**Introduction**

Climate change poses a significant threat to animals around the world, and urgent action is needed to protect the health of all species. Veterinarians, along with other health professionals, are actively engaged in the development and implementation of programs and policies that best support the lives of those with whose care we have been entrusted. There are 3 critical areas on which the health sector must act regarding climate. The first is to prepare for and respond to individual and population health threats. There are 7 well-understood exposure pathways through which climate change impacts health; veterinary teams need to be educated and prepared to prevent and treat these. The next is to develop climate-resilient health systems and structures. Natural disasters have the ability to significantly disrupt both physical and social infrastructure within the health sector, a threat that will only intensify with continued warming. Finally, we need to mitigate the harms associated with healthcare delivery. The human healthcare sector has been estimated to contribute between 3% and 10% of greenhouse gas emissions globally, depending on location. While the impact of the veterinary sector remains unquantified, reducing the footprint of professional services is a well-recognized priority within the industry.

Understanding where greenhouse gas emissions come from is an essential part of emissions-reduction planning, as it enables groups to focus efforts on the greatest reduction opportunities. Conventional greenhouse gas accounting has 3 categories, referred to as scopes. Scope 1 emissions are those directly owned or controlled by an organization. These are direct emissions coming from a clinic’s operations, such as HVAC systems or refrigeration. Scope 2 emissions are indirect emissions from purchased energy, and scope 3 emissions are all other indirect emissions apart from energy (e.g., the supply chain, extraction and production of materials, and employee commuting). This framework
is easily used by the veterinary profession to inform decarbonization efforts.\textsuperscript{7} Anesthesia is a particularly important area for health professionals to understand, and it is important that health professionals act to minimize anesthesia’s associated carbon footprint.\textsuperscript{8,9} Volatile anesthetic agents are greenhouse gases that fall within scope 1 emissions and have substantial warming potential. The warming effect of halogenated organic compounds has been approximated to constitute almost 20\% of the radiative warming attributed to human activities, and the global warming potential (GWP) of inhalant anesthetics has been estimated to be roughly equivalent to the annual emissions of 1 million passenger cars.\textsuperscript{10} Not all volatile anesthetics have the same warming capacity. The GWP is a measure of a greenhouse gas’s ability to trap heat in a specified period (typically 100 years; GWP100), and the reference gas is CO\textsubscript{2}, which has a GWP100 of 1.\textsuperscript{6} By comparison, the GWP100 of anesthetic agents ranges from sevoflurane at 130 to desflurane at 2,540.\textsuperscript{9,11}

Reducing anesthetic emissions is also a priority for veterinary teams. In a 2021 review of the literature on sustainability in veterinary practice, the topic of anesthesia made up 33\% of the publications identified, suggesting it was one of the earliest recognized opportunities for action.\textsuperscript{12} Despite this, it is unclear how widely climate-responsible anesthetic practices have been adopted and what barriers exist for veterinary teams. In this article, we explore opportunities for the profession to reduce our environmental impact through more environmentally friendly anesthesia.

Survey of Veterinary Anesthesia Professionals

To better understand the levels of awareness, interest, knowledge, and needs of veterinary anesthesia professionals, we conducted an anonymous online survey of those specialized, or particularly interested, in the topic. Participants were informed of the purpose of the study, that it would take <10 minutes to complete, and that the results would be used for academic research only. No incentives were provided, but investigator names and contact information were shared. The online survey, administered through Qualtrics, consisted of 20 questions: 7 multiple-choice questions (sometimes with a free response), 5 Likert scale questions, 3 drag-and-drop ranking questions, 4 free-response questions, and 1 select-all-that-apply question (Supplementary Material S1). The survey was disseminated electronically through the American College of Veterinary Anesthesia and Analgesia LISTSERV and posted through relevant online groups (eg, Veterinary Anesthesia Nerds) from July 2023 to September 2023. In each case, a single notification of the availability of the survey was sent with a reminder following approximately 30 days later. The survey was reviewed and deemed exempt by the Colorado State University Institutional Review Board. Descriptive and comparative ($\chi^2$) statistics were conducted with commercially available software.

