in their application must reflect the most recent historical climate data as well as appropriate scenarios of the future climate conditions projected to occur over the lifespan of the system, appliance, accessory, component, or equipment. In some cases, based on projected changes, specific risk mitigation (climate change adaptation) measures may be required.

The climate change adaptation recommendations for CSA B149.1, CSA B149.2, and CSA B149.3 include:

- Developing an informative *Climate Change Information Annex* to:
  - provide guidance on the interpretation and use of projected climate conditions and hazards (including priority regional climate hazards);
  - facilitate access to existing and emerging sources of information on climate change and climate hazards; and
  - provide background and guidance on the use of established processes for climate change and infrastructure vulnerability and risk assessment, as well as adaptation and resilience planning.
- Addressing weather- and climate-related considerations directly included in the codes by recommending the use of relevant standards and recent and accurate regional historical and future projected climate data for siting and installation decisions.
- Providing updates on changes to climate-sensitive standards referenced by the codes.
- Enhancing institutional supports within CSA Group to regularly revisit the potential implications of climate change for the efficacy of the codes and standards that fall within their mandates, and to provide technical committees (TCs) and technical working groups (TWGs) with sustained and reliable access to expertise on climate-related topics, including:
  - climate change;
  - climate-related uncertainty; and
  - integrating climate change adaptation considerations into standards.

Key Terms and Definitions

Accessory: A part capable of performing an independent function and contributing to the operation of the appliance or gas piping system that it serves [1].

Adaptation: Process of adjustment to actual or expected climate events and their effects [2].

Adaptive Capacity: The ability of systems, institutions, humans, etc. to adjust to potential damage, take advantage of opportunities, or respond to consequences [2].

Appliance: A device to convert gas into energy or compress gas for the purpose of fuelling. Includes any component, control, wiring, piping, or tubing required to be part of the device [1].

Cascading Impacts: A sequence of secondary impacts triggered by a climate-related event. Cascading impacts are complex and multi-dimensional, often associated with interdependencies between systems where components may be intrinsically dependent or rely upon one another to provide a function [2], [3].

Climate Change: A change in the state of the climate that can be identified statistically (by changes in the mean and/or the variability of its properties), and that persists for an extended period (i.e., decades or longer). It refers to any change in climate over time, whether due to natural variability or as a result of human activity [2].

Climate Hazard: A physical process or event (linked to an aspect of weather or climate) that can cause harm to infrastructure, human health, natural resources, etc. [2].

Climate Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through the preservation, restoration, or improvement of its essential basic structures and functions [4].

Component: An essential part of an appliance or equipment [1].

Equipment: A device, other than an appliance, accessory, or component that is connected to a piping or tubing system [1].

Exposure: The presence of people, livelihoods, services, resources, infrastructure, or economy in places and settings where they can be adversely affected [2].

Impact: The consequence of realized risks (e.g., from climate-related hazards) on natural, built, and human systems [2].

Infrastructure: A variety of facilities, equipment, systems or assets, including but not limited to, storage tanks and gas transmission lines that are necessary to produce, generate, transmit, or distribute natural gas or propane to a retailer, distributor, or customer [5], [6].

Likelihood: The chance of a specific outcome occurring, estimated probabilistically [2].

Risk: The potential for adverse consequences on human or ecological systems, including those on lives, health, economic, social, and cultural assets and investments, infrastructure, etc. [2].

Sensitivity: The degree to which a system is adversely or beneficially affected by the climate variable to which it is exposed [2].

Vulnerability: The extent to which a system or component is predisposed to be adversely affected by climate change [2].



"There is a growing imperative to assess and proactively adapt to the impacts that the changing climate will have on infrastructure in general, and gas sector infrastructure in particular."

1 Introduction

1.1 Background and Context

Canada's climate is changing. Studies have shown consistent warming trends since 1948, with Canada's rate of change measuring approximately twice the global average [7]. Warming is especially pronounced in northern regions of the country, where mean annual temperatures have increased at approximately three times the global average rate [7]. Other observed trends in Canada include reductions in the frequency and duration of extreme cold events, more frequent and prolonged extreme heat events, shifting rainfall patterns, glacial melt increase, permafrost degradation, sea level rise, and more frequent and more severe extreme weather events [8], [9].

According to the Intergovernmental Panel on Climate Change (IPCC), extreme events such as heat waves and heavy precipitation will become more prevalent in Canada over time and will be characterized by greater frequency, magnitude, and spatial extent [9]. Changes in extreme temperatures can increase the likelihood and severity of hazards such as wildfires, droughts, and permafrost degradation. Changes in precipitation patterns and extremes can also increase the likelihood and severity of some of these hazards, as well as the likelihood of greater snow accumulations and more frequent and more severe flooding [7], [10], [11]. Because of their potential to cause abrupt and devastating impacts, extreme weather events are of particular concern for engineered systems and built infrastructure, including those of the gas sector.

Gas infrastructure is critical to Canadian society. The performance and condition of this infrastructure is fundamentally affected by the climate within which it operates. As the impacts of climate change continue to intensify, the risks of damage and service disruption — and the potential consequences for human health and safety — may worsen. However, if these risks can be identified early and better understood, then measures can be taken to help address them.

Historically, the narrative of climate change and the gas sector has focused on the role of energy production and related greenhouse gas (GHG) emissions as contributors to climate change. Existing, elevated GHG concentrations in the atmosphere are expected to drive further rapid climatic change over the coming decades. Most energy sector infrastructure has been designed and constructed based on an assumption that future climate conditions (averages, extremes, and variability) will mirror historical records and experience [12], but this may not be the case.

There is a growing imperative to assess and proactively adapt to the impacts that the changing climate will have on infrastructure in general, and gas sector infrastructure in particular. Like the rest of society, the gas sector must become more resilient to weather and climate change.

Adapting to the risks of climate change can significantly reduce the threats to infrastructure and to the organizations and people who depend on the services and safe functioning of these assets. Adaptation measures depend on the availability of up-to-date climate information, system-specific climate design guidance and requirements, and information and support to adaptively manage for impacts and effectively carry out emergency management planning and response.

Codes and standards that effectively integrate climate change information and related adaptation measures can enhance the resilience of not only infrastructure but also Canadian governments, businesses, communities, and households. There is an urgent need to understand how to accurately and effectively update Canadian codes and standards to prepare for the changing climate.

To help address this need and meet the goals of the Pan-Canadian Framework on Clean Growth and Climate Change [13], several initiatives were launched, including the National Research Council's (NRC) Climate-Resilient Buildings and Core Public Infrastructure Initiative [14], and the Standards Council of Canada's (SCC) five-year Standards to Support Resilience in Infrastructure Program [15]. The NRC's initiative includes updating building codes [16], specifications, guidelines, and assessment tools to help increase infrastructure resilience and population safety and well-being in the changing climate. The SCC's program contributes to the creation of standardization strategies and solutions that will ensure climate change adaptation and resilience are reflected in current codes, guidelines, and standards, to enable the design, construction, operation, and maintenance of infrastructure that can better withstand climate conditions now and in the future. As part of both programs, CSA Group has led the development of a number of climate change adaptation standards and reports, addressing infrastructure vulnerabilities to climate change to support the resilient design, construction, and maintenance of infrastructure systems across Canada [17]. CSA Group's completed research projects have focused on climate change adaptation solutions within the framework of Parts I, II, and III of the *Canadian electrical code,* [18], climate change provisions for CSA S6, *Canadian highway bridge design code* [19], climate change adaptation for dams [20], masonry materials, design, and construction [21], and assessing climate change vulnerabilities of northern airports [22].

However, CSA B149.1, *Natural gas and propane installation code,* CSA B149.2, *Propane storage and handling code,* and CSA B149.3, *Code for the field approval of fuel-burning appliances and equipment* [1], [23], [24] — and supporting codes and standards that influence the planning, design, construction, and management of gas installations — have yet to be evaluated regarding whether and how they should be modified to better foster climate resilience. This important gap needs to be addressed.

1.2 Objectives

Given the above-mentioned gap, this report has two main objectives. The first is to inform and educate about the potential impacts of severe weather, climate variability, and climate change on natural gas and propane installations, as well as specific climate adaptation measures that have been incorporated in different regions. The second is to develop specific climate change adaptation recommendations for consideration for CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24], as well as general recommendations for other relevant codes and standards in the gas sector.

This report focuses on areas where adaptation may be needed to improve the climate change resilience of natural gas and propane installations in the scope of CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24].

CSA B149.1 [1] applies to the installation of appliances, equipment, components, and accessories that burn gas (e.g., natural gas or propane) as fuel. It also applies to the installation of piping and tubing systems that extend from the termination of the utility installation or from the distributor's propane tank, vehicle-refuelling appliances and associated equipment, and stationary gas engines and turbines.

CSA B149.2 [23] applies to the storage, handling, and transfer of propane, to propane used as engine fuel (in other than motor vehicles), and to the installation, operation, and maintenance of containers and equipment used for propane at customer and distribution locations and at filling plants.

CSA B149.3 [24] applies to the field approval of fuel-burning appliances and equipment, and specifies the minimum requirements for all fuel-related components and accessories to ensure safety for gas-fired equipment while addressing potential hazards to the public and property. It contains additional requirements for process ovens, process furnaces, atmosphere generators used by industry for the processing of materials, and liquid and solid fuel-burning appliances.

This report addresses important linkages and interdependencies between the gas sector, natural gas and propane installations, and other critical infrastructure sectors and systems, particularly the telecommunications and electricity sectors. It also identifies the role of emergency preparedness plans and procedures, and related guidelines and standards, in improving gas infrastructure resilience and protecting public safety, health, and welfare.

2 Methods

This report is based on a comprehensive literature review, interviews with stakeholders from the Canadian gas sector, and a series of focus group discussions with the Project Advisory Panel.

2.1 Literature Review

The literature review considered codes, standards, guidance documents, peer-reviewed publications, and grey literature, focusing on Canada and on international regions that are leading the research on climate change adaptation and resilience in codes and standards (e.g., Europe) and are important for Canada's gas sector to align with (e.g., the United States (US)). The emphasis of the literature review was on climate change-related vulnerabilities and risks, relevant weather trends, existing and emergent adaptation approaches, and resilience measures within the gas sector specifically, and within the energy and infrastructure sectors more broadly. Key infrastructure vulnerabilities and risks identified in the literature also informed specific questions for discussion with interviewees from the sector (see Appendix A).

2.2 Stakeholder Interviews

The experts interviewed for this research comprised 16 stakeholders from the Canadian gas sector, representing regulatory authorities, inspection bodies, natural gas and propane producers and suppliers, manufacturers and equipment suppliers, industry associations, and those with general or user interest in the topic. The interviews focused on documenting experienced climate-related impacts to natural gas and propane installations, the potential implications of climate change, existing measures and best practices for managing severe weather- and climate-related risks to gas and propane installations, and possible climate resilience revisions to CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24]. Interviewees also provided valuable information on existing barriers to and opportunities for including adaptation considerations in CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24].

3 Vulnerability of Canadian Natural Gas and Propane Installations to the Impacts of Climate Change

Natural gas and propane equipment and installations are vulnerable to extreme weather events, including those associated with the changing climate. The extent of weather-related impact depends on the magnitude and frequency of the adverse climate conditions or hazards, as well as several exposure and sensitivity-related factors, including the type of installation (e.g., propane vs. natural gas, above-ground vs. below-ground), age and design of equipment and materials, and geographic location [25], [26], [27]. Additionally, climate-related impacts may change the operational activities and maintenance required to sustain service reliability, public health, and safe work conditions [27], [28], [29].

The research conducted for this report identified key mechanisms by which climate variability and severe weather have impacted natural gas and propane installations in the past, which suggest that climate

change will increase the related risks unless proactive adaptation measures are taken. Studies examining the impacts of natural hazards on the gas sector indicate that above-ground installations are generally more vulnerable than below-ground components to extreme events like floods, hurricanes, and wildfires. These hazards are projected to become more frequent and more severe due to climate change [25], [30], [31]. However, below-ground installations could also face adverse impacts related to ground shifting and movement resulting from the changing water table (e.g., due to permafrost melt) [25].

Overall, changes in climate, especially temperature, are expected to affect the localized demand for energy sources such as natural gas [27], [32]. Canada is making efforts to phase out traditional coal-fired electricity by 2030 [33] and the increased demand for energy will affect the ability of natural gas pipelines and equipment to distribute gas to consumers in sufficient amounts [27], [32], [34].

The resilience of natural gas and propane equipment, appliances, components, accessories, and systems to climate-related impacts can depend on a range of factors, including infrastructure age, location (siting), design, materials, and the capacity of owners, managers, and users to address climate variability and extremes through the development and use of asset management and emergency response plans and practices [8], [25], [35], [36].

Findings from the literature review and expert interviews indicate that flooding, wildfires, heavy snow and ice conditions, temperature variability, and extreme weather events are the climate hazards of greatest concern for natural gas and propane installations in Canada. Climate hazards of lower concern include precipitation variability, permafrost thaw, high winds, and soil movement.

The risk level of some climate hazards for propane and natural gas installations may also be region dependent. For example, wildfire was most frequently noted by sector experts from western Canada (British Columbia, Alberta) while heavy snow and ice conditions were most frequently noted by interviewees from the Atlantic region (Nova Scotia, New Brunswick). In contrast, flooding was identified by all interviewees as a highly impactful hazard for both natural gas and propane installations. Flood events have impacted installations in western Quebec, Manitoba, Alberta, and the lower mainland of British Columbia.

Interviewees also discussed the need to address climate change impacts on the supporting infrastructure systems, such as communication and electricity. Service disruptions in the gas industry (delivery schedules, supply issues, and supervisory control and data acquisition systems) due to weather-related damage of the supporting infrastructure were noted as an increasing concern. Natural gas supply interruptions caused by operational aspects and interconnection between gas and electricity systems were also reported in the literature [34]. Interviewed stakeholders also commented on the role of energy system policy in the overall resilience of the system, and the importance of embracing opportunities provided by a combination of energy sources and alternative supplies (e.g., liquefied natural gas) to avoid negative consequences of current and future extreme weather events.

