

Guidelines

Action guidance for addressing pollution from inhalational anaesthetics

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Summary

Climate change is a real and accelerating existential danger. Urgent action is required to halt its progression, and everyone can contribute. Pollution mitigation represents an important opportunity for much needed leadership from the health community, addressing a threat that will directly and seriously impact the health and well-being of current and future generations. Inhalational anaesthetics are a significant contributor to healthcare-related greenhouse gas emissions and minimising their climate impact represents a meaningful and achievable intervention. A challenge exists in translating well-established knowledge about inhalational anaesthetic pollution into practical action. CODA is a medical education and health promotion charity that aims to deliver climate action-oriented recommendations, supported by useful resources and success stories. The CODA-hosted platform is designed to maximise engagement of the global healthcare community and draws upon diverse experiences to develop global solutions and accelerate action. The action guidance for addressing pollution from inhalational anaesthetics is the subject of this article. These are practical, evidence-based actions that can be undertaken to reduce the impact of pollution from inhalational anaesthetics, without compromising patient care and include: removal of desflurane from drug formularies; decommissioning central nitrous oxide piping; avoidance of nitrous oxide use; minimising fresh gas flows during anaesthesia; and prioritising total intravenous anaesthesia and regional anaesthesia when clinically safe to do so. Guidance on how to educate, implement, measure and review progress on these mitigation actions is provided, along with means to share successes and contribute to the essential, global transition towards environmentally sustainable anaesthesia.

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Recommendations

1. Resource stewardship presents an opportunity for leadership and environmental action by providers of anaesthesia. This acknowledges globally limited resources, the contribution of the healthcare sector to climate change and the impact of climate change on healthcare [1].
2. If inhalational anaesthetics are used, providers should avoid those with disproportionately high climate impacts, such as desflurane and nitrous oxide [2]. Further, desflurane is more expensive than other volatile anaesthetics, with little evidence of clinical benefit justifying its use, and avoidance may have a cost savings benefit [3, 4].
3. Most nitrous oxide is lost prior to use through central piping systems that should be decommissioned in existing infrastructure and avoided in new construction [5, 6]. Portable canisters should be substituted, and these should be closed between uses to avert continuous leaks.
4. If inhalational anaesthetics are used, the lowest possible fresh gas flow (FGF) rates should be selected during all stages of anaesthesia (e.g. $< 1 \text{ l.min}^{-1}$ during maintenance) [7–9]. To speed induction, low flows can be combined with high concentrations. Lower flows will, however, result in faster consumption of traditional carbon dioxide absorbers.
5. Regional anaesthesia and total intravenous anaesthesia (TIVA) are alternatives with fewer embodied greenhouse gases, even accounting for additional consumable materials [10]. Care should be taken to avoid unnecessary high flow rates of oxygen in patients who are maintaining their own airway during anaesthesia, as this can add considerably to the resultant greenhouse gas emissions [11].
6. More research is needed before recommending investment in waste anaesthetic gas capture (for volatiles only) or destruction (nitrous oxide only) technology. Avoidance of inhalational anaesthetics, decommissioning centralised nitrous oxide and reduction of FGFs are higher mitigation priorities than waste treatment technological solutions [12, 13].
7. Inhalational anaesthetic greenhouse gas emissions should be measured at institutional and provider levels, and performance improvement tracked, with clear guidance on science-based targets and timelines for mitigation.

Why was this guidance developed?

Global engagement in implementing solutions that minimise pollution from inhalational anaesthetics is

essential to urgently address the impact of anaesthesia on the climate. Over the past two decades, substantial evidence has emerged on the environmental footprint of inhalational anaesthetics, but there has been insufficient progress in translating this information into mitigation action. While some hospitals and providers have made environmental improvements, more are considering it and require guidance. There are meaningful actions that reduce pollution from inhalational anaesthetics that are feasible to implement without compromising patient care. Implementing these changes is an important opportunity for anaesthetists to do their part, demonstrating environmental leadership and contributing to the momentum urgently required for global climate action. This action plan is also designed to provide a platform that engages health professionals as an active learning community, and invites sharing of success stories and evolving solutions across varied global practice settings.

What other (similar) documents are available?