Results

The survey was accessed 167 times. After excluding those who did not consent to participate, failed to answer any questions beyond consent, or only answered demographic questions, we included 150 responses in the final analysis. Of these, the majority (71\%) were veterinarians, 28\% were veterinary technicians, and the remaining 1\% did not specify. Veterinarians included diplomates of an anesthesia specialty college such as the American College of Veterinary Anesthesia and Analgesia or the European College of Veterinary Anaesthesia and Analgesia (75\%); veterinarians with, or currently in, residency training (11\%); and veterinarians with an interest in anesthesia (14\%). Respondents represented a range of employment sectors: academia (45\%), private practice (31\%), corporate (15\%), retired (3\%), and other (6\%), which included research, shelter, rehabilitation, and individuals whose work spans multiple settings. Most respondents had a career focused on anesthesia for 5 to 10 years (28\%), followed by >20 years (26\%), 10 to 15 years (19\%), 0 to 5 years (16\%), and 15 to 20 years (11\%).

Respondents were asked to rate a series of anesthetic protocol factors by level importance on a 5-point scale, with 5 indicating high importance and 1 indicating unimportance. The factor of highest importance was the patient’s assessed pain score (mean rank, 4.7 ± SD 0.5), followed by comfort of use with chosen anesthetic agent(s) for self/staff (4.0 ± 0.9), duration of recovery (4.0 ± 0.8), postoperative nausea and vomiting (3.8 ± 1.1), reversibility of medication (3.3 ± 0.9), environmental impacts (3.1 ± 1.1), and financial costs (3.0 ± 1.1).

Respondents were also asked to rate how knowledgeable they were about the environmental impacts of anesthesia on a 5-point scale from “extremely” to “not at all,” revealing a statistically significant difference in the knowledge level between all groups ($P < .001$) as well as when comparing veterinarians to nonveterinarians ($P = .019$). Anesthesia specialists self-reported the highest level of knowledge (mean, 3.3 ± SD 0.8), followed by residents (2.8 ± 0.4), technicians (2.6 ± 1.0), and veterinarians (2.5 ± 0.7).

Where respondents first learned about the environmental impacts of anesthesia differed significantly by respondent category ($P < .001$). All responding specialists reported having learned something about the topic. Specialists learned largely during their residency (43\%), although a substantial number (32\%) learned through their own research outside of formal education/training, with the remainder exposed to the topic during their DVM program, continuing education (CE), or internship. The proportion of specialists learning about environmental impacts of anesthesia differed statistically based on the number of years they had been practicing anesthesia ($P = .017$), with exposure to the topic being much more common in
more recent trainees. In contrast to specialists, 27% of non–residency-trained veterinarians and 19% of technicians reported never having learned about the environmental impacts of anesthesia. For those with some exposure to the topic, the 3 most common places non–residency-trained veterinarians first learned about the topic were at veterinary school, in practice, or on their own, while technicians learned through CE, during their veterinary technician program, or in practice.

When asked to rank sevoflurane, isoflurane, and desflurane by their GWP100, only 32% of respondents got them in the correct order (sevoflurane, approx 130; isoflurane, approx 510; desflurane, approx 2,540). Respondents’ self-reported knowledge regarding the environmental impacts of anesthesia was a statistically significant predictor of the correct order (P = .012); however, the category of respondent (diplomate, residency trained, etc) was not (P = .86).

When asked to rank their level of agreement to the following statements (1, indicating “strongly disagree,” to 5, indicating “strongly agree”), the highest mean agreement score was with the statement “I feel there is room for improvement in reducing the greenhouse gas emissions associated with general anesthesia in veterinary medicine” (mean, 4.3 ± SD 0.9). There was also general agreement with the statement “I use low-flow or closed-circuit anesthesia whenever possible to reduce the consumption of inhaled anesthetics and oxygen” (3.8 ± 1.1). The statement “The costs associated with injectable anesthesia for maintenance are a significant barrier to its use” yielded a more neutral response (3.0 ± 1). Respondents were more likely to disagree with the statements “I routinely use injectable anesthesia (TIVA/PIVA) to reduce or eliminate the use of inhaled anesthetics” (2.6 ± 1.1) and “The waste, and therefore greenhouse gas emissions, associated with injectable anesthesia is higher than a similar anesthetic utilizing inhalants for maintenance” (2.5 ± 0.8).