3.1 Flooding

Natural gas and propane infrastructure and equipment are vulnerable to flooding, with above-ground installations (e.g., propane tanks) facing greater risks compared to buried installations, mostly for distribution of natural gas [29]. Reported damages to infrastructure and equipment that led to service disruptions have primarily been caused by flooding resulting from intense rainfall and sea level rise [29], [30], [37]. While above- and below-ground infrastructure and equipment were affected by water intrusion, underground elements were damaged via watercourse erosion and soil subsidence [38]. The risks for assets and infrastructure installed closer to coastlines, water bodies, floodplains, and erodible terrain are greater than for those in more distant or elevated locations, although pluvial (or overland) flooding is a growing concern, particularly in urban areas [30], [36], [37], [39], [40].

With respect to flooding, mean annual precipitation in Canada increased by more than 18% between 1948 and 2012, with the greatest changes observed in northern regions, and increasing implications for river flows and the frequency and magnitude of riverine flooding events [13]. Precipitation-related trends observed in Canada since 1948 include increased frequency of extreme rainfall events that are known to change the physical environment of water bodies and often trigger flooding [41]. Additionally, changes in ice and snow patterns have affected annual water cycles in snowmelt-dominated catchments in western and eastern regions of the country, including earlier spring streamflow peaks and increased winter flows resulting in greater likelihood of flooding events [42].

By the end of the 21st century, Canada is expected to experience an increase in average precipitation of between 7% and 24%, according to the respective low and high GHG emissions scenarios projected by the IPCC [7]. Extreme precipitation is likely to become more frequent in Canada by the late 21st century, when events with a current return period of 20 years are projected to become five-year events under the high GHG emissions scenario [7]. Increases in the frequency, length, and intensity of heavy rainfall events are expected to result in more frequent flooding in eastern Canada [43], [44]. Furthermore, sea level rise is expected to contribute to coastal flooding and erosion hazards on Canada's coasts, resulting in storm surges, high tides, and more frequent flooding events [45], [46].

Additional details on historical and projected trends in flooding and precipitation events are provided in Appendix B.

3.1.1 Impacts of Water Intrusion

Natural gas systems have an innate resilience against many extreme weather events because they are typically buried underground [25]. This is supported by anecdotal evidence from extreme weather events, including Hurricane Fiona in Nova Scotia in 2022 and the Texas cold snap in 2021, both of which resulted in minimal impacts to natural gas systems compared with other energy systems that are typically found above ground.

The vulnerability of equipment such as cylindrical vessels, shell and tube heat exchangers, and separators increases when the magnitude of an event augments the depth and velocity of flood waters. Vessels with a larger surface are more likely to be damaged by severe flood events than smaller vessels due to the added external pressure and velocity of the water, which can compromise the structural integrity of the vessel, resulting in failure. However, smaller vessels are most likely to fail due to buoyancy. For all vessels, regardless of size, flooding related damage and failure generally occurs when vessels are empty. Because of their lower weight, empty vessels more readily dislodge when exposed to flood water; this displacement interrupts service, often results in damage to the vessel, and can also impact adjacent equipment, such as storage and connections [47].

Due to the weight of their internal components, tubes and shell heat exchangers are less vulnerable to direct flood water-related impacts than vessels. Nonetheless, they may become susceptible to the impacts of flooding due to the effect of normal (i.e., perpendicular) stress [47].

It is important to note that the pressure design of installation equipment determines the thickness of the shell and weight of the tare. Because equipment designed for higher pressures is generally heavier, it is less likely to shift or move when exposed to flood waters [47].

Gas valves and controls are highly vulnerable to flooding, and internal corrosion can begin even when the outside of the equipment is clean and dry [48]. Because floods can carry corrosive chemicals, regulators in the vent lines of natural gas and propane systems may be damaged if a vent line protector is not installed [48], [49]. Other equipment, such as furnaces and boiler burners, operating in damaged conditions during and following a flood event can cause incomplete combustion [50]. If burners from heating systems are hot when exposed to flood waters, parts can be cracked [51]. Finally, filters and the insulation inside furnaces, water heaters, boilers, and other appliances will typically be damaged and must be replaced after exposure to flood waters [52].



"The annual area burned by wildfires in Canada has increased since 1979, with changing precipitation patterns, resultant drought conditions, and higher air temperatures among the main contributing factors."

Experts interviewed for this report expressed concerns that more frequent and more intense flooding could cause severe impacts on gas installations. One of the primary concerns was the dislodgement, damage, and compromised integrity of above-ground components of installations due to equipment being submerged for prolonged periods. Propane installations located above ground are particularly vulnerable. Some interviewees noted that difficulties in assessing damage to propane cylinder and tank integrity could pose further risks to public safety if compromised equipment is reinstalled and reused.

3.1.2 Impacts of Erosion and Soil Subsidence or Movement

Natural gas and propane installations are also vulnerable to soil subsidence or movement and geotechnical instability caused by water intrusion or erosive terrain conditions [25], [37], [18]. Studies have shown that risks of failure relate to the equipment material bending, crack propagations, cross-sectional fractures caused by axial tension, and buckling caused by soil overloading [53]. The probability of failure is likely to increase if the material is corroded or compromised [53].

3.2 Wildfire

The annual area burned by wildfires in Canada has increased since 1979, with changing precipitation patterns, resultant drought conditions, and higher air temperatures among the main contributing factors [7].

Projections suggest that higher air temperatures in the future will contribute to increased fire potential, and fires could burn double the current average area per year in Canada by the end of the 21st century [54]. Furthermore, fire season length is projected to increase by an average of 35 days, with British Columbia, western Alberta, northern Ontario, and northern Quebec experiencing the largest increases [55].

Additional details on historical and projected trends in wildfire events are provided in Appendix B.

Propane and natural gas tanks are susceptible to high temperatures and damage from debris from wildfires, with above-ground equipment and installations (predominantly propane installations) being especially vulnerable [36]. Overall susceptibility to wildfire impacts depends primarily on the location of gas and propane installations, but with propane installations, it also depends on the filling level of the tank. The heat from wildfires will increase the internal pressure of any exposed propane vessels, and when combined with low filling level conditions, may weaken the steel of the tank or cylinder [56]. This can be particularly problematic if the vessels continue to be used. Propane tanks have a safety relief valve that, if operating properly, releases gas under conditions of high internal pressure. However, relief valves may malfunction under extreme heat, increasing the likelihood of vapour-based explosions, posing risks to the health and safety of users [57], [58], and potentially further propagating fire conditions, as noted by interviewees.

3.3 Snow and Ice

Winter storms are a reality for all regions of Canada and are often characterized by a combination of heavy snowfall, cold temperatures, and high winds. In addition, freezing rain events that lead to heavy ice accumulations can cause significant damage to infrastructure and disrupt operations.

Since 1948, the ratio of snowfall to total precipitation has decreased in southern Canada, particularly during spring and fall [59]. Snowfall declines in the Arctic have also been observed, with snow being replaced by rain in the summer months [7]. Increasing variability of precipitation events has resulted in multiple extreme snow and ice storms impacting areas of Atlantic Canada and southern Ontario and Quebec, which are susceptible to freezing rain events and related heavy ice accumulation.

Regional climate model projections suggest there will be an increase in freeze-thaw cycles and rain-on-snow events over the mid- to late 21st century [60]. Although it is challenging to make high-level projections regarding the frequency of snow and ice storms, they are expected to intensify over time [44]. Warmer winter temperatures are also expected to contribute to changes in the intensity and frequency of freezing rain events, which are currently infrequent [61].

Additional details on historical and projected trends in snow and ice events are provided in Appendix B.

3.3.1 Impacts of Snow

Heavy snowfall can impact natural gas and propane installations by various mechanisms, resulting in property damage, human injury, or death.

Gas systems located below rooflines or other elevated areas can be impacted by snow accumulating on and shedding from these areas. Meters, regulators, and other above-ground components, including piping, are typically most susceptible to damage or failure due to falling snow [62], [63]. Accumulated snow may place stress on meter piping, resulting in a gas leak. A gas meter covered in snow or ice can impede the function of the pressure relief vent controlling the pressure of the gas supplied to a home, which could lead to serious risks [62]. External exhaust vents plugged with snow can cause the carbon monoxide emitted by natural gas appliances to build up inside a home, presenting a safety hazard [62]. Other snow-related failure mechanisms include dense snow accumulation on poorly supported propane lines, especially at elbows and tees, and particularly for systems located on flat roofs, bending or otherwise damaging the lines; equipment placed too close to snow plowing lanes succumbing to collisions; and system vents becoming blocked by snow accumulation, which is a particular concern for systems located on flat roofs [63], as confirmed by interviewees.

3.3.2 Impacts of Ice

Icing, resulting from either freezing rain or freeze-thaw events acting on accumulated snow, can impact natural gas and propane installations in many of the same ways as accumulated snow [64]. This was confirmed by interviewees, who noted that falling ice may be more directly damaging to equipment than snow and more likely to lead directly to human-related injuries. An added impact of icing is the potential blockage of pressure control valves on roofs [64].

3.4 Extreme Temperatures

In Canada, annual mean temperatures increased by 1.7°C between 1948 and 2016, with the trend being most prominent in northern regions, where an increase of 2.3°C was recorded [13]. During the same period, in parts of southern Canada, indices of high temperature, such as hot days (defined as days with maximum temperature above 30°C), increased annually by up to 3 days [13].

By the end of the 21st century, the annual mean temperature is expected to increase above the 1986 to 2005 baseline reference period by 1.8°C or 6.3°C, according to the low and high emissions scenarios, respectively [11]. IPCC projections indicate that extreme heat events will become more prevalent in Canada, characterized by greater frequency, magnitude, and spatial extent [10]. Extreme cold events are expected to become less common, but changes in atmospheric

circulation patterns in the High Arctic (i.e., disruptions of the stratospheric polar vortex and the polar jet stream) are expected to impact different parts of the country, particularly in mid-latitudes, where they are linked to extreme cold air outbreaks [65].

Additional details on historical and projected trends in extreme temperature events are provided in Appendix B.

Extreme heat and extreme cold can negatively impact the condition and function of natural gas and propane installations. Extreme heat can compromise the integrity of pressure vessel systems, especially valves and related components, if temperatures surpass design thresholds. Long-duration exposure to extreme heat can result in vapour leaks from these components [66]. Because extreme heat events also increase the demand for air conditioning, leakages or other performance reductions can affect a gas distribution system's ability to meet the power demand for air conditioning, which can in turn lead to health and safety concerns for those unable to avoid prolonged exposure to extreme heat [66], [45].

Extreme cold weather may affect natural gas and propane installations in two key ways. Cold weather affects the efficiency of propane vessel function by reducing pressure levels inside tanks and causing operational concerns. This means that propane vessels can lose pressure in extremely cold conditions (-42°C), resulting in depletion of gas and low efficiency of the equipment [67]. Cold temperatures can also trigger line heater failures, which impacts the distribution of natural gas [25]. In extreme cold conditions, unheated lines will transport the gas less effectively.

4 Role of Codes, Standards, and Related Solutions in Advancing Natural Gas and Propane Infrastructure's Resilience to Climate Change

Codes and standards that effectively integrate information on climate variability, climate change, and related adaptation measures can enhance the resilience of infrastructure and communities. The broad range of topics that codes, standards, and related solutions (e.g., guidelines and policies) can cover include siting, design requirements (materials, dimensions, mechanics), quality control and appropriate uses of climate information, methods for risk assessment, and asset and emergency management, among others. Given the increasing impacts of severe weather events and the changing climate on infrastructure in different sectors, efforts have begun in Canada, the US, and internationally to determine how codes and standards might be updated to help attenuate the impacts of climate change and produce more resilient infrastructure systems.

Translating the growing awareness of multiple complexities and interdependencies into policies, practices, and standards that effectively address climate change risks requires rethinking how systems are managed to identify opportunities for risk reduction or greater efficiency. Consideration is being given, in the US as well as in Canada, to the development of standardized approaches for better cross-system risk assessment and management practices, with particular focus on emergency management.

Sections 4.1 through 4.3 present a broad overview of international, US, and Canadian policy and institutional directions related to climate adaptation, resilience, and emergency management, and address important linkages and interdependencies between the gas sector, natural gas and propane installations, and other critical infrastructure sectors and systems, particularly the telecommunications and electricity sectors. Specific changes to the gas sector codes and standards in each region are described and informed the recommendations presented in Section 5 for areas of standardization and changes in CSA B149.1, B149.2, and B149.3 [1], [23], [24].

4.1 International Activities

4.1.1 Overview of Policy and Institutional Directions

The European Union (EU) Strategy on Adaptation to Climate Change [68] identifies the construction, transport, and energy sectors as the highest priorities for developing and maintaining climate resilience [69], [70]. Information and communication technology infrastructures are interconnected with and support

these three sectors and have been noted as another priority. To support implementation of the strategy, European standardization organizations were asked to identify and revise the existing European standards most relevant for adaptation to climate change in the three priority sectors, and if necessary, draft new standards, with a focus on standardization supporting engineering design [70]. The EU strategy also calls for the development of guidance documents and tools to ensure that adaptation to climate change in European standardization is considered in a systematic way [70].

The European Commission (EC) foresees a key role for standardization in strengthening the climate resilience of critical infrastructure [71]. To that end, the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) established the Adaptation to Climate Change Coordination Group (ACC-CG) to coordinate climate change standardization activities and foster collaboration [71]. ACC-CG offers support in standardizing adaptation measures (e.g., building green roofs to absorb rainfall as prevention of storm sewer overflow) and inclusion of forecasted climatic data in standards.

