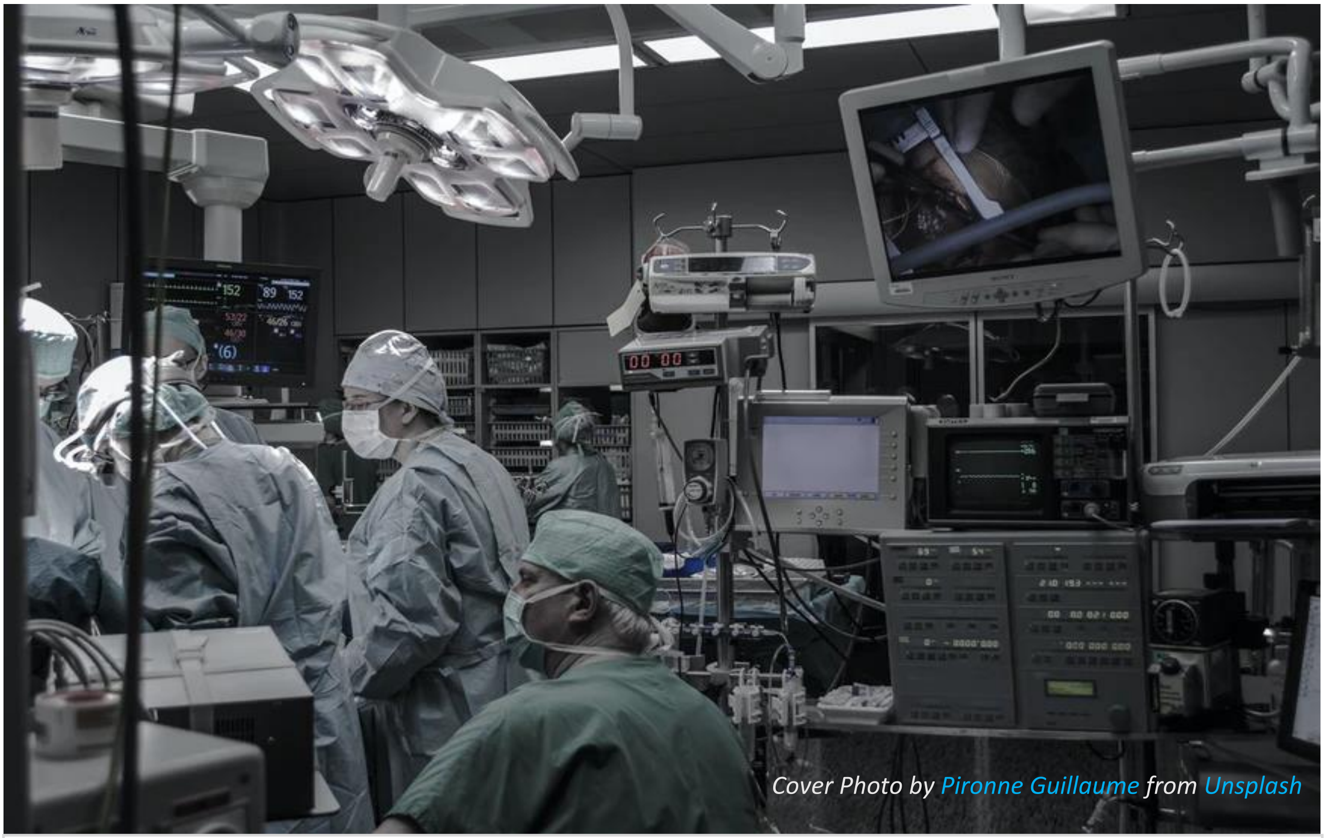

Advancing Sustainable Healthcare Innovations through a Policy and Engagement Strategy

(Mitigating Anesthetic Carbon Footprint)

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

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Executive Summary

The healthcare sector is responsible for approximately 5% of Canada's total greenhouse gas emissions. The release of anesthetic gases represents a major challenge to environmental sustainability in healthcare. Global estimates reveal that as of 2014, 3.1 million tons of carbon dioxide was generated from the accumulation of these anesthetic gases in the atmosphere. There is considerable variability amongst inhaled anesthetics in terms of their global warming potentials (GWP_{100}) with desflurane exerting a disproportionately larger climate impact compared to the alternative, sevoflurane. One of the environmentally sustainable opportunities for health systems to improve starts with anesthetic gases.

The purpose of this project is to better understand anesthetic gas use and emissions across Canada and understand efforts and challenges to mitigate emissions from inhaled anesthetics. An environmental scan and literature review was conducted to understand efforts and strategies to reduce anesthetic emissions and their impacts and challenges. Pharmacy purchasing data for desflurane and sevoflurane from 2016 to 2021 were procured from six provinces. Interviews were conducted with 11 anesthesiologists/environmental experts in academic and health institutions across Canada to understand prior and existing local and global efforts to mitigate emissions from volatile anesthetics especially desflurane.

There have been substantial local and individual efforts to mitigate anesthetic emissions by limiting the use of desflurane. The primary efforts involve education on best practices and advocating for the choice of sevoflurane over desflurane. A few anesthesia departments in Canada have banned the use of desflurane in their facilities. Approximately half of the anesthesiologists interviewed opined that enforcement in the form of carbon taxes and the banning of desflurane is necessary while the remaining half were not in support of this mitigation strategy. Pharmacy purchasing data revealed that between 2016 and 2021, desflurane purchase across the provinces has decreased considerably resulting in a corresponding increase in sevoflurane purchase and overall decreasing trend in anesthetic carbon footprint.

While anesthetic gases make surgery safe and comfortable, they also generate greenhouse gas emissions which contribute to climate change. For climate smart anesthesia, environmental initiatives involving practice change must be led by clinicians and strongly supported by hospital administrators and the local government. In addition to leading practice change, clinicians and administrators have a role in advising on and advocating for organizational and facility change and to enable it through shifts in organizational policy, purchasing practice, infrastructural development, and/or facilities management.

Introduction

Overview of Partnering Organization (CASCADES)

CASCADES (Creating a Sustainable Canadian Health System in a Climate Crisis) is a multi-year capacity building initiative to address healthcare's contribution to the climate crisis. CASCADES thus supports Canada's health care communities to transition towards a sustainable, climate-resilient net-zero health system in support of the Pan-Canadian Framework on Clean Growth and Climate Change(1). This project is currently funded for a five-year term (2021-2026) by Environment and Climate Change Canada's *Climate Action and Awareness Fund for Community-Based Climate Action Projects.* CASCADES is a partnership among University of Toronto Dalla Lana School of Public Health (Center for Sustainable Health Systems) which is the lead organization, Dalhousie University's Healthy Population Institute, University of British Columbia's Planetary Healthcare Lab in the Faculty of Medicine, and the Canadian Coalition for Green Health Care.

The operation of CASCADES is rooted in the 'model of change' that substantial capacity for sustainable health care in Canada exists wherein individuals and groups already have sustainability-related knowledge, skills, and networks and have piloted and implemented diverse sustainable healthcare practices and policies. CASCADES therefore aims to leverage, support, and expand this capacity with these two goals in mind:

- To develop professional development training programs, resources, and events that celebrate and expand existing knowledge, skills, and networks, and
- To provide support to efforts to test and spread sustainable innovations in service delivery and system design.

By leveraging and building upon existing efforts and expertise, CASCADES will contribute to the cumulative and coordinated growth of sustainable health system in Canada as shown in Figure 1 below.

In its efforts to advance climate action, CASCADES collaborates with a team of health professionals, administrators and/or leaders in the Canadian health system to develop and test sustainable healthcare innovations that reduce the climate impact of healthcare or increase climate resilience in their setting. Some of the innovations for 2021/2022 are as follows:

- **Sustainable inhaler prescribing** to minimize inhaler emissions by encouraging primary care providers and patients to consider replacing metered dose inhalers with dry powder inhalers where appropriate.
- **Virtual care carbon savings calculator** which provides a standardized and accessible tool to allow healthcare providers to assess the environmental savings associated with virtual care (i.e., reduced emissions from reduced travel).

- **Sustainable anesthesia in breast surgery** to encourage and support the use of regional anesthesia as an environmentally preferable alternative to general anesthesia in breast surgery.
- **A framework for organizational performance related to sustainability** to support health institutions to coordinate and accelerate their organizational readiness for sustainability, in support of the transition to climate-resilient, low carbon sustainable health systems.

Figure 1. CASCADES' Contribution to Cumulative and Coordinated Growth of Sustainable Health System Capacity in Canada (Source: CASCADES Guidebook Version 3)

Research Objectives

One of healthcare's contributions to escalating greenhouse gas (GHG) emissions results from the use of inhaled anesthetic agents in operating rooms(2). Global estimates reveal that as of 2014, 3.1 million tons of carbon dioxide was generated from accumulated anesthetic gases in the atmosphere(2). There is considerable variability amongst inhaled anesthetics in terms of their global warming potentials (GWP_{100}) with desflurane exerting a disproportionate climate impact compared to the alternative sevoflurane(3). Anesthetic strategies that avoid inhaled agents have been shown to have significantly lower climate impacts(4). Towards achieving environmentally sustainable health systems, opportunities and innovations which drive practice, organizational, and facility changes to mitigate emissions from anesthetic gases are warranted. As part of efforts to transition to environmentally sustainable anesthesia, CASCADES is working with a team of experts to develop an innovation "test case" to mitigate the environmental impact of anesthetic gases through the development of a prototype playbook that serves as a step-by-step guide for innovation implementation and assessment. The playbook will be used for widespread implementation and to inform policy for what is now considered best practice in sustainable health care.