The frequency with which respondents discussed the environmental impacts of anesthesia with others in the profession differed significantly by respondent category (P < .001) and by level of self-reported knowledge (P < .001) with specialists. Those identifying as more knowledgeable were shown to have had such conversations most often. Less than half (42%) of respondents had engaged in (ie, either delivered or attended) CE regarding the environmental impact of anesthesia. The frequency of engaging in such CE varied significantly by respondent category (P = .002), with diplomates more commonly engaging in CE, followed by technicians, DVMs, and residents.

Surprisingly, most respondents worked at a practice that does not have (45%) or they were not aware of having (28%) an environmental sustainability initiative. For respondents working at practices that do have an environmental sustainability initiative, these typically consisted of implementing low fresh gas flow (FGF) anesthesia; choosing sevoflurane rather than isoflurane; using efficient equipment; recycling (including efforts to recycle medical waste such as personal protective equipment and other plastic items not accepted through curbside recycling) or other waste management efforts; reducing the use of single-use items; and using reusable consumables or reusing items when appropriate. Nonmedical sustainability efforts consisted of decreasing the use of electricity, promoting transportation by bike or public transport, and collaborating with local sustainability organizations.

Respondents were asked to rate the “level to which you perceive the following options to be a barrier in implementation of more environmentally friendly anesthesia” (where 5 indicated “extreme barrier” and 1 indicated “not at all a barrier”). From highest to lowest, mean barrier rankings were as follows: lack of knowledge regarding the topic (3.4 ± 1.2), lack of mandate from leadership (3.3 ± 1.3), lack of support from clinical team (3.3 ± 1.2), personal comfort/experience level (3.2 ± 1.2), perceived economic costs (3.1 ± 1.1), and patient safety concerns (2.5 ± 1.3). Other write-in barriers included the following: accessibility, availability, and reliability of associated equipment; training for those administering anesthesia and personnel involved in the perianesthesia period; shortages regarding both staff and drugs; constraints within an academic curriculum; status of controlled drugs; and regional limitations.

When asked if they would be interested in participating in CE regarding the topic of reducing the environmental impacts of anesthesia, 72% of respondents selected “yes,” 23% selected “maybe,” and only 5% selected “no.” The frequency of the different responses did not differ by respondent category (P = .07). The rank order of incentives to participate in CE on the topic of reducing the environmental impacts of veterinary anesthesia was first price (low cost or free education), followed by schedule (asynchronous delivery, accessible on own schedule), time (support from employer to complete training), and acknowledgment (receipt of CE credit). The rank order of format to access CE on reducing the environmental impact of veterinary anesthesia was first online CE, followed by journal-based CE, local CE meetings, national CE meetings, and regional CE meetings. Selecting from a series of topics that could be taught, respondents chose “improved techniques to lessen greenhouse gas emissions from inhalant anesthetics” most commonly (n = 122), followed by “how to mitigate single-use consumable waste generated from the use of anesthetics” (115), “best practices in alternatives to inhalant anesthetics” (106), and “scavenging methods” (96). Additional write-in topics of interest included the environmental impacts of injectable versus inhalant anesthesia; cradle-to-grave accountability for inhalant anesthetics; improved techniques to lessen the environmental impacts of anesthesia; the use of filters on inhalant scavenging systems; updated initiatives; technological innovations regarding the capture of inhaled anesthetics for reuse, recycling, or destruction; the health implications of humans exposed to inhaled anesthetics within their vet-
Actions for More Sustainable Veterinary Anesthesia

Collectively, the results of our survey highlighted interest and opportunities for making veterinary anesthesia less harmful to the environment. There are also regulatory efforts underway. For example, the legislature of Washington recently created a bill that intends to reduce greenhouse gas emissions associated with anesthetic inhalants without compromising safe and effective care, through the guidance of subject-matter experts in different regulatory agencies. Regardless of the motivation, with more than 82,000 veterinarians in clinical practice in the US, small changes across the profession have the potential to result in significant professional reductions in greenhouse gas emissions. Here, and shown in Figure 1, we summarize broad categories of action to make veterinary anesthesia more environmentally friendly.

