https://doi.org/10.60115/11055/1382

Back to the future: A return to point-of-care nitrous oxide cylinders

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Edited by Dr Brenton Sanderson

INTRODUCTION

Millions of litres of the anaesthetic gas Nitrous Oxide (N_2O) are currently leaking from medical gas pipeline systems around the world, including in Australia and Aotearoa New Zealand.[1-7] Most of the N_2O that a hospital buys never reaches a patient. This article will explore how such a wasteful system became ubiquitous in healthcare design and the evidence-based steps that the anaesthetic community can take to manage the problem.

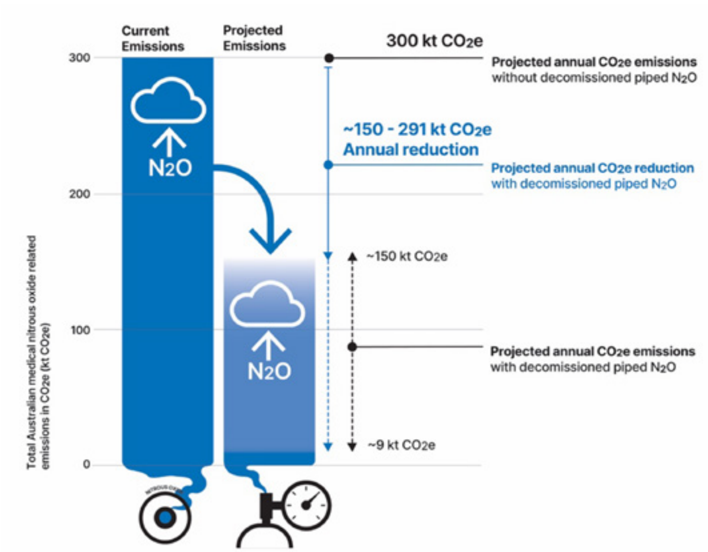
N_2O is a potent greenhouse gas, with a 100-year time horizon global warming potential 273 times that of carbon dioxide.[8] The Australian government's Health and Climate Strategy has identified reducing emissions related to N_2O as a key strategy, while New Zealand has not identified this as a government target.[9]

The strategy estimates emissions related to medical N_2O for 2020-2021 financial year in the Australian healthcare sector equates to the equivalent emissions of 300,000 tonnes of CO_2 (CO_2e), representing 20% of Scope 1 emissions, which are direct emissions that result from sources that are owned or controlled by a healthcare facility. Most of this footprint related to N_2O is likely a result of leakage and not clinical administration.[10]

The international community is acting. The United Kingdom and Ireland intend to phase out N_2O pipelines by the end of the 2026-2027 financial year and the American Society of Anaesthesiologists has called for all N_2O pipework to be decentralised.[11,12] With the support of RANZCOG and ANZCA the Australasian Health Facilities Guidelines have been updated to state that piped nitrous oxide is "not mandatory for any healthcare service and point-of-care cylinders can meet clinical requirements".[13]

Our college agrees that the climate crisis is a public health emergency and recently committed to the Australian Commission on Safety and Quality: "Working together to achieve sustainable high-quality health care in a changing climate".[14] Reducing emissions from leaked N_2O is an evidence-based opportunity to reduce harm without impacting patient care. The interim Australian Centre for Disease Control guidelines recommend "decommissioning N_2O pipelines where possible, avoiding installation of new N_2O pipelines, and instead supplying N_2O via cylinders at the point of clinical administration".[15] This adjustment has been demonstrated to reduce N_2O related emissions by up to 97%.[1,16] Our estimates, based on published literature and unpublished internal audits across Australia and New Zealand, suggest 150,000-291,000 tonnes CO_2e could be prevented *annually* across the Australian healthcare sector if piped N_2O supply was decommissioned and point-of-care cylinders were used instead (Figure 1).

Figure 1. Comparison of current and projected N_2O related emissions



Data from National Health and Climate Strategy. Current emissions represent CO_2e from Australian healthcare sector 2020-2021 financial year.[9] Projected emissions estimated from international and local published and unpublished data. Realised emission reduction will depend on the leak fraction across the Australian healthcare sector.

This article intends to be a "how to" guide to support this supply change. We aim to provide detail on existing N_2O infrastructure, outline the evidence regarding leak and provide necessary information to assist healthcare facilities in Australia and New Zealand to provide N_2O via cylinders at the point of care where necessary. We also suggest that anaesthetists review their practice to consider if N_2O administration is necessary for, and consistent with, providing the best care for their patient's current and future health.

HISTORY OF N_2O AND THE NEED FOR PIPED SYSTEMS

The discovery of N_2O in 1772 is well described.[17,18] First trialled as an anaesthetic in 1844, it was used sporadically by dentists until the widespread adoption of the drug in the late 1860s. It was then rapidly introduced into general anaesthesia, with the first records of Australasian clinical use in the 1870s.[19] It provides both sedation and analgesia with rapid onset and offset which led to its ongoing use into the 21st century as an inhaled carrier gas for anaesthesia as well as for obstetric and procedural analgesia. It remains on the 2023 version of the World Health Organization's list of essential medicines.[20]

In the mid-20th century, developments in anaesthesia such as curare, intubation, positive pressure ventilation, and muscle relaxants evolved to facilitate surgery.[21,22] Advanced centres had access to mixed Oxygen/N_2O/volatile techniques, though measurement of gas delivery and uptake was not standardised.[22]

In that era, anaesthesia circuits were typically open to semi-closed, as the absence of end-tidal gas monitoring made efficient low-flow techniques risky due to the potential for hypoxic or anoxic mixtures.[21] The introduction of halothane in the mid-1950s encouraged more economical flow rates and the uptake of exhaled gas analysers in the 1990s improved safety.

Medical gases became available in cylinders in the 1870s, a vast improvement on the original practice of preparing and storing the gas on site in ox-bladders or free standing gasometers.[23] Theatre gases were supplied by large point-of-care cylinders until the 1960s-1980s when piped or reticulated systems became more widespread.[24] The development of medical gas pipeline systems improved convenience, supply reliability, and safety through non-interchangeable screw thread (NIST) connections and sleeve index system *(SIS)* used in Australia for common medical gases.[25] Medical gas pipeline systems supplied from bulk gas sources allowed cost savings through lower gas costs per unit volume, reduced cylinder rental charges and improved logistical efficiencies.

