Towards zero carbon healthcare: anaesthesia

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What you need to know

- Sevoflurane and isoflurane have smaller atmospheric impacts than desflurane and nitrous oxide
- Intravenous anaesthetic agents have minimal atmospheric impacts, but drug waste and urinary excretion of drugs and metabolites causes pollution in soil and ground water
- Nitrous oxide is a common cause of medication waste and greenhouse gas emissions due to leaks in supply systems, over-ordering, and unused gas in cylinders returned to suppliers being vented to the atmosphere

Providing anaesthesia for approximately 310 million surgical procedures worldwide every year, 1 and contributing to peri-operative medicine, critical care, and pain management, generates emissions of greenhouse gases (GHGs) and vast amounts of waste.

In this paper, we suggest ways that anaesthesia teams can mitigate their environmental footprints while integrating their primary aim of providing safe, high quality patient care.

What is the evidence?

Life cycle assessments of the “carbon footprints” of anaesthetic equipment, medications, and procedures, 2 3 global endorsement of sustainable anaesthesia practice, 4 and expanding literature on the atmospheric effects of inhalational anaesthetics 5 -8 show the problem; however, strong evidence for specific solutions is relatively sparse and novel compared with other aspects of healthcare. 4 9 10

What is the problem?

Inhalational anaesthetics are greenhouse gases 5 7 Anaesthetic gases have markedly different global warming potentials (GWP)s, eg, those of sevoflurane and isoflurane are far lower than those of desflurane.

System level initiatives, such as the Greener NHS plan, aim to reduce the use of desflurane and nitrous oxide (N2O), which have the highest CO2e at clinically relevant doses (infographic). 11 The CO2e of less clinically potent anaesthetic agents (eg, desflurane and N2O) is magnified because more is needed to achieve the same clinical effect (table 1). 5

<table>
<thead>
<tr>
<th>Agent</th>
<th>GWP20 (CO2e)</th>
<th>GWP100 (CO2e)</th>
<th>Potency (MAC, %)</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sevoflurane 6</td>
<td>508</td>
<td>144</td>
<td>1.8</td>
<td>~70% volatile agent sales 12</td>
</tr>
<tr>
<td>Isoflurane 5</td>
<td>1800</td>
<td>510</td>
<td>1.2</td>
<td>~10% volatile agent sales 12</td>
</tr>
<tr>
<td>Desflurane 5</td>
<td>6810</td>
<td>2540</td>
<td>6.6</td>
<td>~20% volatile agent sales 12</td>
</tr>
<tr>
<td>Nitrous Oxide 513</td>
<td>289</td>
<td>273</td>
<td>104</td>
<td>Diminishing in UK anaesthesia practice; mostly used in maternity, dentistry and emergency medicine 14</td>
</tr>
</tbody>
</table>

MAC = minimum alveolar concentration; the mean percentage end-tidal anaesthetic agent concentration at which a patient of 40 will be unresponsive to surgical stimulation

Case 1—A 30 year old woman attends the obstetric anaesthetic clinic at 36 weeks’ gestation. This is her first pregnancy. The baby was in the breech position, and, after an unsuccessful attempt to turn the baby, she has been offered the option of planning for a vaginal delivery or a caesarean section. The anaesthetist discusses the anaesthetic and analgesic options for both and reassures the patient that all options appropriate to the mode of delivery are safe. Her priority is a safe delivery but she recently read online that both anaesthetic agents and “gas and air” contribute to global warming. Concern about the world in which her child will grow prompts her to ask which is the “greenest” option.

Case 2—A 55 year old man is listed for total knee replacement for osteoarthritis, which is limiting his mobility and affecting his ability to pursue his passion for fell walking. When offered a choice of spinal or general anaesthesia, he says he has no preference providing both are safe, but he has noticed the enormity of hospital waste and asks which is the most sustainable option.

