Editorial

Consensus on decommissioning piped nitrous oxide from UK and Ireland operating theatre suites: a rational approach to an increasingly ignoble gas

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Short title: Decommissioning of piped nitrous oxide in UK and Ireland

Nitrous oxide is unique among sedative drugs because it is typically supplied to operating theatres via pipelines connected to a bank of cylinders via a manifold. This piped supply system treats nitrous oxide as an essential service – providing an uninterrupted supply throughout the hospital, analogous to the systems used for water, electricity, air and oxygen. Maintaining an uninterrupted widespread supply relies on surplus (i.e. replenishment of cylinders before they are empty), and makes use of a complex system of pipes, valves and terminal outlets. With this approach comes inefficiency, which becomes proportionally greater as use reduces. As the use of nitrous oxide has diminished in clinical practice, multiple institutions have found that > 90% of supplied nitrous oxide goes to waste without being administered to patients [1]. This is clearly unacceptable, not just for reasons of monetary cost at a time of financial stress, but because nitrous oxide is a potent and long-lived greenhouse gas which contributes to a worsening climate crisis [2].

In July 2024, a consensus statement was jointly published by the Association of Anaesthetists, Royal College of Anaesthetists (RCoA), College of Anaesthesiologists of Ireland (CAI), Obstetric Anaesthetists Association (OAA) and Association of Paediatric Anaesthetists of Great Britain and Ireland (APAGBI) (Box 1 and online Supporting Information Appendix S1) [3]. This stated that piped nitrous oxide should no longer be considered essential and called on healthcare institutions to decommission their piped supply systems and (where nitrous oxide is deemed still to be needed in the operating theatre) move to more efficient methods of supply. In this editorial, we review the context and evidence for this statement, consider the challenges that might be encountered in its implementation, and consider what comes next in our collective efforts to reduce the environmental impact of anaesthetic practice.

That nitrous oxide has remained part of clinical practice for more than 150 years is testament to the fact that it has some desirable qualities: it is inexpensive; unlikely to provoke allergic reactions; and has both analgesic and hypnotic properties. Because it is non-irritant and lacks a strong odour or taste it can be administered to patients without intravenous access as part of an inhalational induction of anaesthesia [4]. When used in combination with a volatile anaesthetic agent, nitrous oxide exerts a 'concentration effect' because it moves rapidly from the alveoli to the plasma, leaving a higher fractional concentration of volatile in the alveoli. This then diffuses into the plasma at a greater rate because of the increased concentration gradient (i.e. the second gas effect) [4]. Based on pharmacokinetic principles, this would be expected to increase the speed of inhalational induction and, though this may have been clinically relevant when halothane was used, there is little clinical evidence of this effect with sevoflurane. Randomised controlled trials of adults receiving inhalational induction with incrementally increased sevoflurane [5], adults receiving single-breath vital capacity inhalational induction with sevoflurane 8% [6] and children receiving single-breath vital capacity inhalational induction with sevoflurane 8% [7] have all found no reduction in induction times with oxygen/nitrous oxide mix vs. oxygen as the carrier gas. Where differences have been observed, these are small in magnitude (< 10 s) and of questionable clinical relevance [8], and there are no consistent data relating to adverse events [5,8]. Nitrous oxide is excreted rapidly via the alveoli, and this is associated with more rapid emergence from inhalational anaesthesia, but when used with sevoflurane the difference is again small (i.e. 2–4 min [9,10]), and the inverse of the concentration effect can lead to diffusion hypoxia.

Though the lack of benefit when used in combination with rapid-acting, low-solubility volatile anaesthetic agents such as sevoflurane explains in part why nitrous oxide is now seldom used in general anaesthesia, the availability of alternatives which offer a better quality of patient experience is also important. In particular, the availability of remifentanil as a rapid-acting (and less emetogenic [11]) analgesic, and efforts to increase engagement with regional anaesthesia by a wider range of anaesthetists are likely to have diminished the range of clinical circumstances in which nitrous oxide provides a clear benefit [12].

Furthermore, the increased use of total intravenous anaesthesia (TIVA) has rendered nitrous oxide irrelevant in an increasing number of cases [13]. The increased adoption of TIVA and regional anaesthesia may be motivated in part by anaesthetists' desire to deliver 'greener' anaesthesia by avoiding the point-of-care emissions of greenhouse gases (i.e. volatile anaesthetic agents and nitrous oxide) [14], but where nitrous oxide continues to be supplied via pipeline, the disconnect between procurement and clinical use means that the benefits of these efforts will remain incompletely realised [1].

The potential impact of medical nitrous oxide on the climate has been documented since the early 1990s [15]. Because of the longevity of the gas within the atmosphere and the variety of additional sources, accurate estimates of the contribution of medical nitrous oxide to overall climate change can be difficult, with estimates ranging from 0.05–2% [16-17]. However, unlike volatile anaesthetic agents – where controversy remains as to their 'real world' contribution to climate change given their short atmospheric lifespan – there is little scientific dispute on the impact of atmospheric nitrous oxide as a driver of climate change, nor that decreasing overall nitrous oxide emissions is an important part of reducing the overall anthropogenic impact on the climate.