N_2O has been commonly used as an analgesic in labour since the late 1930s, but patterns of use vary worldwide.[26,27] In Australia, 40% of labouring women use N_2O during labour.[28] It has a favourable profile and is a common first or second line midwifery initiated analgesic option, although unwanted side effects such as dysphoria and nausea are acknowledged limitations to its use in some women.[28] It is less invasive yet less effective than alternative therapies such as remifentanil PCA or epidural analgesia.[29]

N_2O is also used for procedural analgesia and sedation either in isolation or as an adjunct to other agents. It is used in emergency departments, dental clinics and procedure rooms for various interventions in both adult and paediatric populations.[29,30]

N_2O INFRASTRUCTURE

N_2O medical gas pipeline systems exist in most hospitals in Australia and New Zealand to meet the needs of birthing units, operating theatres, emergency departments, and procedure rooms. As hospitals expand and these networks become more extensive, healthcare facilities often lack updated schematics of their gas pipelines and associated wall outlets.

A N_2O medical gas pipeline system is pressurised by a dual manifold comprising one active and one inactive cylinder bank and may have a smaller reserve manifold for failures or servicing. Cylinder pressure ranges from 4600–5200 kPa and is regulated to 400 kPa before entering the main pipeline.[31,32] Supplying N_2O in this manner has allowed bulk purchasing of gas and decreased transport costs. N_2O is an inexpensive gas, costing 1-2c per litre.

In general, Australian facilities have a pure N_2O supply that is blended with oxygen at the point of care, whereas New Zealand facilities follow the UK and Ireland style, with separate pipelines for both N_2O and Entonox (50:50 N_2O:oxygen).[32]

N_2O is administered via an anaesthetic machine or a N_2O and oxygen blender, while Entonox requires only a demand regulator. Waste gas scavenging or adequate ventilation is recommended where N_2O is administered in either form. For maximum effectiveness, expired gases should be exhaled directly into a circuit connected to a scavenging system.[33,34]

N_2O PORTABLE CYLINDERS

N_2O is stored in white cylinders with ultramarine shoulders (with a Pin Index Safety System, configuration of 3,5.). These cylinders are commonly made of carbon steel but can also be made of MRI-safe aluminium. The cylinder pressure is 4600–5200 kPa at room temperature and sea level. Stored below its critical temperature, N_2O exists simultaneously in liquid and vapour phases, with respective proportions depending on ambient temperature. To mitigate the risk of cylinder rupture due to liquid expansion, cylinders are partially filled to a specified filling ratio and equipped with a pressure relief valve.[35]

N_2O cylinders are available in sizes from 900-18,000 L. The Australian, New Zealand, UK, and US cylinder sizes follow different scales and are not directly comparable. Cylinders appropriate for point-of-care use in Australia are sizes C or D and in New Zealand, sizes A or D2. There are slight discrepancies in cylinders sizes between medical gas companies and the below figures represent a guide for temperate climate areas.

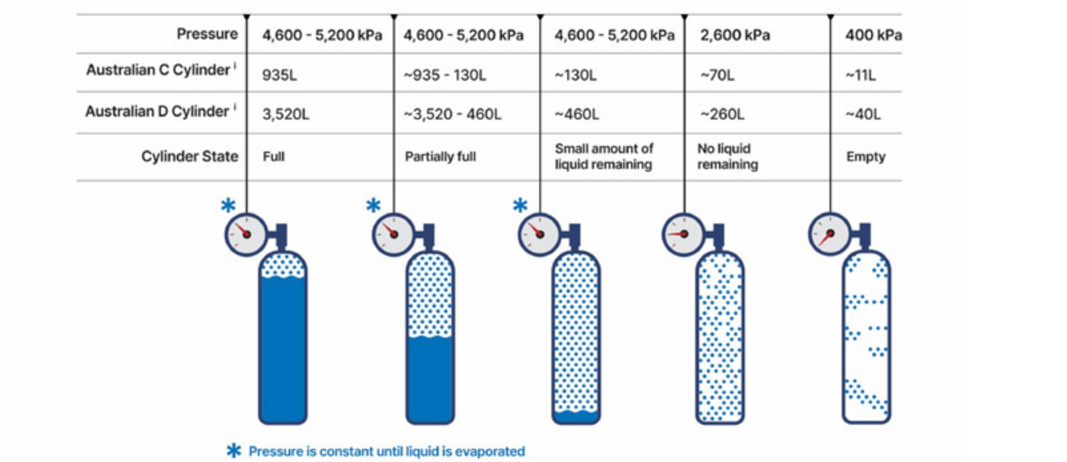
Table 1. Point-of-care N_2O cylinders in Australia and Aotearoa New Zealand

Size	Volume N_2O (L)	Weight N_2O (kg)	Water Volume (L)
Australian cylinders			
C	935	1.75	2.8
D	3520	6.6	10
E	8970	16.8	23
Aotearoa New Zealand cylinders			
A	1090	1.99	2.85
D2	3524	6.6	10

Values from British Oxygen Company.[36,37] Local and supplier variance in exact values is expected.

Determining the remaining N_2O volume in a cylinder is straightforward, and combined with advancements in knowledge regarding administration volumes, it is safe to provide point-of-care N_2O via cylinders. The gas volume is calculated from the pressure and water volume of the cylinder. Cylinder gas supply is commonly used when there is interruption to the piped N_2O supply, and cylinders of other medical gases, such as carbon dioxide, are commonplace in theatre environments.

Figure 2. Physical characteristics of N_2O cylinders



Cylinder pressure will remain stable until liquid in cylinder has been evaporated. Values from British Oxygen Company. Exact values may vary based on supplier.

HARMFUL EFFECTS OF N_2O

Environmental

N_2O is a powerful greenhouse gas, with an atmospheric lifetime of over 100 years, and is a major contributor to global warming. It also depletes the ozone layer.

The 100-year Global Warming Potential (GWP-100) of N_2O is 273 times that of carbon dioxide.[38] GWP-100 is the commonly accepted measure for understanding the impact of different gases on global warming.

