WHITE PAPER

Anesthesia and climate change
Why anesthetists should care

The environmental footprint of anesthetic agents

Greenhouse gases are the main drivers of climate change. Anesthesia practice and contemporary technologies can help anesthetists reduce anesthetic waste to minimize the negative impact on our environment.

Author: Dr. Alain F Kalmar, MD, PhD

First, do no harm

Reducing our environmental impact can protect both patients and planet, and save money

Human activity is drastically changing our atmosphere[1,] and anesthetic agents contribute to climate change.[4] By implementing relatively simple changes in choice of anesthetic agent or ventilator settings, every individual anesthetist can make a difference for our planet.

Experts agree: human activity is changing our planet[1]

The Earth is becoming warmer overall. The 10 hottest years ever recorded have occurred since 1998, with seven of the 10 occurring between 2010–2017.[2] This temperature increase is resulting in a dramatic change in ecosystems, leading to unpredictable weather patterns, devastating storms, biodiversity loss, long-term droughts, wildfires, and desertification.

The Intergovernmental Panel on Climate Change, operating under the authority of the United Nations, identified human-caused emissions as the primary source of increases in atmospheric greenhouse gases. These levels have increased by more than 40% in the last 150 years.[1]

How do anesthetic agents contribute to climate change?

Modern anesthetic agents are potent greenhouse gases. In typical use, less than 5% of the total delivered halogenated anesthetic is metabolized by the patient; the remainder is routinely vented into the atmosphere through the operating room scavenging system.[3]

Two main attributes determine the global warming potential (GWP) of a volatile agent: the atmospheric half-life, and the potency of the agent to capture infrared light in addition to the natural greenhouse gases. There is a significant divergence in each agent's global warming effects due to differences in heat-trapping capacity and atmospheric half-life.

>95%

"... probability that greenhouse gases have caused increases in the Earth's temperature.[1]

The global warming potential of a halogenated anesthetic is up to 3,700 times greater than CO_2.[4]

Halothane and isoflurane are halogenated chlorofluorocarbons (CFC) while sevoflurane and desflurane are hydrofluorocarbons (HFC), all known as high-GWP gases. These gases have GWP numbers in the hundreds or thousands.[4] This means that for their mass, they trap hundreds to thousands of times more heat than CO_2, which is the baseline by which all other emissions are measured.[6]

By definition, the GWP of CO_2 is 1. In comparison, 1 kg of nitrous oxide (N_2O) has a GWP of 296, the same heat trapping effect as 296 kg of CO_2 (Table 2).

The atmospheric concentrations of anesthetic gases – particularly desflurane – are rapidly increasing (Table 1).[7] There are dramatic differences in the length of time that these gases remain in the atmosphere. While sevoflurane clears from the atmosphere relatively quickly, N_2O emitted today remains in the atmosphere for more than 100 years, on average (Table 3).[6]

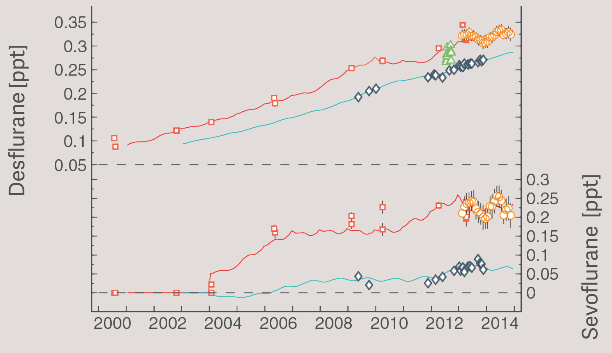

Table 1: Atmospheric record of halogenated anesthetics. Red line: Northern hemisphere. Blue line: Antarctica[5]

Anesthetic gases are typically excluded from environmental agreements because of their medical necessity. Nonetheless, the effects of anesthetic agents are significant. The anesthesia practice in an average midsize hospital has an environmental effect comparable to that of up to 1,200 cars per year.[8]

Table 2: Global Warming Potential (GWP)[3]

Molecule	GWP (100y)
CO_2	1
CH_4	28
N_2O	296
Isoflurane	350
Sevoflurane	575
Desflurane	1526
SF_6 (sulfur hexafluoride)	23,500

Table 3: Tropospheric lifetime of inhaled anesthetics[4]

Compound	Lifetime (y)
Sevoflurane	1.2
Isoflurane	3.6
Desflurane	10
Nitrous oxide	114

2 weeks of desflurane use* equals driving a car around the globe!