As nitrous oxide is a relatively inexpensive drug to produce and procure, the financial savings associated with a switch to point-of-use nitrous oxide cylinders are unlikely to be substantial, although the recurring costs associated with maintaining the manifolds themselves will be eliminated. Despite a general reduction in clinical usage of nitrous oxide within anaesthesia, the overall estimated emissions from nitrous oxide remain high: over 10,000,000 litres of nitrous oxide, equivalent to approximately 5200 tonnes of CO_2 equivalents (tCO_2e), are procured by hospitals in England for delivery via a piped supply each month [18].

The recommendations in the consensus statement may seem straightforward at first glance but, despite this issue having been identified in 2020 [19], only around 20% of eligible UK healthcare organisations are thought to have completed any nitrous oxide decommissioning work [18]. One reason for this might be because there has been, until now [3], no explicit statement from standard-setting bodies and specialist societies to support this activity. However, even in the presence of clear guidance, removing a service from clinical practice can be fraught with challenges in implementation [1].

The first step in decommissioning piped nitrous oxide is to seek agreement from key stakeholders including clinical staff who use it in practice (typically anaesthesia providers, but potentially also clinicians who use oxygen/nitrous oxide blenders for sedation or analgesia), and pharmacy and estates colleagues who are responsible for its supply. In some cases, it may become apparent that nitrous oxide has disappeared from clinical use, but in others there may be colleagues who use it as part of their typical anaesthetic technique or wish to have it available for specific circumstances.

Achieving behaviour change among healthcare providers is challenging [20], and where piped nitrous oxide supply is associated with a high proportion of waste, priority should be given to changing the way the drug is supplied rather than getting bogged down in encouraging individual colleagues to abandon the clinical use of nitrous oxide altogether. Where nitrous oxide is deemed to be required, consideration should be given to how to maintain supply in the most efficient way; typically, this involves the use of small nitrous oxide cylinders at the point of care, attached to the anaesthetic machine via a yoke or a Schrader valve adapter. Once a strategy has been agreed, institutional agreements must be secured (typically involving committees responsible for medical gases and pharmaceuticals), and then the works must be carried out by an authorised engineer. Depending on the anaesthetic machines in use, alarm triggers may need to be adjusted to accommodate the connection of nitrous oxide on a 'per-patient' basis, so medical engineering colleagues (with technical support from machine manufactures if required) should be involved at the planning stage. Although piped nitrous oxide decommissioning generally results in net financial savings, the decommissioning process incurs financial costs, and capital spending may be required to procure cylinder trolleys, pressure regulators with Schrader sockets and yokes for anaesthetic machines [21]. The logistical complexity of this work may seem overwhelming in some institutions, and the importance of dedicated time for project leadership cannot be overstated. The *Guidelines for the Provision of Anaesthetic Services* highlight that departments of anaesthesia should have a named environmental lead, who would be an ideal person to lead on this work [22].

The success of nitrous oxide decommissioning should be monitored, both in terms of environmental and financial impact (i.e. based on the procurement of nitrous oxide cylinders) [21], and any potential or actual impacts on patient care. On a local level this can be done using incident reporting forms; on the national level the ongoing NOBLE non-inferiority trial (part of the Greener Surgery Programme [23]) will provide system-level data on patient outcomes. Where issues are identified, Trusts and health boards should be prepared to adjust mobile nitrous oxide supply systems (e.g. through procuring additional mobile cylinders or deploying them to more appropriate areas) and decommissioning should initially be done in a reversible way, by removing the nitrous oxide cylinders from the manifolds and capping off the pipelines and terminal outlets. Pipelines can be removed at a later stage if desired (for example, during refurbishment of operating theatre facilities).

Since 2020 when loss and waste mitigation of nitrous oxide was proposed as a priority area for health policy with a supporting implementation framework [19], it rapidly became an exemplar of implementation science whereby successful local quality improvement translated into a generalisable approach with national and international impacts [24-27]. As many sites transition to a nearby portable supply of nitrous oxide, this route will also require the same rigorous iterative evaluation to develop optimal processes that reduce theft as well as minimising loss and waste [28].

