5. Anaesthesia

Section key points

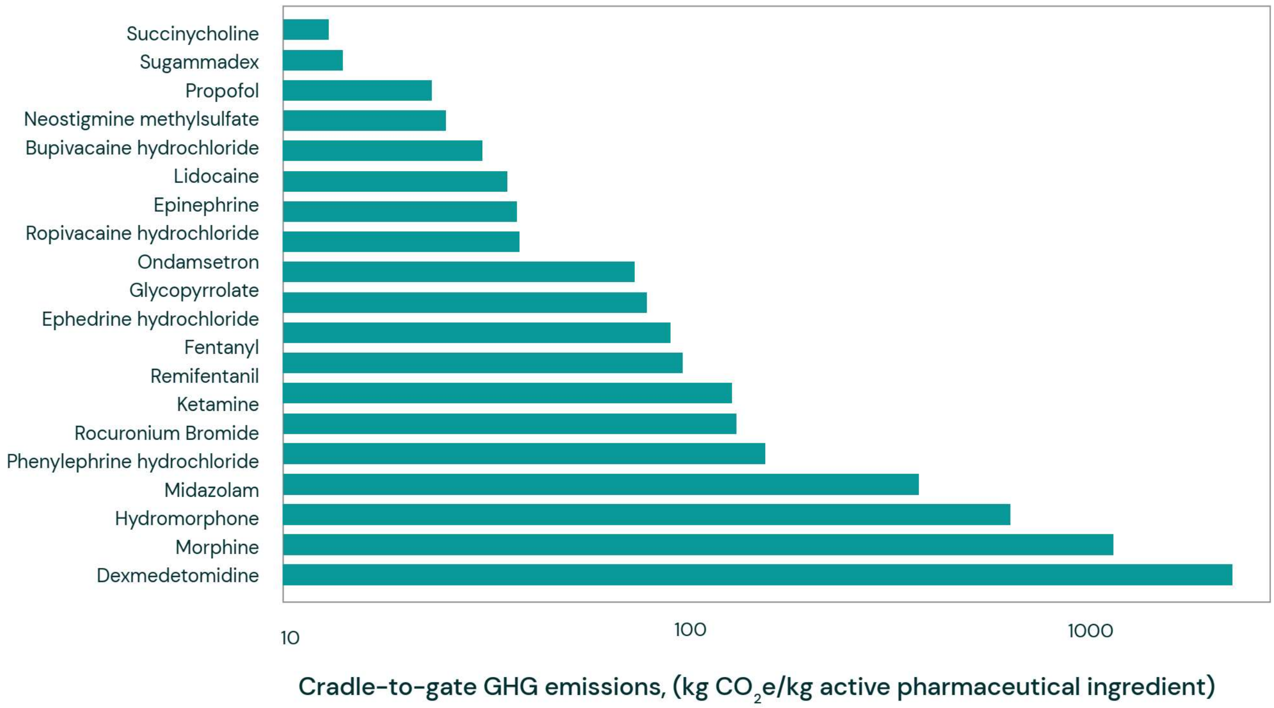
- Local, regional, and intravenous anaesthetic techniques may be associated with lower carbon footprint, compared with inhaled anaesthetics.
- Where inhaled anaesthetics are used, sevoflurane followed by isoflurane hold lowest global warming potential, and environmental impact can be further reduced through minimising fresh gas flows.
- Desflurane should not be used, bar exceptional circumstances.
- Nitrous oxide is another powerful greenhouse gas, and emissions can be minimised through non-pharmacological methods to manage patient anxiety, decommissioning of centrally piped nitrous oxide (and substitution by portable cylinders), and nitrous oxide cracking technologies.
- Pharmaceutical wastage can be reduced through only opening what is needed; all pharmaceutical waste should be disposed of appropriately.
- There is currently a lack of robust evidence on capture rates of volatile capture technologies for anaesthetic gas waste.