Another metric reported by the Intergovernmental Panel on Climate Change (IPCC) is effective radiative forcing, and it has been recently argued in the anaesthetic literature that this may be a better metric to use when considering anaesthetic gases.[39] The debate over metrics is semantic and relates to how we should measure the global warming effect of halogenated volatile anaesthetic agents. In comparison, the evidence for environmental harm with N_2O is unanimously agreed. The radiative forcing effect of N_2O is significant due to its long stratospheric half-life and the high concentration of N_2O found in the atmosphere.[40]

Healthcare carbon emissions are considered in three “scopes”. Scope 1 refers to all direct emissions from a source that is owned by the organisation, Scope 2 refers to emissions related to energy purchased by the organization, and Scope 3 are emissions related to all products in the external supply chain.[41] Emissions related to N_2O that enter the atmosphere directly from a healthcare facility via clinical administration or leak are classified as Scope 1.

Due to the large volumes of N_2O purchased by hospitals, and its high 100-year GWP, N_2O is a significant contributor to healthcare emissions, accounting for 20% of the Scope 1 emissions of the Australian health system.[15]

Occupational health and safety

Chronic N_2O exposure has been associated with psychomotor, cognitive, hepatic and embryo-foetal adverse effects.[42,43] Both the United States National Institute for Occupational Safety and Health, and Safe Work Australia have recommended a safe occupational time-weighted average exposure standard of less than 25 ppm.[43,44]

Efforts to reduce staff exposure to N_2O in operating theatres have been successful with use of closed circuits, less frequent use, scavenging of anaesthetic gases and mandatory air conditioning standards. Australian Standards for operating theatres require 20 air changes per hour.[45] In comparison, high level exposure to N_2O has been documented in birth suites which poses a risk to staff.[34,46,47] The requirements for air changes in Australian birth suites has been significantly increased in the 2024 version of AS 1668.2, which many hospitals may not yet have implemented.[45] New Zealand follows the UK Health Technical Memorandum guidance also updated in 2024, which requires 25 air changes per hour for operating theatres, and 15 air changes per hour for birth suites.[48]

Benefit versus harm in 2025

The role of N_2O in anaesthesia has been explored thoroughly, and its routine use does not confer a benefit to patients.[49-52] Furthermore, it is known to inhibit vitamin B12, which can lead to neurologic toxicity and megaloblastic anaemia, and its use is associated with a higher risk of severe postoperative nausea and vomiting, and lower quality of recovery scores.[51] These findings, and alternative medications, have led to a widespread move away from N_2O use for maintenance of anaesthesia. This change in practice occurred before the general acknowledgement of environmental issues, and certainly before the extent of N_2O pipeline leakage was identified.[49,50,53,54] In 2025 the most common use for N_2O in operating theatres is for paediatric gas inductions and as a component of general anaesthesia for emergency caesarean sections.

N_2O outside the operating theatre has an established and ongoing clinical role for providing labour analgesia, and sedation for dentistry and paediatric procedures. Its safety profile and ability to be administered without intravenous access continues to confer significant benefits in these settings though research into alternative therapies is expanding.

N_2O PIPELINE LEAKAGE

N_2O leakage was first identified in 2020 by Chakera at NHS Scotland.[55] By assessing clinical use and procurement in three hospitals, they identified system loss of 83-100% from the pipeline infrastructure. By March 2021, 15 sites in the Lothian District had reported N_2O pipeline annual losses of 84-100%.[55] In Australia, local case reports have subsequently identified large N_2O leaks in their pipeline infrastructure (Table 2) using one or more of four key methods endorsed by the interim Australian Centre for Disease Control (Text Box A).[15]

Text Box A. Leak detection methods

1. *Discrepancy method*
   An estimation method to identify the discrepancy between purchasing volumes and estimated or measured administration volumes.
2. *Cylinder weighing method*
   Tracks the reduction in weight of a cylinder in a manifold bank and compares this to administered volumes for the same period (weeks to months).
3. *Pressure testing method*
   Similar to testing that occurs as part of pipeline commissioning. Tracks pressure in a fixed volume of pipework during a period of no clinical use. Can be done in small or large segments of the reticulated system.
4. *Flow monitoring method*
   Flowmeters are installed into key sections of the system to measure flow. If installed close to a delivery device it can measure administration volumes, or if installed at the manifold it can detect a system leak.

Table 2 summarises the publications regarding N_2O leakage. Many departments in Australia and New Zealand have performed internal audits that have not been published and reached similar conclusions.

Table 2. Summary of published reports of N_2O leakage from medical gas pipelines

	Year	Method	Annual leakage (L/year)	Individual site leakage (%)	Annual tonnes CO_2e due to leak
Australian/New Zealand					
Footscray Hospital, Melbourne[6]	2021	Discrepancy	160,000	75	75
The Alfred hospital, Melbourne[4]	2023	Cylinder weighing	197,789	83.5	100
Sydney Children's Hospital at Westmead[5]	2024	Flowmeter	273,312	50	563
International					
Tenon Hospital, APHP Sorbonne Université, Paris, France[42]	2019	Discrepancy	1,191, 892	87.5	600
NHS Scotland (multi-site study)[55]	2021	Discrepancy	13,771,800	83-100	37,462
University of San Francisco California/ Providence Health (multi-site study)[1]	2022	Discrepancy	This is empty now	47.2-99.8	5500
Greater London Network (multi-site study)[3]	2023	Discrepancy	5,311,852	51-100	2615

How did this major problem with the N_2O pipeline system remain undetected for so long? Despite meeting all Australian Standards maintenance and testing requirements, hospitals have shown through specific testing using a method described above that they have a significant leak. One reason behind this inconsistency is that post installation the Australian Standards only requires relatively rudimentary testing for local leaks at outlets and regulators in the clinical care environment and do not address other areas of the pipeline enclosed within the building.[25] Another issue is that the system is tested in segments with equipment disconnected, rather than the dynamic system, as a whole. This will exclude leaks occurring in at the back bar, and seals at NIST or Sleeve Index S fittings. In effect, the current standards are not appropriately sensitive.