The mitigation of piped nitrous oxide for analgesic purposes (either pre-mixed with oxygen or blended at the point of use) is a more complex challenge than nitrous oxide supplied to operating theatres, as analgesic nitrous oxide remains of clinical value, most notably as a labour analgesic in UK practice. Perhaps because of its ongoing utility, pre-mixed oxygen/nitrous oxide represents the greatest single source of anaesthetic gas-related greenhouse gas emissions in the UK (approximately double that of pure nitrous oxide in NHS England [18]). Piped system losses have been observed and mitigated through application of the original Nitrous Oxide Project protocol [25, 29]. Extrapolation of these results suggests that the pre-utilisation system loss of piped pre-mixed oxygen/nitrous oxide is close to 50% of its annual turnover. Since late 2023, Scotland has been deploying a nationwide programme of mitigating loss and waste and ensuring continued site-based improvements in planned preventative maintenance, leak assessments and careful maintenance of demand valves [29]. This has translated to a 1200 tCO_2e decrease in emissions comparing 2022/2023 with 2023/2024 (data courtesy of Scottish Government).

In addressing the emissions associated with analgesic nitrous oxide, catalytic destruction ('cracking') of nitrous oxide to nitrogen and oxygen, which are not greenhouse gases, has garnered much interest. Indeed, bedside mobile destruction units have shown a 70–80% reduction in ambient levels of nitrous oxide on the labour ward [30]. In principle, this should align with environmental emission mitigation, particularly if used with a portable supply of oxygen/nitrous oxide to minimise waste. However, this does not necessarily translate to substantial impacts when oxygen/nitrous oxide is supplied by pipeline. The first UK installation of a central catalytic destruction unit (i.e. incorporated into gas scavenging) destroyed only 78 tCO_2e of nitrous oxide in its first year, just 6% of the 1366 tCO_2e of piped oxygen/nitrous oxide turnover at that institution (personal communication, Newcastle Upon Tyne Hospitals NHS Foundation Trust). Even allowing for improvements in technique and adjusting for system loss and waste, this appears to be a poor return on investment, and indicates that wasteful supply systems are a significant factor in the emissions, not only of pure nitrous oxide, but also pre-mixed oxygen/nitrous oxide. As such, point-of-use cylinder supply may also prove to be a useful part of a mitigation strategy in environments where analgesic nitrous oxide is used.

The medical gas industry will need to support efforts towards minimising waste of nitrous oxide, and it has been heartening to see positive engagement in the switch from pipeline to mobile nitrous oxide supply in recent years [21]. Further actions from industry should include a reasonable extension of expiry dates of medicinal nitrous oxide products to reduce the return of part-full expired cylinders, as well as bringing an end to the practice of venting returned medical gas cylinders to the air before refilling, contributing to significant emissions and unnecessary waste. This is an obligation of the rules governing medicinal products in the European Union [31] and, as the UK Medicines and Healthcare Regulatory Authority (MHRA) is no longer bound to the European Union regulatory frameworks, the UK's leading medical gas supplier (BOC) has been pursuing permission from the MHRA to allow for direct refill (top-up) of returned medical gas cylinders (personal communication, BOC).

As we move ever further into a worsening climate crisis, clinicians must focus not only on the patient in front of them but also on the environment that we all inhabit. Anaesthetists have shown a willingness to change their behaviour to minimise the environmental harms of practice [32]. However, nitrous oxide presents a unique challenge because, unlike many pharmaceutical products, its procurement (and hence, environmental impact) is not driven principally by clinical practices or patient preferences, but by how institutions choose to supply the drug. The multi-society consensus statement is significant because it targets the top of the nitrous oxide mitigation ‘hierarchy of controls’ (Fig. 1) and empowers institutions to do what is right for the planet, without affecting patient care [3].

The methods and techniques by which anaesthesia is practiced are continually changing and techniques that were historically ubiquitous are becoming less common in modern practice. While clinical quality and safety remain the bedrocks of our specialty, the environmental impact of our clinical practice has become an important consideration for healthcare. This has led to focus on the areas of practice where change can be embraced without adverse impact on the quality and safety of the care that we provide. Changing the way we think about and use nitrous oxide is one such area. By embracing environmental considerations as a central tenet of our individual and institutional practices, we will continue to not only provide the highest quality care for our current patients but contribute positively to the health and prosperity of generations yet to come.

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Figure Legend

Figure 1: Suggested hierarchy of controls for nitrous oxide mitigation; higher-impact measures are at the top of the diagram, indicating the most important areas of focus.

Online Supporting Information

Appendix S1: Final text of the Consensus Statement on the Removal of Pipeline Nitrous Oxide in the United Kingdom and Republic of Ireland [3].

Box 1: Summary of the consensus recommendation on piped nitrous oxide from UK and Ireland stakeholders [3].

- Nitrous oxide should no longer be considered an essential drug in modern anaesthetic practice.
- Continuous supply of nitrous oxide to theatre suites via a pipelined supply is no longer essential.
- Trusts and Health Boards should decommission their nitrous oxide manifolds as soon as possible, switching to point-of-use cylinders where access to nitrous oxide remains desirable.
- Trusts and Health Boards are advised to liaise with their nitrous oxide supplier at an early stage, to ensure that the increased demand for point-of-use nitrous oxide cylinders can be met and maintained.