*8h/day at a Fresh Gas Flow (FGF) of 2 L. [4,8]

Other factors that determine the climate effects of anesthetic agents

Ventilator settings also dictate the amount of volatile anesthetic waste. The combined effect of agent choice and ventilator setting results in a strikingly divergent environmental impact for an equal depth of anesthesia.

The heat-trapping effects of eight hours of volatile anesthetic use is comparable to driving an average car between 100–13,000 km (60–8,000 miles), depending on the choice of volatile agent and ventilator setting.

Using another comparator: In a timeframe of only 5 days of anesthesia of 8 hours per day with 1 MAC sevoflurane at 2 L FGF, an anesthetist emits an equivalent of 280 kg CO_2. The same period with 1 MAC desflurane at 6 L FGF emits 16,000 kg of CO_2 equivalent. As such, an anesthetist can unknowingly emit in one week as much CO_2 equivalents through volatiles alone as an average US citizen emits in a whole year. [4]

Some anesthetic gases also damage the ozone layer

In addition to greenhouse effects, some volatile anesthetics also have the capability to deplete the ozone layer.

CFCs, such as halothane or isoflurane, eventually reach the upper stratosphere into the ozone layer. When a CFC is hit by an ultraviolet (UV) photon from sunlight, a free chlorine radical is released. The chlorine acts as a catalyst to turn ozone (O_3) into oxygen (O_2), after which the chlorine radical is regenerated. This cycle can be repeated millions of times, and as such, a single CFC molecule can destroy millions of ozone molecules before the chlorine radical is finally neutralized. 80% of all stratospheric ozone depletion is attributed to released CFCs. Sevoflurane and desflurane lack chlorine atoms, and have therefore no effects on the ozone layer. [17]

How can we reduce the impact of anesthetic gases on climate change?

It's clear that the impact of anesthetic agents is significant. Lacking a standardized global approach, improving awareness of the impact any individual anesthetist can make, is an essential first step to dramatically reducing the emissions from the anesthesia sector.

The impact of greenhouse gas emissions from anesthetic agents can easily be reduced significantly by adhering to a few basic principles. These changes can be made without risking patient safety.

Change the anesthetic agent

Not all anesthetic agents have the same GWP nor are they used equally. Because both the MAC and the intrinsic GWP dictate the ultimate effect, desflurane has a 26-fold effect as sevoflurane for an equal level of anesthesia with an equal FGF. As such, one hour of anesthesia at equal ventilator settings and depth of anesthesia with desflurane emits the same amount of heat trapping effect as 26 hours of anesthesia with sevoflurane.[4]

Replacing desflurane with sevoflurane is therefore an obvious first step that can dramatically reduce any anesthetist's greenhouse gas emissions.

Reducing fresh gas flow to reduce consumption

Minimizing the fresh gas flow will decrease the consumption of volatile anesthetics and their emission in the atmosphere. In low-flow anesthesia – conventionally defined as a fresh gas flow of less than 1.0 L/min – a rebreathing system uses less anesthetic agent than open systems. Such settings emit less gas into the atmosphere, and improve the flow dynamics of the inhaled air.

Reducing the fresh gas flow (FGF) during general anesthesia is a simple strategy that leads to cost savings from reduced consumption of volatile anesthetics.[9] Lower fresh gas flows can be achieved by manual adjustments of the gas settings, or by using an automated gas control function.