The piped N_2O system is prone to leakage at many points, where much of it is enclosed in building walls or ceilings that is difficult to inspect, maintain and repair. N_2O molecules can escape well maintained systems through various points. Sites of leakage that have been identified include diffusing through flexible pipeline hoses that connect anaesthetic machines to the terminal wall outlet, flexible pipeline in operating theatre pendants, sections of pipeline in high-vibration areas such as near medical imaging equipment and terminal wall outlets.[6,56,57]

Current infrastructure relies on a pressurised gas system to pipe large volumes of N_2O throughout the hospital buildings, while modern anaesthesia practice uses only small volumes of the gas. Leaks of 500-1000 ml/min from a hospital pipeline can account for most of the facility's total N_2O consumption and subsequent N_2O related emissions. The financial gains of transitioning will depend entirely on the leak rate of a facility. One example, the Prince Charles Hospital in Queensland, Australia, expect a return on investment of two years after decommissioning.[58]

DECOMMISSIONING N_2O PIPELINES

Testing a pipeline for leaks can be helpful to demonstrate the issue to a healthcare service, but in our experience testing beyond the discrepancy method is arduous, time consuming and costly. Institutions can instead move straight to implementing a point-of-care cylinder solution and decommissioning their N_2O pipeline.

As of March 2025, a small number of Australian and New Zealand healthcare facilities have already decommissioned their centralised N_2O pipeline supply, with a greater number of international locations performing this evidence-based intervention (Text Box B).

Table 3. Reports of decommissioned N_2O piped medical gas systems

International sites	Sites decommissioned (n)
NHS Scotland[59]	27
NHS Wales[16]	6
Providence Healthcare[1]	25
Tenon Hospital[2]	1
Australian sites	
Prince Charles Hospital[58]	1
Broome Hospital	1
Sir Charles Gairdner Hospital	1
Modbury Hospital	1
Aotearoa New Zealand Sites	
Christchurch Public Hospital – Riverside	1
Burwood Hospital	1
Dunedin Hospital (except Birth Suite)	1

Environmental benefits reported from the decommissioning of pipeline systems are large, as would be expected given the size of the measured leaks. Across the UK, the NHS has reported a reduction of over 37,000 tonnes of carbon dioxide equivalents from piped N_2O emissions from 2018 to 2023, with no increase in portable emissions over that timeframe.[16] In the US, decommissioning by 25 hospitals across two health systems have mitigated more than 5500 tonnes of N_2O related greenhouse gas emissions annually.[1]

Unfortunately, N_2O is cheap and financial benefits of decommissioning N_2O pipelines are modest until a carbon price is considered. Though a change to point-of-care cylinders is not expensive, this lack of substantial financial savings may reduce the incentive to healthcare facilities to invest this change. As discussed, centres with high leak rates will benefit the most from this project. Financial savings will occur through decreased maintenance and decreased building costs of new buildings if N_2O pipework is excluded.

Other benefits for hospitals to consider include improved occupational safety, and the benefit of increased mobility for labouring women by having a portable N_2O supply in the birthing suites. It may also reduce the risk of patient death due to administration of hypoxic gas from a cross-over error.[60,61]

There are no reports of a hospital moving to point-of-care cylinders and increasing N_2O related emissions. There are also no reports of patient harm or near misses. Healthcare facilities can retrospectively determine the extent of the leak based on purchasing reduction over time after decommissioning.

CYLINDER BASED SOLUTIONS

Development of a resilient point-of-care solution requires three phases: assessment, establishment of portable supply, and decommissioning.

Assessment phase

Management of N_2O related emissions requires a collaborative multidisciplinary approach.[1,11] To answer five key questions (Text Box C), a working group including all major stakeholders should be assembled early (Text Box D). It is important to build an agreed shared vision and strategy with all members of the project team. A suggested goal is "to provide N_2O to necessary clinical areas in the least wasteful method possible while ensuring safety". Time and patience may be needed, particularly when there may be competing interests, such as when public-private partnerships exist with long term fixed contracts. Improving government regulation and carbon emission reduction targets would help to provide incentives to healthcare facilities in this area.

Text Box B. Questions for N_2O needs assessment

1. Where is N_2O piped to?
2. Where is N_2O required?
3. How much N_2O is purchased?
4. How much N_2O is required to supply each clinical area?
5. What equipment is required for each clinical area?

Text Box C. Working group membership

1. Project lead
2. Clinician stakeholders
   a) Anaesthesia
   b) Emergency
   c) Obstetrics
   d) Midwifery
   e) Paediatrics
3. Biomedical engineering
4. Facilities management
5. Medical gas supplier
6. Hospital sustainability officer
7. Procurement
8. Senior hospital leadership

Establishing portable supply phase: point-of-care cylinders

Implementing a point-of-care cylinder approach requires significant project management skills, but the physical work is not complex. Ongoing quality cycles will enhance this process. N2O compatible equipment must be used, including Pin Index Safety Systems and NIST or Sleeve Indexed Bayonet fittings. ANZCA PS54 provides guidance on minimum safety requirements for N_2O administration.[62]

Anaesthesia machines

To supply N_2O via an anaesthetic machine there are two options: cylinders connected directly to the back of the anaesthetic machine via an inbuilt yoke, or a portable cylinder with a 400 kPa regulator, to allow a connection similar to wall outlets, via a flexible hose with Sleeve Indexed Bayonet fittings.

1. Inbuilt N_2O yokes

Many anaesthetic machines have capacity for up to three cylinders to be connected via inbuilt yoke.[35,63] If not already in place, these can be ordered when anaesthetic machines are upgraded or can be retrofitted for $500-2500 per machine.[1]

Inbuilt yokes are familiar and N_2O is immediately available. Cylinders should be installed to the back of all machines, or high frequency use locations until review demonstrates that this is oversupply. A cylinder plug needs to be installed when a cylinder is not installed to avoid entrainment of air through imperfect seals. Cylinders stored in the open position will slowly leak, whilst closed cylinders do not.[1]

When this system is used, a low-pressure alarm will occur at 2633 kPa for GE machines, which correlates to about 70 L remaining in an A or C cylinder (see Figure 2).[64] This should give ample warning (280 minutes at 250 mL N_2O per min, or 14 minutes at 5 L N_2O per min) to allow a cylinder change.

