SHTG Recommendation
May 2024

In response to enquiry from the Health Infrastructure Division, Scottish Government

Volatile anaesthetic gas capture technology

Recommendations for NHSScotland

There is insufficient evidence to support the purchase, installation and maintenance of volatile anaesthetic gas capture technologies (VCTs) in NHSScotland.

More evidence is required on the capture efficiencies of VCTs when used in clinical settings. Based on two small studies, VCTs have been shown to capture only up to 50% of volatile anaesthetic agent (by mass).

Robust life-cycle assessments are required to define the direct and indirect environmental impact of VCTs. The life-cycle analyses should compare use of VCTs with alternative strategies that take into account current and planned changes to anaesthetic practice.

Further considerations which limit the applicability of VCTs include:

- the recent reductions in the environmental impact of volatile anaesthetic gas emissions within NHSScotland, driven largely by the decommissioning of desflurane
- the lack of agreement on the extent to which the remaining volatile anaesthetic gases contribute to climate change particularly at current atmospheric concentrations.

NHSScotland is required to consider the Scottish Health Technologies Group (SHTG) recommendations.

What were we asked to look at?

The Scottish Government's Health Infrastructure Division asked SHTG to independently evaluate the use of VCTs in anaesthetic rooms and operating theatres. The intended purpose of VCTs is to reduce anaesthetic volatile gas emissions (greenhouse gases) entering the atmosphere and contributing to global warming and climate change.

Why is this important?

The gases that are used for anaesthetics and pain relief are greenhouse gases, and include the volatile gases desflurane, sevoflurane and isoflurane. Volatile gases are defined as those that evaporate readily at normal temperatures. Reducing the environmental impact of anaesthetic gases has been highlighted by the Scottish Government as a key priority.

Desflurane, isoflurane and sevoflurane are reported as having 100-year time horizon global warming potentials (GWP_{100}) that are respectively 2,540, 510 and 130 times more potent than carbon dioxide.[1] Some climate experts suggest these figures are misleading, and that the impact of these gases on climate change is insignificant because the lifetimes of the gases are too short and the concentrations are too low to have a meaningful environmental impact.[2] In NHSScotland an 82% reduction in volatile gas emissions was achieved over the period of 2018/19 to 2021/22 as a result of various mitigation measures (for example, low flow anaesthetic techniques and switching from desflurane to sevoflurane).[1]

An impartial assessment of VCTs was requested to establish whether the purchasing, installation and maintenance of VCTs offers good value for money and whether they provide net environmental benefit.

What was our approach?

We produced an SHTG Recommendation based on a review of published evidence on the effectiveness of VCTs.

What next?

Our SHTG Recommendation will be summarised and communicated via the National Green Theatre Programme and shared with colleagues within NHS England (Greener NHS Programme), Wales and Health and Social Care Northern Ireland.

Key points from the evidence

1. The two VCT systems currently available for use in NHSScotland are CONTRAfluran™ (manufactured by ZEOSYS), and SID-Dock (manufactured by SageTech Medical). We identified four studies that evaluated how well VCTs work in capturing volatile anaesthetic gases. All studies were small and preliminary in design and were described in letters that had been submitted to journals.
   - Two UK-based bench studies (that is, studies that did not involve patients) both reported that the SID-Dock system captured approximately 95% of available volatile anaesthetic gases.
   - Two studies were conducted with patients. One, conducted in Germany (n=80), evaluated CONTRAfluran™ and reported a capture efficiency of 25%. The other, conducted in the UK (n=50), evaluated SID-Dock and reported a capture efficiency of 51%.
2. SageTech Medical submitted an unpublished life-cycle assessment for our consideration. Their analysis suggested that the use of the SID-Dock system could reduce the total carbon impact from volatile gas emissions from a hospital by 57%. The model assumes that implementation of the VCT system would allow volatile gases to be recycled. At this moment, there is no established process for recycling volatile anaesthetic gases in the UK, nor is there regulatory approval for the reuse of recycled gases. This limits the applicability of the model to NHSScotland.
3. A small study (n=32) conducted within NHS Lothian reported that staff attitudes towards use of the CONTRAfluran™ system were favourable overall. The majority of respondents said that they found the technology easy to use and that it did not significantly increase workload.
4. No economic evaluations of VCTs were identified. We were not able to obtain the information required to develop our own economic model (for example, technology costs were not available) and so it was not possible for us to assess the cost effectiveness of VCTs compared with current practice from the perspective of NHSScotland.
5. Reducing the environmental impact of the volatile anaesthetic gases (desflurane, isoflurane and sevoflurane) is a key priority for Scottish Government. Various measures have already been taken across NHSScotland, most importantly the decommissioning of desflurane in March 2023. Desflurane is reported to be the most polluting of the three volatile anaesthetic gases.
6. Total intravenous anaesthesia (TIVA) has been highlighted as a way to reduce the amount of volatile anaesthetic gases that are used. It cannot be assumed that TIVA is the ‘greener’ option and TIVA should be subject to the same level of environmental scrutiny as volatile anaesthetic gases. In preparing this report, we asked our peer

reviewers (mostly anaesthetists) the extent to which they felt TIVA could replace volatile anaesthetic gases. While several respondents agreed that the use of TIVA would probably increase over coming years, no one felt that it could (or should) be used in all general anaesthesia cases.

7. Before measures are taken to capture, recycle and reuse volatile anaesthetic gases, the topic experts we consulted highlighted the importance of reducing the volume of gases that are used in the first place, for example, by enabling the use of low fresh gas flows.