The goal of this project is to gain a better understanding of anesthetic gas use and emissions across Canada's provinces and develop an evidence-based framework to prioritize action and support widespread implementation of innovations to mitigate these emissions. The objectives of this project are:

a. To understand prior and existing efforts or strategies to mitigate greenhouse gas emissions from inhaled anesthetics.
b. To quantify inhaled anesthetic use across hospitals and/or health authorities in Canada's to understand opportunities to mitigate the use of these agents on a national level.
c. To examine attitudes and practices of Canadian anesthesiologists regarding anesthetic gases and their climate impacts.

Background

Climate change and Climate Crisis

Climate change which is defined as the long-term shift in temperature and weather patterns is the biggest global threat facing humanity and health professionals worldwide. It affects the environmental and social determinants of health including quality air, safe drinking water, sufficient food, and safe shelter. Climate change negatively impacts health in diverse ways resulting in heatwaves, storms and flood from extreme weather events, disruption of food systems, increase in zoonotic and food/water/vector-borne diseases, and mental health issues(5)(6)(7)(Figure 2 below). According to the World Health Organization, climate change is projected to cause approximately 250,000 additional deaths per year from malnutrition, malaria, diarrhea, and heat stress between 2030 and 2050 (WHO, 2021). It is estimated that the direct damage costs to health (excluding costs in health-determining sectors as agriculture and water sanitation) is between USD 2-4 billion per year by 2030 (WHO, 2021).

Today's climate change is driven by human activities and carbon dioxide is the main cause of human-induced climate change. Carbon dioxide and other heat-trapping greenhouse gas (GHG) emissions from industrial processes of the energy, transportation, agriculture, and health sectors, among others are responsible for global warming and climate change. Climate change threatens to annul progress and advancement in social development, global health, and economic growth that nations have achieved in the past century. It also continues to widen the health gap between and within populations and endangers the realization of universal health coverage by aggravating existing burden of disease and barriers to accessing health services. Approximately 12% of the world's population (930 million people) spend at least 10% of their household budget to pay for health care (WHO, 2021). Among impoverished communities with no health insurance, existing health shocks and stresses drives about 100 million people into poverty every year and these numbers will escalate further with the impacts of climate change.

Climate crisis which is the term used to describe the impacts of global warming and climate change has been declared by over 1900 local governments in 34 countries including Canada as of June 2021. A climate emergency declaration is an action taken by governments and scientists to acknowledge humanity is in a climate emergency. Global conferences such as the UN Climate Change Conferences of Parties (COP) have brought together world leaders to deliberate on strategies to halt practices which increase GHG emissions(8). Climate change debates advocate that, changes to human actions across different sectors are required to transition towards net-zero sustainable low-carbon lifestyles by 2050(9). This goal requires support and engagement from all parts of the society.

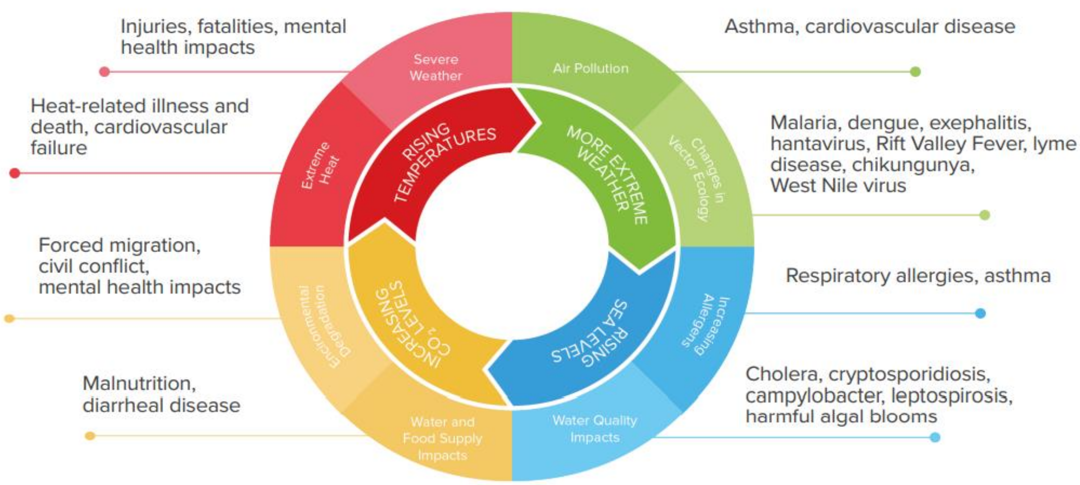

Figure 2. Impact of Climate Change on Human Health (Source: US Centers for Disease Control and Prevention)

Climate Action Efforts in Canada from a Policy Lens

Adopted in December 2015 at the annual gathering of parties to the United Nations Framework Convention on Climate Change, the Paris Agreement sets forth a new international legal regime aimed at strengthening the global response to climate change(10). Under this agreement, countries are required to submit national greenhouse gas emission reduction targets, called Nationally Determined Contributions (NDCs), every five years(10). Each successive NDC is required to be more ambitious than the previous one. Canada’s emissions were projected to increase steadily by 12 percent above 2005 levels by 2030. In April 2021, Canada announced its new NDC of achieving a 40 to 45 percent reduction below 2005 levels by 2030. With a goal to raising its climate and economic ambition and actions, since 2015, Canada has been on a path to significantly reduce emissions.

Canada's first-ever national climate plan, the *Pan-Canadian Framework on Clean Growth and Climate Change* was adopted in 2016(11). This plan was developed with the provinces and territories and in consultation with Indigenous people to meet emission reduction targets and boost economic growth. The plan includes a pan-Canadian approach to pricing carbon pollution, and initiatives to realize emission reduction targets across all sectors of the economy. It also aims at driving innovation through investment in technology to ensure Canadian businesses remain globally competitive in a low-carbon economy. The Government of Canada introduced a strengthened climate plan, *A Healthy Environment and a Healthy Economy* which is geared towards providing specific initiatives that would reduce emissions by 31 percent below 2005 levels by 2030.

The Canadian Net-zero Emissions Accountability Act, which became a law on June 8, 2021, enshrines in legislation, Canada's commitment to achieve net-zero greenhouse gas emissions by 2050(12). The Act establishes a legally binding process to set five-year national emissions-reduction targets and develop credible science-based emissions-reduction plans to achieve each target. It also establishes the 2030 GHG emissions target as Canada's Nationally Determined Contribution (NDC) under the Paris Agreement emissions reductions of 40-45 percent below 2005 levels by 2030. The 2030 Emissions-Reduction Plan provides a roadmap for how Canada can achieve this emission target. Finally, the Act establishes a requirement to set national emissions reduction targets for 2035, 2040, and 2045 ten years in advance, with each target realization plan backed by credible and scientific evidence.

Climate Change and Health Adaptation Capacity Building Program (HealthADAPT)(13) is a multi-year capacity-building program managed by Health Canada to support the human health and well-being objectives of the Pan Canadian Framework on Clean Growth and Climate Change. The program which started in 2019 provided $3 million over 3 years to support 10 projects at local, regional, provincial, and territorial levels of the Canadian health sector to prepare for and respond to the impacts of climate change. The objectives of the program re to increase understanding of climate change on health systems and the health of Canadians; identify communities or at-risk populations; support the design, testing, and implementation of local and regional climate change health adaptation plans with partners; and monitor and evaluate the effectiveness of these plans.

To complement these mitigation strategies, adaptation efforts are also being considered to reduce the health impact of climate crisis especially among highly sensitive and vulnerable populations. The Government of Canada is developing a National Adaption Strategy (NAS) by working with provincial, territorial, and municipal governments, Indigenous Peoples, and other key partners. The development of the NAS proceeds in two phases. Working with experts, and collaborating with provinces and territories, national Indigenous organizations, and representatives, the first phase which was completed in March 2022 saw the development of the strategic framework which encompasses long-term transformational goals, and medium-term objectives. Phase II which seeks to further expand on public, partner, and expert engagement on specific measurable and achievable action is projected to be completed by the end of 2022.

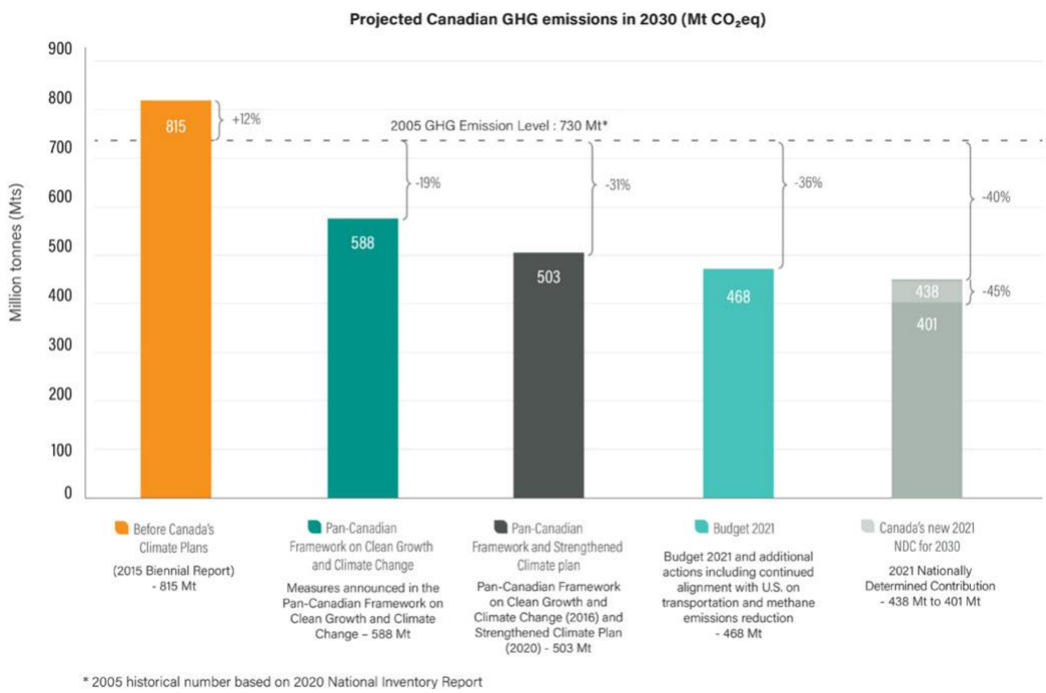

Figure 3. Projected Canadian GHG Emissions in 2030 with Climate Action Plans (Source: Canada's Climate Actions for a Healthy Environment and a Healthy Economy)