2. Portable N_2O trolley systems

A portable N_2O system that can act as a surrogate medical gas pipeline consists of a cylinder with cart, a regulator and hosing with Sleeve Indexed Bayonet fitting (Figure 3). When required, this apparatus is wheeled into theatre and connected to the N_2O inlet at the back of the anaesthetic machine. In this system, pressure regulation to 400 kPa occurs prior to the machine via the yoke and regulator. There is an analogue Bourdon pressure gauge and no audible alarm. A D or D2 cylinder will start to depressurise once the volume remaining is approximately 460 L (Figure 2). The first audible alarm will vary between each machine, with alarms being triggered occur when the pressure reaches 180-260 kPa.[64] At this threshold, there is approximately 25 L of N_2O in a D cylinder, providing enough warning to allow for a cylinder change.

Figure 3. Portable N_2O trolley systems

Example of portable N_2O trolley system demonstrating a D-Cylinder, regulator and hosing. Photo courtesy M. O'Shea and K. Williams. The Prince Charles Hospital, Queensland.

Table 4. Comparison between inbuilt yoke and portable trolley systems for point-of-care N_2O

Portable N_2O supply	Inbuilt yoke	Portable trolley
Upfront cost	$500-2500 per machine	Minimal
Cylinder size	A/C	A/C or D/D2
Number of cylinders required	One per machine	Department dependant
Alarms	Audiovisual Cylinder Pressure Alarm 2633 kPa for GE	Audiovisual Pipeline Pressure Alarm Visual "Low" on Pressure Gauge 180-260 kPa
Volume remaining when alarm reached	70 L (C Cylinder)	18-26 L (D Cylinder)
Advantages	Intuitive and familiar Avoids flexible N_2O hose/attachments More warning of low N_2O supply	Larger capacity possible Requires active decision to employ N_2O
Disadvantages	Cylinder changeover takes about 1 minute Cylinder plugs required if cylinders no longer installed Pressure alarms set by manufacturer	Shorter warning time Extra piece of equipment in theatre environment Extra step in clinician workflow.

Non-operating theatre locations

Locations that use blenders can adapt to portable N_2O supply easily, and some require no equipment changes at all. These systems usually rely on visual pressure gauges to detect when cylinders need to be changed. This provides an opportunity to review practice and determine if N_2O blenders or Entonox cylinders would be a more suitable choice.

Emergency departments have adapted from piped N_2O without issue. Birthing units that use portable systems report excellent patient satisfaction as it allows patients increased mobility (Figure 4).

Figure 4. Portable N_2O and oxygen blender in use at Broome Regional Hospital Birth Suite

Photo courtesy of P Mareyo. Broome Hospital, WA

OTHER CONSIDERATIONS

Scavenging

Any delivery of N_2O without an anaesthesia machine must also consider how the exhaled or administered drug is scavenged. A suggested scavenging system in procedural spaces is a bassoon-scavenger (Figure 5) which can accept a volume of exhaled air while scavenging the bassoon-shaped container at a constant rate.[65] Use of a demand valve for N_2O in birthing suites can reduce the amount of N_2O wasted and can reduce exposure to other personnel in the room.

Figure 5. The Bassoon-style scavenging setup in birth suite at Flinders Medical Centre, South Australia

Photo courtesy of J Duke. Southern Adelaide Local Health Network, SA

Cylinder storage

Sufficient portable N_2O cylinders will need to be stored in an area that will be compliant with storage of an asphyxiant and medical gas systems.[25,66] A practical solution is a larger supply in an external area, with a smaller supply in a suitable internal location. N_2O is a Schedule 4 drug and is subject to national storage and administrative requirements. A dangerous goods consultant may be required to approve the designated storage areas. Supply chain disruption is a consideration for remote or more vulnerable locations.

Detecting filling status of a cylinder

As cylinders returned to the supplier are vented to the atmosphere before being refilled, the balance between returning partially full cylinders and running empty mid-case needs to be struck. While the decision to change a cylinder during theatre use ultimately lies with the anaesthetist, a system that reduces intraoperative changes is preferable and is likely to still be less wasteful than piped N_2O.

The three methods of checking the contents of a cylinder are pressure, weight and percussion. Pressure monitoring is the most straightforward, but departments need to consider the pros and cons of each and provide education.

Pressure

When the pressure in a cylinder is between 4600-5200 kPa there will be liquid remaining in the cylinder. As N_2O is withdrawn, liquid will evaporate inside the cylinder and the cylinder will cool. Only once all of the liquid contents have evaporated does the cylinder pressure drop below 4600 kPa. This occurs after 87% of the gas has been withdrawn (Figure 2).[35,67] During the vapour phase of emptying (that is, no liquid remaining), the pressure will fall linearly in the same manner as an oxygen or air cylinder according to Boyle's law. Low pressure alarms for GE anaesthesia machines are triggered at 254 kPa for pipeline or 2633 kPa for cylinders.[64]

Percussion

A percussion test is used to determine the tone change and identify the fluid level in the cylinder. Starting from the bottom, the cylinder is struck with an instrument until the tone changes from dull to resonant. This fluid level can be tracked over time.

Weight

The weight of gas remaining in a cylinder is the most accurate method of determining the volume of gas remaining. The gross, tare and net weights of all the cylinders are known, with 1 kg of liquid N_2O equivalent to 534 L at sea level and room temperature. The weight of a cylinder can be tracked over time. This method requires cylinders to be disconnected from equipment and is cumbersome if cylinders are heavy, or if multiple require weighing.

Table 5. Methods of detecting volume of N_2O remaining in cylinder

Method	Advantages	Disadvantages
Pressure	Most reliable method to detect depressurisation	Portable regulators do not have auditory alarm Pressure is constant during liquid phase of cylinder emptying
Percussion	Cylinder can remain connected to equipment Can be performed as often as required	Requires interpretation Interindividual variability No tone change once fluid evaporated
Weight	Most accurate	Requires excess equipment Requires cylinder to be disconnected from delivery device

Decommissioning pipelines phase

Decommissioning the reticulated N_2O supply can occur once a resilient portable system has been established and tested in the relevant clinical areas. Formal approval from hospital executive and the head of each affected department is necessary prior to works on the medical gas pipeline system. The following steps need to be considered and conducted by suitable personnel.