8. The existing evidence is not sufficient to support the purchase and installation of VCTs in NHSScotland. Important uncertainties remain around:

    - the capture efficiencies of VCTs in real-life settings
    - whether VCTs offer net environmental benefits over and above the mitigation measures already implemented to reduce release of volatile anaesthetic gases into the atmosphere (for example, the decommissioning of desflurane)
    - possible changes in the types of anaesthesia that are administered in NHSScotland, in particular whether TIVA is going to be used more widely
    - how TIVA compares with volatile anaesthetic gases in terms of environmental impact and patient outcomes
    - the extent to which volatile anaesthetic gases contribute to climate change at the concentrations used currently
    - the process for recycling the volatile gases, and whether this will be regulated and implementable in NHSScotland.

SHTG Council considerations

1. The Council noted that the evidence on VCTs is rapidly evolving with further studies underway which would inform the relative capture rates of the technologies in clinical practice. The Council is aware of the work being undertaken by VCT manufacturers to establish a process for recycling volatile anaesthetic gases in the UK, and to obtain regulatory approval for the process. For these reasons, the evidence and use case surrounding VCTs may need to be revisited.

2. The Council discussed the need for high quality life-cycle assessments, which systematically assess the relative environmental impact associated with all stages of the life cycle of VCTs. Life-cycle analyses should take into account the direct effects of VCT manufacture and use, alongside any indirect effects most relevant to the delivery and provision of healthcare. When comparing the environmental impact of alternative anaesthetic strategies (for example, TIVA) the direct and indirect environmental impact of the alternatives should be subject to the same level of assessment.

3. The Council reiterated that factors beyond the environmental impact of volatile anaesthetic gases and VCTs need to be considered when determining the value of VCTs in clinical practice. The impact of anaesthesia strategy on patient care remains a vital determinant of value, as does the cost and cost effectiveness of the technology.

4. The Council heard from two consultant anaesthetists. The first summarised the published views of several climate experts, that the impact of volatile anaesthetic gases on climate change has been overstated. The consultant anaesthetist highlighted literature which documents this view (a summary is included in our evidence review). While volatile anaesthetic gases are greenhouse gases, they are not said to 'force the climate' because of their short atmospheric lifespans and overall low quantities within the atmosphere. The anaesthetist stressed their view of the need to ensure that approaches to protecting the climate did not inadvertently cause more environmental damage. In other words, we should be mindful not to introduce new technologies – with their own carbon impact – if they are not sufficiently offsetting environmental impact elsewhere.

5. The second anaesthetic expert highlighted that VCT technologies, and the evidence informing their use, are rapidly evolving. The expert noted that our recommendations may need revisiting in light of any new and compelling evidence. They acknowledged that while the contribution of volatile anaesthetic gases to climate change may have been overstated, there were other factors to take into consideration when weighing up the relative environment impact of VCTs. For example, optimising anaesthesia protocols may improve the capture efficiency of VCTs; the recycling of the gases and the associated reduction of virgin gas manufacture could result in improved environmental benefits for VCTs; and because hospital anaesthetic gas scavenging systems (AGSSs) require energy to run, the opportunity to use VCT systems that do not rely on a hospital AGSS could potentially boost their relative environmental benefit.

6. The Council recognised the challenges for decision makers in assessing environmental impact alongside more usual domains of value such as effectiveness, safety and cost effectiveness. The Council agreed that the low quality and quantity of evidence for VCTs across all domains of value was the determining factor in informing their recommendations, but in doing so highlighted the need for improved and standardised methodologies for weighing up environmental impact alongside other domains of value.

7. The Council noted that ongoing comprehensive data collection and auditing of anaesthetic practice in NHSScotland will be important in informing future life-cycle assessments and subsequent decision making.

Contents

Key points from the evidence ... 3
SHTG Council considerations ... 4
Definitions ... 7
Introduction ... 7
Health technology description ... 8
Literature search ... 9
Effectiveness ... 10
Efficiency of VCTs ... 10
CONTRAfluran™ ... 10
SID-Dock ... 11
Modelling the carbon footprint of volatile anaesthetic gases ... 12
Life-cycle assessment by SageTech Medical Ltd ... 13
Staff acceptability and opinion ... 14
Cost and emissions considerations ... 14
Discussion and conclusion ... 16
How the evidence needs to develop ... 17
Consideration of the wider NHSScotland context ... 17
Acknowledgements ... 20
Healthcare Improvement Scotland development team ... 21
SHTG Evidence Review Team ... 21
SHTG Council ... 22
References ... 24

Definitions

Anaesthetic gas scavenging system (AGSS): an active system that removes mixed anaesthetic gases from operating rooms or other areas fitted with nitrous oxide terminal units.

Life-cycle assessment: a process of evaluating the effects that a product has on the environment over the entire period of its life.

Total intravenous anaesthesia (TIVA): a technique of general anaesthesia which uses a combination of agents given exclusively by the intravenous route without the use of inhalation agents.

Volatile anaesthetics (isoflurane, desflurane, and sevoflurane): are liquids at room temperature and require the use of vapourisers for inhalational administration.

Volatile gas capture technology (VCTs): adsorb volatile anaesthetic gases from the expiratory limb of the anaesthetic breathing circuit, preventing them from being released into the atmosphere.

Volatile gas: easily evaporated at normal temperatures.