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104273289
6.625406810
513
~20% volatile agent sales 12
The ongoing release of anaesthetic agents at a rate that exceeds their atmospheric breakdown means that atmospheric concentrations are rising. Although GWP100 (ie, GWP over 100 years) is the most often quoted value, the 100 year time horizon does not reflect the dynamic (and worsening) situation. All inhaled agents except N₂O exert most of their greenhouse gas effects within the first decade following release, so shorter time horizons may be more appropriate when assessing climate impacts.¹⁵

**Waste-intensive practice**

Most supplied N₂O is wasted, either because of leaks in the cylinder manifold or pipes, or because cylinders are returned to the supplier part full.¹⁶¹⁷ Returned cylinders cannot currently be “topped up,” so surplus gas is vented to the atmosphere.

Anaesthesia practice also generates landfill, microplastics, and noxious pollutants associated with equipment disposal, packaging, single use items, and clinical waste.² Equipment for monitoring and for vascular access, airway devices (eg, tracheal tubes), and numerous medications in pre-operative, operative, peri-operative, and postoperative care all involve multiple single use items, which may account for the greatest proportion of the total environmental impacts.²¹⁸⁻²² Sustainable alternatives to plastics and sterile packaging are currently lacking.

**Reduce anaesthesia agent waste**

Automated control of inhaled anaesthetic agent delivery, and vapour capture technology can remove inhalational vapours (but not nitrous oxide) from waste anaesthetic gas.⁷ However, further research is needed.²⁷ Furthermore, in many jurisdictions captured agents cannot yet be re-administered, limiting current benefits.

Catalytic destruction technology (known as “cracking”), in which a catalyst breaks down the N₂O exhaled by the patient into nitrogen and oxygen, offers a way to reduce its environmental impact when used as an analgesic (eg, in labour),²⁸ but the proportion of gas “cracked” depends on the proportion of exhaled breath that can be directed into the machine, eg, via a facemask. Mitigating institutional waste (eg, leaks from N₂O manifolds) requires collaboration between anaesthesia teams, those involved in procuring and storing drugs and equipment, and colleagues responsible for estates and infrastructure.¹⁶¹⁷

Abandoning the routine use of desflurane and N₂O can reduce climate impacts without affecting patient outcomes.²⁹ Since direct emissions of GHGs are avoided, the carbon footprint and atmospheric pollution of total intravenous anaesthesia (TIVA) (fig 2) is substantially lower than any inhalational anaesthetic, despite the increased use of disposable items such as syringes and syringe pumps.⁷³⁰ However, the ecological and aquatic toxicity of intravenous agents and their metabolites is a concern.³¹ Adoption...
of TIVA in institutions where it is not already widely used requires training and equipment procurement, which can be prohibitively expensive.

Regional anaesthesia may have a lower carbon footprint than general anaesthesia as it minimises medication and use of airway equipment. However, consider each component of regional anaesthesia technique separately, as, depending on the carbon intensity of electricity production, the carbon footprint of the neuraxial (ie, spinal or epidural) anaesthesia can be similar to that of low flow sevoflurane general anaesthesia, owing to the carbon footprints of sterile equipment reprocessing and supplemental oxygen administered intra-operatively. Anecdotally, wide variation exists in practices for regional anaesthesia. For example, performing spinal anaesthesia with a full "surgical scrub" is considered standard practice in the UK, but this is not typical for many institutions in the US.

Intra-operatively, N₂O can be substituted for alternatives such as remifentanil or regional anaesthesia. However, for labour analgesia this may require a marked change in practice (for example, the need for intravenous access and continuous fetal monitoring). In maternity services where N₂O is already an established analgesic technique it is likely to have a role for some time to come.

Take an integrated approach
Systemic changes, such as optimising drug formularies and equipment, and creating cultures that value sustainability, would have notable effects—for example, removing desflurane from drug formularies. However, explanation, behavioural suggestions, and making the “greener” option easier, may be easier to instigate. In one author’s institution, explaining desflurane’s GWP, together with moving desflurane vaporisers from the anaesthetic machines to a nearby cupboard (thereby requiring practitioners to make an active decision to use them), led to a noticeable reduction in desflurane use.