Text Box D. Steps in deactivation of central supply

1. Update the map of existing N_2O network
   a. Deactivation of N_2O alarm systems
   b. Manifold – change over alarm and line pressure alarm
   c. Isolation valve box alarms
   d. Theatre – medical gas panel alarms
2. Isolation of the N_2O supply to building
3. Vent the outlets
4. Plug the N_2O gas outlets to make them inoperable
5. Apply "decommissioned" labels to all N_2O outlets, isolation valves, manifold and emergency connection inlets.
6. Return hired manifold cylinders to supplier

Pipelines may remain in situ, but the decommissioned status must be labelled clearly at outlets (Figure 6) and the manifold to ensure the infrastructure is not inadvertently used. Purpose-built "decommissioned" fixed outlets may soon be available.

Figure 6: Decommissioned N_2O outlet

Photo courtesy M.O'Shea and K. Williams. The Prince Charles Hospital, Qld

UNRESOLVED ISSUES

Birth suite

Most N_2O clinically administered in Australia and New Zealand is delivered by non-anaesthetists to provide labour analgesia in birth suites. RANZCOG supports decommissioning N_2O manifolds, referencing internal audits demonstrating leakage. With the current evidence base it is not yet clear if birth suites would be better served by limited piped N_2O and central destruction devices, portable N_2O blenders with or without destruction or a combination thereof.[68,69] Portable N_2O is the method of delivery in Broome Hospital and reports of high patient satisfaction are encouraging. More research and education to determine the best path forward in this area is necessary. It is worthwhile noting that when asked, some patients would have changed their analgesic choice based on the environmental impact.[70]

Quaternary paediatric centres

N_2O is used by many clinicians as part of paediatric gas inductions and procedural sedation. Paediatric centres with multiple anaesthetising and procedural locations throughout the facility will require the most investment to change. Each centre will need to evaluate their usage volumes and patterns to determine the most suitable solution. There is growing consensus that N_2O is not required for successful and atraumatic paediatric gas induction.[71]

Hazards

Diversion of N_2O for use as a recreational drug of abuse is a common concern raised when considering decommissioning. Our opinion is that this risk is likely to be lower with portable supply than with piped systems. As N_2O is a Schedule 4 drug, it should be secured appropriately and records kept. Medical gas companies are obligated to ensure that delivered stock is returned. As such, there is a greater likelihood of being able to detect misuse with point-of-care cylinders than with the current unmonitored outlets. Anecdotal reports of patients and support persons self-administering N_2O from wall outlets are very common. Removing piped N_2O also reduces the risk of cross connection while, whilst rare, can result in fatalities.[60,61]

FUTURE DIRECTIONS

N_2O is becoming less relevant in anaesthesia due to the availability of faster acting intravenous and volatile agents. Challengers to N_2O in the procedural sedation sphere include intranasal agents and inhaled methoxyflurane.[72,73] Methoxyflurane has historically been used in labour and more recently as a bridge to epidural.[74]

Destruction of waste and exhaled N_2O, which reduces the environmental and occupational hazard, may be a path to ensure continued acceptability of this agent.[46] Central and portable N_2O destruction units are in use in Europe, scavenging waste N_2O at point of care or centrally.[68,69] These "nitrous cracking" devices break N_2O into N_2 and O_2, however they rely on the exhaled N_2O being scavenged to the destruction device and are unable to process gas contaminated with volatile agents.

N_2O cylinders are returned to the medical gas company with residual N_2O. Current practice, for regulatory reasons, is to vent the remaining drug in the cylinder to the atmosphere before the cylinder is refilled. In our opinion, medical gas companies have an ethical obligation to pass this waste gas through N_2O destruction units and avoid this emission event entirely.

SUMMARY

N_2O has a long and important history in anaesthesia and pain medicine but is notorious now as a greenhouse gas leaking millions of litres annually from hospital infrastructure. Health services have an obligation to control these leaks by going back to the future and implementing point-of-care cylinders and decommissioning N_2O pipelines.

Thank you to members of the Main Manifold Group for contributions and expertise.

Appendix A. Key physical characteristics of N_2O

Sweet-smelling, colourless, tasteless gas	
Molecular weight	44.01
Boiling point 1ATM	-88.5°C
Density gas 0°C 15°C 21°C Density liquid 1ATM	1.977 kg/m3 1.947 1.88 kg/m3 1227 kg/m3
1 kg liquid N_2O is the equivalent to 534 L	
Critical temperature	36.5°C
Blood/Gas coefficient	0.47
Oil/gas partition coefficient	1.4
MAC	105%
Non-flammable, but supports combustion Oxidising agent	 Oxipotential 0.6 (100% O2 = 1.0, Air = 0.21)
100-year global warming potential	273

Appendix B. Estimated cylinder requirement and emissions per episode
Based on Australian D cylinder (3520 L) and Australian C cylinder (935 L) allowing for 10% wastage

Type of episode	Estimated N_2O per episode (L) (74)	Episodes per C cylinder	Episodes per D cylinder	CO_2e (kg)	Equivalent emissions from car travel (km)
Paediatric gas induction	50	17	64	25.5	180 km
One hour maintenance anaesthesia at 500 mL/min @50%FiN_2O	15	56	213	7.65	52 km
One hour maintenance anaesthesia at 2 L/min 50%FiN_2O	60	14	53	30.6	208 km
Paediatric sedation in ED	60	14	53	30.6	208 km
Labour analgesia	500	1.6	6	255	1740 km

Conversion from CO_2e to kilometres based on 2021 average petrol passenger car in Australia (146.5 g/km)[76]