The ACC-CG has prioritized modification of several standards across the construction, transport, and energy sectors. The selection process was based on each standard's potential for increasing infrastructure resilience to climate change by supporting design of products or systems (e.g., infrastructure), organization of the processes (e.g., decommissioning of assets), or testing and measurement activities (e.g., measurement of gas volume, pressure, or flow under different conditions). Other prioritization criteria included the impact of each standard on the resilience of an infrastructure system (e.g., addressing more vulnerable parts of a building) and the impact of the infrastructure on the overall resilience of the economy (e.g., elimination or reduction of blackouts).

The following standards from the energy sector were selected for revision:

- EN 15399, *Gas infrastructure – Safety Management System for gas networks with maximum operating pressure up to and including 16 bar* [72];
- EN 16348, *Gas infrastructure – Safety Management System (SMS) for gas transmission infrastructure and Pipeline Integrity Management System (PIMS) for gas transmission pipelines – Functional requirements* [73];
- EN 17649, *Gas infrastructure – Safety Management System (SMS) and Pipeline Integrity Management System (PIMS) – Functional requirements* [74];
- EN 1594, *Gas infrastructure. Pipelines for maximum operating pressure over 16 bar – Functional requirement*s [75]; and
- EN 1473, *Installation and equipment for liquefied natural gas – Design of onshore installations* [76].

The International Organization for Standardization (ISO) published ISO 14090, *Adaptation to climate change — Principles, requirements and guidelines* [77] in 2019, which was the first international standard for climate change adaptation. Additions followed in 2020 with ISO 14091 [78], which provides guidance and requirements on adaptation planning for local governments and communities, and in 2021 with ISO 14092 [79], which provides guidelines on vulnerability, impacts, and risk assessment in climate change adaptation. ISO 14090 helps organizations assess climate change-related risks and develop plans for effective short-, medium-, and long-term adaptation. It also supports environmental management and asset management standards, such as ISO 14001 [80] and ISO 55000 [81], and its application as a supplement to ISO 14001 has been outlined in an ISO white paper [82]. ISO 14090 has been used by many organizations around the world to address current and future climate change impacts and to prioritize measures to respond [83]. In Canada, the SCC has identified ISO 14090 as a foundational standard that provides overlapping support for other standards that seek to advance sustainability, adaptation, and mitigation [84].

Both ISO and CEN-CENELEC have published several guides that provide recommendations to account for climate change in planning, drafting, revising, and updating standards. ISO Guide 84 [85] outlines a framework and general principles that standards developers can use to develop their own approach to addressing climate change on a subject-specific basis.



"CEN-CENELEC Guide 32 encourages standards developers to consider climate change issues, adaptation measures, as well as cascading impacts and interdependencies between different standards."

The guide enables standards developers to include requirements for adaptation to climate change, climate change mitigation, or both. CEN-CENELEC Guide 32 [86] provides guidance on addressing various aspects of adaptation to climate change only. Its step-by-step approach for including climate change issues is based on the principle of lifecycle thinking to enable consideration of all relevant aspects of a product (e.g., acquisition, production, use, and end-of-life of infrastructure) [86]. The guide encourages standards developers to consider climate change issues (e.g., impacts of severe weather, current and future climate hazards), adaptation measures (e.g., emergency plans, changes in product design), as well as cascading impacts and interdependencies between different standards. The focus on cascading impacts could be of particular relevance to natural gas and propane installations, since delivery of gas and operation of installations fundamentally rely on the services of other critical infrastructure sectors and systems, such as electricity and telecommunications. CEN-CENELEC Guide 32 [86] was a key reference during the development of SCC's Guide for Integrating Climate Change Adaptation Considerations into Canadian Standards [87].

More tailored guidance for climate change considerations for infrastructure is provided in a guideline for European infrastructure standards that was co-developed by CEN-CENELEC and the Royal Netherlands Standardization Institute (NEN) [88]. The guide helps standards committees determine whether their standards should explicitly consider impacts, risks, and vulnerabilities associated with climate change, and outlines a systematic approach to addressing climate-related issues, including considerations during the design, operation, and end-of-life phases [88]. As such, it is targeted toward all types of infrastructure standards, including fundamental standards that include terminology and conventions, test methods and analysis standards, specification standards, and management standards.

In 2021, building on the evaluation of the 2013 EU climate change adaptation strategy [89], the EC adopted the new EU Strategy on Adaptation to Climate Change [68], which outlines a long-term vision for the EU to become a climate-resilient society by 2050. The new strategy covers a broader range of standards with the goal of increasing the standardization of adaptation solutions by updating existing standards on the safety and performance of infrastructure for future climate conditions and by promoting technical solutions to adapt assets to the changing climate. The need to leverage synergies with broader work on disaster and risk prevention is also recognized. The EU's new strategy also calls for increased cooperation between international and national standardization organizations to update existing and develop new standards for climate adaptation solutions, incorporating climate adaptation considerations and requirements.

4.1.2 Climate Considerations and Revisions to Gas Sector Codes and Standards

Three gas infrastructure standards developed by CEN/TC 234 (i.e., EN 15399 [72], EN 16348 [73], and EN 1594 [75]) were selected for revision in support of the EU Strategy on Adaptation to Climate Change [89]. EN 15399 [72] and EN 16348 [73] were merged into EN 17649 [74], a standard broadened in scope to cover both gas transmission and distribution infrastructure, to provide guidance not only to the infrastructure operator but also to those designing, constructing, and decommissioning the asset, and to include adaptation to climate change requirements. An initial inquiry was carried out with CEN/TC 234 members and stakeholders to gain insight into experiences with climate impacts and related legal and technical frameworks in European countries [88]. During the revision process, special attention was paid to climate change considerations during the design and management stages of the infrastructure's lifecycle [88]. Changes to EN 17649 included adding provisions for reviewing 1-in-100-year events if relevant climate variables (e.g., temperature, precipitation, wind speed) are significantly altered over the full lifecycle of the proposed infrastructure, incorporating information about potential climate impacts and considerations for locally specific changes in weather patterns and extreme events, and adding recommendations to keep historical data on averages of relevant climate variables up-to-date and to review climate scenarios over the full lifecycle of the asset. Similar updates are being considered for EN 1594 [75].

Three ISO standards dedicated to gas infrastructure, equipment, and installations (ISO 20257-1 [90], ISO 20257-2 [91], and ISO 13623 [92]) contain references to weather conditions. However, when describing requirements for safe design, testing and operation, and maintenance of gas infrastructure, these standards do not yet include considerations for changing climate conditions. Online inquiries and a review of the literature suggests that efforts to update energy sector standards, including these three, are underway in European and other international standardization organizations.

At the time of writing, the Australian and New Zealand standards for storage and handling of natural gas and propane installations (AS 3961 [93], AS/NZS 1596 [94], and AS/NZS 5601.1 [95]) have yet to explicitly address climate change. While these codes do specify requirements regarding the location, design, construction, commissioning, and operation of installations for the storage and handling of gas, including a diverse range of climate-sensitive considerations related to fire and flooding conditions, climate change is not specifically addressed. Online inquiries suggest that efforts have yet to begin with these standards.

4.1.3 Corporate-Level Efforts to Increase Climate Resilience

Energy and gas companies around the world are working to proactively increase energy efficiency, invest in resilient technologies, and incorporate stakeholder considerations in their climate change strategies. Several energy sector companies (ENGIE, GS Caltex, and Iberdrola) have adopted diverse sets of research and innovation objectives to address the environmental and societal risks of climate change specific to the industry [96], [97], [98].

Some of the efforts to increase gas infrastructure resilience to climate change include adaptive management of assets and their condition, as well as designing and constructing infrastructure to better withstand current climatic conditions and extreme weather events, such as floods, wind storms, and more [99]. The use of appropriate software (e.g., Jupiter's ClimateScore™ Planning [100]) can help identify local scale risks and adaptation strategies tailored to the problems and features of specific sites. For example, site risk assessment and disaster management facilitated by the analysis of flood water studies and the integration of detailed climate and weather data can better prepare companies for equipment malfunctions during extreme weather events [99].

ENGIE has implemented the construction of a perimeter wall to tackle the risk of heavy flooding in Belgium, a vegetation project to prevent soil erosion in the event of storms in Mexico, and the construction of ditches and a reservoir to deal with the risk of flooding in the United Kingdom [96]. GS Caltex has integrated physical climate change considerations into asset design and conducted

a climate scenario analysis to prepare a three-year climate change risk strategy [97]. Iberdrola has implemented better maintenance and technical specification of equipment, the use of early warning systems for weather extremes, and activation of emergency plans in advance of catastrophic events [98].

Key components of climate change adaptation strategies that contribute to proactive risk management include cross-sector collaboration and use of new technologies, risk management (e.g., weather instruments to help monitor climate change over time at different sites), and expanding community engagement to address issues such as access to energy and safety [99].

4.2 US Activities

4.2.1 Overview of Policy and Institutional Directions

The growing number of weather-related disasters experienced in the US since 2000, such as hurricanes and tropical storms that have damaged parts of the southern and eastern US, and wildfires and droughts that have affected the western and central parts of the country, has contributed to a growing focus on disaster preparedness and resilience as well as on emergency management. Climate and weather extremes have changed from historical values in ways that are difficult to predict or project, posing challenges for civil infrastructure systems during their full-service lives and requiring a new design philosophy to meet these challenges [101].

As the US moves forward to incorporate disaster resilience as a national priority, standards development organizations are expected to play a critical and complementary role in achieving this goal. ANSI/EMAP 5, *Emergency management standard* [102], was developed by the Emergency Management Accreditation Program, establishes performance criteria for emergency management plan development, and serves as a tool for improving the voluntary accreditation process for emergency management programs. Each program is expected to identify natural (e.g., weather-related) and human-caused hazards, assess vulnerabilities to these hazards and related risks, and identify resource requirements and agreements needed for emergency preparation, response, and recovery. Other elements include communications, alert and warning plans, as well as training and public education and information activities for different hazards. The National Fire Protection Association (NFPA) also developed a supporting standard for emergency preparedness and crisis management, NFPA 1600, *Standard on continuity, emergency, and crisis management* [103], which covers disasters resulting from natural, technological, or human events and provides information for emergency management officials in the private, public, and non-profit sectors.

Although most codes and standards for buildings and other structures do not incorporate requirements for adaptation planning or climate change, several guidance documents and plans provide best practices related to climate change and resilience.

The National Institute of Standards and Technology published a report on how changing environmental conditions are affecting community buildings and infrastructure systems. The report noted that too little has been done to incorporate future climate conditions into design practice, and that codes and standards in the US have only recently begun to progress in this direction [104]. The report also identified key technical gaps and areas where improvements are needed to increase the resilience of infrastructure and support community resilience. Some of the key priorities noted were updates to design criteria for flood-induced erosion, wind design pressures, and design methods that address the performance and recovery of infrastructure as an integrated system, considering interdependencies between buildings, electric power, transportation, and other systems [104].

The NFPA conducted a high-level review of selected design and construction codes, reference standards, and best practices to examine the impact of changing environmental conditions on infrastructure design and performance, and identified areas needing improvement [105]. The report highlights increased coordination in codes and standards development as a key element for creating more resilient built environments in communities [105]. The report also recommends the development of a guidance document for incorporating

resilience concepts into NFPA codes and standards, along with establishing new performance objectives for responding to disruptive events.

Similarly, the American Society of Civil Engineers (ASCE) Committee on Adaptation to a Changing Climate published a manual that provides guidance on monitoring and measuring methods, infrastructure analysis, adaptive design, risk management, and climate resilience technologies [101]. The committee highlighted the need to establish loading criteria and evaluation and design procedures for buildings and other infrastructure, including energy, transportation, and communications [106], and approved a set of recommendations for updating their standards to keep pace with climate change [107]. For example, the next edition of ASCE/SEI 7, *Minimum design loads and associated criteria for buildings and other structure*s [108], will incorporate new provisions for considering climate-related environmental hazards.

Along with publications from standards development organizations, US state public codes provide detailed and useful information on emergency preparedness, public safety, and climate considerations for a variety of sectors and applications and for special local conditions. These codes highlight the importance of adaptation efforts on different sectors being coordinated between various state agencies.

The *Virginia flood risk management standard* [109] establishes a series of requirements, based on climate change considerations, for flood elevations for all new state-owned buildings.

The Port Authority of New York and New Jersey's *Climate resilience design guidelines* [110] evaluate sea level rise by determining the design flood elevation based on the 500-year recurrence interval, or 0.2% annual chance of a flood event, and a function of asset location in the floodplain, criticality, and useful lifetime.

Amendments to the *Florida building code* [111] included special hurricane protection standards for the high velocity hurricane zone for several coastal counties as well as higher standards for building components, attachments, and equipment.

California's *Public resources code* [112] ensures that all state departments and agencies are prepared to respond to extreme weather events. The code highlights the importance of public education on climate change, the availability of scientific data for policy- and decision-makers, the consideration of climate change impacts and adaptation measures when developing physical infrastructure, and the importance of collaborative efforts to address current and future regional climate change impacts and adaptation strategies [112].

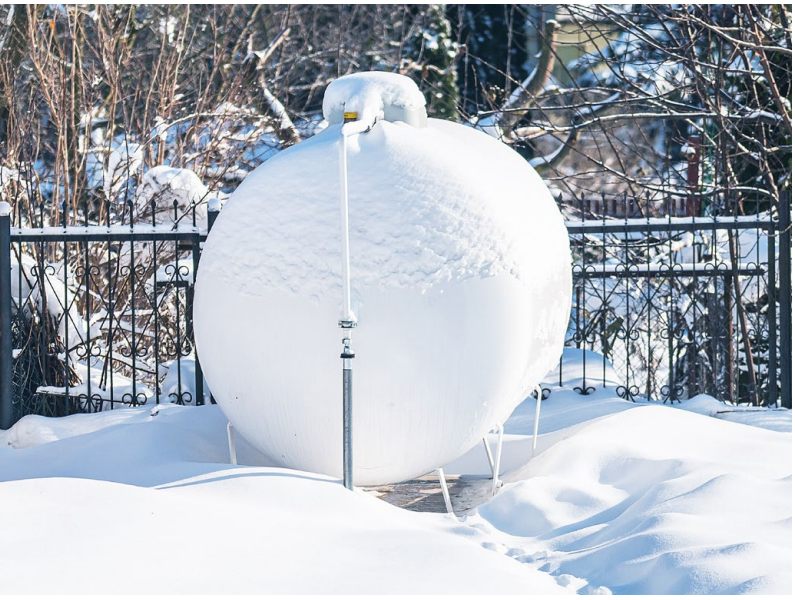
Assembling data and information on climate change, adjusting standards, codes, policies, and other instruments to account for the changing climate and local conditions are necessary for successful adaptation and resilience building. Some of these measures adopted at the regional level in the US could provide best practices and lessons learned for Canadian jurisdictions as they work to incorporate climate change resilience considerations and adaptation measures into their codes, standards, policies, and guidelines.