Healthcare's Contribution to Climate Crisis

According to a landmark international report, the healthcare sector contributes approximately 4.4% of global net emissions (2 gigatons of carbon dioxide equivalent), making it a major contributor to the climate crisis(15). A non-governmental organization, Health Care Without Harm and a consultancy firm Arup reported that if healthcare were to be a country, it would be the fifth largest GHG emitter on the planet(16). A strong positive correlation exists between healthcare spending and emissions. Generally, the higher the spending measured as a percentage of the country's Gross Domestic Product (GDP), the higher the per capita health care emissions of that country. Other factors that determine emission levels include the energy intensity of a country's economy and the emissions intensity of its energy system(16). Healthcare is responsible for about 5% of Canada's total GHG emissions. In the United Kingdom, Australia, and the United States, health sector pollution accounts for 3-4%, 7%, and 10% of national emission respectively(17)(18). Canada's healthcare system is the third highest emitter of GHG per capita compared to other countries(19). The healthcare sectors of the United States, Australia, Canada, and England produce a cumulative estimate of 748 million metric tons of GHG each year – and this magnitude is greater than the carbon emissions of all but six nations worldwide(17).

Greenhouse gas emissions from health care result from energy consumption, transport, and product manufacture. Emissions which are directly from health care facilities and health care owned vehicles are categorized as Scope 1 and they constitute 17% of the sector's worldwide footprint(16). Indirect emissions from purchased energy sources such as electricity, steam, cooling, and heating are categorized as Scope 2, and they comprise 12% of healthcare carbon footprint(16). Scope 3 – which constitutes the bulk of the emissions (71%) are primarily from health care supply chain through production, transport, and disposal of goods and services such as pharmaceuticals and other chemicals, food and agricultural products, medical devices, hospital equipment, and instruments(16). About 75% of all health care emissions, including those from its supply chain, are generated domestically while the remaining 25% comes from outside of the country where the healthcare product is ultimately consumed. Staff, visitor, and patient commutes account for about 14% of emissions. Anesthetic gases/inhalers as well as commissioned health services each contribute 5% and 4% respectively to healthcare's carbon footprint(15).

Fossil fuel consumption is a key driver of health care's emissions. Energy generated from the combustion of fossil fuel contributes over half of health cares' footprint when measured across all three scopes. Different production sectors within health care delivery contribute to emissions and a breakdown of the relative contributions are presented in Figure 4 below.

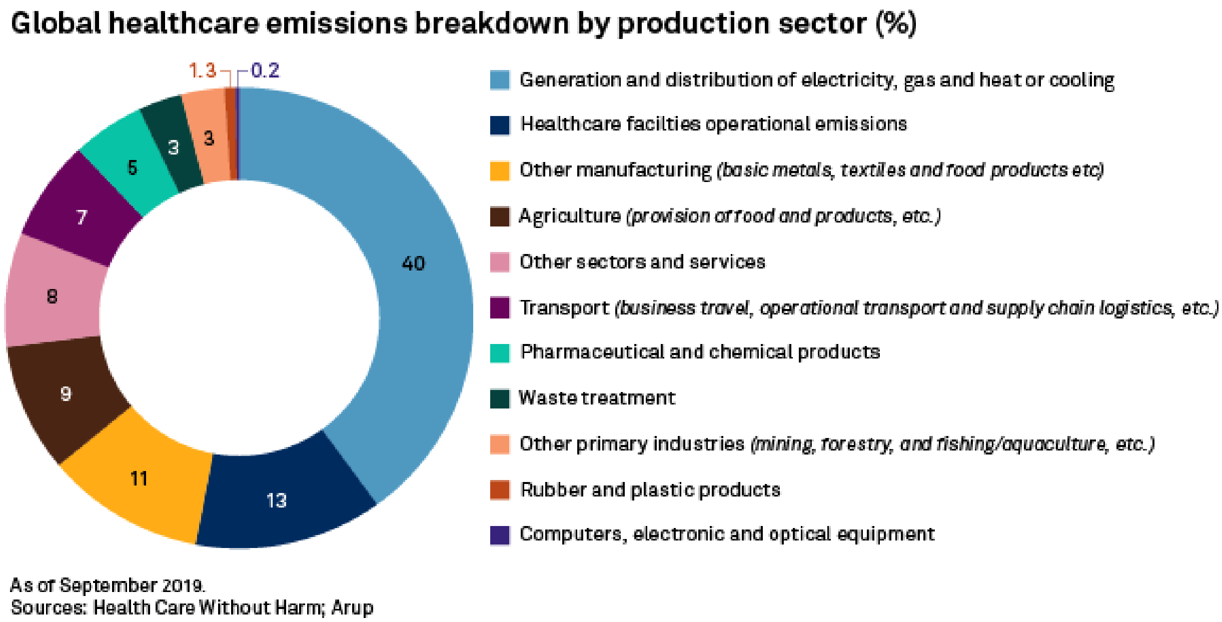

Figure 4. Global emissions from healthcare by production sector (Source: Health Care Without Harm, Arup)(16)

Climate Smart Health Care

To reduce health care's contribution to climate crisis," Health Care Without Harm" put forth six actions for a climate-smart health care in their 'Climate-smart health series Green Paper one'. These actions are as follows:

Reduce health care's climate footprint now: Stakeholders and actors at all levels in the health sector have a role to play in building on historic and existing projects of hospitals, institutions, climate-action groups/networks, etc. already addressing climate footprint. Building on such precedents to push forward similar and related agenda can go a long way towards achieving net zero emissions. The Greenhouse Gas Protocol(20) can be used as a guide to outline key steps which will include: taking immediate steps to reduce health care facility emissions (Scope1 emissions); investing in and advocating for the decarbonization of local and national energy systems and the implementation of clean, renewable energy (towards addressing Scope 2 emissions); and setting and implementing criteria for low-carbon or zero emissions procurement so as to begin to decarbonize the supply chain (towards mitigating Scope 3 emissions).

Support a societal transition to clean, renewable energy: The health sector in every country should advocate for a phase-out of high-carbon fossil fuels and a transition to clean, renewable energy to help move health care energy consumption to net zero emissions while also protecting public health from both local pollution and global climate impacts.

Chart the course for zero emissions health care by 2050: A comprehensible global road map is necessary to identify key sustainable pathways forward, while establishing specific timelines and strategic frameworks for action. The road map should be based on principles of global equity for climate and health, a unified, climate-smart approach to mitigation and resilience, and an approach that fosters action at all levels.

Make development assistance for health climate-smart: Bilateral aid agencies, multilateral financial institutions, other health funding agencies, and benevolent organizations should integrate climate-smart principles and strategies into their health aid, lending, and policy guidance for developing countries. The funders of climate mitigation and adaptation should integrate health into their programs. This should be done in alignment with the outcomes of the UN Secretary General's 2019 Climate Action Summit(21).

Establish and implement government action plans for climate-smart health care: National and sub-national governments should build on existing initiatives to establish action plans to decarbonize their health systems, foster resilience, and improve health outcomes. Implementation should contribute to government climate policy and nationally determined contributions to the Paris Agreement. The countries most responsible for the problem should lead the way.

Deepen research on health care and climate change: Given climate change is complex and multifaceted, further research is necessary to better understand trends and patterns of the association between health care and climate change, and the factors that influence health care emissions. Research should also involve an analysis of the future trajectory and projections of health care emissions, in-depth analysis of the supply chain and its climate impact, national and sub-national level health care climate foot printing, economic and health analysis of the costs and benefits of transitioning to climate-smart healthcare, etc.

Anesthetic Gas Use in the Operating Room and Environmental Impact

It is estimated that 234.2 million major surgical procedures are undertaken every year worldwide(22). More than one million surgical procedures are carried out in Canada and the global volume continues to increase due to increase in the ageing population(23). Anesthetics are commonly used during surgery with the goal of providing the patient with a comfortable and safe surgery experience. The administration of anesthetics is thus necessary in the inhibition of individual pain pathways (local anesthesia) or rendering a patient unconscious so that surgical procedures can be carried out (general anesthesia). Local anesthetics act by causing a reversible block to conduction along nerve fibers, and they can act on any part of the nervous system and on every type of nerve fiber, causing both sensory and motor paralysis(24). General anesthetics are chemical agents that produce a drug-induced absence of perception and a resulting loss of consciousness by acting on multiple sites of action and affecting the central nervous system at multipole levels(25).

Depths of anesthesia that are required to maintain surgical anesthesia can be achieved by a wide variety of drugs either alone or in combination. General anesthesia can be administered by a variety of routes including inhalation and intravenous routes which are the most preferred. Inhalational agents include xenon and nitrous oxide (N_20), or the more sophisticated volatile halogenated agents (vapors). The three most used inhaled anesthetics are isoflurane, sevoflurane, and desflurane which undergo very little metabolism. Less than 5% of these volatile anesthetics is metabolized by the patient and the remaining exhaled gases serve as waste to pollute the environment(26). Inhaled anesthetics are exhaled and scavenged by anesthesia machines with little or no additional degradation(27) and are typically vented into the outside environment as waste anesthetic gases (WAGs). The WAGs from volatile anesthetics contribute to greenhouse gas warming and depletion of the ozone layer(28).