REFERENCES

1. Chesebro BB, Gandhi S. Mitigating the systemic loss of nitrous oxide: a narrative review and data-driven practice analysis. British Journal of naesthesia [Internet]. 2024 Dec 1 [cited 2024 Dec 2];133(6). Available from: https://pubmed.ncbi.nlm.nih.gov/39322471/
2. Hafiani EM, Teilhet M, Camus F, El Maleh Y, Burey J, Taconet C, et al. Evaluation of a protocol to reduce the environmental impact of anaesthetic gases. Br J Anaesth. 2024 Dec 1;133(6):1489–91.
3. Thomas MAF, Ward CJ, Sinnott ME, Davies TW, Wong JM, Wong JKL, et al. Nitrous Oxide Manifold and Other Reduction of Emissions (NoMoreGas): a multicentre observational study evaluating pre-utilisation loss of nitrous oxide. Br J Anaesth. 2024;133:1427–34.
4. Gaff SJ, Chen VX, Kayak E. A weighing method for measuring nitrous oxide leakage from hospital manifold-pipeline networks. Anaesth Intensive Care [Internet]. 2024 Mar [cited 2024 Apr 18];52(2):127–30. Available from: https://journals.sagepub.com/doi/abs/10.1177/0310057X231198123?journalCode=aica
5. Skowno JJ, Kahlaee HR, Inglis AJ, McKinnon D, Asher K. Hospital-level flow measurement to detect nitrous oxide leakage. Anaesthesia [Internet]. 2024 Aug 1 [cited 2024 Jul 31];79(8):880–1. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/anae.16309
6. Seglenieks R, Wong A, Pearson F, McGain F. Discrepancy between procurement and clinical use of nitrous oxide: waste not, want not. Vol. 128, British Journal of Anaesthesia. Elsevier Ltd; 2022. p. e32–4.
7. Chakera A, McQuillan R, Waite A, Marchant A. Establishing system waste of piped nitrous oxide: Lothian nitrous oxide mitigation project. Anaesthesia. 2021 Sep;76((Suppl. 6)):15.
8. Forster P, Storelvmo T, Armour K, Collins W, Dufresne JL, Frame D, et al. The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity. In: Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, et al., editors. Climate Change 2021: The Physical Science Basis Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2021. p. 923–1054.
9. Department of Health and Aged Care. National Health and Climate Strategy [Internet]. 2023 Dec [cited 2024 Dec 2]. Available from: https://www.health.gov.au/resources/publications/national-health-and-climate-strategy
10. Hu EP, Burch H, Kayak E, McGain F. Variations of nitrous oxide procurement per public hospital bed between Australian states and territories: A cross-sectional analysis. Anaesth Intensive Care [Internet]. 2024 Aug 30 [cited 2024 Sep 16];52(5):321–7. Available from: https://journals.sagepub.com/doi/full/10.1177/0310057X241262796
11. Southall P, Shelton C, Chakera A. Consensus on decommissioning piped nitrous oxide from UK and Ireland operating theatre suites: a rational approach to an increasingly ignoble gas. Anaesthesia. 2024 Dec 1;79(12):1274–9.
12. Committee on Environmental Health. Statement on Deactivating Central Piped Nitrous Oxide to Mitigate Avoidable Health Care Pollution [Internet]. 2024 Oct [cited 2024 Dec 4]. Available from: https://www.asahq.org/standards-and-practice-parameters/statement-on-deactivating-central-piped-nitrous-oxide-to-mitigate-avoidable-health-care-pollution
13. Australasian Health Facilities Guidelines, Part B, Health Facility Briefing and Planning 0510 - Maternity Unit. Section 3.10.7. Updated April 2025. https://aushfg-prod-com-au.s3.amazonaws.com/HPU_B.0510_8_update%20nitrous%20oxide_0.pdf
14. Department of Health and Aged Care. Joint Statement: Working together to achieve sustainable high-quality health care in a changing climate | Australian Commission on Safety and Quality in Health Care [Internet]. Canberra; 2024 Oct [cited 2024 Dec 2]. Available from: https://www.safetyandquality.gov.au/publications-and-resources/resource-library/joint-statement-working-together-achieve-sustainable-high-quality-health-care-changing-climate
15. Kayak EEBJSCWJC, McGain F, Burch H, Dunne B, Gu Y, Davies J, et al. Detecting and reducing nitrous oxide leaks in healthcare facilities: a practical guide [Internet]. Canberra; 2024 Aug [cited 2024 Sep 5]. Available from: https://www.health.gov.au/resources/publications/detecting-and-reducing-leaks-from-nitrous-oxide-in-healthcare-facilities-a-practical-guide?language=en
16. Chakera A, Harrison S, Mitchell J, Oliver C, Ralph M, Shelton C. The Nitrous Oxide Project: assessment of advocacy and national directives to deliver mitigation of anaesthetic nitrous oxide. Anaesthesia [Internet]. 2024 Jan 11 [cited 2024 Feb 8];79(3):270–7. Available from: https://associationofanaesthetists-publications.onlinelibrary.wiley.com/doi/epdf/10.1111/anae.16211
17. Boyle HEG. Nitrous Oxide: History and Development. Br Med J [Internet]. 1934 Jan 27 [cited 2025 Jan 23];1(3812):153–5. Available from: https://www.bmj.com/content/1/3812/153
18. Lew V, McKay E, Maze M. Past, present, and future of nitrous oxide. Br Med Bull [Internet]. 2018 Mar 1 [cited 2025 Jan 23];125(1):103–19. Available from: https://dx.doi.org/10.1093/bmb/ldx050
19. Westhorpe RN. The History of Anaesthesia in Australia and New Zealand. The Wondrous Story of Anesthesia [Internet]. 2014 Oct 1 [cited 2025 Jan 23];9781461484417:303–20. Available from: https://link.springer.com/chapter/10.1007/978-1-4614-8441-7_24
20. WHO Emergency Medicine List 23rd List (2023). 2023 [cited 2025 Jan 23]; Available from: http://apps.who.int/bookorders.
21. Smith WDA. A history of nitrous oxide and oxygen anaesthesia. XII: Developments in America and nitrous oxide anaesthesia between world wars. Brit J Anaesth [Internet]. 1972 [cited 2025 Mar 6];44(2):215–21. Available from: https://www.bjanaesthesia.org/article/S0007-0912(17)51282-9/pdf
22. Romero-Ávila P, Márquez-Espinós C, Cabrera Afonso JR. Historical development of the anesthetic machine: from Morton to the integration of the mechanical ventilator. Brazilian Journal of Anesthesiology [Internet]. 2021 Mar 1 [cited 2025 Mar 6];71(2):148–61. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC9373687/