### Figure 1—Actions that veterinary teams can take to reduce negative externalities associated with anesthesia include reducing the overall quantity of anesthetic agent used (compressing arrows); expanding learning through formal education, experience, and research (lightbulb); choosing lower-impact anesthetics (syringe); considering the fate of the anesthetic end product (recycle logo with leaf); and reaching beyond anesthesia to implement a range of sustainability initiatives at veterinary workplaces (hand with plant).

### Reduce the use

As inhalant anesthetics have some of the most significant environmental impacts in veterinary anesthesia (and anesthesia in general), it is logical to reduce the amount of agent used during general anesthesia. Not only does this reduce the atmospheric impacts, it also decreases the cost associated with their use. Reducing the FGF and using low-flow or closed-circuit anesthesia will decrease the amount of inhalant used to a minimum without impacting patient care. The use of end-tidal agent monitoring can facilitate low-flow inhalant anesthesia through goal-directed targeting of anesthetic concentration; this technology can be incorporated into most multiparameter monitors that evaluate end-tidal CO₂. The use of appropriately sized anesthetic circuits can also help reduce waste when using inhaled agents. Pediatric corrugated tubing is smaller in diameter than typical tubing, and when used with the proper rebreathing bag (3X to 6X the tidal volume), its use will minimize excess oxygen and inhalant necessary to fill the circuit, thus increasing the rate of change of anesthetic concentration in the circuit and patient. The use of nonrebreathing circuits with their much higher FGF should be minimized (or even eliminated) for all but the smallest of patients. Although recommendations of < 3 to < 7 kg for nonrebreathing circuits can be found in the literature, a author (GG) commonly uses pediatric rebreathing circuits on canine and feline patients down to 1.5 kg with appropriate monitoring. While it is true nonrebreathing circuits eliminate the waste due to CO₂ adsorbents, the increased FGF and inhalant waste carry significantly higher environmental impacts.

Reductions in inhaled anesthetic usage can also be easily achieved through the administration of other drugs that will reduce the inhalant dose requirement, a practice often referred to as partial intravenous anesthesia. The addition of infusions to the maintenance protocol (opioids, α₂ agonists, etc) can reduce the dose of inhalant necessary by 60% or more depending on the drugs used. Other common practices such as appropriate premedication of patients with a sedative and an opioid (if necessary) will also reduce the dose of inhalants.

The concept of reduction should also be extended to other anesthetic agents and supplies. While single-use patient circuits are uncommon in veterinary medicine, the switch to reusable anesthesia supplies such as corrugated tubing and rebreathing bags has been shown to significantly reduce CO₂ equivalent waste in human healthcare. Injectable drug waste, while not having the global warming impact of inhalants, is still waste that has both a cost and an environmental impact of its own. It has been calculated that up to half of all propofol dispensed is wasted or goes unused in human healthcare, something that can be minimized by appropriate drug calculations and/or switching to agents with a longer shelf life, such as the preservative-containing formulations of propofol and alfaxalone.

### Select lower-impact options

When inhalant anesthesia is necessary due to technical, safety, or patient concerns, agents with
lower GWP should be given preference. Desflurane and nitrous oxide have the most significant environmental impacts of all the inhaled agents and have not been shown to provide significant benefit over other inhalants in most situations; therefore, these should likely be phased out of clinical practice. Indeed, the removal of desflurane from hospital formularies has already been mandated in some healthcare systems and is likely to happen soon in others. Nitrous oxide is not commonly used in veterinary medicine, but given the marginal and clinically irrelevant differences in anesthetic variables, recovery time, and recovery quality, there is little to be gained by its use. Isoflurane use should probably be abandoned in favor of sevoflurane given that the costs are not significantly different, especially when combined with low FGF, and the GWP100 of isoflurane is 4 times that of sevoflurane.