Introduction

The gases that are used for anaesthetics and pain relief are greenhouse gases and include the volatile anaesthetic gases desflurane, sevoflurane and isoflurane. In healthcare systems in high-income countries, a 2012 report highlighted that emissions of anaesthetics are estimated to account for more than 3% of total healthcare climate impact.[3] The NHSScotland climate emergency and sustainability strategy (2022-2026), published by the Scottish Government, highlights the reduction of the environmental impact of anaesthetic gases as a key priority. It includes an action to establish multidisciplinary project teams within health boards to work towards zero emissions of anaesthetic gases at each acute site in their area.[4]

At present, all hospitals rely on AGSSs to remove patient exhaled anaesthetic gases (including volatile gases and nitrous oxide), and these gases are subsequently released directly into the atmosphere. An AGSS is an active system that removes mixed anaesthetic gases from operating rooms or other areas fitted with nitrous oxide terminal units. VCTs are intended to capture volatile anaesthetic agents (not nitrous oxide), resulting in reduced greenhouse gas emission. There is also the potential for the captured volatile gases to be extracted, reprocessed and resold, reducing the environmental impact associated with virgin gas manufacture. As yet, regulatory approval for reuse of these recycled gases is not in place in the UK.

The atmospheric lifetimes of the volatile anaesthetic gases that are reported in the literature varies, but are between 9–21 years for desflurane, 3–6 years for isoflurane and 1–5 years for sevoflurane.[5] These are relatively short lifetimes, compared with carbon dioxide, which can remain in the atmosphere for centuries, and nitrous oxide which has a 114 year lifetime.[6] Desflurane, isoflurane and sevoflurane are reported as having 100-year time horizon global warming potentials (GWP_{100}) that are respectively 2,540, 510 and 130 times more potent than carbon dioxide. While these figures are accepted by some experts, others argue that they are misleading. GWP_{100} has been criticised by some climate experts as an unhelpful outcome with limited relevance for short-lived gases. While these gases are potent greenhouse gases, their impact on climate change may not be as large as is often reported.[2, 7, 8] Some experts suggest that the lifetimes of volatile anaesthetic gases are too short and the concentrations are too low to make any meaningful contribution to climate change. The GWP_{100} for sevoflurane has been debated as a significant over-estimation and it has been argued that the value reported by scientific and regulatory committees should be 31−41% lower.[9]

Driven by these debates, there is an increasing awareness of the environmental impact of inhaled volatile anaesthetics, and as a result many hospitals and relevant professional groups have undertaken stewardship measures, for example:

- the use, where appropriate, of TIVA[6]
- a shift from desflurane to alternatives such as sevoflurane[3]
- a reduction in fresh gas flows.[3]

An example of the stewardship measures making a difference was presented in a conference abstract from 2021. The abstract described an audit measuring the use of volatile anaesthetics undertaken at a hospital in NHS England. Anaesthetists were encouraged to reduce use of desflurane and to use low flows during general anaesthesia. Results suggested a reduction in average carbon dioxide equivalence (CO_2e) per hour of anaesthesia by 74%, and these findings indicate the value of simple stewardship measures.[10] Similar measures have been taken across NHSScotland. For example, desflurane fell from a mean of 17.2% to 9.6% of volatile use across larger Scottish hospitals from 2018 to 2021.[11]

In March 2023, desflurane was withdrawn from NHSScotland, before being withdrawn from NHS England in March 2024.[12] The European Union has formulated a proposal to ban or at least severely restrict the use of desflurane from January 2026.[3] In NHSScotland, sevoflurane is currently the most commonly used volatile anaesthetic gas.

Health technology description

Two systems currently in use in two boards in NHSScotland (NHS Ayrshire & Arran and NHS Lothian) are:

- CONTRAfluran™ (manufactured by ZEOSYS, Luckenwalde, Germany)
- SID-Dock (manufactured by SageTech Medical, Paignton, UK).

VCTs adsorb anaesthetic gases from the expiratory limb of the anaesthetic breathing circuit into canisters. The canisters are collected and processed, allowing for desflurane, sevoflurane and isoflurane to be desorbed. The eventual intention is for the gases to be recycled and later reused, though as yet there is no licence approval for such a pharmaceutical re-entering the market. At the time of writing, desorption of canisters for the CONTRAfluran™ system takes place in Germany, and for SID-Dock, in the UK. Experts who took part in our peer review advised that, at the time of writing, canisters used with the CONTRAfluran™ system were not being transported back to Germany for desorption and were either being destroyed by incineration or stockpiled.

Both systems use activated carbon to bind sevoflurane, isoflurane and desflurane. The CONTRAfluran™ system is designed to work with both passive and active scavenging systems. This differs from the SID-Dock, which is placed between the anaesthetic machine and the AGSS wall or pendant outlet with the anaesthetic machine still in the active setting. The SID-Dock provides the negative draw necessary to achieve the correct anaesthetic performance and is not dependent on the draw from the AGSS.

A third system, Deltasorb® (Blue-Zone Technologies, Ontario, Canada), uses silica zeolites as a molecular sieve within a stainless steel canister placed between the anaesthetic machine and scavenging system. Exploratory searching found no published studies on this system, though a literature review by Gandhi *et al*[13] identified a 20-year-old preliminary investigation on silica zeolite scavenging of exhaled isoflurane. The manufacturer's website includes a non-peer-reviewed pilot study (n=32), presented as an abstract. The Deltasorb® system does not seem to be used anywhere in NHSScotland and has not been considered further within this review.

Research question:

Does the use of VCTs in anaesthetic rooms and operating theatres reduce greenhouse gas emissions, and do they offer good value for money?

Literature search

A systematic search of the primary and secondary literature was carried out between 16 and 18 October 2023 to identify articles, systematic reviews, HTAs and other evidence-based reports. The Medline and Embase databases were searched and results were limited to English language publications. No date restrictions were applied.

Key websites were searched for guidelines, policy documents, clinical summaries, economic studies and ongoing trials. Anaesthesia journals related to this topic were also searched.

Concepts used in all searches included: volatile gas capture technologies, isoflurane, desflurane, sevoflurane, CONTRAfluran, SID-Can and SID-Dock. A full list of resources searched, and terms used is available on request.