Collaborative work with hospital’s quality improvement teams, equipment manufacturers (including designing greener alternatives to plastics and sterile packaging), and colleagues in other institutions is also needed.

With further research, evaluation, and patient engagement, aim to:

- Better define the role and impact of novel technologies (eg, vapour capture/destruction, N₂O cracking)
- Understand how best to achieve sustainable changes in practice
Build on existing life cycle assessments for anaesthetic drugs and procedures.\textsuperscript{2-31}

Discover how anaesthetists in resource limited settings can achieve more financially and environmentally sustainable anaesthesia without compromising patient care. This may require financial support for infrastructure development and equipment procurement.

Understand patient perceptions about the role of sustainability in making decisions about anaesthetic choice.\textsuperscript{11-26}

**Make shared decisions**

It is difficult to justify advising a patient to decide about anaesthesia and analgesia based on sustainability alone. However, more sustainable options (ie, regional anaesthesia, TIVA) may have concurrent patient benefits,\textsuperscript{2-26} and if the patient desires a spinal anaesthetic, an open discussion on minimising sedation and oxygen requirement may be beneficial.\textsuperscript{2}

Peri-operative care is daunting and extraordinary from many patients’ perspectives. It may be more reasonable to discuss environmental anaesthesia impacts in shared decision making for scheduled minor surgery than for emergency or major procedures.\textsuperscript{4, 26}

**Case 1 discussion**

Childbirth is often unpredictable. The lowest carbon option would be to have an uncomplicated vaginal delivery without pharmacological analgesia. But labour analgesia needs to be universally available, and uncomplicated childbirth cannot be guaranteed. A prolonged labour using N\textsubscript{2}O for anaesthesia followed by an emergency caesarean section would generate the largest carbon footprint.\textsuperscript{2, 5-8, 34}

If the patient opted to plan for a vaginal delivery, analgesia with remifentanil or an epidural would have a lower carbon footprint than N\textsubscript{2}O, unless the labour is very short (ie, less than half an hour), in which case the high GWP of N\textsubscript{2}O may theoretically be offset by avoiding the use of disposable items, intravenous access, and monitoring.\textsuperscript{36} If remifentanil or epidural analgesia were used, the patient would need to be cared for in a consultant led unit, but this may not align with their wishes. Furthermore, remifentanil and epidural analgesia carry additional risks and may not be suitable for all patients. Intramuscular opioids (eg, diamorphine, pethidine) involve little single-use equipment and do not mandate continuous monitoring, so are likely to have the lowest environmental impact, but are of limited efficacy.

The “anaesthesia” component of a caesarean section would likely have a lower carbon footprint than using N\textsubscript{2}O for (prolonged) labour analgesia,\textsuperscript{7, 14} but considering the full procedure, operative delivery is likely to have a greater environmental impact than an uncomplicated vaginal delivery owing to the surgical equipment, operating theatre resources (including energy), and longer hospital stay required.\textsuperscript{9, 35} Home births may use fewer resources than hospital births, but they are generally restricted to those at lower risk of complications. As this patient has a known breech presentation, a home birth would not be advisable, and any environmental comparison would not be appropriate in terms of patient safety and healthcare quality.

**Case 2 discussion**

Options for this patient’s care are more predictable than for the patient in case 1. General or spinal anaesthesia would be clinically appropriate for this lower limb procedure of relatively short duration.

If general anaesthesia were used, TIVA would generate the lowest carbon footprint,\textsuperscript{7, 16} with sevoflurane-based inhalational anaesthesia using minimal fresh gas flows via a circle system as the next best option from a climate perspective. However, TIVA leads to the production of more plastic and drug waste than inhaled anaesthesia, and if volatile capture technology were used, the carbon footprint of a low flow sevoflurane anaesthetic could theoretically be similar to that of TIVA, but this remains to be shown in practice.\textsuperscript{1} Using desflurane and/or N\textsubscript{2}O would substantially increase the carbon footprint of general anaesthesia, and these should be avoided given the absence of clear clinical benefits.