Professional guidelines and checklists on how to reduce the environmental footprint of anaesthetic practice are provided by several professional organisations including the World Federation of Societies of Anaesthesiologists [14], American Society of Anesthesiologists [15], Association of Anaesthetists [16] and the Australian and New Zealand College of Anaesthetists [17].

How does this differ from existing guidance?

Considering their significant climate impacts and feasible interventions, this guidance document specifically focuses on actions that mitigate pollution from inhalational anaesthetics. It builds upon previous recommendations with updated evidence and advice, such as addressing nitrous oxide central piping leaks, adds consideration for shifting burdens such as additional consumption of carbon dioxide absorbers resulting from lowering FGFs and suggests caution in the uptake of technological solutions for treating inhaled anaesthetic waste.

Introduction

Anaesthesia is a carbon-intensive specialty, involving the routine use of inhalation agents that are potent greenhouse gases. These gases are exhausted directly to the atmosphere, contributing to global warming. Relevant inhalational anaesthetics include volatile halogenated organic compounds (sevoflurane, desflurane, isoflurane, halothane) and nitrous oxide. While the environmental

impacts of these agents should be mitigated, those of desflurane and nitrous oxide are several times greater in clinically relevant quantities, making them an even greater priority for intervention [12].

Volatile anaesthetic agents have been estimated to be responsible for 0.01–0.10% [4, 18] of total global carbon dioxide equivalent (CO₂e) emissions contributing to global warming. Based on atmospheric sampling of volatile anaesthetics, their accumulation is increasing (particularly desflurane) [19]. Whilst these are a seemingly small contribution to total global emissions, inhalational anaesthetics account for 5% of acute hospital CO₂e emissions and 50% of peri-operative department emissions (in high-income countries) [12, 20, 21]. Use of inhalational anaesthetics is directly within the control of anaesthesia providers and safe alternatives exist; thus, environmental stewardship is an important opportunity for greenhouse gas mitigation and professional sustainability leadership.

Moving from knowledge to action

The United Nations Intergovernmental Panel on Climate Change (IPCC) has made increasingly strident calls for humanity to reduce anthropogenic greenhouse gases. The latest IPCC report states that “*strong, rapid, and sustained*” greenhouse gas reductions are needed to limit global heating to 1.5°C and avert millions of deaths worldwide [22]. We have known for decades that climate change is a real and accelerating existential risk. We are already experiencing worsening frequency and severity of extreme heat events, storms and flooding, droughts, wildfires, food and water insecurity, political instability and forced migration. To avert the worst predicted harms to civilisation before the end of this century, the world must act urgently to transition to a low carbon society [22], and everyone has an important role to play. Within anaesthesia, there have been calls for action on climate change mitigation at work and beyond for more than a decade, and to move from sustainability research to action [23]. Accelerating engagement of the clinical community is essential and urgent.

CODA is a medical education and health promotion charity that, amongst its aims, seeks to provide meaningful, achievable and sustainable actions to reduce healthcare’s carbon footprint. CODA is broadening its global network of health professionals across multiple disciplines and countries via online interactive platforms, face-to-face gatherings and social media. CODA provides individual action templates, authored by small groups of clinical

experts, to distil mitigation actions supported by scientific evidence (including case reports) and provides helpful links. Whilst recommendations are intended for inclusivity, there is enormous diversity of global medical practice. The CODA website, however, provides a dynamic platform for crowdsourcing global solutions for continuous learning. To maintain engagement of the healthcare community, the actions are sustained by self-reporting measures and gamification. The CODA community is engaged with positive feedback and interactions, such as amplification of actions on social media, showcasing success stories on the CODA website and integration of collective wisdom into the action template.

There are numerous, evidence-based and practical interventions available to minimise the environmental impact of inhalational anaesthetics, whilst maintaining patient safety. Applying the CODA clinical action template to inhalational anaesthetics, this article seeks to synthesise action-oriented recommendations, give examples of success stories and provide resources and strategies to engage providers and accelerate action.

Background to action guidance

The evidence for the comparative environmental impact of different anaesthetic choices is relatively advanced, particularly for inhalational anaesthetics. The recommendations in this document are supported by scientific literature, professional society guidelines and a global consensus statement on principles of environmentally sustainable practice from the World Federation of Societies of Anaesthesiologists [14]. In order to help providers improve environmental performance in peri-operative environments on an individual and organisational level, a list of suggested reading, calculators and other resources is available in online Supporting Information (Table S1).