Types of Inhalational Anesthetics used in Surgery

Nitrous Oxide (N_2O): This is the most popular and one of the safest anesthetics, which was discovered in 1844. Nitrous oxide is widely known for its adjunct role in surgical procedures for decades and it serves as a significant analgesic to elevate the pain threshold during surgery(29). In addition, when used in a gas mixture administered to a patient, N_2O reduces the minimum alveolar concentration when used in tandem with other anesthetics (typically halogenated agents)(30). This reduces the amount of volatile anesthetic required when in synergy with N_2O compared to when the volatile agent is used alone. Despite its numerous benefits in surgery, this widely used gas has undesirable effects which may affect not only health care workers, but the environment and its inhabitants. Because N_2O has a negligible metabolism rate (approximately 0.004%), it retains its pharmacological effect when exhaled into the environment. These exhaled gases are widely recognized as greenhouse gases, accounting for about 6% of global warming in the atmosphere. Worse of all, N_2O emissions are currently the single most important ozone-depleting gas(31).

Halogenated Agents: The inhalational anesthetics are halogenated chlorofluorocarbons (halothane, enflurane, isoflurane) or fluorinated hydrocarbons (sevoflurane and desflurane) which carry potentially damaging effect to the earth’s ozone layer and contribute to global warming(32). These anesthetic agents are liquid agents added to the anesthetic breathing circuit in a carrier gas mixture (which may contain N_2O) that the patient inhales. Because they undergo minimal metabolism, the exhaled excess gases are channeled out of the patient breathing circuit and collected by scavenging systems in the anesthesia machines(26). These scavenging systems reduce operating room personnel exposure to anesthetic gases. Waste anesthetic gases (WAGs) from scavenging are vented as medical waste directly into the surrounding environment(33).

Global Warming Potential: Greenhouse gases have varying potentials to contribute to climate change. The potency of a GHG is dependent on several factors including atmospheric lifetime, total radiation absorbed, and concentration of compounds in the atmosphere that absorb the same wavelength of radiation(34). It is estimated that sevoflurane remains in the atmosphere for 1.4 years, desflurane for 21.4 years and N_2O stays the longest for up to 150 years(28). Once they linger in the atmosphere, they contribute to the greenhouse effect and climate change. The impact of anesthetic gases and their concomitant emissions on the environment is measured by assessing their Global Warming Potential over 20 years (GWP_{20}). The GWP_{20} is a relative scale which measures a gas' capacity to trap heat in the atmosphere compared to an equivalent mass of carbon dioxide (CO_2) which has a standardized GWP of 1.00(34). This implies that gases with higher GWP_{20} trap more heat in the atmosphere over a 20-year period horizon and contribute more to the greenhouse effect and climate change compared to gases with lower $GWP_{20.}$

Amongst the inhaled anesthetics, desflurane has the highest GWP_{20} estimated at 5550 while isoflurane and sevoflurane have a GWP_{20} of 1800 and 795 respectively. When anesthetic potency and flow rates are accounted for, desflurane has a twenty-six-fold and thirteen-fold larger environmental impact than sevoflurane and isoflurane if used in large quantities(4). Given this marked differential $GWP_{20,}$ desflurane is considered the most problematic of the commonly used halogenated anesthetic gases and globally contributes 80% of the equivalent 3.1 million tons of carbon dioxide released by anesthetic gases per 2014 estimates(3). To put this in familiar context, it is demonstrated that the use of anesthetic machine for 1 hour of desflurane anesthesia is equivalent to driving 370kn in a car, compared to only 50 km for 1 hour of sevoflurane. The GHG emissions and carbon footprint of each volatile anesthetic can be quantified from the $GWP_{20,}$ and volume of gas used and expressed as the carbon dioxide equivalent (CDE)(3).

Table 1. 1 Environmental Metrics for Inhalational Agents

Agent	Use per 1 MAC-hour [g]	GWP20	Lifetime	$C0_2e$	Km per OR-day
Sevoflurane	5	795	2.2	3975	145
Isoflurane	2.75	1800	3.5	4950	181
Desflurane	12.6	5550	10.8	69930	2554
Nitrous oxide	36.3*	264	121	9583	350

$C0_2e$ = carbon dioxide equivalent; Km = kilometers; Lifetime = atmospheric lifetime in years; MAC = minimal alveolar concentration per hour; OR-day = seven-hour workday in the operating room using 0.5L/min of fresh gas flow; **Calculated for 66 volume percent instead of 1 MAC*

Methodology

Procurement of Pharmacy Purchasing Data

Pharmacy purchasing coordinators and environmental and sustainability offices in each participating province were contacted to gain access to anesthetic gas-purchasing data from 2016 to 2021. The number of bottles of inhaled anesthetic agents (desflurane and sevoflurane) were requested. The annual carbon dioxide equivalent over 20 years (CDE_{20}) for sites and/or regions of each province was calculated using purchasing data and GWP_{20} (Appendix A).

Environmental Scan & Literature Review

A review of both scholarly literature and non-scholarly documents was conducted to identify programs, initiatives, and interventions to mitigate emissions from anesthetic gases. The review was conducted between May 8 and July 15, 2022.

Subject Matter Expert Interview

To understand current efforts to eliminate desflurane in Canada, 30-minute interviews were conducted with 12 anesthesiologists in anesthesia departments and/or academic institutions across Canada's regions and provinces. The interview guide is shown in Appendix B and the information on anesthesiologists interviewed are presented in Appendix C. Thematic analysis was used to identify various themes in the interview transcripts. The results are presented as aggregated findings from all the anesthesiologists who were interviewed.

Findings

Emission Reduction Principles and Strategies

Redefining the 3Rs of sustainability

The working principles of sustainability are summed up by the mantra of 3Rs which is to Reduce, Reuse, and Recycle. Timur and colleagues proposed a modified 3R approach adapted to inhalational anesthetics – which includes Reduce, Refine, and Replace(35).

It is posited that reduction in anesthetic usage is the first step to mitigating emissions from anesthetics gases. Advancements in technology have made it possible for developed countries including Canada to have anesthesia workstations which allow anesthesiologists to deliver closed-circuit ventilation at metabolic flow while semi-closed-circuit systems can effectively be run at minimal fresh gas flow (FGF) rates. With the technique of lowering FGF, less amounts of anesthetic gases are used which in turn reduces the environmental burden and also results in significant cost savings(36). Across the globe, sevoflurane is used daily in anesthetic practice in all flow ranges with no report of human morbidity, and most countries abandoned strict flow recommendations in the 1990s. Second, refining the practice of releasing inhalational anesthetics into the atmosphere by recapturing them can be a next step. The life-cycle assessment of inhaled anesthetics shows that manufacturing and transportation account for only 5% of their GHG impact(37). Anesthetic agent reclamation technology holds promise for mitigating anesthetic emissions even though the technology is still in its exploratory stages. Finally, the choice of inhalational agent plays is associated with the magnitude of environmental impact. Thus, replacing inhaled anesthetics with other alternatives should be actively considered when feasible. In addition, regional anesthesia is a preferable option to general anesthesia with respect to reducing carbon emissions and should always be considered where appropriate.

Different strategies have been proposed to mitigate the environmental impact of anesthetic gases. Some of the general approaches or strategies are outlined below:

Use low impact gases like sevoflurane: Arguably the most important consideration for mitigating the environmental impact of anesthetic gases is to choose an appropriate gas with a lower GWP_{20}. This means that if desflurane is eliminated from anesthetic practice and formulary and hospitals and institutions resort to volatile anesthetics like sevoflurane, there could be substantial reduction in anesthetic carbon footprint. Given its relatively shorter atmospheric lifespan, and lower $GWP_{20,}$ a choice of sevoflurane over desflurane and other halogenated anesthetics is most desirable. Studies have shown that the differential emissions among hospitals is mainly driven by the amount of desflurane used(38). Similarly, opting for a suitable carrier gas such as oxygen/air mixture over nitrous oxide is an environmentally sustainable choice.

Adopt closed-circuit anesthesia: Closed-circuit anesthesia is a technique that maintains a constant anesthetic state by adding gases and vapors to the breathing circuit at the same rate that the patient's body redistributes or gets rid of them(39). Traditionally, the desired anesthetic state is initially attained using a high fresh gas flow (FGF) composed of gases such as oxygen and nitrous oxide or air, and vapors (halogenated anesthetics). As soon as a steady state is attained, inspired and end-expired gas concentrations are noted, and FGF is decreased. However, in closed-circuit anesthesia, carbon dioxide is removed from exhaled gas, and the remaining exhaled gases and vapors join the FGF to produce inhaled gas. One advantage of this technique is that all the exhaled gases are kept warm and humidified by the patient and are thus suitable for rebreathing(40). A major advantage of closed-circuit is that there is huge cost and environmental savings.

Adopt low flow practices to reduce waste: Although the closed-circuit anesthetic technique is the most ideal method to reduce GHG emissions, its practicality or feasibility in today's operating room is questionable. A more realistic and viable approach is to use low-flow anesthesia(41). While there are no standard or established guidelines for low-flow practices, many experts consider low-flow anesthesia to consist of flow less than 1L/min with the minimum of 0.5L/min(41). Using low-flow anesthesia throughout anesthetic delivery and turning fresh gas flow (rather than the vaporizer) off during intubation can significantly reduce total anesthetic gas emissions(42). Modern anesthesia delivery systems have been designed to effectively accommodate lower fresh gas flow rates to both maximize gas recirculation and reduce waste. An auxiliary benefit of lower flow rate is that it positively impacts the surgical environment by reducing the overall temperature and humidity(38). This consequently leads to diminished usage of central air and heating and a reduction in energy expenditure and cost.