4.2.2 Climate Considerations and Revisions to Gas Sector Codes and Standards

The US *Code of Federal Regulations* mandates inspection and appropriate testing requirements of pipeline facilities and specifies requirements for securing and installing appliances and equipment, considering conditions in the area where they are located (e.g., potential for flooding, exposure to extreme weather, etc.) [113].

In addition to federal safety regulations for pipelines, which are developed and managed by the US Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) [114], [115], most states add additional standards and state-specific safety regulations applicable to pipelines, installations, and materials used in natural gas and propane appliances, equipment, and infrastructure [116].

Standards development organizations typically update and revise their published standards every 3 to 5 years to reflect modernized technology and best technical practices [117]. The literature review showed that gas quality, GHG mitigation, and public safety are key



"The literature and standards that inform gas sector stakeholders on resilience considerations for changing climate conditions are growing."

issues for the gas sector, with few climate-focused updates and adaptation-specific standards released to date [105], [116], [118].

Following NFPA's review of disaster resilience and emergency response in their standards [105], they updated several codes and standards applicable to the gas sector. NFPA 54, *National fuel gas code* [119] added requirements that large above-ground and underground propane tanks be securely anchored to avoid displacement during extreme events such as floods. NFPA 58, *Liquefied petroleum gas code* [120] updated fire resistance ratings for vessels storing liquefied petroleum gas and added snow loading requirements to account for heavy snowfall events and to mitigate potential damage from snow and ice, based on the characteristics of the installation site and the forces that are anticipated. Minimum safety requirements for the design and installation of fuel gas piping systems in homes and other buildings referenced in NFPA 54 [119] were also updated to account for practices, materials, trends, and technology, with references to special local conditions (e.g., tornadoes, unstable ground, or flood hazards). NFPA 110, *Standard for emergency and standby power systems* [121] updated design requirements for the performance of emergency and standby power systems (including those fuelled by natural gas) to include provisions for protection from floods, fire, wind, lightning, snow and ice accumulation, and other weather events, and to account for the probability of power failures that can occur as a result of these hazards. NFPA 110 specifies the need for equipment to be located above previously known flooding elevations and for system designs to consider the 100-year flood level or the flooding level predicted by the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model for a category 4 hurricane [121].

The literature and standards that inform gas sector stakeholders on resilience considerations for changing climate conditions are growing. In addition to standards, the literature review identified best practices, guidance on incorporating climate data in energy systems, equipment, and infrastructure, and emergency management plans [105], [122]. The Propane Education and Research Council provides emergency preparedness safety tips and weather safety news pertaining to a number of hazards, including winter storms, floods, wildfires, and more [123]. Featured climate considerations include the use of light-reflecting paint colours for propane tanks to keep temperature levels down, ensuring the area around the tank is clear of flammable materials, watering tanks during extreme heat events to lower the gas pressure and elevated temperature levels inside the tank, and ensuring propane tanks are properly marked with a pole or flag higher than the average snow depth of its location. Although the council has yet to include climate change projections and derived products (e.g., climate change-adjusted flood maps) in its information for gas practitioners, the provision of climate hazard information in an accessible format is valuable and can serve as an example for organizations in other countries, including Canada.

4.2.3 Corporate-Level Efforts to Increase Climate Resilience

In the US, some energy and gas companies are strengthening their sustainability portfolios, emphasizing risk management and disclosure, increasing energy efficiency, and investing in low carbon technology. The variety of these energy sector companies (e.g., Chevron, PG&E Corporation, NRG Energy, and Marathon Petroleum) reflects the wide range of US corporate-level efforts to increase climate resilience through extensive climate science and modelling [124]–[126].

Some of the efforts to increase the climate resilience of gas infrastructure include design and asset operations that consider local extreme events such as flooding, hurricanes, and wildfires, and asset integrity programs to ensure infrastructure is functioning according to relevant codes and standards [124]–[126]. Extensive risk management procedures and committees have also been established to promote risk identification, mitigation, and integration into strategic and emergency response planning, expanding outreach to first responders in events of emergency, strengthening agreements between utilities (e.g., gas and electricity), and planning for potential scenarios that could impact natural gas and propane installations [31], [124]–[128].

NRG Energy has implemented a winter preparedness plan whereby equipment is winterized, new staff are hired and trained, and additional equipment is purchased to generate electricity in the case of an outage during a winter storm [127]. Marathon Petroleum has implemented several tools to protect assets from extreme weather, including building levees, installing pump stations, hardening infrastructure, using flood modelling, and adopting a "Focus on Water" program to identify and mitigate water-related risks for facilities in water stressed regions [126]. PG&E Corporation is building wildfire resilience through enhanced vegetation management around facilities, hardening infrastructure, investing in wildfire response tools, and bolstering community engagement through wildfire resources and early warning notifications [128].

While progress has primarily been on value protection via risk management, emergency response planning, and altering design and operations to prepare for extreme weather conditions, there are also opportunities for innovative strategies that leverage community engagement, new technology, and cross-sector collaboration to build climate resilience [99]. Many of the US corporate adaptation strategies focus on upstream assets with less emphasis on downstream infrastructure such as installations. There is an opportunity and a need for companies to ensure that assets throughout the energy supply chain are climate resilient.

4.3 Canadian Context

4.3.1 Overview of Policy and Institutional Directions

To address the need to update codes and standards in response to the changing climate and to meet the goals set out in the Pan-Canadian Framework on Clean Growth and Climate Change [7], several initiatives have been launched in Canada, including the NRC's Climate-Resilient Buildings and Core Public Infrastructure Initiative [14] and the SCC's Standards to Support Resilience in Infrastructure Program [15]. The goal of the NRC initiative is to integrate resilience to climate change and extreme events into Canada's infrastructure and building design, guides, codes, and standards. The SCC's program has planned 36 projects that include developing standardization guidance for weather data, climate information, and climate change projections, funding of new infrastructure standards, updating of existing standards to ensure infrastructure projects across Canada are climate ready, and investing in new technical standards targeted toward infrastructure adaptation and resilience in northern Canada. As part of both programs, CSA Group has led the development of several climate change adaptation standards, and the updating of other existing codes and standards, to address the potential climate change vulnerabilities of a range of infrastructure types and to support the resilient design, construction, and maintenance of infrastructure systems across Canada [17].

In 2021, the SCC published a guide [87] to educate and support standards developers in incorporating climate change adaptation considerations into Canadian standards. It provides a consistent methodology to help standards developers apply climate change

considerations when updating existing or developing new standards through the introduction of principles, methods, and techniques. The guide also encourages standards developers to familiarize themselves with background information on climate change, its impacts, and adaptation in Canada at the onset of their work, seeking advice from climate experts if necessary and applying a systems-based approach when addressing cascading impacts or interdependencies between the standard's subject, its use, and the surrounding environment. Responses to climate change considerations may be included as requirements, recommendations, statements, assumptions, supporting annexes (normative or informative), information notes, commentaries, or records held by the responsible technical committee.

A companion document to the SCC guide, which will provide detailed information on the understanding and use of climate information, is currently under development [87]. In addition to the SCC guide and companion document, standards developers are also encouraged to consult and apply (as appropriate) the risk management framework provided in Infrastructure Canada's Climate Lens guidance document [129], and the assessment of the impact of climate change on climatic design data for buildings and infrastructure in Canada [130], published as part of the NRC's initiative.

Historical information is critical for the design of all types of infrastructure to better withstand and adapt to the changing climate across the country. To improve the quantity, quality, and sharing of empirically collected Canadian weather and climate data, and to enable professionals to access recent and location-specific climate statistics, CSA Group published CSA R100 [131], a standard on collecting and sharing metadata from hydrometeorological stations.

Other key areas of practice that are applicable across sectors and potentially critical for the pursuit of climate resilience include adaptive management and emergency management and preparedness. Several CSA standards guide practice in these areas, including CSA Z767 [132], CSA Z731 [133], and CSA Z1600 [134]. These standards apply across a variety of sectors and support the development of effective tools and systems to facilitate emergency preparedness and response, providing frameworks to identify, analyze, and manage hazards and risks. They also underscore the importance of risk-based decision-making and emphasize the need for emergency communication and resilience that consider multiple aspects of society. Although climate change is not explicitly addressed in any of these standards, they do include considerations regarding hazard types, local topography, weather conditions, and impacts to people, environment, and infrastructure.

4.3.2 Climate Considerations and Revisions to Gas Sector Codes and Standards

Canada's natural gas industry and its delivery systems are subject to regulations that reference multiple codes and standards, all of which serve to enhance the gas sector's safety and efficiency and facilitate the development of technology and innovation [135].

Core and supporting codes and standards that influence the planning, design, construction, and management of gas installations must be modified to foster climate resilience. One third of the experts interviewed for this report noted that in some instances resilience measures are implemented reactively rather than proactively, with industry changes driven by lessons learned from past experiences or inspired by efficiency standards for appliances and equipment.

Several standards have incorporated climate-related considerations to address the impacts of events such as flooding and wildfire. For example, ULC has updated several standards related to above-ground and underground fuel storage tanks to increase resilience to flooding and prevent tank damage and pollutant spills in flooded areas. These standards include CAN/ULC-S601 [136], CAN/ULC-S603.1 [137], and CAN/ULC-S677 [138], each of which contain an appendix entitled "Optional Climate Change Adaptation Requirements." Requirements and tests vary according to each standard's scope and may be related to temperature, flooding, rain and humidity, snow and ice, and winds.

The principal codes and standards used in gas sector regulations in Canada include:

- CSA B149.1, *Natural gas and propane installation |code* [1];
- CSA B149.2, *Propane storage and handling code* [23];

- CSA B149.3, *Code for the field approval of fuel-burning appliances and equipment* [24];
- CSA B51, *Boiler, pressure vessel, and pressure piping code* [139];
- CSA Z662, *Oil and gas pipeline systems* [140]; and
- CSA Z246.2, *Emergency preparedness and response for petroleum and natural gas industry systems* [141].

A review of these standards showed that weather-specific considerations include protection against solar heating, ultraviolet damage, wind, ice build-up, flooding, and blockage of ventilation by snow, ice or water, as well as temperature and pressure of operating conditions. Additionally, stress design requirements and appropriate environmental loads are considered, if relevant, and examples of appropriate weather-specific practices and techniques (e.g., warming pipes prior to unspooling to decrease susceptibility to damage or having control measures to address risks in areas conducive to wildfires) are provided. The standards also prescribe mandatory inspections of equipment exposed to hazards such as fire and flood, or other damage, prior to it being reinstalled, reactivated, or reconnected to the supply, with additional requirements in adverse climate conditions, such as cold weather, high wind, and rain. Finally, assessment of operating conditions has to be maintained with a continued inspection plan that includes factors such as safety risks, elevated stress and high temperature locations, material susceptibility to damage, operational history, and industry experience.

Where applicable, requirements for emergency preparedness, risk management, and response programs specifically for petroleum and natural gas industry systems are listed and include prevention, preparedness, response, and recovery within an organization's emergency and continuity management program [140], [141]. The suitability of different measures for addressing site-specific considerations, including local weather conditions, topographical features, and additional hazards (e.g., wildfire and flooding) is also prescribed.

In agreement with the reviewed codes and standards, interviewees highlighted the importance of emergency response programs and stressed that participating in such programs is a significant opportunity for propane and gas utilities to support the community.

It is important to note that although several climate hazards and impacts are considered within these gas sector codes and standards, they do not directly address climate change.

The Canada Oil and Gas Installations Regulations (SOR/96-118) [142] require that every installation is designed, constructed, and equipped to ensure that all equipment parts remain operational in cold and hot weather conditions and are protected from ice, snow, and freezing. Requirements for the general design of installations include considerations for ambient temperatures, soil conditions, erosion, permafrost, and wave impacts, as well as annual probability of exceedance for critical events.

Although provincial and territorial gas regulations and recommended practices (e.g., Northwest Territories [143] and Ontario [144]) are often supported by codes and standards developed by standards development organizations and address specific regional considerations, most do not include climate change considerations, focusing instead on other safety requirements. At the time of writing, existing asset management practices are the main approach used to cope with atmospheric hazards, as utilities already pay specific attention to climate variations [145].

Examples of region-specific considerations to address climate-related issues include fuel safety notifications, which can be issued as notices, bulletins, alerts, and directives to inform the public about safety issues, interpretation of acts, standards and regulations, and more. Nova Scotia's fuel safety bulletin FS17-04 [146] requires that all appliance sidewall vent terminations, appliance air intakes, and regulator vent openings be at least 36 inches above grade, or above the roof surface for roof installations, to provide a minimum clearance to a grade of 12 inches plus the anticipated snow level. This is based on historical snow level data, which indicates that the additional 24 inches of clearance is required to ensure appliance and regulator vents remain above the snow level. This will prevent blockage of vent openings, which can cause gas pressure and leakage issues, as well as potential fire and explosion hazards [146].

According to one interviewee, climate-related recommended practices that have been adopted by the Technical Safety Authority of Saskatchewan include

considerations of equipment vulnerability to freeze damage and soil stability. Additionally, the Saskatchewan Codes of Practice Gas Installation Supplement [147] to CSA B149.1 [1] includes emergency flood guidelines for waterway spillovers, flash floods, and community water/sewer system failures, and lists solutions for a number of potential impacts on gas and propane installations.