Since the discovery that inhaled anaesthetics are potent GHGs, efforts to mitigate pollution have been underway in the field of anaesthesia. This includes efforts to find low emissions substitutes, and to improve efficiency of existing materials.[255,256] Potential areas of improvement include: **minimising use of inhaled anaesthetics (including by using total intravenous anaesthesia (TIVA)), local, and regional anaesthesia as first-choice techniques**; shifting to reusable medical devices whenever clinically safe and feasible to do so; and reducing waste generation.[257-260] Surgeons have a role to play in ensuring that perioperative environmental impact is minimised by understanding where hotspots are, and facilitating environmentally preferable anaesthesia practices.[38]

5.1 Local, regional, and intravenous anaesthesia

Anaesthetic drugs used by surgeons and anaesthetists for local or regional techniques, and for intravenous administration, have embodied carbon emissions several orders of magnitude lower than inhaled anaesthetic drugs. This suggests they are environmentally preferable to inhaled anaesthetic drugs at equivalent doses (Figures 8 and 9)[261,262] even accounting for GHG emissions associated with manufacture, packaging, transportation, and waste.[261] However, care must be taken to ensure that **supplies are not opened or used unnecessarily**, otherwise the relative advantages of non-inhaled anaesthetic approaches will not be realised.[263] Surgeons can prioritise these approaches when clinically appropriate, including through ensuring there is sufficient time for performance of regional anaesthesia, and providing an accurate estimate of surgical time at the team brief, to allow dosing of regional anaesthesia to be optimised. Evaluating the environmental impact of different anaesthetic techniques has been identified as a research priority by the James Lind Alliance.[264]

Figure 8: Cradle-to-gate greenhouse gas emissions per kg drug for common injectable drugs used in anaesthesia care



Adapted from Parvatker et al.[262] This was a cradle-to-gate analysis, meaning the material and energy associated with raw material extraction and synthesis were included and evaluated, but the study excluded formulation, packaging, distribution, use, excretion or discard of unused drugs. Note that this accounts for the active pharmaceutical ingredient only, and so excludes excipients, packaging, or delivery systems

CASE STUDY: Switching to local anaesthesia for inguinal hernia repair

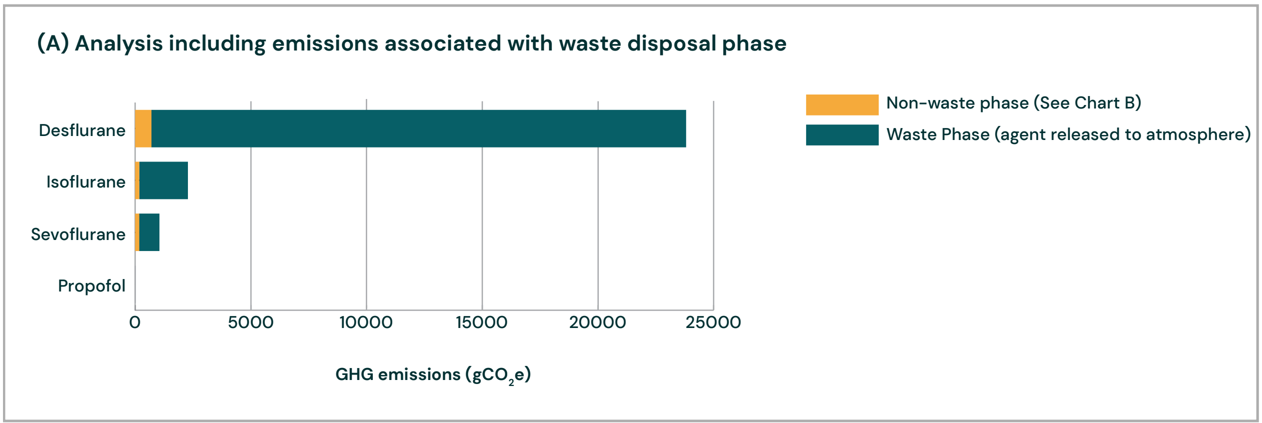
Setting	Imperial College Healthcare NHS Trust
Patients	Patients undergoing inguinal hernia repair
Intervention	Local anaesthesia with/without sedation instead of general anaesthesia
Outcome	Patients under local anaesthesia had a 53% shorter length of hospital stay and 40% lower incidence of complication compared to general anaesthesia
	↓ 10.2 kg CO_2e / case ↓ 2 tonnes CO_2e / year at NHS trust (assuming 64% local anaesthesia rate)
	↓ £16,000 / year