Use appropriate scavenging systems and recycling: Scavenging systems collect and remove waste anesthetic gases (WAGs) that are vented from the breathing circuit and direct them out of the operating room. The scavenging system includes a canister to capture these gases. Canisters of halogenated WAGs have utility in capturing gas which could become a source of a cheaper anesthetic gas(33). Such systems to capture and repurpose WAGs are being developed. An example is the blue-zone technology which captures, reclaim, and purify halogenated inhalational anesthetics. The technology could capture the vented gases and extend the lifecycle of anesthetic gases by 10 to 20 times. If this technology is scaled up, hospitals could achieve significant savings in their expenditures on anesthetic gases and reduce GHG emissions.

Choosing wisely: In alignment with 'Choosing Wisely Canada' recommendations, surgeries can be carefully selected, and unnecessary surgeries avoided to reduce the environmental impact of anesthetics gases. Reducing unnecessary surgeries not only offer environmental benefits through decreased anesthesia use, but also results in major cost savings for the healthcare system. Choosing Wisely Canada is a national campaign with the aim to encourage open conversations between patients and providers about unnecessary tests, treatments, and procedures(43). Such conversations help clinicians and patients make informed choices to achieve quality and sustainable care, and to ease burden on health system resources. For example, clinical guidelines from 2017 discouraged the use of arthroscopic surgery for patients with osteoarthritis(44). Other considerations to avoid unnecessary procedures include opting for regional and local anesthesia where possible in lieu of general anesthesia to reduce the anesthetic gases(45).

Measurement and reporting of anesthetic gas use: To understand the impact of these gases on the environment and assess effectiveness of mitigation efforts, it is important to have in place, tools, and methods to measure and report on these gases at health facilities. Measurement of anesthetic gas use is also important for benchmarking and ongoing monitoring and evaluation purposes. Online tools have been developed to calculate the carbon footprint of anesthetic gases. One of these tools is the '*Yale Gassing Greener'* which allows users to access a form(46) or the Gassing Greener app, and enter anesthetic gas and other inputs which results in various outputs such as the CDE, driving equivalent of gas use, and approximate cost in U.S. dollars. Another tool is the sustainable development unit anesthetic gas carbon calculator which allows users to enter the number of cylinders of each gas used and the CDE is generated.

Stepwise Approach to Reduce Anesthetic Gas Emissions

To successfully mitigate emissions from anesthetic gases, the following steps have been recommended by Practice GreenHealth in establishing a baseline and working towards absolute reduction in GHG emissions from purchased inhaled anesthetics.

Step 1. Identify an anesthesia champion: Given the clinical implications and impact on patient care, advancing emission reduction initiatives should be preferably led by an anesthesia provider who is passionate about environmental sustainability. This individual can have a more compelling influence in educating their peers, and efforts are much more likely to go far compared to when it is being championed by non-clinicians.

Step 2. Identify additional key stakeholders and create a project team: A collaborative workforce which allows for sharing ideas and role execution is needed for such projects. A committee with representatives from anesthesia, in addition to key stakeholders from other departments such as nursing, surgery, supply chain, pharmacy, administration, etc. would be thus useful in advancing these goals. Residents, students, and researchers may also play a significant role. Medical gas vendors may be able to support data reporting and purchasing records needs.

Step 3. Establish a baseline: An important step to mitigating emissions is to establish baseline GHG emissions from inhaled anesthetic gases in order to identify steps. Twelve months of anesthetic gas use or purchasing data will be required and this can be achieved through effective teamwork and coordination with supply chain, pharmacy, clinical engineering, medical gas vendor, etc., 12 consecutive months of anesthetic purchasing data.

Step 4. Conduct an assessment: After a baseline anesthetic gas footprint has been established, current practices should be assessed to identify opportunities and set goals. The anesthetic gas checklist can be used to aid this process.

Step 5. Set a goal: A critical step is to determine a specific goal for one's organization. The selection of an appropriate anesthetic gas reduction goal should be done collaboratively, and this depends on whether a facility has eliminated desflurane from its formulary (Appendix D). The goal should be SMART (specific, measurable, achievable, realistic, and time-bound).

Step 6. Identify and implement target strategies: After specific goals have been established, strategies such as the ones described in 5.1 above need to be identified and implemented in alignment with organizational strengths, and opportunities for success.

Step 7. Track cost savings: It is also important to monitor the financial impact of these strategies as this can also help with making a business case with senior leadership. This can be done by tracking purchased volume and aggregating annual costs per anesthetic agent. Highlighting differential usage, cost, and MTCO2e per agent can help to identify savings opportunities.

Step 8. Develop a communication plan: Consistent information sharing and dissemination about environmentally sustainable anesthesia initiatives is key to reducing anesthetic emissions. This should be done effectively considering language, content, style, and audience. It is important to offer support to providers leading these initiatives. Teaching opportunities like grand rounds can be used to share programs goals, progress, and challenges.

Step 9. Track progress and celebrate success: It is critical to evaluate reduction strategies by tracking anesthetic gas metrics pre- and post-implementation of these strategies. Tracking progress towards waste anesthetic gas reduction goals helps make the case to senior leadership for the continuity of the program, and for validation of efforts of the clinicians leading this work. It is very helpful to maintain consistency with the reporting period. Given their differences, facilities may report data on a monthly, quarterly, or annual basis. Finally, it is rewarding and inspiring to celebrate the individual and collective efforts through recognition, awards, and appreciations at meetings and events.

Step 10. Make the program sustainable: It is important to make the program sustainable and the only way to do that is to work in harmony with different departments including anesthesia providers, supply chain, pharmacy, and others to develop education while incorporating environmental considerations into anesthetic choices. Continuous monitoring and evaluation efforts and a commitment to a maintenance goal are central to sustaining the program.

Anesthetic Gas Emission Reduction Initiatives

The European Climate Initiative (EUKI) Anesthetic Gases Project**:** Towards fostering low-carbon healthcare in Europe, Health Care Without Harm launched a pilot project, with financial support from EUKI to help European hospitals measure their carbon footprint including GHG emissions from the use of anesthetic gases. This project was motivated by the European Union's 2030 climate and energy package targets, and the need for data on health systems carbon footprint and/or emission reduction targets. Six hospitals from France, Germany, Poland, Portugal, Spain, and Sweden were selected to participate in this study and the findings were reported for five hospitals. The project established a baseline carbon footprint of anesthetic gases (Figure 6) for each hospital, and in partnership with anesthetists, identified some recommendations for clinical practice, anesthetic societies, hospitals, and government agencies. The recommendations are based on the principles of maintaining quality and safety of care whilst reducing emissions where possible.

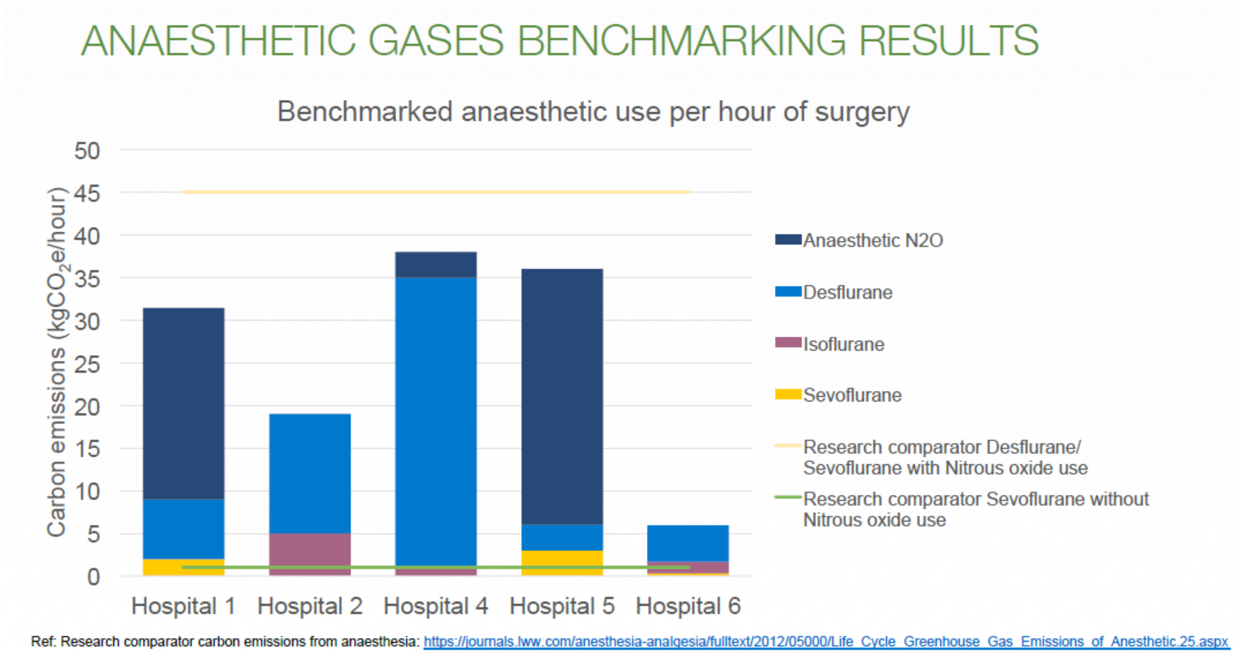

Figure 5. Benchmarked Anesthetic Use per Hour Surgery

The study also estimated potential carbon savings on implementing changes in anesthetic practice. Based on their estimation, between 20% and 40% of potential savings would be achievable. 40% of potential savings would be equivalent to an average of 3% reduction in building energy use for these hospitals. It is further estimated that if half of European hospitals had similar savings, this would amount to 700 kilotons of carbon savings equivalent to 300,000 cars off the road.