In Alberta, energy utilities are not currently required to adopt climate projections or conduct vulnerability assessments, but some are taking proactive steps and have included specific climate hazards, such as wildfire risk, in their asset planning [145]. Moreover, due to low public awareness about climate change, most of the municipalities working in energy resilience communicate and address weather-related hazards through the lens of emergency response management, specifically threats to public safety and infrastructure. Interviewees specified that in addition to provincial regulations, individual Alberta municipalities (e.g., Calgary) have made specific amendments to natural gas and propane installation requirements, increasing the complexity of the climate resilience approach [145].

Several different measures to manage severe weather and climate-related impacts for natural gas and propane installations have been adopted across Canada, with a focus on public safety and integrity of assets and operations. The measures identified during the expert interviews were grouped into the following seven categories, informed by earlier studies (e.g., [148]) and the project team's professional expertise: best practices, guidance, maintenance and operation procedures, operation and asset management plans, risk assessments, financial planning, and policy.

Table 1 lists the seven categories, along with example measures to address the resilience of natural gas and propane installations in Canada that were mentioned by the interviewees. Significantly, approximately one quarter of the interviewed stakeholders noted the current absence of such measures.

Table 1: Example Measures to Address Climate Resilience of Natural Gas and Propane Installations in Canada

Category	Percentage of interviewees who mentioned measure	Examples
Best practices	27%	▪ Common trenching techniques to protect against hazards ▪ Securing tanks to prevent dislodgement
Guidance	18%	▪ Safety campaigns (e.g., raise wildfire awareness, extreme weather preparation)
Maintenance and operation procedures	14%	▪ Implementing protective measures for equipment based on historical data (e.g., snowfall)
Operation and asset management plans	4%	▪ Operation and asset management plans, including emergency response planning
Risk assessments	4%	▪ Risk assessments to assess and validate different effects of risks on infrastructure
Financial planning	5%	▪ Sustainable fund investments (e.g., environmental, social, and governance funds)
Policies	5%	▪ Policies supporting redundancy in energy supply types

Common best practices to mitigate potential equipment damage and supply disruptions include continuous surveying for carbon monoxide detection, use of good quality materials in all installations, and backup systems. Previous events (e.g., 2016 Fort McMurray wildfire) have triggered the implementation of practices and operational adjustments, such as sprinkling the ground around installations with water in areas close to active wildfires, putting protective walls near gas meters, and using common trenching techniques and continued surveying in areas prone to ground disturbance (e.g., due to erosion). The need for training for installers and inspectors, along with educational campaigns for the broader public about climate change and its risks were also highlighted in the interviews.

Maintenance and operation procedures used to manage climate risks include appliance inspections after flooding events, geological analysis before installing new equipment or appliances, and building new infrastructure. Other examples of measures introduced to maintenance and operation procedures in response to climate concerns include the installation of support blocks for rooftop pipes in areas that previously experienced breakages due to heavy snow and ice loads, adjustments to the placement of gas meters and vents, and anchoring requirements for tanks in floodplains where previous damage to installations has occurred.

4.3.3 Corporate-Level Efforts to Increase Climate Resilience

Similar to international and US efforts, Canadian energy and gas companies are bolstering their climate change strategies by increasing energy efficiency, diversifying energy sources, and managing climate-related risks. Many Canadian energy and gas companies (e.g., Enbridge, ATCO, Imperial Oil, Emera, and Suncor) have already started to address climate-related risks and improve climate resilience [149]-[153].

Some of the efforts to increase gas infrastructure's resilience to climate change include establishing risk management processes and assigning advisory committees to monitor, manage, and mitigate potential climate-related risks [149], [150], [152], [153]. Extreme weather considerations are being incorporated into the design and operations of assets, while enhanced inspection and monitoring of weather conditions is being performed to adjust operations accordingly [151]-[153]. In addition, these companies have developed emergency response plans that include emergency response training and coordination with local first responders, which better prepares companies for extreme weather events [149]-[153]. Moreover, industry emergency and risk safety management plans also serve as risk assessment tools to validate the risk effects and provide measures to minimize the impacts and damages of extreme events and emergencies [154].

Experts interviewed for this project noted that emergency planning for larger facilities and installations in the natural gas sector is more robust than for smaller propane installations due to existing corporate requirements for risk and safety considerations in operation and for asset management plans. For example, even when climate change concerns were not explicitly mentioned in corporate emergency response plans [155], [156], there were provisions for extreme weather events and emergency response procedures, as well as clauses for protecting the placement of tanks and cylinders and managing combustible materials.

There are several examples of actions Canadian companies have taken to increase climate resilience. Enbridge has implemented on-site generators at facilities to mitigate the effects of extended power outages during extreme events such as ice storms [149]. Imperial Oil has implemented several strategies that consider extreme weather conditions into their operations, including using a wildfire buffer zone during facility design, adding ponds, ditches, and pumps to facilities to manage water during flooding, and winterizing equipment to maintain operability during cold events [151]. Finally, before acquiring or investing in new assets, ATCO investigates site-specific historical climate and weather conditions and uses tools such as floodplain maps to assess the potential of future flood risk [150].

Many of the Canadian corporate adaptation strategies focus on large-scale upstream infrastructure, which

highlights a gap in adaptive measures for downstream infrastructure such as installations. While there has been progress related to risk management, short-term asset protection, and investing in new assets that are climate-resilient, there is an opportunity to strengthen existing climate change strategies by performing risk assessments that consider long-term climate impacts, collaborating with cross-sectoral experts, and driving innovative and resilient technology and policy [99].

5 Discussion and Recommendations for the Gas Industry

5.1 State of Knowledge, Gaps, and Barriers for Climate Adaptation Implementation

There is increasing awareness of climate change as a complex and evolving issue that has affected, or will affect, oil and gas industry installations. Consequently, standards development organizations in Europe, North America, and other parts of the globe have led programs and developed guidance for standards developers on how to effectively incorporate climate change considerations into codes and standards [79], [87], [157], [158]. In addition to these initiatives, professional organizations such as Engineers Canada and Engineers and Geoscientists BC have published guidelines for engineers to support them in proactively addressing climate change issues in their work [159], [160]. Education, knowledge sharing, and collaboration play an important role in the successful implementation of climate change adaptation considerations in energy infrastructure.

Standards development technical committees (TCs) need to consider the design life of an asset and the potential climate load changes during that life, using a risk-based approach to understand and assess the significance of projections for relevant climate variables because historical values may not be valid for predicting the future [87]. Some infrastructure standards are incorporating the concept of adaptive design, which recognizes that climatic conditions will change over the life of the infrastructure, and alters the design in the present to facilitate making further alterations later [87], [158].

For many infrastructure codes and standards, the importance of infrastructure management and siting, as well as linkages with other systems, is increasing. Translating the growing awareness of multiple complexities and interdependencies into the design of policies, practices, and standards that effectively address climate change risks requires rethinking how systems are managed to identify opportunities for risk reduction or greater efficiency [87], [158]. The natural gas industry's interdependence on other sectors is often seen as a greater point of weakness than the natural gas infrastructure itself. Examples of this include the inability to export gas supply when ports are closed in a hurricane or when downed electric infrastructure reduces the demand for natural gas used in electricity generation [31].

In the energy sector, climate change has been seen as an important issue primarily from a mitigation perspective. Some of the interviewees noted that work on adaptation has generally been reactive, but a different approach is needed — one that is consistent and integrated. There is increasing awareness of the impacts of climate change and related infrastructure vulnerabilities, and there is agreement that a comprehensive approach is required to better protect our natural environment, support the advancement of a low-carbon economy, and improve the resilience of our infrastructure [45].

Approximately one third of the interviewed experts indicated that most changes, amendments, and updates to technology in the gas industry are driven by efficiency standards for the appliances, rather than by environmental or climate-related concerns. Additional challenges for developing uniform and comprehensive climate-resilient gas installations include regional differences (e.g., lack of conformity between requirements of different jurisdictions), multiple and conflicting documents on how to interpret and measure certain events and elements, and an inability to monitor and record performance of equipment or appliances after installation in different climate conditions.

According to the interviewees and the documents reviewed and discussed in Section 4.3.2, in Canada, existing climate change considerations within gas



"Most of the interviewed experts acknowledged the need for TCs to move more quickly to incorporate climate resilience measures."

sector guidance documents, including standards, are neither mandatory nor harmonized. While there is interest in incorporating climate adaptation and resilience considerations into CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24], there are also critical barriers that may impede this, including lack of legal imperative (i.e., regulations), expertise, and guidance. Some interviewees also suggested that the perceived cost of implementing resilience measures on the ground could create reluctance to their integration.

Most of the interviewed experts acknowledged the need for TCs to move more quickly to incorporate climate resilience measures. Most interviewees also acknowledged the importance of identifying, characterizing, and educating TC members about key links between climate change and the safe installation and operation of gas equipment and appliances. Furthermore, they emphasized the need for further collaboration across TCs to more effectively address issues of climate resilience. Conflicting definitions and requirements highlight the need for improved alignment between codes in the future.

One key challenge the gas sector faces is the "patchwork of initiatives and regulatory regimes across North America" [45]. This regionalization creates barriers for the industry because approaches for addressing climate risks may be inconsistent or contradictory across Canada and may lack agreed-upon solutions.

Interviewees commented that although climate conditions may differ among jurisdictions, regional differences in climate change adaptation strategies should be minimized. There is a need for certainty and harmonization of rules as well as more education and sharing between governments, standards development organizations, and industry. It is important to ensure that guidance provided in codes and standards is well aligned to support users in different authorities having jurisdiction to conduct localized interpretations of climate scenarios (see Section 5.2.1).

In light of these issues and challenges, there is interest in Canada in harmonizing and aligning requirements to improve the gas sector's efficiency and increase the climate change resilience of natural gas and propane installations.

5.2 Climate Change Adaptation Recommendations for CSA B149.1, CSA B149.2, and CSA B149.3

This section focuses on CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24] and the role they play in the management of weather- and climate-related risks to the installation, performance, and safety of propane and natural gas appliances, accessories, components, and equipment. It also focuses on the role that these three codes should play in helping to ensure the continued resilience of these assets and related services in the changing climate.

Sections 5.2.1 through 5.2.3 identify clauses in each of the codes that directly address weather- and climate-related considerations, identify existing gaps, and provide recommendations for modifications to the codes to address climate change and ensure the codes continue to effectively serve their intended purpose. The sections also note references in the codes to external codes or standards (e.g., prescribing specific equipment, materials, or processes) that are informed by or reliant on one or more climate-related considerations of potential consequence due to climate change. Considerations and recommendations regarding updates to these codes are provided.

5.2.1 Provision of Overarching Climate Change-Related Information and Guidance on its Use

A key step toward ensuring codes and standards remain relevant and continue to serve their purpose despite the effects of climate change is to ensure the climate information used in their application reflects the *most recent* historical climate and contains appropriate scenarios of future climate conditions projected to occur over the lifespan of the system, appliance, accessory, component, or equipment addressed by the code or standard.

Efforts are already underway to update the climate information required for the application of certain codes and standards, including the addition of climate change projection-based design values for key variables in the *National building code of Canada* [16] and the *Canadian highway bridge design code* [161]. However, many infrastructure practitioners, including users of CSA B149.1, B149.2, and B149.3 [1], [23], [24], may have difficulty keeping up with the full range of climate change and climate hazard information products that are becoming available, or with existing climate information products (e.g., design values) being updated with historical climate data or future scenario-based projections.

Although the SCC has published a guide on incorporating climate adaptation considerations into Canadian standards [87], it does not include a comprehensive list of existing and emerging sources of climate change and climate change hazard-related information. Furthermore, the literature review conducted for this report revealed that there is no such resource for Canadian codes and standards users in general, nor for the users of codes and standards in the propane and natural gas sectors in particular.

All of these considerations informed Recommendation 1.

Recommendation 1.

An informative *Climate Change Information Annex* should be developed for CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24] that:

a. References, provides background on, and gives guidance for the use of applicable standards, including:

- ISO14090 [77] and ISO 14091 [79];
- ASCE's manual, Climate-Resilient Infrastructure: Adaptive Design and Risk Management [101];
- Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol [162]; and
- Infrastructure Canada's guidance document, Climate Lens [129].

b. References applicable sources, provides background on, and gives guidance for interpreting and using projected climate conditions and hazards by:

- Referencing relevant sources of climate change-adjusted hazard and design information products, such as projected design values included in the *National building code of Canada* [16], and Natural Resources Canada's sea level rise projections [163];
- Referencing information sources that provide updates on the status of forthcoming climate change-adjusted design and hazard information products;
- Identifying potential shortcomings in existing climate hazard and design information (e.g., outdated flood maps based solely on historical return period statistics) that have yet to be updated using climate change scenarios; and
- Referencing guidance for the interpretation and use of climate change projections in infrastructure vulnerability and risk assessment, planning, design, and management, such as the Ouranos guidebook on climate scenarios [164].

c. As possible and defensible, provides reference to information on potential priority climate change hazards by region, considering:

- The most recent regional chapters of Canada in a Changing Climate, highlighting the national assessment of climate change impacts and adaptation imperatives across Canada [39], [44], [165], [166]; and
- Regionally-specific and climate change-informed hazard information products like sea level rise mapping for coastal regions [163], and so on.

5.2.2 Addressing Weather- and Climate-Related Considerations Directly Included in the Codes

For all of the recommendations provided in Section 5.2.2, referenced clauses should refer the code user to recent and accurate regional historical and future projected climate data for siting and installation decisions, as discussed in Section 5.2.1.

5.2.2.1 CSA B149.1, *Natural Gas and Propane Installation Code*

Recommendation 2.