Total intravenous anesthesia (TIVA), commonly performed with propofol as the maintenance agent, may also be a viable strategy to reduce the environmental footprint of anesthesia. While the use of TIVA is associated with more plastic and injectable drug waste, a life cycle analysis from 2012 found the carbon emissions associated with propofol were 4 times lower than the emissions associated with desflurane and nitrous oxide. Other studies put the numbers associated with propofol even lower, from 1/6 to 1/23 of the CO₂ equivalent of a similar inhalant-based protocol. Although not well studied in veterinary medicine, propofol-based TIVA has been found to be associated with reduced postanesthesia nausea and vomiting, shorter stays in the postanesthesia care unit, and lower pain scores after extubation in human patients as compared to inhalant anesthesia.

Consider the fate of end products

Given the significant amount of infrastructure present and the familiarity of use with inhalant anesthesia, other strategies are necessary to reduce the environmental impacts of this care. Waste anesthetic gas capture, either for destruction or recycling, has begun to make inroads in human healthcare. However, due to cost, technical considerations, or regulatory hurdles, the use of these technologies in veterinary medicine has been minimal to nonexistent. The use of activated charcoal canisters in particular, often used to prevent local environmental contamination of operating rooms, appears as an attractive option for inhaled anesthetic capture. Unfortunately, these release most of the inhalants back into the atmosphere over time and are a short-term and local solution only.

It is also important to consider the other waste generated in the provision of general anesthesia. Drug wastage can be minimized through the use of multidose drug preparations, appropriately sized vials, and sterile (or clean) technique to extend the shelf life of select agents. When drugs do need to be disposed of, it is important to make sure they do not make their way into the environment via trash, sewers, or landfills. Use of an appropriate drug disposal solution, whether contracted out or used in-house, is necessary for anything that is not water.

Learn

Our target survey audience was veterinary professionals specialized or particularly interested in anesthesia, as we hypothesized they would be the most knowledgeable about the topic. Although those most specialized on the topic (diplomates) were the most knowledgeable of the environmental impacts of anesthetic agents and most likely to discuss the topic, there appears to be substantial interest in and room for improvement and engagement regarding the topic, even within our respondents. As noted earlier, when asked if they would be interested in participating in CE regarding the topic of reducing the environmental impacts of anesthesia, 72% of respondents selected "yes," while only 5% selected "no." Based on other survey responses, priority should be given to free or low-cost, asynchronous CE that is accredited by the American Association of Veterinary State Boards Registry of Approved Continuing Education (or another regulatory body) that focuses on practical changes that can be made in a wide variety of hospitals. Online delivery was a priority to many respondents. Inclusion of sustainability topics should also be strongly considered during formal veterinary medical education, with both veterinarian and veterinary technician respondents noting an overall lack of education on this subject during their formal training. The fact that "comfort of use with anesthetic agents" ranked significantly higher in preference than "environmental sustainability" when building anesthetic protocols indicates that the latter will only become common if the profession educates on the former.

When evaluating CE topics, 3 areas of focus were broadly noted in this survey. These can be briefly stated as follows: techniques to replace or reduce inhalant anesthesia (and greenhouse gas emissions in general); life-cycle assessment in veterinary medicine (specifically anesthesia in this case); and implementation of reuse and recycling programs in the hospital. All of these had broad-based support in this survey and could be easily implemented in several settings. Interestingly, the provision of education on these topics at local CE meetings ranked higher in preference than other meetings, indicating a need for individuals to provide local CE. Priority should be given to identifying individuals that are willing to provide in-person education at a regional level, such as a regional or local manufacturer’s representative, as well as a centralized way to identify these “sustainability educators.” At the national level, inclusion of sustainability-related CE, especially when delivered both in person and online, could be an invaluable resource.

Opportunities also exist for better experiential learning in formal veterinary and technical training programs. Our survey, like others conducted previously, highlights the paucity of exposure to sustainable veterinary care in current curricula. However, teaching hospitals themselves adopting and modeling best practices in sustainable healthcare would be a more critical change than adding in didactic content on the topic. Only by graduating veterinary
professionals already comfortable with protocols, behaviors, and equipment that are less environmentally harmful can we ever expect these actions to be more widely adopted in private practice.

Finally, there remain several knowledge and resource gaps in veterinary-specific sustainability solutions. While much can be gleaned from studies in human medicine, the inherent challenges associated with delivering care to many different species necessitate veterinary-specific research. This includes clinical care topics, like anesthesia, and additional specialty-specific research to help us better understand barriers to the adoption of more environmentally friendly practices. Supporting the nascent research field of veterinary sustainability will not only provide valuable information for practitioners, but it will also help raise awareness and action on climate within our profession.