Effectiveness

Efficiency of VCTs

The studies we identified used different terminology to describe different outcome measures. The lack of consistency made interpretation of the results difficult. In order to simplify the way in which the results are reported the outcome measures are defined as:

- *in vitro mass transfer*: increase in the mass of the capture device as a proportion of the total mass of the volatile agent used, reflecting the ability of the capture medium to bind with the anaesthetic agent with no variables other than water vapour to influence the result
- *in vivo mass transfer*: as above, but with clinical use factors incorporated (such as leak from airway, circuit breaks, humidity and residual agent in patient tissues)
- *capture efficiency*: the mass of volatile anaesthetic recovered (and potentially available for reuse) as a percentage of mass used, which reflects the efficiency of the overall process from capture to agent recovery.[13]

Our literature search identified four studies that assessed how well VCTs capture volatile gases. All studies were small and preliminary in design, and were described in letters that had been submitted to journals. One study evaluated the CONTRAfluran™ system used with desflurane anaesthesia and reported a capture efficiency of 25%.[14] The remaining three studies were on the SID-Dock system. Two were bench studies and did not involve patients.[12, 15] The first used the SID-Dock with sevoflurane, and demonstrated a 95% in vitro mass transfer.[15] The second study evaluated the role of the SID-Dock in the disposal of desflurane from vapourisers following its decommissioning from the health service, and reported an in vitro mass transfer of 94%.[12] The final study was a single-centre observational study of the SID-Dock in a real-world setting, and the authors reported that the capture efficiency for sevoflurane and isoflurane was 51%.[16] The studies are described in more detail below, with the evidence for each system presented separately.

A review by Gandhi *et al*, published after our literature search was conducted, identified the same evidence base as this SHTG Recommendation, and drew similar conclusions.[13]

CONTRAfluran™

Hinterberg *et al* measured the amount of recaptured inhaled anaesthetic (desflurane) in relation to the amount vapourised in patients (n=80) undergoing inhaled anaesthesia (the capture efficiency).[14] A detector (SENSOfluran; ZEOSYS) that allowed identification of inhaled anaesthetic was connected to the gas capture system to indicate saturation of the activated charcoal canister and need for replacement. The weight of the anaesthetic gas vapouriser and the charcoal canister were assessed before and after each anaesthetic with a precision scale. The amount of vapourised desflurane was determined through the change in vapouriser weight in grammes (g). A new charcoal canister was used for each patient. The primary outcome was the fraction of recaptured desflurane expressed as a percentage of the vapourised amount.

Across 80 patients, 6,902 g of desflurane was administered for general anaesthesia. Charcoal desorption (the process of releasing the absorbed desflurane from the charcoal) yielded 1,727 g of desflurane, indicating that 25% of the desflurane was recaptured and could potentially be processed for reuse. The authors hypothesised that this low recapture rate could be partly explained by the fact that anaesthetic gases remain sequestered within a patient's tissue, with differential distribution amongst body compartments, and continues to be eliminated over hours following anaesthesia. This effect is possibly further magnified by longer durations of anaesthesia. In this study, average duration of desflurane administration was 4 hours. The authors hypothesised that a significant residual amount of desflurane after extubation was not captured. This is supported by a secondary analysis indicating a lower fraction of recaptured desflurane with longer durations of anaesthesia.

The authors concluded that the fraction of recaptured anaesthetic can be increased with shorter durations of anaesthesia and use of lower inhaled concentrations. The authors also proposed that the recovery of more soluble inhaled anaesthetics (for example, sevoflurane) would be even lower under similar conditions, but this would need to be tested in future studies.

Kalmar *et al* submitted a comment on the Hinterberg *et al* study, proposing that the lower than expected recapture rate may be partially explained by the use of a new charcoal canister for each patient.[17] The authors argue that the recovery process is suboptimal when the canisters are not used until full. They state that 10% of gas is lost in the recovery process (though not released to the atmosphere), but that this value only applies when desorption is done as a batch process with 80 adequately saturated CONTRAfluran™ canisters. With a lower amount of charcoal, or not fully saturated canisters, the authors argue that the recovery process may be less optimal, resulting in higher relative losses of recovered volatile anaesthetics. The authors note that it is important, when evaluating VCTs, that a clear distinction is made between the amount of anaesthetic gas prevented from polluting and the amount fully recycled.

Shelton *et al* also submitted a comment on the Hinterberg *et al* study. The authors agree that the low recapture rate could be partially explained by desflurane being sequestered within tissues after anaesthesia, before gradually being expelled by the patient.[18] They also highlighted that the fresh gas flow was 'notably economical', meaning that a lower proportion of gas would be wasted than might be expected in 'real-world' clinical practice.

SID-Dock

One of the SID-Dock bench studies aimed to assess the efficiency of the system in capturing sevoflurane.[15] A 2-litre reservoir bag was used as a lung analogue, and the authors ran 23 simulations. The ventilator was set to a minute volume of 6 litres using various end-tidal sevoflurane concentrations (2–8%) and fresh gas flow rates (0.5–15 litres.min^{-1}). The SID-Cans and vapouriser weights were measured and recorded at the start and end of each of the 23 simulations. The contents of the SID-can were extracted and reported by the manufacturer. The authors reported that the overall in vitro mass transfer of volatile anaesthetic gas was 94.8% (362 g of the 382 g sevoflurane was captured).