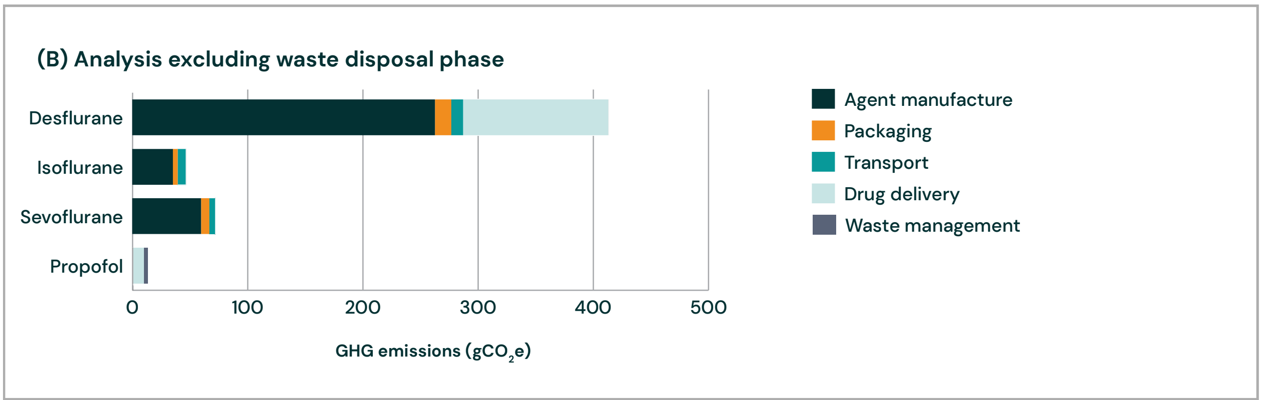
Source: Centre for Sustainable Healthcare[265]

Other emissions to the environment (beyond GHGs) are also concerning, and care must be taken to ensure that one type of pollution is not simply substituted with another; relative trade-offs must be considered. Potential water toxicity of pharmaceutical agents and their by-products, notably from propofol, has raised the question of whether intravenous approaches to general anaesthesia are superior to inhaled gases. Environmental persistence, bioaccumulation and toxicity indices are a means of characterising risk, but are not necessarily reflective of the presence of a substance in the environment. For example, the vast majority of propofol waste is incinerated. Attention to correct waste sorting by all perioperative staff is essential (for example, to **ensure pharmaceutical waste is incinerated**).

There are opportunities to avoid drug wastage, through only opening what is needed. For example, approximately half of propofol was estimated to be wasted over one year at a large tertiary care hospital,[266] with initiatives to reduce wastage including shifting from 50 ml or 100 ml vials to 20 ml.[267]

Figure 9: Life cycle greenhouse gas emissions of general anaesthetics (A) including emissions associated with waste disposal phase (B) excluding waste disposal phase.





Adapted from Sherman and Chesebro.[261] to align with UK practice to omit use of nitrous oxide as co-agent, and assuming fresh gas flows of 0.5 litres per minute; and 100 mcg/kg/min for 70 kg adult for propofol. We note there may be further differences in contributions from transport and energy in a UK setting, which has a higher proportion of renewable energy sources. This analysis included energy and materials required for drug delivery where these differed between the anaesthetic gases (for example syringes, intravenous line, energy required to heat the drug).

5.2 General inhaled anaesthetics

From a global warming perspective, the **environmentally preferable volatile anaesthetic drug of choice is sevoflurane** (Global Warming Potential over 100 years/GWP_{100} = 144), while **isoflurane** (GWP_{100} = 540) is a close second. Given its unique lack of pungency, sevoflurane can be used for mask induction and in the UK has become the preferred volatile anaesthetic from a clinical perspective. Due to the low solubility of desflurane, it can result in marginally faster wake-up times for cases of short duration (less than 90 minutes),[268] but without significant differences in post-anaesthetic care unit discharge times.[269] However desflurane is far less potent than sevoflurane or isoflurane (but more expensive), and so greater quantity of the drug is required to achieve similar anaesthetic effects. Additionally, due to its significantly higher global warming potential (GWP_{100} = 2,540), the climate impacts of desflurane are much greater than all other anaesthetic choices (Figure 9 and Table 5).[255,261] While its mild, transient sympathetic stimulating properties might make it slightly more desirable than sevoflurane and isoflurane in select cases, there is nothing unique about desflurane that cannot be achieved with other medications, meaning it is not essential.

Table 5: Greenhouse Gas Emissions of Common Inhaled Anaesthetic Agents.