Yale's Inhaled Anesthesia Climate Initiative - Project Drawdown: The goal of this initiative is to reduce inhaled anesthetic carbon emissions in facilities by 50% by 2022. Project Drawdown aims to benchmark facility-level inhaled anesthetic carbon footprints, as well as per-case averages, to compare and inspire performance improvement efforts. This project utilizes the free Yale research app (Gassing Greener) for the purposes of anonymous facility data pooling. Through this study, a growing body of knowledge will be generated to help leverage carbon drawdown in the healthcare sector across the globe. Yale Gassing Greener helps anesthesia providers build environmentally conscious practices. Developed by Yale University's Department of Anesthesiology, the app features two calculators that provide reports on carbon emissions based on clinician and facility use of inhaled anesthetics. The clinician calculator allows anesthesia providers to enter amounts and flow rates of inhaled anesthetics in a case and obtain their carbon emission equivalents. A facility calculator allows perioperative personnel to enter amounts of purchased inhaled anesthetics and receive a comprehensive emailed report of their facility's carbon emissions. By informing practitioners about the global warming impact of their anesthetic choices, Yale Gassing Greener hopes to encourage environmental awareness in clinical practice.

Table 1. 2 Anesthetic Gas Emission Reduction Case Examples and Impacts

Jurisdiction	Action and Impact
Department of Anesthesia, University of British Columbia, Canada	This department worked together to create awareness about the environmental impact of anesthetic gases and changed the department's preference to anesthetic gases with the lowest GWP_{20} values. These changes were measured as part of a quality assurance project. As sevoflurane (GWP_{20}) replaced desflurane (GWP_{20}) across the 5-year measurement period, the department recorded an 8.9 million kg difference in total carbon footprint (CDE) and a corresponding 66% reduction in GHG emissions(47)(Figure 7)
Raigmore Hospital, Scotland	Efforts have been championed in this hospital to replace desflurane with sevoflurane. Since January 2019, Raigmore hospital has reduced its usage of desflurane to zero. According to National Health Service (NHS) Highland, the shift to sevoflurane has cut NHS' GHG emissions by an estimated 4.5% and has saved the health board £73,000 a year. It is reported that NHS Highland is the first NHS board in the UK to remove desflurane from stock order(48).
University of Wisconsin-Madison, Department of Anesthesiology, United States	As a call to action, the department of anesthesiology provided staff education and affixed labels to desflurane and sevoflurane vaporizer equipment reminding staff of the environmental impacts of these gases. After tracking purchasing data for over 5 years, they found a 55% reduction in desflurane usage and a 16% increase in sevoflurane usage which led to an estimated monthly savings of $25,000(49).

NHS Trust, England	In 2 years, the staff at the trust have reduced use of carbon intensive desflurane significantly, saving the equivalent to 30,000kg CO2 per month. The monthly reduction when converted to carbon dioxide is equivalent to 166 cars off the road or 105,000 miles driven by an average passenger vehicle(50).
Virginia Mason Medical Center, United States	In 2015, an anesthesiologist and anesthesia technician at this facility worked together on persuading their colleagues to reduce desflurane use in favor of its alternatives. Through casual but persistent conversations over a five-year period, the duo ultimately convinced every member of their department that other gasses could work without harming patient care. Their success culminated in September 2019 when Virginia Mason Medical Center eliminated desflurane use. The medical center has saved more than $30,000 each year since initiating the switch(51).

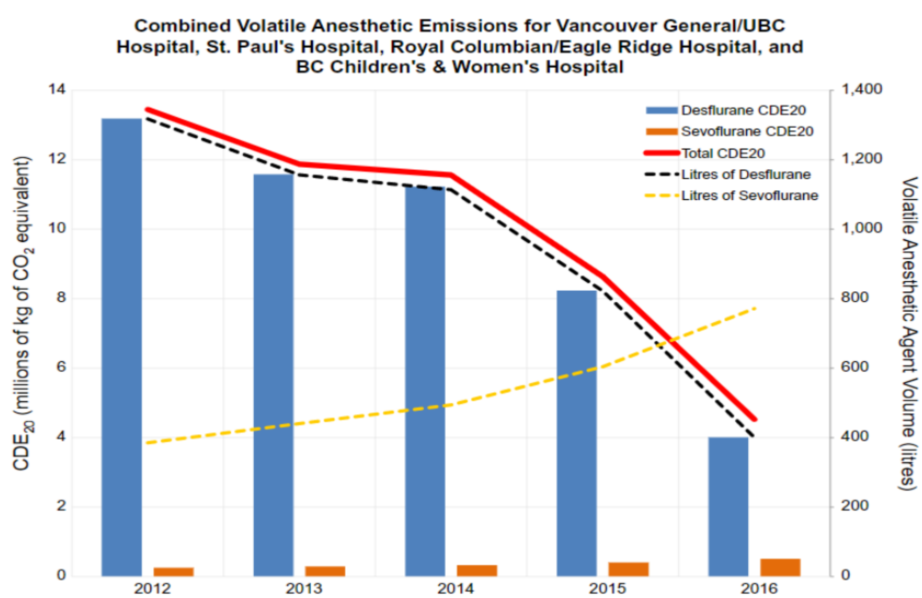

Figure 6. Changes in the use of desflurane and sevoflurane, with resulting environmental impact during 2012-2016

Efforts and Challenges in Limiting the Use of Desflurane in Canada

Overall, efforts to reduce and restrict the use of desflurane and contribute to sustainable anesthesia revolve around three main approaches – education, enforcement, and engineering which are also the 3Es of safety. Each of three approaches have its pros and cons. Primarily, these efforts exist at the local or grassroot level, and has been pioneered by individuals, and small groups of anesthesiologists at their respective hospitals and institutions.

The anesthesiologists interviewed expressed similar opinions about the best strategies to limit the use of desflurane while a few divergent views and priorities were highlighted. Currently, no provincial or national strategy to reduce anesthetic gas emissions have been implemented. Below is a discussion of efforts and strategies to reduce the use of desflurane in light of identified barriers to ongoing desflurane use.

Education: All anesthesiologists identified awareness creation and education as one of the approaches and by far, the most favorable strategy to limit the use of desflurane. One of the drivers to ongoing desflurane use has to do with the belief that desflurane has some clinical benefits to patients (especially those in critical conditions) such as faster wake-up time that other inhaled volatile agents do not offer. Even so, a few practitioners expressed that the difference in wake-up time after using desflurane and sevoflurane is negligible. If patients do not wake up quickly at the end of the surgery and more time must be spent on waking them up, then the overall cost is likely to increase, and clinicians may not be able to do as much surgeries as they ought to do within a specific time frame. Thus, from a purely patient perspective, desflurane is a good inhalational agent. Some experts however argue from the perspective of research studies that equal wake up times is possible for the both desflurane and sevoflurane – for instance, it was indicated by an anesthesiologist that it is the skill and practice that matters, adding that both an expert sevoflurane user and a desflurane user may achieve the same wake-up time.

Educational efforts have been a strategy at the local level across many jurisdictions for many years and has been effective in modifying behavior to shift anesthetic practice. It was opined that environmental safety and associated adverse effects of anesthetics gases on quality of life and wellbeing should be effectively emphasized to clinicians and anesthesiologists. Through education and awareness creation about the risk and benefits of different anesthetic agents, it would serve as an impetus for clinicians to wisely choose agents that have lower global warming potential. Education have been provided through informal discussions, grand rounds and at staff meetings, local and international scientific conferences, sharing of articles on desflurane usage and its environmental effects amongst colleagues, etc. Information and data should be shared in a very compelling and down-to-earth manner to emphasize the need for change. For example, making metaphorical comparisons of desflurane and sevoflurane usage to driving speeds or commutes between two cities could provide a very persuasive context to motivate change. All who were interviewed reported that almost all their colleagues were very receptive of these lectures and grand rounds and supportive of the need and/or importance for desflurane to be used sparingly and/or avoided in anesthetic practice. However, a handful of clinicians expressed their protest and opposition, but they then accepted the fact that this is the direction that the department as a unit was going to take in her bid to be a more climate smart.

While education offers people the independence to choose, and does not stir up resistance and objections, it may take a very long time to have the entire population of anesthesiologists to opt for sevoflurane instead of desflurane. Even so, personal preferences and individual attitudes can also make it difficult to achieve 100% change in anesthetic usage from desflurane to sevoflurane since some anesthesiologists have built their practice around desflurane. Accordingly, some of the experts posit that relying on good will and cooperation that education offers may not be completely successful in evoking change among some practitioners.

Restriction and Enforcement: Restriction and enforcement were reported as another strategy to reduce the use of desflurane especially where educational efforts fail to yield 100% success. Restrictions can be seen as a supplementary strategy to education. Interviewees reported that by removing desflurane canisters or vaporizers off anesthetic machines and moving them to a different location, anesthesiologists were discouraged from using desflurane as most of them would not want to go through the struggle of picking the vaporizer and bringing it to the operating room. In some institutions, a group of people have been lobbying the federal environmental minister to apply the carbon tax on volatile anesthetic agents. If the carbon tax is applied, then desflurane is likely to become cost prohibitive and this would significantly increase the cost of desflurane for hospitals. With regards to enforcement, it was opined that if enforcement is going to have any impact at all, the average anesthesiologist is not going to be a tad bothered or concerned about how much taxes are placed on these agents. Hospital administrators are the ones who are likely going to react to this to cut down cost. According to the European Union, a ban on desflurane has been proposed by the year 2026, and this resonated with a group of anesthesiologists who have eliminated desflurane in their regions and/or who are keen on eliminating it. Conversely, another group of anesthesiologists thought this strategy of banning desflurane is not the best approach since having just a single volatile anesthetic agent, sevoflurane, may hinder the latitude of clinical practice of caring for varying patients with diverse clinical needs. This group suggested that instead of banning desflurane, it is better to have it available and used sparingly in critical situations while recognizing its impact.

In connection with engaging stakeholders to enforce laws that will ban the use of desflurane, a triple bottom line perspective/approach needs to be taken. The first P for “planet” is to make request to the powers that be from an environmental perspective. The second P for “profit” is to ask from a profit perspective explaining how desflurane is comparatively expensive than the other alternative anesthetic agents and how much cost-savings can be realized if the alternatives are chosen over desflurane. The third P for "people" is to approach it from the people perspective, citing evidence and literature that shows there are drawbacks to using desflurane. For this approach, a top-down measures with the involvement of the Canadian Anesthesiologists Society (CAS), health ministers and health authorities, etc. would be more effective.