The other bench study evaluated the role of the SID-Dock system in the disposal of desflurane from vapourisers following its decommissioning from the health service.[12] The authors sourced 32 decommissioned vapourisers, that all contained desflurane, which were emptied by running them through an anaesthetic machine. The authors reported that the in vitro mass transfer was 94%, and that lower fresh gas flows and concentrations appeared marginally more efficient (all yielded a mass transfer greater than 90%). In total, 5,225 g of desflurane was vapourised through the anaesthetic machine attached to the SID-Dock, and this equates to 4,944 g of desflurane captured based on the mean mass transfer of 94%. A further 1,645 g could not be decanted from the vapourisers, and so the authors reported an overall efficiency of 72% [4,944/(5,225 + 1,645)] for the project.

The final study was a single-centre, 10-day observational study of the SID-Dock on 50 elective patients and anaesthetists were requested not to alter their routine practice.[16] Sevoflurane and isoflurane vapourisers were used. Forty-three patients received general anaesthesia and were included in the study. The mass of the vapouriser and SID-Dock capture canisters were recorded at the start and end of each day. Desorption from 11 canisters was undertaken at the end of the study period. One of the canisters was damaged in the extraction process and excluded from the results. Of the 10 canisters successfully analysed, the amount of anaesthetic extracted was 43% of the total mass of volatile anaesthetic used. When the authors extrapolated the contents of the unanalysed canister, they reported that the capture efficiency was 51%. Of the mass captured, 4.5% was water.

Modelling the carbon footprint of volatile anaesthetic gases

One study modelled the synthesis of the three volatile anaesthetic gases, compared with intravenous propofol (used for TIVA). The study estimated the carbon footprint generated throughout their lifetime, from manufacturing of raw materials to emissions of the gases vented from operating theatres.[19] The environmental impact of using VCTs was included in the model.

The results indicated that the carbon footprint of the volatile gases is minimised when using oxygen/air mix as the carrier gas at the lowest flow rate while applying a VCT. In this scenario, the carbon footprint of sevoflurane per minimum alveolar concentration hour is similar to that of propofol. The model assumed that during the procedure the wasted gas is captured by the VCT (SID-Dock capture system; SageTech Medical Ltd) and the recycling ratio is 70%. Based on the existing literature, this is unlikely to reflect the real-life efficiency of VCTs. The model also assumes that the volatile gases can be recycled only once, which may be an underestimation. The authors note that if the manufacturer of propofol uses renewable energy, then the carbon footprint of propofol can be cut by half. This would leave propofol the least carbon intensive approach regardless of VCTs use and efficiency.

The authors reported that the carbon footprint of the volatile anaesthetic gases varies significantly depending on the method of chemical synthesis, and this needs to be factored in when considering the net environmental benefits of VCTs.

The authors concluded that sevoflurane does not necessarily have a lower footprint than desflurane when scaled to the whole health care system, and that the use of intravenous anaesthetics like propofol is not necessarily a better option than gaseous anaesthetics when VCTs are available. Their conclusion is based on numerous assumptions, the accuracy of which is unclear based on the existing literature.

Life-cycle assessment by SageTech Medical Ltd

SageTech Medical provided an unpublished life-cycle assessment for consideration. The assessment was undertaken in accordance with the steps specified in the Greenhouse Gas Protocol, the product life-cycle accounting and reporting standards and aligned with the international standard for life-cycle assessment. This assessment is useful in demonstrating the potential CO_2e savings from using VCTs, but the results are based on the assumption that volatile gases will be recycled and reused and this limits its applicability to NHSScotland.

The assessment modelled the carbon impact of a hypothetical hospital (assumed to consist of 10 theatres operating over a 1-year duration) and compared it with the carbon impact of the same hypothetical hospital based on implementation of the SageTech VCT system. The metric used in the assessment was GWP_{100}. For the modelled hospital (running a mix of 80% sevoflurane, 11% desflurane and 9% isoflurane) the total carbon impact of hospital operations was calculated as 363,870 kilograms carbon dioxide-equivalent (kg CO_2e). With the SageTech VCT system implemented, and assuming that the system captured 60% of the volatile anaesthetic gases, the total carbon impact was calculated as 155,158 kg CO_2e which represents a reduction in carbon impact of 57%.

In NHSScotland, desflurane has been decommissioned. The life-cycle assessment explored the impact on the overall calculations when desflurane is not used. Assuming a capture rate of 60%, and a mix of 91% sevoflurane, 0% desflurane and 9% isoflurane, implementation of the VCT system was modelled to reduce kg CO_2e by 54% (from 204,214 kg CO_2e to 94,766 kg CO_2e). When it was assumed that the VCT system captured 50% (rather than 60%) of the volatile anaesthetic gases, a reduction in kg CO_2e of 44% was modelled.

The life-cycle assessment included all life-cycle stages for both the modelled systems including: virgin anaesthetic agent manufacture, hospital clinical use, waste agent capture, agent collection logistics, and agent extraction and purification (for recycling and reuse of the product). A limitation of this assessment is the assumption that implementation of the VCT system allows the volatile agents to be recycled and reused, and that this results in a negative carbon impact (or system credit) of -50,647 kg CO_2e because of the avoidance of the need to manufacture virgin anaesthetic agent. This limits the applicability of the model to NHSScotland. The life-cycle assessment also calculates the carbon impact of two approaches to virgin anaesthetic manufacture. One approach has a lower carbon impact, and this is used in the baseline assessment. The differences in these manufacturing approaches is not described, but in sensitivity analyses the more carbon intensive approach for gas manufacture has a large impact on the absolute carbon savings. The life-cycle assessment states that this is balanced by an increase in the system credit from avoided agent manufacture, but this claim relies on the recycling and reuse of the volatile gases.

In summary, in the absence of life-cycle assessments reflecting VCT use and application in current practice, it is not possible to reliably gauge the net effect of VCTs on greenhouse gas emissions.