Table 4 shows that one hour of sevoflurane at 2% with a fresh gas flow of 2 L/min emits a heat trapping effect equal to almost 7 kg of CO_2. In contrast, one hour of desflurane at 6% with the same FGF of 2 L, emits a heat trapping effect equal to almost 187 kg of CO_2.[8]

Table 4: Global warming impact of one hour of volatile agent use

Anesthetic	FGF (L/min)	Grams/hour	GWP_{20}	CDE_{20} (g/h)	$Ratio_{20}$ CDE
2% sevoflurane	2	20.0	349	**6980**	1
1.2% isoflurane	0.5	2.8	1401	3881	0.6
	1	5.5	1401	7762	1.1
	2	11.1	1401	15,551	2.2
6% desflurane	0.5	12.6	3714	46,796	6.7
	1	25.2	3714	93,593	13.4
	2	50.4	3714	**187,186**	26.8

Low-flow anesthesia with automated gas control
An automated gas control function automatically adjusts FGF and agent concentration to reach set end-tidal targets for anesthetic agent (EtAA) and inspired O_2. This permits a combination of extremely stable levels of end-tidal volatile concentration with minimal consumption. The system automatically ensures the desired target values for inspired oxygen and EtAA, while efficiently limiting wastage. It provides simultaneously a large reduction in the consumption of anesthetic agent and a completely controlled and stable administration of volatile anesthetics, permitting both maximal patient safety and volatile agent conservation.[10] In addition, even in high fresh gas flow setting, some of these modern ventilators will automatically restrict the fresh gas flow to the minute volume, and as such limit wastage even in the open flow setting.

Advantages of automated gas control
Automated gas control reconciles safe and efficient induction and maintenance of anesthesia with minimized agent wastage.

Automated gas control guarantees a secure combination of stable volatile administration levels with minimal flow without the need for constant adjustments of the ventilator settings, improving workflows. A study comparing manual-controlled low-flow anesthesia to automatic-controlled delivery showed that 244 adjustments were required in manual mode to reach and keep adequate anesthesia levels compared to zero when using automated gas control.[11]

Automated control of gases also reduces the risk of hypoxic mixtures or inappropriate depth of anesthesia and ultimately promotes patient safety.[10]

A higher fraction of rebreathing will also:

- improve the flow dynamics of inhaled gases.
- increase mucociliary clearance.
- maintain body temperature and reduce water loss.

Significant cost savings with lower flows

The cost of anesthetic agent accounts for a large portion of the total cost of ownership (TCO) for anesthesia machines. Implementation of a low-flow strategy easily permits a reduction in consumption of volatile anesthetics by 25–50% compared to conventional fresh gas flow (2L–4L/min), while providing a more stable level of F_iAA and F_iO_2 if using automated gas control.[8] With an average of 10 anesthesia devices running 2000 hours/year, this would account to a reduction of 170,000 to 680,000 ml/year.[8,13] At an estimated price of 0.50 $/ml, this represents a saving of $85,000 to $340,000/year.*

Hospitals have reported significant agent reductions by changing to a low-flow strategy using automated gas control (AGC), many between 30–42%.[12] This results in significant cost savings, as well as dramatic reductions in environmental impacts.

Cost saving/year*

$ 340,000

One doesn’t really appreciate how thin the atmosphere is, to what extent we are capable of destroying the planet – to what extent we need to protect it.

Thomas Pesquet, Astronaut, European Space Agency (ESA)

Simple actions to limit your hospital's ecological impact from anesthetics

In summary, there are easy ways to reduce your facility's environmental footprint without compromising patient safety. By choosing environmentally responsible agents and delivery modes, each anesthetist can reduce their environmental impact at a level equivalent to the total emissions of 1 to 50 average US citizens.

1. **Minimize desflurane usage**
   Keeping all parameters equal, but changing the agent from desflurane to sevoflurane can reduce your environmental impact by as much as 96%.[14]
2. **Use low-flow anesthesia when possible**
   Lower fresh gas flows (FGF), preferably with an automated gas control, greatly reduce agent consumption, delivering positive outcomes for patients, hospital spending, and the environment.
3. **Avoid spills**
   It may sound obvious, but avoiding spills of liquid volatiles can reduce a facility's environmental footprint.
4. **Avoid using nitrous oxide**
   Nitrous oxide is used in higher concentrations than other anesthetic agents and has an extremely long atmospheric half-life. Limiting use of N_2O can dramatically reduce greenhouse gas emissions.[15,16]

Adherence to these few basic principles can result in a 99% reduction in greenhouse gas emissions while preserving the convenience and advantages of volatile anesthesia.