Engineering: The use of anesthetic gas capture technology has the potential to reduce carbon footprint from volatile anesthetic emissions even though only a few hospitals have this technology in their operating rooms. One group of anesthesiologists support the idea of a technological advancement capable of capturing and recycling anesthetic gases even though some did not fully understand the working operations of this technology. Besides, the cost of this technology raises concerns which goes to underscore the need for a cost-benefit analysis of anesthetic capture technology. Another group of anesthesiologists doubted the integrity of these companies who own this technology, expressing that these companies have not clearly defined how they go about recycling and/or reusing the captured gases.

There were mixed opinions from interviewees on the potential effects this technology could have on anesthesiologists' attitude and practice regarding anesthetic gas use. While some believed a capture technology will have no effect on attitude and practice, others also believed this would make clinicians more liberal in their use of gases if a capture system was in place.

Stakeholder Involvement: Some interviewees registered their displeasure and disappointment regarding the lack of top-down approach (i.e., a lack of a clear agenda from the provincial and federal environmental leadership who have the core mandate to reduce the country's carbon footprint. However, other interviewees feel there are no other stakeholders that make decision on the use of anesthetic agents aside from anesthesiologists themselves. That is, each anesthesia department makes their decisions, and nobody can mandate a department to use desflurane if they are not in support of it. Therefore, anesthesia departments have that prerogative to wield power over other departments such as the pharmacy and administration on whether to use a particular anesthetic agent. This suggests that any barriers to desflurane disuse is foregrounded in the personalities and individuals within anesthesia departments – and efforts should be geared towards establishing a common understanding that safe and efficient clinical care can be provided without desflurane.

Table 1. 3 Interview Themes and Illustrative Quotes: Efforts and Considerations to Limit Desflurane Use

Themes	**Illustrative Quote**
Education	"I think it is professional, ethical, and a moral responsibility to provide climate smart, environmentally sustainable care, and education on this topic is I think the main thing. I can't imagine that people after seeing the facts, looking at the numbers, understanding the actual climate impact of their practice will hesitate to adapt and change."
Enforcement	"There is never any oversight from the local pharmacies or the hospital leadership to curb your spending so the carbon tax may help but I think the only thing that's really going to help is to ban it from our institutions."
Clinician-driven effort	"But I think everybody respects our independence as a profession and realize that anesthesiologists are one that use this medication. And we're probably the most well placed to decide whether it needs to be used when it needs to be used, how it needs to be used, and if it needs to be used. And so, I think the drive and push needs to come from us, though, you know, it come from elsewhere as well."
Practice adaptation	"Desflurane simply has certain features that allow it, as I say, quicker onset, quicker clinical offset and so the proponents suggest you know, it allows for quicker wake up and exit from the OR and so on. But one can just adapt one's practice style, as so many of us have, and make up for that." "You have to be able to adapt your practice, you want to create a sense of urgency that it is important to overcome the learning, you have to learn to alter your technique and alter how you do things if you choose to not use desflurane."
Ingrained attitudes and practices	"It has to be each position's, individual choices. It's very hard to be responsible for somebody's life and at the same time, factor in sustainability and global warming. You just don't think of that. Most people tend to do what they're used to doing and what they're comfortable doing."
Pharmacologic diversification	"Regarding eliminating desflurane, it is kind of mix because one of the problems is this: we only use sevoflurane as the alternative and so if you have somebody who is say, allergic to sevoflurane and had a bad

	reaction to sevoflurane and there's for some reason that they would like to be able to have the option in isolation. I think it's a good idea to have an agent available even if it's used rarely and to recognize its impact.”
Cost of anesthetic capture technology	“It's going to be more expensive to capture it and so I think it needs to be mandated like I think it needs to come out on a national level like maybe from the CAS or the Canadian Medical Association.”

Volatile Anesthetic Purchasing Data and Emissions in Canada

Pharmacy purchasing data was procured for different sites and/or regions in six provinces. Analysis of the purchasing data showed a considerable decline in the relative proportion of desflurane purchase and a corresponding increase in sevoflurane purchase over the 5-year period (i.e., from 2016 – 2021) for the six provinces (Figure 7). In Alberta, desflurane purchase declined by 44% within the 5-year period. In British Columbia, there was 46% reduction from 2017 to 2021. Manitoba recorded a 61% decrease in desflurane purchase whereas Newfoundland and Labrador recorded a 57% downward change. In Ontario and Saskatchewan, desflurane purchase decreased by 54% and 41% respectively between 2016 and 2021.

In terms of annual carbon dioxide equivalent, there was a decreasing trend in emissions from 2016 to 2021 for all six provinces (Figure 8). The carbon footprint or emissions calculated was directly proportional to the total volume of desflurane and sevoflurane for a particular region, site, and/or province. For this study, the most populous and largest provinces by area namely Ontario, British Columbia and Alberta had the highest cumulative carbon footprint.

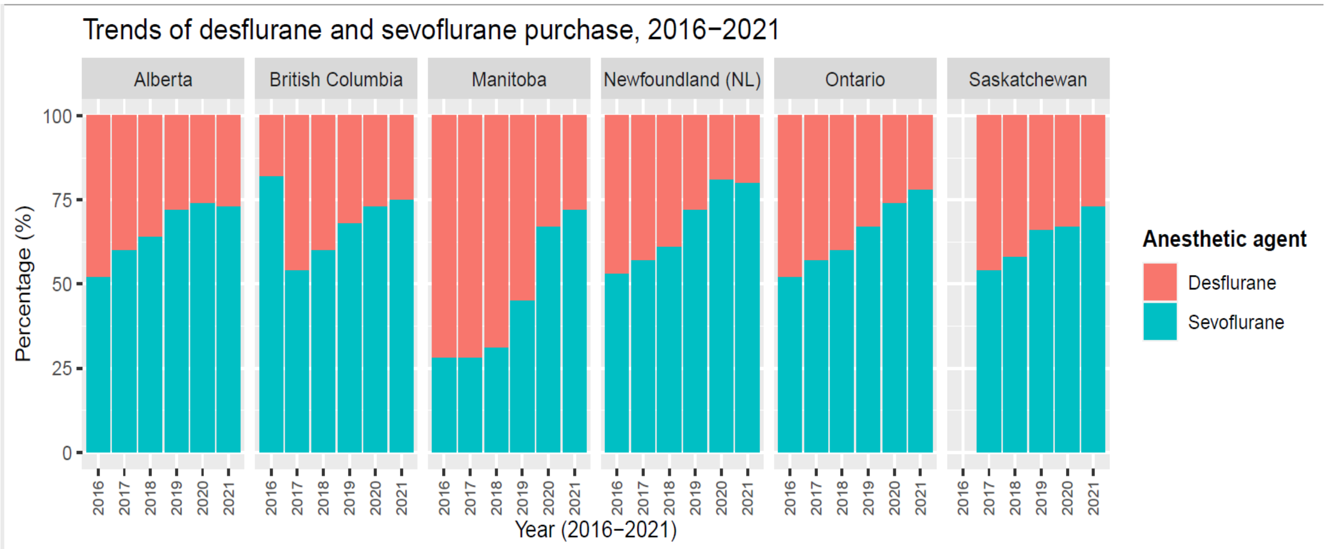

Figure 7. Trends of desflurane and sevoflurane purchase in six Canadian provinces

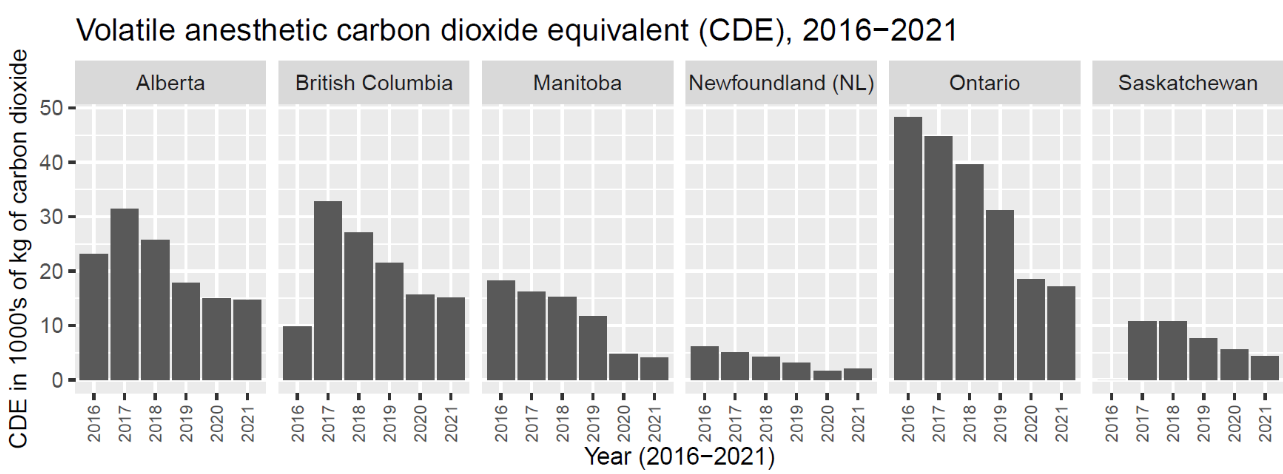

Figure 8.Trends of volatile anesthetic carbon footprint in six Canadian provinces

Summary / Conclusion

Anesthetic gases are very useful in clinical practice as they provide patients with safe and comfortable surgery. These gases also have a global warming potential and environmental impact and thus contribute to the climate change menace. This study showed there has been substantial localized and individual efforts to mitigate inhaled anesthetic emissions by limiting the use of desflurane in the operating room. The primary efforts involve education and/or awareness creation while a handful of anesthesia departments have banned the use of desflurane in their facilities. There is however a lack of consensus among the interviewed experts on whether to ban desflurane. The findings of this study show that from 2016 to 2021, desflurane purchase across the provinces has declined considerably resulting in a concomitant decreasing trend in the carbon footprint during this 5-year period. Thus, institutions can be a part of the change to improve the environmental performance of the operating room. Clinicians and hospital administrators have a critical role to play in reducing the environmental impact of anesthesia. Many environmental initiatives involve practice change, which must be led by clinicians and strongly supported by administrators. In addition to leading practice change, clinicians and administrators have a role in advising on and advocating for organizational and facility change – to spread and normalize practice change, and to enable it through shifts in organizational policy, purchasing practice, infrastructural development, and/or facilities management. It is also critical that policy makers in federal government and provincial environmental ministers provide support to augment the efforts of clinicians to mitigate anesthetic gas emissions.