Spinal anaesthesia can generate a similar quantity of waste to inhaled general anaesthesia but does not release greenhouse gases at the point of use.\textsuperscript{2} Spinal anaesthesia may therefore be a lower carbon option than a general anaesthetic, but this is not always the case. Because of the need to maintain a sterile field around the site of lumbar puncture, many institutions recommend “strict asepsis,” which involves a surgical scrub, skin preparation, and sterile drapes around the area. Supplemental oxygen may be administered, particularly if the patient receives sedation in addition to spinal anaesthesia. As oxygen production and equipment sterilisation require electricity, in regions with a high carbon energy mix (eg, Australia, China) it becomes more likely that spinal anaesthesia may be a higher carbon option than a low flow sevoflurane anaesthetic, whereas in regions with lower carbon electricity (eg, Norway, British Columbia) practitioners can be more confident that spinal anaesthesia is a superior option from a climate perspective.\textsuperscript{2}

**Education into practice**

- How does the environmental impact of a patient’s healthcare feature in your shared decision making discussions?
- Which commonly used anaesthetic and analgesic techniques could be made more sustainable, without adversely affecting patient care?

**How this article was created**

This article brings together the perspectives of an international group of clinicians working in anaesthesia (CS, RS, FM), and a patient representative (RK). We based this work on academic literature from both the clinical and physical sciences, (inter)national policy, professional guidelines, and ongoing discourse to reflect current areas of debate and development. The case studies were developed from a combination of the experiences of the authors to be representative of real life situations. We based the advice on clinical experience and patient perspectives, especially RK’s role as a patient advocate in the maternity setting. We summarised recent narrative literature reviews undertaken by FM, CS, and colleagues, drew on RS’s work on global warming potentials of anaesthetic agents and sustainable procurement, CS and FM’s work on reducing the emissions of nitrous oxide, and the ongoing work of all authors to advocate for more sustainable practices in their areas of work. This article is part of the Towards zero carbon healthcare series that is a collaboration between The BMJ and CSH.

**How patients were involved in the creation of this article**

Author RK has been a patient, and has extensive experience of working as a patient advocate as chairperson of Morecambe Bay Maternity Voice Partnership, and as an engagement officer for Healthwatch Cumbria. We drew extensively on RK’s experiences to create the fictionalised case studies and in considering how best to discuss the environmental impacts of practice with patients. She also made substantial contributions to the design of the article and reviewed and revised the text to make it more relevant and accessible to patients and the public.
The paper was further revised in response to external patient reviewer comments, including more thoroughly explaining the risk / benefit considerations of labour analgesia, and clarifying the explanation of behavioural nudges.

Environmental impact of anaesthesia

Uses and alternatives for inhaled anaesthetics

All commonly used inhalational anaesthetic agents are greenhouse gases that contribute to the climate crisis. Their use is very embedded in clinical practice, but there are alternatives such as total intravenous anaesthesia and regional techniques. These usually have substantially lower climate impacts, despite the greater use of disposables such as syringes. This graphic offers a comparison of some of the most commonly used agents.

<table>
<thead>
<tr>
<th>Anaesthesia Type</th>
<th>Gas</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhaled general anaesthesia</td>
<td>Isoflurane</td>
<td>Used for maintenance</td>
<td>High potency</td>
</tr>
<tr>
<td></td>
<td>Desflurane</td>
<td>Inexpensive</td>
<td>Low potency</td>
</tr>
<tr>
<td></td>
<td>Sevoflurane</td>
<td>Slow onset and offset</td>
<td>Very rapid onset and offset</td>
</tr>
<tr>
<td></td>
<td>Nitrous Oxide</td>
<td>Adjunct for maintenance</td>
<td>Analgesic properties</td>
</tr>
</tbody>
</table>

- Drug levels can be easily monitored by measuring the partial pressure of agents at end-expiration.
- Increased risk of post-operative nausea and vomiting. Volatile agents can provoke malignant hyperthermia in susceptible patients.
- Diffuses into gas containing spaces (such as gastrointestinal tract and middle ear), causing distension.