Alain Kalmar biography

Dr. Kalmar is an MD graduate of Ghent University. He completed a degree in biomedical engineering before training in anesthesiology at Ghent University Hospital. He obtained a PhD in Medical Sciences at Groningen University, a PhD in Engineering at Ghent University and an MBA at Vlerick Business School. He has a particular interest in cerebral hemodynamics and medical device development, and in recent years he has been engaged in growing awareness of the atmospheric effects of volatile anesthetics. He is staff anesthetist and principal investigator at AZ Maria Middelares in Ghent, Belgium, and academic consultant at the faculty of Health, Ghent University.

References

1. http://ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf, http://www.ipcc.ch/
2. "Global Climate Report – Annual 2017". NOAA. Retrieved 18 January 2018
3. Gadani H, Vyus A. Anesthetic gases and global warming: Potentials, prevention and future of Anesthesia. Anesth Essays Res. 2011; 5: 5–10.
4. Sulbaek Anderson MP, Sander SP, Nielsen OJ, et al. Inhalation anaesthetics and climate change. Br J Anaesth. 2010;105:760-766.
5. Vollmer MK, Rhee TS, Rigby M, et al. Modern inhalation anesthetics: Potent greenhouse gases in the global atmosphere. Geophys Res Lett. 2015;42:1606-1611.
6. EPA.gov
7. Charlesworth M, Swinton F. Anaesthetic gases, climate change, and sustainable practice. The Lancet. 2017;1:e216-e217.
8. Ryan SM, Nielsen CJ. Global Warming Potential of Inhaled Anesthetics: Application to Clinical Use. Anesth Analg. 2010; 11: 92-98.
9. Epstein RH, Dexter F, Maguire DP, et al. Economic and Environmental Considerations During Low Fresh Gas Flow Volatile Agent Administration After Change to a Nonreactive Carbon Dioxide Absorbent. Anesth Analg. 2016;122:996–1006.
10. Tay S, Weinberg L, Peyton P, et al. Financial and environmental costs of manual versus automated control of end-tidal gas concentrations. Anaesth Intensive Care 2013; 41: 95-101.
11. Lucangelo U, Garufi G, Marras E, et al. End-tidal versus manually-controlled low-flow anaesthesia. J Clin Monit Comput. 2014; 28: 117-121.
12. AGC greatly reducing anesthetic agent usage, Getinge case studies, MX-6599 rev05.
13. Laster MJ1, Fang Z, Eger EI 2nd. Specific gravities of desflurane, enflurane, halothane, isoflurane, and sevoflurane. Anesth Analg. 1994; 78: 1152-1153.
14. Yasny JS, White J. Environmental implications of anesthetic gases. Anesth Prog. 2012 Winter;59(4):154-158.
15. Axelrod D, Bell C, Feldman J, et al. Greening the Operating Room and Perioperative Arena: Environmental Sustainability for Anesthesia Practice. American Society for Anesthesiologists. Revised 2017. Anest Prog 2012; 59: 154-158.
16. Sherman J, Le C, Lamers V, Eckelman M. Life cycle greenhouse gas emissions of anesthetic drugs. Anesth Analg. 2012; 114: 1086-1090.
17. Langbein T, Sonntag H, Trapp D, et al. Volatile anaesthetics and the atmosphere: atmospheric lifetimes and atmospheric effects of halothane, enflurane, isoflurane, desflurane and sevoflurane. Br J Anaesth. 1999; 82: 66-73.

Manufacturer · Maquet Critical Care AB · 171 54 Solna, Sweden · Phone: +46 (0)10-335 00 00 · info@getinge.com

www.getinge.com