MAC inhaled agent	Atmospheric lifetime (years)	100-year Global Warming Potential (GWP_{100}) (per kg, cf. 1 kg CO_2, where GWP CO_2 = 1)	Equivalent kilometres* driven in average car per MAC-hour anaesthetic use at 1 L/min
Isoflurane 1.2%	3.6	539	12
Sevoflurane 2.2%	1.9	144	6
Desflurane 6.7%	14	2,540	306
60% Nitrous Oxide (0.6 MAC)	114	273	78

*Adapted from Axelrod et al[257] *Based on US Environmental Protection Agency 2022 emission factor of 4.03 x 10^{-4} metric tons CO_2 equivalent/mile. MAC = mean alveolar concentration required to prevent movement upon surgical incision of an average adult patient.*

There is a growing movement led by anaesthetists in the UK to **eliminate desflurane from hospital formularies** on environmental grounds.[260] NHS Scotland was the first to cease procurement of desflurane in 2023,[270] and it is the first medicine to be decommissioned due to environmental impact. NHS England has also committed to decommissioning desflurane by early 2024,[271] and the European Union by 2026.[272,273] A study from the USA estimated substituting desflurane for sevoflurane would lead to cost savings of over US$100,000 in a year at a single medical centre.[274]

Anaesthetic induction rooms are no longer common throughout continental Europe and North America. In addition to equipment cost benefits, and the safety, and moving and handling advantages of avoiding transportation of a recently induced patient, there are also environmental advantages.[275,276] Induction of anaesthesia is a hotspot for waste of inhalational agent, and filling just one anaesthetic circuit, rather than two is beneficial. **Transition away from anaesthetic induction rooms** will require buy-in from surgeons and the wider surgical team.

Rapid advancement to minimal flow (250-300 ml/min) can be achieved by 'overpressure' of agent and control through end tidal agent and FiO_2 (fraction of inspired oxygen) monitoring.[277] Additional mechanisms to reduce wastage of volatile anaesthetics include ensuring that the fresh gas flow (FGF) is turned down for airway manipulation, and reducing loss of gas from the circuit. An educational intervention in the USA targeting flow rate reduction and volatile agent choice estimated carbon reductions of 64% per case, and cost savings of US$25,000 per month.[278] Further, automated end tidal agent target control anaesthetic machines are available, and show reproducible reductions in agent use[279] and should be considered with equipment upgrades.

Nitrous oxide (GWP_{100} 273) is an anaesthetic with relatively low potency, arguably beneficial to speed uptake of volatile gases during mask induction. The Association of Anaesthetists suggests using oxygen/air as a carrier gas, avoiding nitrous oxide.[280] Nitrous oxide is more commonly used for paediatric, obstetric, and dental procedural analgesia, without anaesthetists, and a growing area of decarbonisation interest.[281] Training for procedural sedation/analgesia should include non-pharmacological methods of managing the anxious patient as well as environmental considerations. Methoxyflurane (GWP_{100} = 4)[282] fell out of favour as a general anaesthetic due to nephrotoxicity, however has been used in Australia for many years for procedural pain such as in endoscopy,[283] transrectal ultrasound biopsy,[284] and dental extraction.[285] Methoxyflurane is licenced in the UK as an analgesia for moderate to severe pain associated with trauma,[286] and other indications are being explored.

While **reducing clinical use of nitrous oxide** is important, multiple hospitals on different continents have identified 77% to 95% losses pre-utilisation through leaking central piping manifolds, wasting money and with large environmental impact.[260,281,287] Large losses may go unnoticed where volumes used (demand) are not compared against volumes supplied: better communication between engineers and clinicians may identify leaks early.[288] The Nitrous Oxide Mitigation Project seeks to aid strategic **decommissioning of centrally piped nitrous oxide and substitution by portable cylinders** that should be closed between uses.[257,260,281,289] Clinicians influential in facilities operations management can support this strategy, and may draw upon a tool developed by NHS England for reducing waste emissions from piped nitrous oxide.[290] Nitrous oxide cracking technologies can be used to break nitrous oxide down into nitrogen and oxygen via catalytic destruction, reducing both environmental impact, and occupational exposure for staff.[291]

CASE STUDY: Decommissioning nitrous oxide manifold

Setting	Christie NHS Foundation Trust
Patients	Patients requiring nitrous oxide
Intervention	Decommissioning nitrous oxide manifold, replacing with on-demand portable nitrous oxide cylinders
Outcome	No anticipated negative outcome to patients
	↓ 54 tonnes CO_2e / year
	↓ £1,681 / year