Inhaled general anaesthesia

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Intravenous general anaesthesia

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<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intravenous general anaesthesia</td>
<td>Propofol</td>
<td>Used for maintenance</td>
<td>Potential for ecological contamination from plastics and waste medications</td>
</tr>
<tr>
<td></td>
<td>Remifentanil</td>
<td>Used for induction</td>
<td>Adjunct for maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Used for sedation</td>
<td>Adjunct for induction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Smooth onset and offset</td>
<td>Potential analgesic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suppresses airway reflexes</td>
<td>Rapid onset and offset</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Requires specialised infusion equipment for maintenance</td>
<td>Suppresses coughing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can have toxic effects on aquatic life</td>
<td></td>
</tr>
</tbody>
</table>

- CO2e = Carbon dioxide equivalent
- Assuming 130g CO2 emitted per mile, equivalent to a modern small family car in the UK

Regional techniques

<table>
<thead>
<tr>
<th>Anaesthesia Type</th>
<th>Gas</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional techniques</td>
<td>Nerve blocks, epidural and spinal anaesthesia</td>
<td>Used during surgery intra- and post-operative</td>
<td>Can provide complete analgesia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimise the use of medications</td>
<td>Surgery can be performed awake</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some techniques generate a lot of plastic waste</td>
<td>Risk of procedural failure</td>
</tr>
</tbody>
</table>

Labour analgesia

Limited information is available, but opioid analgesics and epidurals have lower carbon footprints than nitrous oxide in most circumstances.

The BMJ has judged that the authors have no disqualifying financial ties to commercial companies that are relevant to this paper. The authors declare the following other interests: CS is a member of the Association of Anaesthetists Environment and Sustainability Committee and the Health Education England North West Sustainability Healthcare Working Group. He has received travel expenses from the Association of Anaesthetists and Health Education England to attend professional meetings to speak on sustainable healthcare. He has received a grant from the Manchester Foundation Trust Charity to run the ‘Greener Operations’ research priority setting partnership.
Manchester University NHS Foundation Trust, where CS practices, has received a cost free loan of nitrous oxide cracking equipment and associated consumables for clinical evaluation purposes from Medclair Invest and BPR Medical. RK is a member of the steering group of the Greener Operations research priority setting partnership, and has received patient and public involvement payments for this work. RS is vice chair of the American Society of Regional Anesthesia Green Special Interest Group and chair of the Canadian Anaesthesiologists’ Society Section on Environmental Sustainability. FM has received grants from Australia and New Zealand College of Anaesthetists, National Health and Medical Research Council and the Medical Research Future Fund for research on environmental sustainability and healthcare. He is a member of the Australia and New Zealand College of Anaesthetists Sustainability Network and the Australia and New Zealand Intensive Care Society Environmental Sustainability Planning Group, and is vice-chairperson of sustainable healthcare for Doctors for the Environment Australia.

The cases in this article are fictitious and therefore no consent was needed, written consent was provided for the photographs in Figure 1.

Contributorship and the guarantor: The article was designed by CS, RK, and FM. All authors contributed to reviewing and interpreting the relevant literature, writing, and revising the article: CS and RK created the boxes, which were reviewed and revised by RS and FM. RS was the contact for patient involvement. All authors have approved the final version to be published and agree to be accountable for all aspects of the work. CS is the guarantor. The author thanks Frances Mortimer for her original concept of the work, Drs Teresa MacCarrick, Simon Maguire, and Ann Harvey for their assistance with producing the photographs, and David Buckley for drawing the graphic of the circle system.

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