Desflurane

The global warming potential of desflurane, scaled by clinical potency, is approximately 40–50 times that of sevoflurane and isoflurane over a 100-year period [10, 18]. Desflurane is also significantly more expensive than other volatiles [24].

There is evidence of slightly faster wake up times with desflurane compared with sevoflurane, with a mean reduction of 1.3 min in time to tracheal extubation following surgery of up to 3 h, with no significant difference in time to discharge from the post-anaesthesia care unit (PACU) [3]. However, for surgeries of longer duration, desflurane wake up times (time to 85% mean alveolar concentration

decrement in vessel rich groups) are comparable with those of the other volatile anaesthetics [25]. Such small reductions in wake up times for desflurane are of doubtful clinical significance, particularly when accounting for the usual practice of tapering of the volatile anaesthetic at the end of surgery [4]. Similarly, there is minimal difference in either time to emergence or discharge from PACU for desflurane versus propofol-based TIVA [26].

Whether these slightly faster wake up times translate into improved productivity to offset the increased cost of desflurane depends on many factors, and costs should also consider the externalised costs to public health and society from climate change [4]. Ultimately, there are no indispensable qualities of desflurane (e.g. sympathetic tone stimulation, rapid emergence) that cannot be achieved using other means, and with less environmental impact.

Nitrous oxide

Nitrous oxide is less potent than other inhalational anaesthetics and therefore must be used in high concentrations (typically 50%). It has a very long atmospheric lifetime (114 y) [12, 23] and, therefore, its global warming impacts are similar to desflurane in clinically relevant doses. Vast quantities of nitrous oxide are lost before clinical use via central piping manifolds [5, 6]. This has led to calls for decommissioning nitrous oxide central piping and avoiding de novo construction. Substituting portable tanks, and closing them between each use, is feasible and reduces losses dramatically [6].

Nitrous oxide use for analgesia is common outside of anaesthesia practice (e.g. labour suite, dental practice, pre-hospital care), although the precise amount used is uncertain. Working to educate diverse professionals about nitrous oxide environmental emissions and safe, environmentally preferable alternatives is another important task for anaesthesia provider leadership.

Low-flow anaesthesia

Historically, there has been concern about the theoretical risk of renal injury associated with compound A production when sevoflurane is used at low FGFs. This led to the United States Food and Drug Administration (FDA) recommendations for minimum FGF rates of 1 l.min⁻¹ for up to 2-minimum alveolar concentration-hours, then 2 l.min⁻¹ thereafter [27]; this resulted in the common practice of a default FGF of 2 l.min⁻¹. However, there is no clinical evidence of harm associated with compound A in humans, even at low FGFs [8]. Sevoflurane can be used safely with low FGF to minimise its environmental impact [8, 9];

however, it is recommended to use carbon dioxide absorbers that contain low (<2%) or no sodium hydroxide [28].

Total intravenous and regional anaesthesia

The carbon impact of TIVA and/or regional anaesthesia can be substantially less than volatile-based anaesthetic techniques, even when manufacturing, packaging, transportation, administration and waste management of consumables are considered [10]. Non-greenhouse gas emissions are also a concern, but perhaps less so if intravenous drug waste is incinerated as per recommendations and regulations [12, 29]. However, TIVA and/or regional anaesthesia are not default low carbon alternatives as consideration must be given to minimising oxygen FGF, single-use plastics and unnecessary use of drugs and supplies [11]. It must be noted that the use of TIVA may be associated with increased procurement costs, limiting its utility in low- and middle-income countries, where the use of inhalational anaesthetics with low FGF is important.

Waste anaesthetic gas capture and destruction technology

Waste anaesthetic gases are vented to the outdoor atmosphere, virtually unmetabolised and unregulated. Waste anaesthetic gases may be partially mitigated by capture (for volatiles only) and destruction (nitrous oxide only) technologies. Scavenged volatile drugs may be condensed or adsorbed and separated for potential reuse. Nitrous oxide is difficult to capture; however, scavenged nitrous oxide can be destroyed using photochemical treatment [12].