Beyond anesthesia

As potent greenhouse gases with viable reduction strategies are within our control (scope 1 emissions), reviewing and adjusting anesthesia protocols is an excellent place for clinics to begin their climate journey. It is important to recognize there are many additional actions that can be taken to reduce the negative externalities associated with veterinary care. It may be helpful for some veterinary teams to embed climate action within a wider sustainability framework. Sustainability has been broadly defined in United Nations' Brundtland Report as “[meeting] the needs of current generations without compromising the ability of future generations to meet their own needs.” The results from this study indicated only 72% of respondents either did not have a sustainability initiative in their workplace or were unaware of the existence of one, highlighting the need for implementing such initiatives within professional settings.

Environmental sustainability in veterinary workplaces was one of the topics discussed at the 2023 AVMA House of Delegates Meeting, suggesting a sustainability framing that aligns with national association priorities. To guide programmatic action on sustainability, the United Nations has 17 Sustainable Development Goals; these have been grouped into 6 Veterinary Sustainability Goals (VSGs) by a group of UK veterinarians to “highlight the roles of veterinary professionals in driving sustainability, and to unite our professions around actions required to address multiple challenges facing our society.” The 6 VSGs span a range of sustainability topics including warming, waste, water, wildlife, animal welfare, and human well-being.

Extensive resources for each of the VSGs are beyond the scope of this article, but the veterinary community is beginning to aggregate and disseminate resources that support each of these goals. For example, the recently formed Veterinary Sustainability Alliance maps their educational content to the VSGs. Reducing greenhouse gas emissions from anesthesia, as discussed in this article, is action toward minimizing warming. However, there are many other opportunities for greenhouse gas emission reduction at veterinary clinics, most notably energy use (reductions) and sourcing (renewables over fossil fuels). Procuring sustainably sourced materials and equipment is another way to reduce our clinical impact, as these make up about 60% of the carbon footprint of hospitals. A recent JAVMA article focused on conduct of a waste audit at a veterinary hospital and ways to reduce waste production in veterinary clinics, including the barrage of single-use plastics. Water conservation includes not only the reduction of use, but also protection of watersheds through responsible use of pharmaceuticals and other potential contaminants. Veterinary teams can be champions for wildlife and biodiversity by using their voices and their actions to support policies that conserve natural spaces needed to sustain them. Protecting the health and welfare of all animals, both wild and domestic, is a critical VSG as it supports both social and environmental priorities within our communities. We are inspired by efforts within the profession to expand access to veterinary care to meet this growing need. Finally, we need to support the well-being of people, particularly the most vulnerable and most marginalized, if we are to meet our goals of a sustainable future for all of us.

Conclusion

Globally, 2023 was the hottest year on record, and there is scientific consensus on the critical need to rapidly curtail greenhouse gas emissions. How we choose to deliver clinical care, including anesthesia, matters. Vaporizing one 250-mL bottle of isoflurane is equivalent to emitting 190.74 kg of CO₂, which is equal to driving 489 miles in an average gasoline-powered passenger vehicle or burning 214 lb of coal. While your use may not seem to matter on an individual level, your changes could be replicated tens of thousands of times across the profession as a whole. There lies opportunity in choice to achieve substantial reductions, both within a practice and throughout the field of veterinary medicine.

Acknowledgments

The authors would like to thank everyone who took the time to complete our online survey. Particularly informing, and inspirational, were the comments shared in open text. There were many excellent ideas and questions, some of which have been incorporated into this manuscript, while others have kindled complementary projects. We are grateful to be part of a profession dominated by such caring and enthused people. Thanks also to the anonymous supporters of the Climate Change Is Animal Health fund who provide funds in support of veterinary trainees at Colorado State University.

Disclosures

The authors have nothing to disclose. No AI-assisted technologies were used in the generation of this manuscript.

Funding

The authors have nothing to disclose.
References


**Supplementary Materials**

Supplementary materials are posted online at the journal website: avmajournals.avma.org.