This recommendation applies to:

- Clause 4.9, *Hazardous and corrosive locations;*
- Clause 6.7, *Location [of gas piping systems]*; and
- Clause 6.16, *Protection of piping and tubing.*

Above-ground and below-ground installations are expected to be primarily affected by atmospheric and soil corrosion, respectively, with potential increases in material degradation due to changes in temperature, humidity, condensation, and corrosive pollutants [167]. The time-of-wetness, when the surface of a metal appliance, accessory, component, or equipment is likely to be covered in a film of electrolyte that can cause atmospheric corrosion, is another key vulnerability factor expected to be affected by changing precipitation and flooding [167]. Therefore, the TC should review and consider referencing ISO 12944-2 [165], ISO 12944-4 [168], ISO 12944-5 [169], ISO 12944-7 [170], and ISO 12944-8 [171] to support corrosion requirements that are outlined in CSA B149.1. Other applicable documents, such as ASTM G84-89 [172], that consider multiple climatic and atmospheric phenomena with respect to moisture deposition and possible corrosion on different surfaces, should also be reviewed and referenced, if appropriate.

Recommendation 3.

This recommendation applies to:

- Clause 4.13, *Appliance clearances to combustible material;* and
- Clause 7.26, *Pool heaters.*

The location of gas installations in relation to combustible materials is a critical factor in their susceptibility to wildfire impacts. The likelihood of wildfires is changing — and increasing in many cases — across Canada because of climate change (see Section 3.2 and Appendix B for more details). The heat from wildfires creates risks to the exposed elements of appliances and equipment, increasing the likelihood of malfunction and damage. To further support proper siting and adequate protection of appliances, accessories, components, and equipment from wildfire risks, the TC should review and consider referencing the NRC's National Guide for Wildland-Urban-Interface Fires [173] and relevant CSA standards that provide requirements for fire resilience planning (e.g., CSA S504 [174]).

Recommendation 4.

This recommendation applies to:

- Clause 4.23, *Protection of appliances from physical damage;*
- Clause 5.2, *Pressure regulators;* and
- Clause 9.1, *Installation of compressors.*

The provision of adequate protection for gas appliances, accessories, components, and equipment from inclement weather, including heat waves, rain, snow and ice storms, and flooding, is expected to become more critical due to the projected increases in the frequency and magnitude of extreme weather events and greater climate variability (see Section 3 and Appendix B for more details). To draw code users' attention to sources of damage and to further support proper siting, installation, and adequate protection of appliances,

accessories, components, and equipment prone to damage by inclement weather conditions, the TC should include references to sources of damage, including requirements for consideration of adverse weather conditions such as floods, ice storms, and permafrost melt (permafrost-related impacts and considerations are not currently included in CSA B149.1).

Recommendation 5.

This recommendation applies to:

- Clause 5.2, *Pressure regulators;*
- Clause 5.6, *Termination of vents;*
- Clause 6.21, *Gas connectors;*
- Clause 7.2, *Generators, compressors/ pressure boosters, engines, and turbines;*
- Clause 10.1, *Installation [of residential fuelling appliances and vehicle fuelling appliances];* and
- Clause 10.2, *Pressure relief devices and other vents and vent lines.*

Above-ground infrastructure, including piping and tubing, chimneys and vents, as well as equipment installed outdoors (e.g., natural gas compressors and cylinders) are at a greater risk of exposure to and possible damage from the changing climate (see Section 3 and Appendix B for more details). To further support proper siting and adequate protection of appliances, accessories, components, and equipment from entry of water, ice build-up, and blockage of ventilation by snow, these clauses should be reviewed to include references to standards that contain requirements and recommendations for flood resilience, such as CSA W204 [175], CSA W210 [176], CSA S502 [177], and other relevant, hazard-specific standards as they become available.

Recommendation 6.

This recommendation applies to:

- Clause 8.14, *Vent and chimney termination.*

Potential changes in loads on vents and chimneys require adjustments to design and installation-related considerations to reflect increased wind speeds and projected further increases in the future. In addition to creating positive pressure near vent or chimney termination, wind can also cause brick and mortar to crumble, with freezing temperatures and high humidity exacerbating the impact, which affects chimney and vent performance and creates risks to gas installations and human safety [130], [178]. This issue has been addressed in certain new standards (e.g., CSA S505 [179]) and in updates to existing codes and standards, including the *National building code of Canada* [16]. To further support adequate protection of chimneys and vents from wind impacts, Clause 8.14 of CSA B149.1 should be amended with references to CSA S505 [179] and the *National building code of Canada* [16].

Recommendation 7.

This recommendation applies to:

- Clause 6.16, *Protection of piping and tubing;* and
- Clause 6.25, *Rooftop gas piping systems.*

Changing climate conditions, including heat waves, snow and ice storms, and flooding are expected to become more frequent and more intense (see Section 3 and Appendix B for more details), making it critical to ensure piping and tubing are protected from exposure and adverse impacts. The CSA B149.1 clauses containing requirements for protection against damage or breakage due to strain, wear, and mechanical impacts should be updated to include reference to sources of damage, including adverse weather conditions such as floods, ice storms, and permafrost melt.

Recommendation 8.

This recommendation applies to:

- Clause 6.2, *Material [of gas piping systems];*
- Clause 6.13, *Drip and dirt pockets;* and
- Annex G, *Piping expansion and flexibility.*

Both extreme heat and extreme cold can negatively impact the condition and function of natural gas and propane installations, as noted by the interviewees. Given that extreme events are projected to become more frequent and more intense with the changing climate (see Section 3.4 and Appendix B for more details), it is important to consider adjustments to

piping and tubing materials and siting. Annex G of CSA B149.1 should be changed from informative to normative, and the considerations outlined in Annex G should be referenced in clauses 6.2 and 6.13, as appropriate.

5.2.2.2 CSA B149.2, *Propane Storage and Handling Code*

Recommendation 9.

This recommendation applies to:

- Clause 4.19, *Protection of appliances from physical damage;*
- Clause 5.3, *Protection of containers and equipment;*
- Clause 6.5.3.8, *Cylinders on building rooftops;* and
- Clause 9.1, *General [information on vaporizers].*

Due to projected increases in the frequency and magnitude of extreme weather events and greater climate variability (see Section 3 and Appendix B for more details), propane appliances, accessories, components, and equipment installed outdoors are expected to become more exposed and vulnerable to heat waves, rain, snow and ice storms, and flooding. Accordingly, the provision of adequate protection from inclement weather will be critical. Clauses 4.19, 5.3, 5.4, 6.5.3.8, 8.2, and 9.1 of CSA B149.2 should be updated to include references to sources of damage, including adverse weather conditions such as floods, ice storms, and permafrost melt (permafrost-related impacts and considerations are not currently included in CSA B149.2).

Recommendation 10.

This recommendation applies to:

- Clause 5.3, *Protection of containers and equipment.*

The location of propane containers and equipment in relation to combustible materials is a critical factor in their susceptibility to wildfire impacts. The likelihood of wildfires is changing — and increasing in many cases — across Canada because of climate change (see Section 3.2 and Appendix B for more details). The heat from wildfires creates risks to exposed elements of appliances and equipment, increasing the likelihood of malfunction and damage. To further support proper siting and adequate protection of propane containers and equipment from wildfire risks, the TC should reference and recommend the NRC's National Guide for Wildland-Urban-Interface Fires [173] and relevant CSA standards on wildland urban interface design (e.g., CSA S504 [174]).

Recommendation 11.

This recommendation applies to:

- Clause 6.7, *Installation of cylinders;* and
- Clause 7.11, *Tank supports.*

Changing temperatures and precipitation, as well as flooding are expected to make propane installations more exposed and vulnerable to the impacts of inclement weather (see Section 3 and Appendix B for more details). Above-ground installations are expected to be affected by atmospheric corrosion, with potential increases in material degradation due to changes in temperature, humidity, condensation, and corrosive pollutants [171]. Clauses 6.7 and 7.11 of CSA B149.2 should be updated to include references to sources of damage, including adverse weather conditions such as floods, ice storms, and permafrost melt. With respect to corrosion protection, the TC should consider adding references to ISO 12944-2 [167], ISO 12944-4 [168], ISO 12944-5 [169], ISO 12944-7 [170], and ISO 12944-8 [171], and other applicable documents, such as ASTM G84-89 [172], that consider multiple climatic and atmospheric phenomena with respect to moisture deposition and possible corrosion on different surfaces.

Recommendation 12.

This recommendation applies to:

- Clause 7.1, *General [requirements for tank systems, filling plants and refill centres].*

Hazards such as snow and ice storms are expected to intensify over time in different parts of Canada (see Section 3.3 and Appendix B for more details). Heavy snowfalls can impact propane installations by way of various mechanisms, resulting in property damage, human injury, or death. Above-ground components, including tanks and piping, are most susceptible to damage or failure because of falling snow and dense snow accumulation (see Section 3.3.1). Clause 7.1 of CSA B149.2 should be amended to include reference to CSA S502 [177] and other relevant hazard-specific standards as they become available.



"Changing climate and weather conditions, including more intense rain events and frequent floods are expected to impact elements of below-ground and above-ground propane installations, including propane tanks and dispensing systems."

Recommendation 13.

This recommendation applies to:

- Clause 7.8, *Installation of underground tanks;*
- Clause 7.11, *Tank supports;* and
- Clause 7.20, *Dispensing system.*

Changing climate and weather conditions, including more intense rain events and frequent floods (see Section 3.1 and Appendix B for more details) are expected to impact elements of below-ground and above-ground propane installations, including propane tanks and dispensing systems. Consequently, it will be necessary to address adjustments to siting and installations. To further support proper siting and adequate protection of underground propane installations (as well as any above-ground components and equipment connected to them) from damage due to water intrusion, erosion, or soil subsidence as a result of flooding and increases to the water table, clauses 7.8, 7.11, and 7.20 of CSA B149.2 should be updated with references to CSA W204 [175], CSA W210 [176], CSA S502 [177], and other relevant hazard-specific standards as they become available.

Recommendation 14.

This recommendation applies to:

- Clause 7.12, *Filling plants and refill centres.*

The dynamic nature of projected changes in extreme weather events (e.g., rain and snow storms, flooding, and high wind events) and their impacts on natural gas and propane installations (see Section 3 and Appendix B for additional details) make the provision of adequate protection from inclement weather critical. To support the climate resilience and operation of propane filling plants and refill centres and to raise code users' awareness of the implications for natural gas and propane installations, Clause 7.12 of CSA B149.2 should refer to different types of hazards and explicitly mention the need to consider ones linked to climate change (e.g., flooding, wildfire, etc.).

Recommendation 15.

This recommendation applies to:

- Clause 7.22, *Operations and maintenance procedures;* and
- Annex L, *Risk and safety management plans.*

Operating and maintenance procedures, as well as documentation, for propane facilities outlined in Clause 7.22 and Annex L of CSA B149.2 do not explicitly specify weather conditions or climate change, which is an important gap that needs to be addressed. Clause 7.22 should refer to different types of climate hazards that can impact propane appliances, accessories, components, and equipment (e.g., flooding, wildfire, etc.).

Recommendation 16.

This recommendation applies to:

- Annex E, *Piping expansion and flexibility.*

Extreme heat and extreme cold, as well as heavy rain and snow storms, can negatively impact the condition and function of propane installations, as noted by the interviewees. Given that extreme events are projected to become more frequent and more intense with the changing climate (see Section 3.4 and Appendix B for more details), it is important to consider adjustments to piping and tubing materials and siting. Annex E of CSA B149.2 should be changed from informative to normative, and the considerations should be referenced in Clause 5.9 and other clauses pertaining to piping and tubing, as appropriate.

5.2.2.3 CSA B149.3 *Code for the Field Approval of Fuel-Burning Appliances and Equipment*

Recommendation 17.

This recommendation applies to:

- Clauses in Section 7, *Pilot safety shut-off valves and burner;*
- Clauses in Section 8, *Main safety shut-off valves, input flow control systems, and main burners;* and
- Clauses in Annex J, *Mobile outdoor food service unit.*

Given projected changes in severe weather events and their impacts on outdoor components of gas installations (see Section 3 and Appendix B for more details), the absence of references to climate hazards in sections 7 and 8, and in Annex J of CSA B149.3 is a gap. These sections should therefore include references to different types of hazards, and explicitly mention the need to consider ones linked to climate change (e.g., flooding, wildfire, etc.). The inclusion of references to CSA W204 [175], CSA W210 [176], CSA S502 [177], and other relevant hazard-specific standards as they become available, is also recommended.

Recommendation 18.

This recommendation applies to:

- Clause 10.1, *Installation [of fuel-burning equipment];* and
- Clause 18.7, *Installation of flare pilots.*

Although not explicitly mentioned in these clauses, changing climate conditions, including heat waves, snow and ice storms, and flooding, are expected to become more frequent and more intense (see Section 3 and Appendix B for more details), making it critical to ensure piping, tubing, and hosing are protected from exposure and adverse impacts. Clauses 10.1 and 18.7 of CSA B149.3 should be updated to include references to sources of damage, including adverse weather conditions such as floods, ice storms, and permafrost melt.

Recommendation 19.

This recommendation applies to:

- Clause 17.3, *Engines and turbines.*

Above-ground infrastructure, including regulators, relief valves, and vents, is likely to face increasing risks of exposure to and possible damage from the changing climate (see Section 3 and Appendix B for more details). To further support proper siting and adequate protection of appliances, accessories, components, and equipment from entry of water, ice build-up, and blockage of ventilation by snow, Clause 17.3 of CSA B149.3 should be amended to include references to CSA W204 [175], CSA W210 [176], CSA S502 [177], and other relevant hazard-specific standards as they become available.

Recommendation 20.

This recommendation applies to:

- Clause 18.1, *Flare pilot.*

Projected changes in severe weather events, including high winds and rain storms (see Section 3 and Appendix B for more details), are expected to make elements of propane installations, such as flare pilots, more vulnerable to the impacts of inclement weather. Consequently, requirements to withstanding severe weather conditions will need to be reassessed and updated to reflect the dynamic nature of climate change. Clause 18.1 of CSA B149.3 should be amended with references to regional historical and future projected climate data for siting and installation decisions, as recommended in the *Climate Change Information Annex* proposed in Recommendation 1 (see Section 5.2.1).