There are several limitations to waste anaesthetic gas treatment technologies. Only a fraction of waste anaesthetic gas makes it into the medical gas evacuation systems for potential capture or destruction. Reasons for this include: leaks when performing face-mask ventilation; continued exhalation of anaesthetic gases postoperatively; improper self-administration of nitrous oxide analgesia by parturients; and significant infrastructure losses of centrally piped nitrous oxide before use. Furthermore, treatment efficiency diminishes as FGF increase [30]. In addition, reclaimed volatile drugs are not broadly approved for re-use, creating new storage and transportation challenges. Ultimately, the financial and environmental impacts of these technologies themselves have not been fully characterised [12].

While these technologies are promising, more research is needed before investment can be recommended [30].

Avoidance of inhalational anaesthetics, decommissioning centralised nitrous oxide and reduction of FGF are higher mitigation priorities than waste treatment solutions [12, 13].

Tracking progress on environmental impact

There are several free calculators available to help providers estimate the environmental impact and costs associated with anaesthesia. These may be used to track institutional performance, inform policy, teach and encourage personal practice improvement. Examples are provided in online Supporting Information (Table S1).

Lessons in practice: some inhalational anaesthetic climate mitigation success stories

Due to its disproportionately high global warming impact, desflurane was eliminated from the Yale New Haven Health System (CT, USA) formulary in 2013 in favour of sevoflurane [31]. The resultant annual savings were approximately £769,230 (€909,090, \$USD 1,200,000; using 2013 figures [32]) across the health system and 1600 tonnes CO₂e (the equivalent of 360 passenger vehicles over 1 y, based on calculations using 2012 fuel efficiency figures [33]) from the largest hospital alone. This is the first known healthcare organisation to eliminate a drug based on environmental grounds.

After labelling vapourisers with environmental impact information, desflurane use at the University of Wisconsin was reduced by 55% in 2015. This resulted in monthly savings of £16,340 (€22,537, \$USD 25,000; using 2015 figures [34]) that year and an average emissions reduction per anaesthetic case from 163 kgCO₂e to 58 kgCO₂e [35]. Desflurane was removed subsequently from the formulary in 2020.

In Australia and New Zealand, anaesthetic trainees formed TRA2SH (Trainee-led Research and Audit in Anaesthesia for Sustainability in Healthcare [36]), a network aiming to encourage research and quality improvement initiatives around environmental sustainability. It promotes an online pledge encouraging anaesthetic departments to immediately reduce their use of desflurane and remove it from their hospital formulary by 2025. Several institutions removed desflurane, whilst many others have pledged to do so by 2025 [36]. At the Fiona Stanley Hospital (Perth, Australia) the removal of desflurane in 2020 saved approximately £51,916 (€58,572, \$USD 66,560; based on 2020 figures) and approximately 300 tonnes CO₂e per year (personal communication, C Mitchell). At Western Health, a district health service with 960 beds in Melbourne, Australia, this same action saved £17,308 (€19,527, \$USD 22,190;

based on 2020 figures) and reduced emissions by 140 tonnes CO₂e per year. Following their action in 2021, the Alfred Hospital, a 683-bed tertiary hospital in Melbourne, Australia, reported only positive, supportive departmental feedback [37].

Interventions may also be undertaken to reduce FGF rates. The University of California (San Francisco, CA, USA) implemented an electronic clinical decision support tool, aimed at nudging providers to reduce FGFs in real time. This electronic health record tool alerts providers if FGF exceeds 0.7 l.min⁻¹ for desflurane and 1 l.min⁻¹ for sevoflurane during maintenance anaesthesia. In 2018, researchers demonstrated reductions in (already low) mean FGF by 0.6 l.min⁻¹ for sevoflurane and 0.2 l.min⁻¹ for desflurane (personal communication, S Gandhi).