Limitations and Recommendations

Anesthetic purchasing data presented in this paper is not representative of all the provinces and purchasing sites in Canada. Thus, further data collection is needed to capture volatile anesthetic agent purchases from other sites and provinces to provide a holistic picture of carbon emissions from anesthetic gases in Canada. For example, for provinces where pharmacy purchasing data is classified, data disclosure agreement (DDA) and data transfer agreement (DTA) applications need to be put in before data can be accessed. This study also sought to examine attitudes and practices of anesthesiologists regarding anesthetic gas use in the operating room. The survey has been designed and ethics application has been approved by the UBC Research Ethics Board (REB). As a next step, this survey will be disseminated to the Canadian Anesthesiologist Society with the help of the anesthesiologists who participated in the interviews and have expressed their support in that regard.

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Appendices

APPENDIX A: Example Calculation of Carbon Footprint of Anesthetic Gases

Anesthetic agent	Number of bottles purchased in 2018	Size	Footprint ($MTCO_2e$)
Desflurane	1513	240mL	Multiply the number of bottles purchased by the size to get the number of milliliters (mL) 1513 x 240 mL = 363,120 mL Divide by 1000 to convert to liters (L) 363.120 mL /1000 = 363.12 L Multiply the liters purchased by the density of the gas 363.12 x 1.46 = 530.1552 Multiply by the 100-year GWP of the gas 540.1552 x 2540 =1,346,594.208 Multiply by 0.001 to get MTCO2e 1,346,594.208 x 0.001 = 1346.59421 *The facility generated 1,346.59 $MTCO_2e$ from desflurane in 2018*
Sevoflurane	7068	250mL	Multiply the number of bottles purchased by the size to get the number of milliliters (mL) 7068 * 250 mL = 1,767,000 mL Divide by 1000 to convert to liters (L) 1,767,000 mL /1000 = 1,767 L Multiply the liters purchased by the density of the gas 1,767 x 1.522 = 2,689.374 Multiply by the 100-year GWP of the gas 2,689.374 x 130 = 349,159.2 Multiply by 0.001 to get MTCO2e 349,159.2 x 0.001 = 349.61862 *The facility generated 349.62 $MTCO_2e$ from sevoflurane in 2018*

APPENDIX B: Key Informant Interview Guide

Introduction

CASCADES (Creating a Sustainable Canadian Health System in a Climate Crisis) is undertaking a study to develop an implementation framework to support innovations to mitigate emissions from inhaled anesthetics. This study is supported by the University of British Columbia (UBC) Sustainability Scholars Program, an innovative summer internship program which matches UBC graduate students with on- and off-campus sustainability partners to work on applied research projects that advance sustainability across the region.

Anesthesiologists and environmental enthusiast across academic institutions will be interviewed to understand and assess efforts that have been made hitherto to restrict and/or eliminate desflurane use in hospitals and institutions in Canada. The interview also seeks to aggregate experts' opinions on best or optimal strategies to eliminate desflurane from formulary and anesthetic practice.

The interview will take approximately 45 minutes and will be conducted in English. Your participation in this interview is voluntary. Also, please be assured that the information gathered through this interview is considered confidential to the extent permitted by the Access to Information Act and the Privacy Act. The information we gather through this interview will be summarized in aggregate form.

Since this interview covers a diverse range of activities, you will only be asked to speak to those areas where you are most involved or knowledgeable; feel free to skip any questions you do not feel comfortable answering. If you have any questions about this study, please contact Andrea MacNeill, Clinical Associate Professor, General Surgery, Vancouver Coastal Health @ Andrea.MacNeill@bccancer.bc.ca or Andrews Nartey, MPH Candidate and Sustainability Scholar, University of British Columbia @ andrews.nartey@ubc.ca .

Your feedback is appreciated and will help in advancing sustainable initiatives to mitigate anesthetic emissions and lower healthcare carbon footprint.

Interview Questions on Desflurane Elimination Efforts and Strategies

Please answer the following questions to the best of your ability. If there is a question where you do not know or would prefer not to say the answer, we can move to the next.

Section 1: Involvement in desflurane restriction efforts

1. Have you been involved in the planning and/or implementation of anesthetic gases emission reduction initiatives or strategies?
2. What is your motivation for partaking in the initiative?
3. What role did you play in the planning and/or implementation?

4. What is your overall satisfaction and assessment of the entire process? i.e., level of support, impact, challenges, reaction from colleagues and other department, etc.

Section 2: Efforts and strategies to restrict and/or eliminate desflurane

1. What efforts (locally and globally) are you aware of to reduce the use of desflurane?
2. What, if anything, has been tried at your institution and what was the experience with this? How was it received? Was it effective? What measures of restriction are currently in place at your institution? Is there a monitoring and evaluation mechanism for this initiative?
3. What, in your opinion, is/are the most effective strategies for limiting desflurane use?

Section 3: Considerations for successful implementation of emission reduction initiatives

1. Who are the major stakeholders required for implementation?
2. Can you comment on the overarching feasibility of implementing these initiatives?
3. What resources (if any) will be needed in the implementation?
4. Are there any key intersectoral/multidisciplinary collaborations and engagements to consider? How do you think such engagements can be best coordinated and sustained?
5. What will be the role of clinicians and hospital administrators in advancing these initiatives?
6. What do you perceive to be the main drivers of ongoing desflurane use and, relatedly, what are the barriers to eliminating it both at your institution and more broadly?

Section 4: Miscellaneous questions

1. Apart from the gas scavenging system in the OR, do you know if your institution has an anesthetic gas capture system to prevent waste anesthetic gas from being expelled to the atmosphere? If such a system were in place, how do you think it might affect your colleagues' use of inhaled anesthetics?
2. Are there relevant resources and materials you would like to share? Is there anything else we haven't discussed that you think is important? Do you have any recommendations on subject matter experts (SMEs) you feel we should engage to glean more information?

Appendix C: List of Anesthesiologists interviewed

Name of Anesthesiologist	Institution	Location
Dr. Timur Ozelsel	University of Alberta	Edmonton, AB
Dr. Anita Rao	University of Toronto	Mississauga, ON
Dr. Myles Sergeant	St. Peters Hospital	Hamilton, ON
Dr. Stephan Malherbe	University of British Columbia	Vancouver, BC
Dr. Ali Abbass	University of Toronto	Toronto, ON
Dr. Nam Lee	Mt. Sinai Hospital	Toronto, ON
Dr. Tamara Miller	St. Boniface Hospital	Winnepeg, MN
Dr. Mary Hanna	Ottawa Hospital	Ottawa, ON
Dr. Melinda Davis	Foothills Medical Center	Calgary, AB
Dr. Melanie Jaeger	Kingston Health Science Center	Kingston, ON
Dr. Phillip Richebe	University of Montreal	Montreal, QC
Dr. Robert Weiler	University of Saskatchewan	Saskatoon, SK

APPENDIX D: Anesthetic gas reduction how-to guide

	Goal	**Measure**	**Calculation**
Baseline	Conduct baseline assessment of total anesthetic gases purchased per year / 12 consecutive months	Total metric tons of carbon dioxide equivalent ($MTCO_2e$) for isoflurane, sevoflurane, desflurane, nitrous oxide per year Total dollars spent on anesthetic agents per year	Calculate MTCO2e for each anesthetic agent to get total footprint Add dollars spent for each anesthetic agent to get total spent on anesthetic gases
If desflurane has NOT been eliminated from hospital formulary			
Level 1	Reduce GHG emissions specific to anesthetic gases by 20 percent from baseline	Percent change in total $MTCO_2e$ of purchased anesthetic gases	Subtract baseline year footprint from current year footprint Divide by current year footprint Multiply by 100 This is the percent reduction from baseline *Consider also tracking dollars spent per anesthetic agent and percent change from baseline
Level 2	Reduce GHG emissions specific to anesthetic gases by 50 percent from baseline	Percent change in total $MTCO_2e$ of purchased anesthetic gases	Subtract baseline year footprint from current year footprint Divide by current year footprint Multiply by 100 This is the percent reduction from baseline *Consider also tracking dollars spent per anesthetic agent and percent change from baseline
If desflurane has been eliminated from hospital formulary			
Level 1	Reduce GHG emissions specific to anesthetic gases by 5 percent from baseline	Percent change in total $MTCO_2e$ of purchased anesthetic gases	Subtract baseline year footprint from current year footprint Divide by current year footprint

			Multiply by 100 This is the percent reduction from baseline *Consider also tracking dollars spent per anesthetic agent and percent change from baseline
Level 2	Maintain 5 percent reduction from baseline	Percent change in total $MTCO_2e$ of purchased anesthetic gases	Subtract baseline year footprint from current year footprint Divide by current year footprint Multiply by 100 This is the percent reduction from baseline *Consider also tracking dollars spent per anesthetic agent and percent change from baseline