Recommendation 21.

This recommendation applies to:

- Clause 18.2, *Valves for flare pilots;* and
- Annex K, *Recommended requirements for automatic safety shutoff valves and automatic vent valves installed on gas turbines having capacities greater than 12.5 MMBtu/h (3.66 MW) and inlet pressures greater than 150 psi.*

The implications of the changing climate on conditions in which an appliance, accessory, component, or equipment will be situated and need to operate should be considered when such items are approved for use, installed, and operated. To support adequate functioning of appliances, accessories, components, and equipment in the changing climate, a note should be added to each clause referencing the different materials' tolerance to ambient climate conditions in order to draw code users' attention to the possible climate change implications.

Recommendation 22.

This recommendation applies to:

- Clause 10.1, *Installation [of fuel-burning equipment];*
- Clause 18.7, *Installation of flare pilots;*
- Annex G, *Liquid fuels;*
- Annex H, *Solid fuels;* and
- Annex I, *Risk-based program for determining requirements for an appliance in a complex and integrated facility.*

To support adequate functioning of appliances, accessories, components, and equipment in the changing climate, clauses 10.1 and 18.7, and annexes G, H, and I of CSA B149.3 should refer to different types of hazards, and explicitly mention the need to consider ones linked to climate change (e.g., flooding, wildfire, etc.).

5.2.3 Addressing Weather- and Climate-Related Considerations in Documents Referenced in the Codes

Some of the external documents referenced in CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24] may also be affected by climate implications because they prescribe specific loading requirements or outline design and materials provisions for relevant components, accessories, and equipment addressed by the codes (e.g., to accommodate the need for expansion and contraction of materials in installations exposed to a wide range of temperatures, rain, or snow).

The external documents included in the three tables in Appendix C were selected based on their reference to an appliance, accessory, component, equipment, or related activity (e.g., installation or maintenance) that is:

a. Typically or potentially situated or carried out in an outdoor environment; and

b. Characterized in the literature or identified through interviews as potentially vulnerable to one or more specific climate-related hazards, such as heavy snow or ice, rapidly changing temperatures, and so on.

For each of these external documents, the tables note if climate change-related updates have been made and were made public (e.g., via web posting) or if there have not been any updates. Otherwise, the status of updates is indicated as *unknown.*

Considering all of these points, the following recommendations is suggested:

Recommendation 23.

If the status of updates to a potentially climate-sensitive code or standard is unknown, TCs should inquire with the responsible standards development organization to ask (a) whether climate change has been considered, and (b) whether related updates have been proposed or implemented.

5.3 Enhancing Institutional Supports within CSA Group

Section 5.2 presents 23 recommendations for TCs to consider to ensure that CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24] continue to fulfill their purpose, despite the impacts of climate change. However, the issue of climate change must be considered by TCs on an ongoing basis, over time.

Recommendation 24 reflects this ongoing need for CSA Group's TCs to regularly revisit the potential implications of climate change for the efficacy of the codes and standards that fall within their mandates.

It envisages the establishment of further institutional capacity to support such efforts, both at an organization-wide level and for the TCs for CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24], in particular.

Recommendation 24.

CSA Group should provide TCs and technical working groups (TWGs) with sustained and reliable access to expertise of the following types:

- Climate and climate change science and services;
- Climate change vulnerability and risk assessments of natural, built, and human systems;
- Engineering design under climate change-related uncertainty;
- Infrastructure system-specific and hazard-specific climate change adaptation measures, including resilient design approaches; and
- Use of SCC's Guide for Integrating Climate Change Adaptation Considerations into Canadian Standards [87] and complementary portions of other similar guides, such as NEN/CEN-CENELEC's Tailored Guidance for Standardization Technical Committees [88] and others with more sector-specific content.

This could be accomplished by including members with the different types of expertise on each TC or TWG, or by creating a separate advisory group comprising the different types of expertise to advise the TCs and TWGs on climate change adaptation.

6 Conclusions

Developing and updating codes and standards to address the impacts of climate change can help build more resilient infrastructure, protect human health and safety, and safeguard local communities and the economy. It can also encourage the development of clean and diverse energy systems by drawing attention to the importance of redundancies.

A detailed literature review and interviews with gas sector stakeholders provided key information and insights that helped identify floods, wildfires, heavy snow and ice events, and extreme temperature conditions as the hazards of greatest concern for natural gas and propane installations in Canada.

Changes in climate conditions could intensify or increase the frequency of these hazards, making natural gas and propane installations more vulnerable to adverse impacts.

Based on the review of the priority hazards, and of international, US, and Canadian advancements in incorporating climate change adaptation and resilience considerations into built infrastructure and gas sector codes and standards, it is clear that the CSA B149 series of codes require key updates to adapt to climate change

Sections 5.2 and 5.3 present a total of 24 recommendations for proposed updates to CSA B149.1, CSA B149.2, and CSA B149.3 [1], [23], [24].

Recommendation 1 pertains to the development of an informative *Climate Change Information Annex,* which would provide guidance on the interpretation and use of projected climate conditions and hazards (including priority regional climate hazards); facilitate access to existing and emerging sources of climate change and climate hazard-related information; and provide background and guidance on the use of established processes for climate change and infrastructure vulnerability and risk assessment, as well as adaptation and resilience planning.

Recommendations 2 through 23 address weather- and climate-related considerations directly included in the codes, referencing the recommended use of relevant standards and recent and accurate regional historical and future projected climate data for siting and installation decisions. These recommendations also address the need to closely review external climate-sensitive standards referenced by the codes, including whether these standards have been updated to reflect climate change and any related implications.

Finally, Recommendation 24 addresses the enhancement of institutional supports within CSA Group, to regularly revisit potential implications of climate change for the efficacy of the codes and standards that fall within their mandates, and to provide TCs and TWGs with sustained and reliable access to expertise on climate-related topics, including climate change, climate-related uncertainty, and integrating climate change adaptation considerations into standards.

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Appendix A – Stakeholder Interview Questionnaire

The following questions were used to guide each interview. Depending on the expertise, knowledge, and interest of the respondent, certain questions were adjusted, abbreviated, or received more emphasis than others.

Opening Questions

Could you say a few words about your role and experience in the gas sector, specifically related to natural gas and propane installations? Which jurisdictions have you worked in?

Climate Hazards, Risks, Impacts, and Adaptation

1. From your perspective, what are the greatest weather- and climate-related risks for natural gas and propane installations in Canada? Please consider hazards such as extreme events, flooding, wildfire, permafrost thaw, etc.

2. Based on your experience and knowledge, how have severe weather and climate variability impacted natural gas and propane installations in your region or area of mandate? How do you expect this might change as a result of climate change?

3. What measures are currently in place to manage severe weather- and climate-related impacts to natural gas and propane installations? Please consider best practices, guidance, maintenance and operations procedures, operation and asset management plans, risk assessments, financial planning, and policy.

4. Which of the above-noted adaptation measures are currently informed by the consideration of climate change (i.e., projected shifts in average climate conditions and the frequency and intensity of weather- and climate-related extremes)? Please explain.

5. Can you share any notable examples of new measures, used to manage the impacts of severe weather and climate variability on natural gas and propane installations that have been adopted specifically to better account for the effects of climate change? In Canada? Internationally?

Resilience Measures in Current Codes, Guidance, and Literature

6. Have there been any changes in regulations, policy, operations management, design, or best practices related to the physical risks associated with the exposure of natural gas and propane installations to the impacts of climate change?

7. How could B149 series codes (specifically, B149.1, B149.2, and B149.3) be revised to better support the development of climate resilient gas infrastructure in your region or area of mandate?

8. What are the most important things to do to ensure climate resilience-related updates are included in B149 series codes (specifically, B149.1, B149.2, and B149.3)?

9. What are the barriers and opportunities to integrating climate change resilience considerations in B149 series codes (specifically, B149.1, B149.2, and B149.3)? (e.g., lack of available literature, guidance, time, funding, motivation, expertise, or knowledge.)

10. Are you aware of other codes, guidance, or literature in Canada or other jurisdictions that could help inform revisions of the B149 series codes (specifically, B149.1, B149.2, and B149.3) to improve climate resilience?

11. Is there any final input you would like to provide?

Appendix B – Trends and Projected Changes in Key Climate Hazards for Natural Gas and Propane Installations

B.1 Trends and Projected Changes in Flood-Related Climate Conditions in Canada

Observation data show that mean annual precipitation in Canada increased by over 18% between 1948 and 2012, with the greatest changes (up to 32.5%) observed in northern regions, leading to implications for river flows and the frequency and magnitude of riverine flooding events [7]. Significant increases (10% to 12%) were also experienced in eastern Manitoba, western and southern Ontario, and Atlantic Canada [7]. The absolute amount of precipitation increases, linked to higher mean precipitation, was greater in southern Canada [7].

Seasonally, precipitation has increased throughout the year in northern Canada, with increases ranging from 18% in summer to 54% in winter. In southern Canada, precipitation has also increased in most seasons but the increase is generally not statistically significant. Importantly, a statistically significant decrease in winter precipitation has been observed in British Columbia (-9%) and in the Prairie provinces (-5.9%) [7], [59].

Precipitation-related trends observed in Canada since 1948 include increased frequency of extreme rainfall events that are known to change the physical environment of water bodies and often trigger flooding [39], [44]. Additionally, changes in ice and snow patterns have affected annual water cycles in snowmelt-dominated catchments in western and eastern parts of the country, including earlier spring streamflow peaks and increased winter flows, resulting in greater likelihood of flooding events [11].

By the end of the 21st century, Canada is expected to experience an increase in average precipitation of between 7% and 24%, according to low and high GHG emissions scenarios, respectively [7]. Annual and winter precipitation are projected to increase everywhere in Canada over the 21st century, with larger percentage changes in northern Canada. Summer precipitation is projected to decrease over southern Canada under a high GHG emissions scenario toward the end of the 21st century, in part due to changes in atmospheric circulation [7], [180].

As the climate warms, particularly in northern Canada, the likelihood of precipitation falling as rain rather than snow (including rain-on-snow events), especially in the autumn and spring, will increase [7], [60]. In association with precipitation and temperature increases, annual streamflow and earlier spring freshets are projected to increase across the country, potentially impacting the frequency of inland flooding, along with extreme precipitation events, sudden thaws, and rain, combined with snowmelt and ice jamming [44], [165], [181]. In the Prairies, projected increases in drought and summer convective storms could lead to increased risk from overland flooding as rainfall becomes more intense and rain-on-snow events increase in frequency [182], [183]. Other implications of changing precipitation patterns include altered water accumulation and discharge, including the timing of spring thaw, timing and duration of summer-autumn low flow, and increased strength and frequency of atmospheric river events[1] [184].

1 "Atmospheric rivers are narrow bands of concentrated moisture in the atmosphere that enter western Canada from the Pacific Ocean and can lead to extreme precipitation events" [134, p. 25].

Extreme precipitation is likely to become more frequent in Canada by the late 21st century, when events with a return period of 20 years are projected to become five-year events under the high GHG emissions scenario (RCP 8.5) [7]. Increases in the frequency, length, and intensity of heavy rainfall events (during which precipitation exceeds 10 mm) and maximum five-day precipitation are expected to result in more frequent flooding events in eastern Canada, including Quebec [43], [44].

Sea level rise is expected to contribute to coastal flooding and erosion hazards on Canada's coasts, with Atlantic provinces seeing the sea level rise by 75 to 100 cm by the end of the 21st century [9], [39]. In Halifax specifically, a 20 cm rise in sea level is projected to occur in the next three decades, increasing the frequency of flooding by a factor of four [39]. The melting of Antarctic ice is likely to contribute to high levels of sea level rise in Vancouver, increasing by as much as 135 cm by 2100, resulting in storm surges, high tides, and more frequent flooding events [46].

B.2 Trends and Projected Changes in Wildfire-related Conditions in Canada

The annual area burned by wildfires in Canada has increased since 1979, with changing precipitation patterns, resultant drought conditions, and higher air temperatures among the main contributing factors [7].

Fire risk in Canada is characterized by the Canadian Forest Fire Weather Index (FWI) System – a collection of indices that use weather variables, including temperature and precipitation [7]. However, large temporal and spatial variability in temperature and precipitation hinders the detection of trends in FWI indices [185], [186]. Despite inconsistencies in trends, there has been an increase in the mean number of fire-spread days across the country between 1979 and 2002, as well as a significant increase in the annual area burned by wildfire [187], [188].

Projections suggest that higher air temperatures in the future will contribute to increased fire potential. Future scenarios rarely include sufficient increases in precipitation to compensate for the drying effect of warmer temperatures [182]. As a result, fires could burn twice as much average area per year in Canada by the end of the 21st century as they have burned in the recent past [54]. Fire season length is projected to increase by an average of 35 days, with British Columbia, western Alberta, northern Ontario, and northern Quebec experiencing the largest increases [55].

B.3 Trends and Projected Changes in Snowfall and Icing Conditions in Canada

Since 1948, the ratio of snowfall to total precipitation has decreased in southern Canada, particularly during spring and fall [59]. Snowfall declines in the Arctic have also been observed, with snow being replaced by rain in the summer months [7]. Other trends include decreases in the portion of the year with snow cover and seasonal snow accumulation (presented as maximum snow water equivalent) across most of Canada, except southern Saskatchewan and parts of Alberta and British Columbia [42]. Days with heavy snowfall (i.e., greater than the annual 90th percentile from all events greater than 1mm per day) have decreased by a few days in western Canada (British Columbia and the Prairie provinces), while increases were observed in the North [7]. At the same time, increasing variability of precipitation events has resulted in multiple extreme snow and ice storms impacting areas of eastern Canada, southern Ontario, and Quebec that are susceptible to freezing rain events and related heavy ice accumulation.