Staff acceptability and opinion

A conference abstract discussed the results of a questionnaire that had been sent to a department in NHS Lothian that was implementing the CONTRAfluran system.[20] Thirty-two responses were received, 27 from anaesthetists and five from operating department practitioners. Respondents were mostly very familiar with the technology, with 17 having used it 10 times or more, nine fewer than 10 times, and six only once or twice. Attitudes towards implementation were favourable, with the majority reporting that they found the technology easy to use (n=23) and that it did not significantly increase workload (n=29). Three out of 32 respondents thought that there was the potential to distract from patient care, and one thought it distracted from checks of the anaesthetic machine.

Cost and emissions considerations

No economic evaluations of VCTs were identified.

The costs for VCT machine purchase, installation, anaesthetic machine conversion (CONTRAfluran™), operating AGSS (assuming CONTRAfluran™ in passive-capture mode), ongoing filter purchase, maintenance and staff training are not available. Without these cost data, it was not possible to undertake a cost-effectiveness analysis of VCT from an NHSScotland perspective.

There are approximately 387 operating theatres across NHSScotland (personal communication, National Green Theatres Programme, 17 January 2024. Figure correct at time of publication). It is not known how many operating theatres would require a VCT machine as not all anaesthesia uses volatile anaesthetic gas. Without this information, coupled with an absence of cost data, the budget impact of adopting VCT in NHSScotland could not be calculated.

Volatile anaesthetic gas emissions from desflurane, isoflurane and sevoflurane purchased by NHSScotland Health Boards have decreased over the last 5 years, 2017-2023 (*Figure 1*). This appears to have been driven by a large reduction in the use of desflurane (*Figure 2*).

Figure 1: Aggregate annual emissions (tCO_2e) of desflurane, isoflurane and sevoflurane purchased by NHSScotland Health Boards 2017-2023 (data provided by Public Health Scotland)

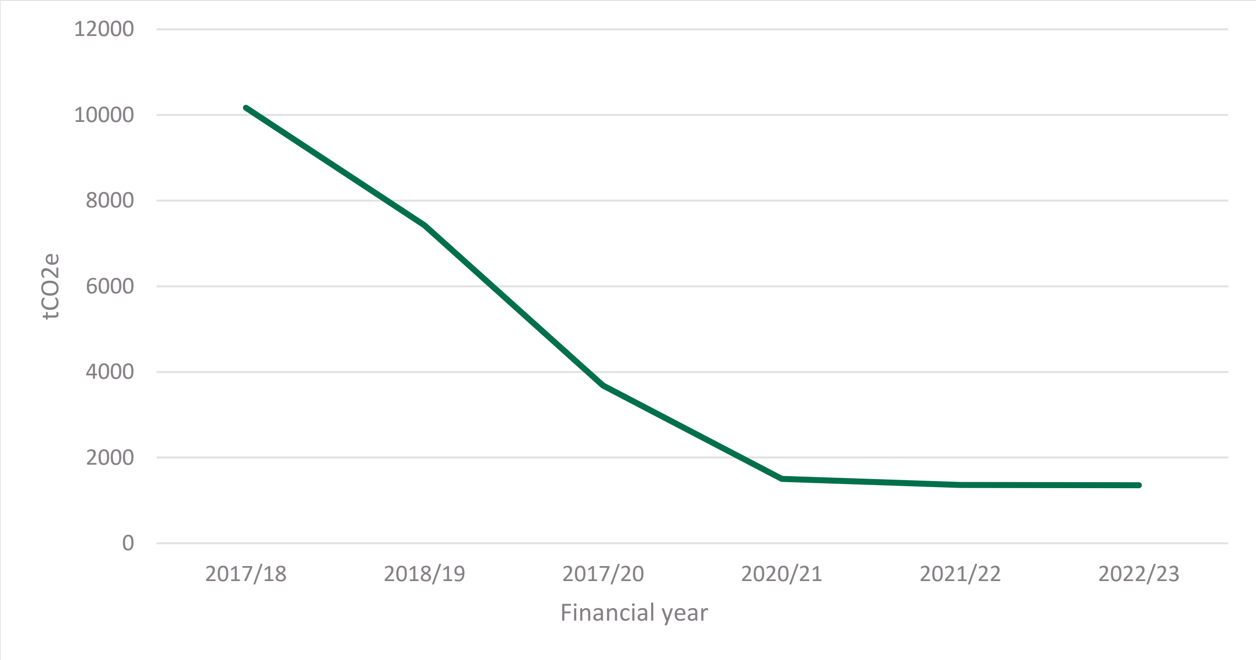
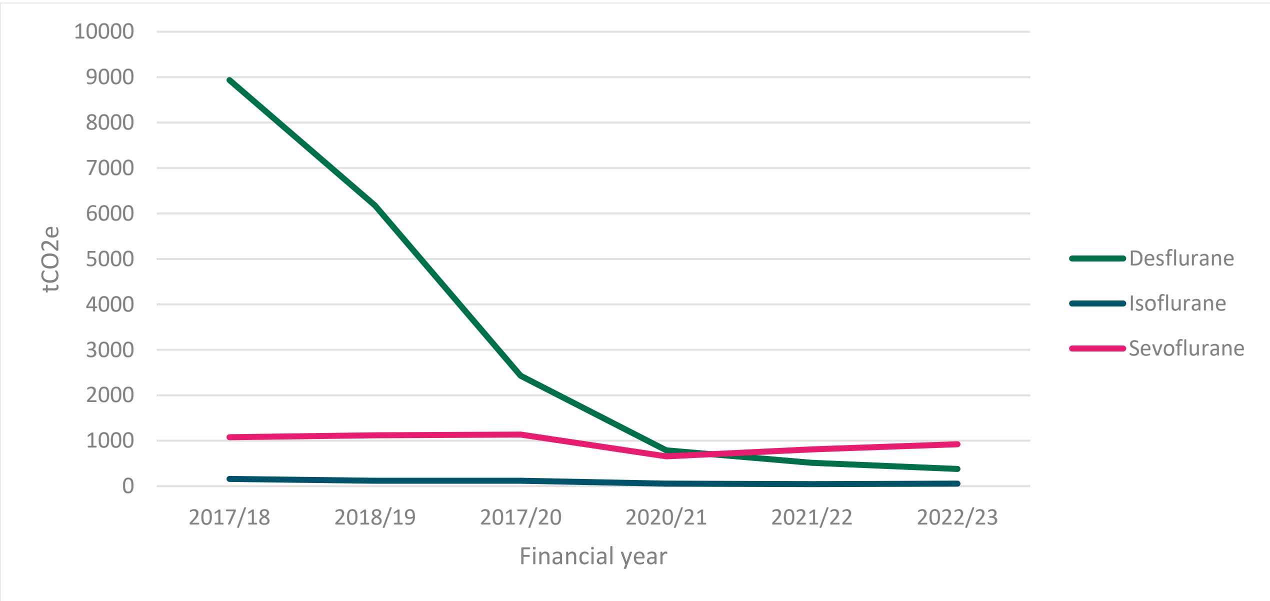
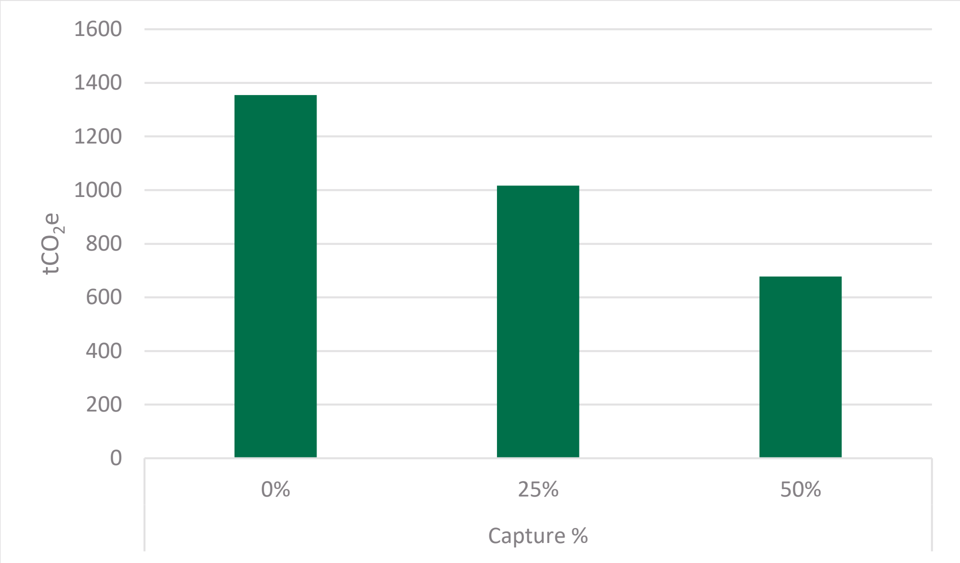