Source: Centre for Sustainable Healthcare[98]

Waste anaesthetic gases (WAGs) are partially collected through vacuum scavenging systems and typically vented off building rooftops. Waste volatile anaesthetics may be captured and purified, and stored or subsequently destroyed. WAG treatment technologies are commercially available and others are under development, and at present re-use of desflurane is only permitted in Canada. Currently, there is a lack of robust evidence on the capture rate of these technologies (which may be as low as 25%),[292] efficacy and efficiency of the technology, and actual vented WAG volumes, and how these balance in environmental impact when considering the manufacture, distribution, and processing associated with such technologies.

Belief in the value of WAG treatment may lead to lax behaviours by clinicians, and so, at present, avoiding inhaled anaesthetics (particularly desflurane and nitrous oxide) and **minimising fresh gas flows** (low flow anaesthesia) remain higher priorities.[257,260,281] Clinicians and hospitals are encouraged to wait for more research before investing in WAG treatment technologies, and to prioritise and facilitate clinician practice solutions.

CASE STUDY: Adopting cold sticks for testing spinal/ epidural blocks

Setting	University Hospitals Dorset NHS Foundation Trust	
Patients	Patients undergoing spinal/epidural blocks	
Intervention	Use 'cold sticks' (solid stainless-steel sticks with handles that can be reused and kept in the fridge) for testing spinal/epidural blocks in place of ethyl chloride spray	
Outcome	Satisfactory and accurate block level achieved when used appropriately	
	↓ 4.6 tonnes CO_2e / year	
	↓ £4,827 / year	

In 2020, Helen Spencer Jones, Emily Young, Sharon Clyde, and João Fontes, members of the Recovery Team at University Hospitals Dorset NHS Foundation Trust undertook a project to reduce the use of ethyl chloride spray for testing spinal/epidural blocks in RBH Recovery.

The two recovery units at the Trust used six cans of ethyl chloride spray in a week; a high use rate since the Trust is a centre for elective orthopaedic surgery. These were disposed of in the domestic waste stream, and if released into the environment ethyl chloride is acutely toxic to birds, animals and aquatic life and affects the growth rate of plants.

The team designed a project to switch to 'cold sticks' (solid stainless-steel sticks with handles that can be reused and kept in the fridge) for testing spinal/epidural blocks. They conducted a poster campaign to promote the use and audit of cold sticks, reviewing collected data on a weekly basis.

They found that the metal sticks were effective at assessing blocks, and patients were reported to 'jump' less when sticks were used in comparison with the spray, indicating a better patient experience. The team estimated overall carbon savings of 4,613 kg CO_2e and financial saving of £4,827 over one year. If the project was spread to 8 surgical wards the hospital could save 36 tonnes CO_2e (-13.76 kg CO_2e for procurement of 20 metal sticks for the hospital) and save £37,413.

Source: Centre for Sustainable Healthcare[293]

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R5.1 Opt for anaesthetic modality with lowest environmental impact (as clinically appropriate)	For each patient consider whether local, regional, or intravenous techniques could be appropriate[a,b]	Further research into environmental impact of different anaesthetic techniques[c] Education[d]	Anaesthetists[a] Surgeons[b] Academics[c] Educators[d]
R5.2 Where inhaled anaesthetics are clinically necessary, avoid desflurane and minimise fresh gas flows	For each patient opt for lowest carbon inhaled anaesthetic gas that is clinically appropriate, and minimise fresh gas flows[a]	Decommission desflurane[a,e,f] Further research required to evaluate waste anaesthetic gas capture technologies[c] Education[d]	Anaesthetists[a] Theatre managers[e] Pharmacists[f] Academics[c] Educators[d]
R5.3 Reduce nitrous oxide use and waste	Consider non-pharmacological methods for managing anxious patients[a]	Decommission centrally piped nitrous oxide, substitute with portable cylinders[a,e,f] Introduce nitrous cracking technologies[a,e] Education[d]	Anaesthetists[a] Facilities and estates[e] Pharmacists[f] Educators[d]
R5.4 Minimise pharmaceutical wastage	Only open what is needed, and dispose of pharmaceuticals in medicinally contaminated waste appropriately[a,b,f]	Education[d]	Anaesthetists[a] Surgeons[b] Pharmacists[f] Educators[d]