The primary source of nitrous oxide emissions from hospitals is through losses via central piping delivery infrastructure [5, 6, 38]. In 2019, Providence St. Vincent Hospital (Portland, OR, USA) procured 991 tonnes of nitrous oxide. Investigators discovered infrastructure leak rates, ranging from < 0.1 l.min⁻¹ to > 3.5 l.min⁻¹ at manifolds, resulting in use efficiency of 5–40%. Central piped nitrous oxide was subsequently decommissioned and portable cylinders substituted. This resulted in saving 958 tonnes CO₂e in one year, equivalent to 2,407,640 fewer car miles driven and £9747 (€11,501, \$USD 12,000) in procurement costs (personal communication, B Chesebro). Similarly, in 2020, NHS Lothian (Scotland) demonstrated system losses from three centrally piped nitrous oxide systems across two hospital sites of approximately 790,000 and 685,000 litres, respectively. Mitigation activities, including fully decommissioning centrally piped nitrous oxide, eliminated the equivalent of 806 tonnes CO₂e per annum. The national Nitrous Oxide Project [38] was launched subsequently in January 2021. By the end of March 2021, 16 hospitals reported an annual system loss of 13,770,000 l, equivalent to 95% of total procured nitrous oxide. This is equivalent to 7219 tonnes CO₂e, comparable to 7600 flights from Paris to New York [39].

Making a difference and measuring the impact of action

The success stories above highlight several effective interventions that can be undertaken to reduce inhalational anaesthetic emissions, and that both an environmental and business case can be made. Similar pollution prevention initiatives can be adopted more broadly.

It is suggested that readers begin by teaching their departments about the environmental impact of anaesthetic practice. This should include institutional- and provider-

level inhalation anaesthetic CO₂e performance and strategies to reduce emissions. It is important to set target emissions reductions and timelines (e.g. 50% reduction by 2023). Emissions performance can be tracked over time through simple audits of quantities of purchased volatile anaesthetic and nitrous oxide within a facility. For volatile anaesthetics, providers may request procurement data from their pharmacy on quantities purchased on a semi-annual basis. Procurement data on quantities of nitrous oxide canisters purchased can be obtained through the medical gas department on a semi-annual basis. Where electronic health record data are available, average FGF, inhaled drug types, concentrations and numbers of hours of anaesthetic performed can be obtained to calculate emissions for each provider. This information can be translated into meaningful metrics that help to characterise impact, compare performance, aid interpretation and define best practice; for example, CO₂e emissions per minimum alveolar concentration-hour and equivalent distance driven per minimum alveolar concentration-hour. The resources contained in online Supporting Information (Table S1) can be used to educate and calculate institutional- and provider-level impacts.

It is essential to share the outcomes of these initiatives in order to engage staff in continual environmental practice improvement. As a minimum, this should take the form of presenting departmental outcomes (using procurement data) and individual performance reports (where available) on a regular basis (e.g. quarterly). Results and lessons learned should also be shared through anaesthetic professional societies, informal professional networks, symposia, newsletters and case reports. The CODA website provides a crowdsourcing platform to also share this information with others around the world and provides a portal for feedback in a continuous learning community. Providers should also contribute to collaborative data collection about inhalational anaesthetic use, to build an effective knowledge base for quality improvement. Examples include the American Society of Anesthesiologists web-based institutional benchmarking tool [40], collaborative audits by trainee groups such as TRA2SH in Australia [36] and GASP (Greener Anaesthesia and Sustainability Project) in the UK [41] and the CODA website. Finally, it is suggested that anaesthesia providers encourage environmental sustainability for their institutions and professional societies as part of routine quality assurance in anaesthesia.

There is an urgent need for co-ordinated action to minimise the environmental harms associated with healthcare delivery, and anaesthesia providers are well placed to contribute to this. Removing desflurane from

formularies, decommissioning central nitrous oxide manifolds, avoiding nitrous oxide use and minimising FGF are essential, powerful and feasible actions to mitigate pollution from inhalational anaesthetics. But this is only the beginning; we need to consider the impact of all that we do as anaesthesia providers. Sharing success stories and practical actions with learning communities such as CODA and our professional societies are valuable means to identify global solutions, engage more clinicians and accelerate change. These successes can seed further environmentally conscious practices, amongst an ever-growing sustainable healthcare community, motivated to address the climate emergency and buoyed by what has already been achieved.

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Supporting Information

Additional supporting information may be found online via the journal website.

Table S1. Sustainable anaesthesia guidance and supporting information.