Figure 2: Disaggregated annual emissions (tCO_2e) of desflurane, isoflurane and sevoflurane purchased by NHSScotland Health Boards 2017-2023 (data provided by Public Health Scotland)



In the most recent complete financial year (2022/23) the equivalent carbon emissions (GWP_{100}) of the volatile anaesthetic gases purchased by NHSScotland was 1,355 tonnes carbon dioxide-equivalent (tCO_2e). To illustrate the potential impact of VCTs, if implemented in NHSScotland and assumed to achieve a 50% capture rate, then volatile anaesthetic gas emissions for 2022/23 would have been 678 tCO_2e, whereas with a 25% capture rate these would have been 1,016 tCO_2e (*Figure 3*).

Figure 3: Impact of VCT capture rate on combined desflurane, isoflurane and sevoflurane emissions (tCO_2e) by quantity purchased by NHS Scotland Health Boards 2022/23 (data provided by Public Health Scotland)



Discussion and conclusion

To inform our SHTG recommendations we sought to understand the effectiveness of VCTs in reducing greenhouse gas emissions. We identified four studies, published as letters, that focused on the in vitro mass transfer and capture efficiencies of VCTs. These outcomes indicate the volume of volatile gases that VCTs prevent from being released into the atmosphere, but this is just one element that needs to be considered when evaluating the overall impact of VCTs on greenhouse gas emissions. Of the two studies that were conducted in patients, the first reported a capture efficiency of 25% (for the CONTRAfluran™ system) and the second reported a capture efficiency of 51% (for the SID-Dock system). These figures may give an early indication of how well the systems work in capturing volatile gases, but they are not sufficient to inform a decision on the purchasing and installation of VCTs in NHSScotland.

Before a reliable and informed decision can be made for NHSScotland, consideration needs to be given to the wider Scottish context and how anaesthesia is likely to be delivered in the near future. For example, steps have already been taken to reduce volatile anaesthetic gas usage which limits the value of VCTs. Further actions that affect anaesthetic gas usage are being considered as part of programmes such as the National Green Theatres Programme.

How the evidence needs to develop

The evidence base on the efficiency of VCTs consists of four small, single-centre studies that have not been peer reviewed. They each used different approaches, for example in how anaesthesia was delivered, and in how VCT effectiveness was measured. The capture efficiencies reported by the studies varied. It is not clear to what extent the differences can be attributed to variations in how the studies were designed and conducted, or to differences in the way in which the two systems operate. Additional multicentred studies using a standardised approach would allow more robust conclusions and comparisons to be drawn.