Consistent with historical trends, a decrease in the fraction of precipitation falling as snow, especially in the autumn and spring, is expected in the future [7]. Declines in snow cover are also expected across the country, accompanied by reductions of seasonal snow accumulation (presented as maximum snow water equivalent) of up to 10% per decade in southern Canada, with the greatest changes in the Maritimes and British Columbia [42]. Snow depth can vary significantly at the local scale, driven by winds and interactions with vegetation and topography, making snow depth at individual locations significantly higher than projected averages [189].

Regional climate model projections show an increase in rain-on-snow events over the coming century [60]. Hazards such as snow and ice storms and freeze-thaw cycles are expected to intensify over time, but it is challenging to make projections about their frequency with a high level of confidence [44]. Warmer winter temperatures are also expected to contribute to changes in currently infrequent freezing rain events, impacting their intensity and frequency [61].

B.4 Trends and Projected Changes in Extreme Temperatures in Canada

In Canada, annual mean temperatures increased by 1.7°C between 1948 and 2016, the trend being most prominent in northern regions, where an increase of 2.3°C was registered [7]. Western regions have experienced stronger warming events than eastern regions (annual mean temperature increased by 1.9°C and 0.7°C in British Columbia and Atlantic provinces, respectively) due to fluctuations in circulation patterns in the large-scale atmospheric ocean [10].

Warming has not been uniform across seasons, with greater increases observed in winter compared to summer months [7]. Between 1948 and 2016, seasonal mean temperatures increased by by 3.3°C in winter, 1.7°C in spring, 1.5°C in summer, and 1.7°C in autumn, with uneven distribution across the country [7]. Marked winter warming was observed in northern British Columbia, Alberta, the Yukon, the Northwest Territories, and western Nunavut, with a similar pattern (albeit of a smaller magnitude) recorded in spring. Autumn temperatures increased the most in the Northwest Territories and Nunavut, while summer temperature increases were the most uniform and the least pronounced.

Warming in winter and spring resulted in a marked decrease in the number of frost days (days with daily minimum temperature of 0°C or lower) and ice days (days with daily maximum temperature of 0°C or lower), with decreases of 15 and 10 days across the country, respectively [41]. Indices of high temperature, such as hot days, defined as days with maximum temperature above 30°C, increased annually by up to 3 days in parts of southern Canada over the 1948 to 2016 period.

By the end of the 21st century, the annual mean temperature is expected to reach 1.8°C or 6.3°C above the 1986 to 2005 baseline according to the low and high GHG emissions scenarios, respectively [11]. Enhanced warming is projected to occur at higher latitudes, a trend that is particularly pronounced in the winter months [7]. In southern Canada, projected winter temperature changes are more prominent in the east, while western regions (e.g., British Columbia) are expected to warm less than other parts of the country [7]. Projected summer changes present a more uniform pattern across the country

According to the IPCC, extreme hot events will become more prevalent in Canada compared to historical conditions, characterized by greater frequency, magnitude, and spatial extent [9]. Averaged over the country, annual highest daily maximum temperatures are projected to increase by 2°C in the middle of the 21st century (2031–2050) under a high GHG emissions scenario (RCP 8.5) compared with the current climate (1986–2005) [7]. A much larger increase of approximately 6°C, is expected by the end of the 21st century (2081–2100) under the same scenario [7]. It is important to note that under RCP 8.5, the annual highest daily temperatures that would occur once every 10 and 50 years in the current climate will become once-every-two-year and once-every-five-year events by 2050, corresponding to a 5-fold and 10-fold increase in frequency, respectively [7], [190].

Extreme cold events will become less common, but changes in atmospheric circulation patterns in the High Arctic (i.e., disruptions of the stratospheric polar vortex and the polar jet stream) are expected to impact different parts of the country, particularly in mid-latitudes where they are linked to extreme cold air outbreaks [65].

Future warming will be accompanied by longer growing seasons, fewer heating degree days (i.e., the number of °C when a day's mean temperature is below 18°C), and more cooling degree days (i.e., the number of °C when a day's mean temperature is above 18°C) [7].

Appendix C – External Documents Referenced in CSA B149.1, CSA B149.2, and CSA B149.3 with Weather- and Climate-Related Considerations

C.1 Climate Change Update Status of External Documents Referenced in CSA B149.1

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
CSA Z662 [140]	No climate change updates	Meter and service regulator installations	4.6
Local electrical code or CSA C22.1 [191]	Updated in 2021 (CSA C22.1)	Electrical connections between an appliance and building wiring	4.7
CSA Z240.4.1 [192]	Unknown	Installation of gas-burning appliances and the gas piping system in mobile homes and recreational vehicles	4.8
Local building code or CSA-B365 [193]	Unknown	Installation of a solid-fuel-fired portion of the appliance	4.18
CSA 2.17 [194]	Unknown	High-altitude installations (between 2000 and 4500 ft)	4.22
ANSI Z21.80/CSA 6.22 [195]	Unknown	Certification of pressure regulators	5.2
UL 144 [196]	No climate change updates	Certification of pressure regulators	5.2
ASTM A53/A53M [197]	Unknown	Gas piping systems	6.2
ASTM A106 [198]	Unknown	Gas piping systems	6.2
CSA Z662 [140]	Updated in 2019	Pipe fittings	6.2
ASME B16 series [199]	Unknown	Pipe fittings	6.2
ANSI LC-4/ CSA 6.32 [200]	Unknown	Pipe fittings	6.2
ASTM B837 [201]	Unknown	Copper tubing	6.2
ASTM B88 [202]	Unknown	Copper tubing	6.2
CAN/CSA-W117.2 [203]	No climate change updates	Hoses and hose connections used in cutting or welding systems	6.2

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
ASTM A179/A179M [204]	Unknown	Seamless steel tubing	6.2
CSA B137.4 [205]	Unknown	Plastic piping and tubing	6.2
CSA B137.4.1 [206]	Unknown	Fittings for plastic piping and tubing	6.2
ANSI LC 1/CSA 6.26 [207]	Unknown	Corrugated stainless steel tubing (CSST) and associated fittings	6.2
CAN/ULC-S642 [208]	No climate change updates	Joining sealant	6.9
ANSI Z21.90/CSA 6.24 [209]	Unknown	Gas convenience outlet	6.11
ANSI Z21.41/CSA 6.9 [210]	Unknown	Quick-disconnect device	6.11
CSA 3.11 [211]	No climate change updates	Manual shut-off valve	6.18
CSA 3.16 [212]	No climate change updates	Manual shut-off valve	6.18
ANSI Z21.15/CSA 9.1 [213]	No climate change updates	Manual shut-off valve	6.18
ANSI Z21.75/CSA 6.27 [214]	Unknown	Gas connector	6.21
ANSI Z21.101/CSA 8.5 [215]	Unknown	Gas connector	6.21
CSA B51 [139]	No climate change updates	Discharge piping for compressors and pressure boosters	7.2
CSA C282 [216]	No climate change updates	Fuel systems serving emergency power supplies	7.2
ULC S636 [217]	Unknown	Vents constructed using plastic piping	8.9
ANSI Z21.13/CSA 4.9 [218]	Unknown	Venting systems for boilers	8.10
Local building code or National Building Code of Canada (NBCC) [16]	Updated in 2020	Gas connector	8.12
CAN/ULC-S605 [219]	No climate change updates	Vent that a residential appliance certified with an automatically operated vent damper device is connected to	8.26
CAN/ULC-S609 [220]	No climate change updates	Vent that a residential appliance certified with an automatically operated vent damper device is connected to	8.26
CAN/ULC-S604 [221]	No climate change updates	Vent that a residential appliance certified with an automatically operated vent damper device is connected to	8.26

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
CAN/ULC-S629 [222]	No climate change updates	Vent that a residential appliance certified with an automatically operated vent damper device is connected to	8.26
UL 959 [223]	No climate change updates	Vent that a residential appliance certified with an automatically operated vent damper device is connected to	8.26
CSA/ANSI NGV 5.2 [224]	No climate change updates	Vehicle fuelling appliance	10.1
CSA B108.1 [225]	No climate change updates	Vehicle fuelling appliance	10.1
CSA B108.2 [226]	No climate change updates	Vehicle fuelling appliance	10.1
CSA 8.1 [227]	No climate change updates	Compressor	N.1.2
CSA 8.3 [228]	No climate change updates	Compressor	N.1.2
ULC/ORD C536 [229]	Unknown	Compressor	N.1.2

C.2 Climate Change Update Status of External Documents Referenced in CSA B149.2

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
CAN/CGSB-3.14 [230]	No climate change updates	Propane	4.1
CAN/CGSB-3.13 [231]	No climate change updates	Butane	4.1
CSA B149.1 [1]	No climate change updates	Piping, tubing, gas hose, and fittings	5.9
CSA B339 [232]	No climate change updates	Refillable cylinders, 39M non-refillable cylinders	6.1
CGSB-43.123 [233]	No climate change updates	2P, 2R, and 2Q non-refillable aerosol containers	6.1
CSA B340 [234]	No climate change updates	Cylinder relief valve	6.1
UL 2227 [235]	No climate change updates	Cylinder overfill prevention device	6.1
CSA B620 [236]	No climate change updates	Tank trucks, tank trailers, and cargo liners	8.1
CSA C22.1 [191]	Updated in 2021	Electric motors, wiring, equipment, and fixtures	8.2
CSA B149.5 [237]	No climate change updates	Propane engine fuel system	8.3
CSA B51 [139]	No climate change updates	Indirect vaporizer	9.2
ULC/ORD-C1349 [238]	No climate change updates	Direct-fired vaporizer	9.3

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
UL 1349 [239]	No climate change updates	Direct-fired vaporizer	9.3
CSA IEC 31010 [240]	Unknown	Risk assessment guidance	L.1
ISO 14121-2 [241]	Unknown	Risk assessment guidance	L.1
IEC 60812 [242]	Unknown	Risk assessment guidance	L.1
IEC 61882 [243]	Unknown	Risk assessment guidance	L.1
CSA Q850 [244]	Unknown	Risk management principles	L.1
CSA ISO 31000 [245]	Unknown	Risk management principles	L.1
ISO 14971 [246]	Unknown	Risk management principles	L.1
ISO 17776 [247]	Unknown	Risk management principles	L.1

C.3 Climate Change Update Status of External Documents Referenced in CSA B149.3

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
CSA 3.11 [211]	No climate change updates	Manual shut-off valve	6.2
CSA 3.16 [212]	No climate change updates	Manual shut-off valve	6.2
ANSI Z21.15/CSA 9.1 [213]	No climate change updates	Manual shut-off valve	6.2
ANSI Z21.21/CSA 6.5 [248]	No climate change updates	Pilot train shut-off valve	7.1
CSA ANSI LNG 3.9 [249]	No climate change updates	Pilot train shut-off valve	7.1
ANSI Z21.78/CSA 6.20 [250]	Unknown	Combination circuit control	7.1
ANSI Z21.20/CSA C22.2 NO. 60730-2-5 [251]	Unknown	Thermocouple-type combustion safety control	7.1
ANSI Z21.78/CSA 6.20 [250]	Unknown	Safety shut-off valve	8.1
ANSI Z21.21/CSA 6.5 [248]	No climate change updates	Safety shut-off valve	8.1
ANSI Z21.20/CSA C22.2 NO. 60730-2-5 [251]	Unknown	Safety shut-off valve	8.1
CSA 8.1 [227]	No climate change updates	Hose and hose fitting	10.10
CSA 8.3 [228]	No climate change updates	Hose and hose fitting	10.10
CGA CR96 [252]	No climate change updates	Hose and hose fitting	10.10

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
ANSI Z21.20/CSA C22.2 NO. 60730-2-5 [251]	Unknown	Electric ignition system	11.2
CAN/CSA-C22.2 NO. 199-M89 [253]	Unknown	Electric ignition system	11.2
CSA C22.2 NO. 13 [254]	Unknown	Electric ignition system	11.2
CSA C22.1 [190]	Updated in 2021	Electrical installation	13.1
CSA 8.1 [227]	No climate change updates	Compressor	17.2
CSA 8.3 [228]	No climate change updates	Compressor	17.2
ULC/ORD C536 [229]	Unknown	Compressor	17.2
CSA B149.6 [255]	No climate change updates	Flare pilot	18.1
AER Directive 60 [256]	No climate change updates	Flare pilot	18.1
Saskatchewan Directive S-20 [257]	No climate change updates	Flare pilot	18.1
CSA 3.11 [211]	Unknown	Manual shut-off valve of a flare pilot	18.2
CSA 3.16 [212]	Unknown	Manual shut-off valve of a flare pilot	18.2
CSA C22.2 NO. 13 [254]	No climate change updates	Automated valve (for automated flame front generator installed at the flare tip and used to ignite a flare pilot)	18.2
CSA C22.2 NO. 13 [254]	Unknown	Risk management principles	L.1
CSA B149.1 [1]	No climate change updates	Vent lines (e.g., from vent valves, relief valves, regulator vents, pressure limit sensors, or other controls)	20.5
NFPA 86 [258]	No climate change updates	Appliances intended to operate with liquid fuel	G.1
NFPA 85 [259]	No climate change updates	Appliances intended to operate with liquid fuel	G.1
CSA B139 [260]	No climate change updates	The installation of an appliance, the method of installing the components of the valve train, and the piping and tubing materials	G.2
CSA B365 [193]	No climate change updates	Solid fuel burning appliances	H.1

Referenced document	Climate change update status	Consideration/element affected	Applicable CSA B149.1 clause
NFPA 85 [259]	No climate change updates	Solid fuel burning appliances and their appliances	H.1
CAN/CSA-ISO 9001 [261]	Unknown	Development of a Quality Management System	I.3
IEC 61511-1 [262]	Unknown	Development of a Quality Management System	I.3
ANSI-Z83.11/CSA-1.8 [263]	No climate change updates	Open style trailers and carts	J.1
ANSI Z21.24/CSA 6.10 [264]	No climate change updates	Appliance connectors	J.4
ANSI Z21.21/CSA 6.5 [248]	No climate change updates	Automatic safety shutoff valves and automatic vent valves	K.1

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

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