There are substantial gaps in the evidence on how various factors impact on the capture efficiencies of VCTs. This includes patient factors, surgical factors (for example, duration of surgery) and anaesthetic factors (for example, fresh gas flow rates). The literature also includes discussions around the issue of volatile anaesthetic gases remaining sequestered in patient tissues after anaesthesia, and being gradually expelled by patients when they are in recovery. Further research into all these factors would help inform the effectiveness of VCTs.

Robust life-cycle assessments are required that systematically assess the environmental impact associated with all the stages on the life cycle of VCTs. These models are important for making reliable decisions on the environmental impact of technologies such as VCTs. Our literature search identified one modelling study, which concluded that sevoflurane does not necessarily have a lower carbon footprint than desflurane when scaled to the whole health care system, and that the use of intravenous anaesthetics like propofol is not necessarily a better option than gaseous anaesthetics when VCTs are available. The results of this study must be treated with caution because of an absence of underlying evidence. A life-cycle assessment submitted by SageTech demonstrated the potential carbon savings that could be achieved with VCT installation, but this assessment is based on a usage model that does not exist in NHSScotland.

The contribution of volatile gases to climate change needs further consideration. While there is little doubt that volatile anaesthetic gases could be damaging in sufficient quantities and that their release into the atmosphere should be minimised, there is disagreement on the extent to which they contribute to climate change at current concentrations.[2, 7] Some climate experts feel that the gases have virtually no impact on climate change at existing quantities, and argue that attention would be better focused on other greenhouse gases such as carbon dioxide and nitrous oxide, which have much longer atmospheric lifetimes. This opinion is not held universally, which further complicates the decision around the purchasing of VCTs.

Consideration of the wider NHSScotland context

It is not possible to establish whether the installation and ongoing maintenance of VCTs will offer net environmental benefits in Scotland without a clear understanding of how anaesthesia is going to be delivered in the near future, and how often volatile anaesthetic gases will be used. The less that volatile anaesthetic gases are used, the less gas will be released into the atmosphere. Measures are already being taken across NHSScotland to reduce the release of volatile anaesthetic gases into the atmosphere, for example awareness raising amongst anaesthetists, reducing fresh gas flows and the decommissioning of desflurane.

The Scottish Government's climate emergency and sustainability strategy highlights reducing the environmental impact of anaesthetic gases as a key priority, and includes an action to work towards zero emissions of anaesthetic gases at each acute site.[4] If volatile anaesthetic gases continue to be used at the current rate, and the goal is to substantially reduce their emissions, then VCTs may have a role in lowering emissions. If the goal is *zero* emissions, then VCTs would need to demonstrate near perfect capture efficiencies.

Two relevant actions from the National Green Theatres Programme also need to be considered:

- First action: 'Fully assess decommissioning of gas scavenging systems'[21]

  The two systems currently used in NHSScotland are the SID-Dock system and the CONTRAfluran™ system. There are differences in how these systems work. The SID-Dock system works in conjunction with the AGSS, but the CONTRAfluran™ system is designed to work with both passive and active scavenging systems. The way in which gas scavenging systems are used in the future in NHSScotland will influence which VCT systems are appropriate for purchase and use.

- Second action: 'Encourage total intravenous anaesthesia (Consider 2% Propofol)'[21]

  If TIVA replaces the use of volatile anaesthetic gases then this negates the need for VCTs. According to the National Audit Project conducted by the Royal College of Anaesthetists in 2021, approximately 25% of general anaesthesia cases in the UK used TIVA.[22]

  The National Green Theatres Programme has advised that this action is currently on hold until further evidence is available.

In preparing this report, we asked our 14 peer reviewers (including 8 anaesthetists) the extent to which they felt TIVA could replace volatile anaesthetic gases. Several respondents agreed that the use of TIVA would probably increase over coming years, but no one felt that it could, or should, be used in all general anaesthesia cases. Respondents noted that an increase in the use of TIVA would require training, familiarity and the availability of appropriate equipment. They also reported that there are practical limitations of TIVA, which makes it unsuitable for some situations (for example, elements of paediatric anaesthesia). Patient outcomes were highlighted as being of primary importance and for some people, volatile anaesthetic gases will be the more appropriate option.

Some respondents said that they did not agree that TIVA should be actively encouraged over volatile anaesthetic gases, and that the decision on which anaesthetic to use should be made purely based on what is best for the patient. They argued that as the evidence stands, TIVA cannot be assumed to be environmentally less damaging than volatile anaesthetic gases. It is not known how switching to TIVA compares environmentally, particularly if the climatic impact of volatile anaesthetic gases has been overestimated. For example, the manufacture of the single-use plastics that are used for TIVA generates carbon dioxide, and propofol is classified as highly toxic to aquatic life. TIVA should be scrutinised to the same extent as volatile anaesthetic gases by policy makers.

In conclusion, it is not possible to reliably assess the effectiveness of VCT systems, including their cost effectiveness and environmental impact. Key uncertainties include whether VCTs offer net environmental benefits over and above the mitigation measures already implemented to reduce the release of volatile anaesthetic gases into the atmosphere and the extent to which these gases contribute to climate change at current concentrations.

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- Dr Sarah Cross, Anaesthetic Consultant, NHS Lothian
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Declarations of interest from all reviewers are published alongside the review on our website. All contributions from reviewers were considered by the SHTG Evidence Review Team and the SHTG Council. Reviewers had no role in authorship or editorial control and the views expressed are those of Healthcare Improvement Scotland and the SHTG Council.

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