23. Smith WDA. A History of Nitrous Oxide and Oxygen Anaesthesia. X: The early manufacture, storage and purity of nitrous oxide. British Journal Anaesthesia. 1967;39:351–81.
24. Haupt J. The History of Anaesthesia at Dräger [Internet]. 2nd ed. Anaesthesia Product Group, editor. Hamburg: Dragerwerk AG; 2012 [cited 2025 Mar 6]. Available from: https://www.draeger.com/Content/Documents/Content/history-of-anaesthesia-br-4212-en.pdf
25. AS 2896:2021 Medical gas systems - Installation and testing of non-flammable medical gas pipeline systems | Standards Australia Store [Internet]. [cited 2025 Jan 29]. Available from: https://store.standards.org.au/product/as-2896-2021
26. Collins MR, Starr SA, Bishop JT, Baysinger CL. Nitrous Oxide for Labor Analgesia: Expanding Analgesic Options for Women in the United States. Rev Obstet Gynecol [Internet]. 2012 [cited 2025 Jan 23];5(3–4):e126-131. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC3594866/
27. Eley VA, Callaway L, van Zundert AA. Developments in labour analgesia and their use in Australia. Anaesth Intensive Care [Internet]. 2015 Jul 1 [cited 2025 Jan 23];43 Suppl:12–21. Available from: https://pubmed.ncbi.nlm.nih.gov/26126071/
28. Bradfield Z, Rose MS, Freeman N, Leefhelm E, Wood J, Barnes C. Women's perspectives of nitrous oxide for labour and procedural analgesia: A prospective clinical audit and cross-sectional study. "It's the best thing." Women and Birth [Internet]. 2023 Nov 1 [cited 2025 Jan 23];36(6):529–37. Available from: http://www.womenandbirth.org/article/S1871519223001002/fulltext
29. Brown SM, Sneyd JR. Nitrous oxide in modern anaesthetic practice. BJA Educ. 2016 Mar 1;16(3):87–91.
30. O'Sullivan Í, Benger J. Nitrous oxide in emergency medicine. Emergency Medicine Journal [Internet]. 2003 May 1 [cited 2025 Jan 23];20(3):214–7. Available from: https://emj.bmj.com/content/20/3/214
31. WG-7 Medical and Breathing Gases. Medical Gas Cylinder Colour Coding [Internet]. 2020 [cited 2025 Jan 23]. Available from: www.eiga.eu
32. Westwood MM, Rieley W. Medical gases, their storage and delivery. Anaesthesia & Intensive Care Medicine. 2012 Nov 1;13(11):533–8.
33. Van Der Kooy J, De Graaf JP, Kolder ZM, Witters KD, Fitzpatrick E, Duvekot JJ, et al. A newly developed scavenging system for administration of nitrous oxide during labour: safe occupational use. Acta Anaesthesiology Scandavia [Internet]. 2012 Mar [cited 2025 Jan 23];56:920–5. Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1399-6576.2012.02668.x
34. Neice A. Nitrous oxide cracking technology in the labour ward to reduce occupational exposure and environmental emissions. Anaesthesia. 2022;
35. Dorsch J, Dorsh S. A Practical Approach to Anesthesia Equipment [Internet]. First. Philadelphia, PA: Lippincott Williams & Wilkins; 2011 [cited 2025 Jan 23]. Available from: https://oce-ovid-com.ezproxy.anzca.edu.au/book?SerialCode=01437497
36. British Oxygen Company New Zealand. British Oxygen Company. [cited 2025 Mar 6]. Medical Nitrous Oxide. Available from: https://www.boc.co.nz/shop/en/nz/nitrous-oxide---medical
37. British Oxygen Company Australia. British Oxygen Company. [cited 2025 Mar 6]. Medical Nitrous Oxide. Available from: https://www.boc.com.au/shop/en/au/medical-nitrous-oxide#product1
38. Intergovernmental Panel on Climate Change (IPCC). The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity. Climate Change 2021 – The Physical Science Basis. 2023 Jun 29;923–1054.
39. Slingo JM, Slingo ME. The science of climate change and the effect of anaesthetic gas emissions. Anaesthesia [Internet]. 2024 Mar 1 [cited 2025 Mar 13];79(3):252–60. Available from: https://pubmed.ncbi.nlm.nih.gov/38205585/
40. Anderson WA, Rao A. Anesthetic Gases: Environmental Impacts and Mitigation Strategies for Fluranes and Nitrous Oxide. Environments - MDPI [Internet]. 2024 Dec 1 [cited 2025 Mar 5];11(12):275. Available from: https://www.mdpi.com/2076-3298/11/12/275/htm
41. Ranganathan J, Corbier L, Schmitz S, Oren K, Dawson B, Spannagle M, et al. The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard [Internet]. Conches-Geneva, Washington; 2024 [cited 2025 Mar 6]. Available from: https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf
42. Cohen EN, Gift HC, Brown BW, Greenfield W, Wu ML, Jones TW, et al. Occupational Disease in Dentistry and Chronic Exposure to Trace Anesthetic Gases. The Journal of the American Dental Association. 1980 Jul 1;101(1):21–31.
43. Safe Work Australia. Nitrous Oxide Exposure Standard Documentation [Internet]. 1990 [cited 2022 Nov 23]. Available from: http://hcis.safeworkaustralia.gov.au/ExposureStandards/Document?exposureStandardID=453
44. Dames B, McGlothlin J, Domeny L. Controlling Exposures to Nitrous Oxide During Anesthetic Administration. Cincinnati OH; 1994.
45. Australian Standards ME-062. AS 1668.2:2024 The use of ventilation and airconditioning in buildings, Part 2: Mechanical ventilation in buildings [Internet]. 2024 Jun [cited 2025 Mar 6]. Available from: https://store.standards.org.au/product/as-1668-2-2024
46. Mills GH, Singh D, Longan M, O'Sullivan J, Caunt JA. Nitrous oxide exposure on the labour ward. Int J Obstet Anesth. 1996 Jul 1;5(3):160–4.
47. Munley AJ, Railton R, Gray WM, Carter KB. Exposure of midwives to nitrous oxide in four hospitals. Br Med J (Clin Res Ed) [Internet]. 1986 Oct 25 [cited 2025 Jan 23];293(6554):1063–4. Available from: https://pubmed.ncbi.nlm.nih.gov/3768665/

48. NHS England & NHS Improvement. Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises [Internet]. 2024 Jan [cited 2025 Feb 8]. Available from: https://www.england.nhs.uk/publication/specialised-ventilation-for-healthcare-buildings/
49. Sun R, Jia WQ, Zhang P, Yang K, Tian JH, Ma B, et al. Nitrous oxide-based techniques versus nitrous oxide-free techniques for general anaesthesia. Cochrane Database of Systematic Reviews. 2015 Nov 6;2015(11).
50. Peyton PJ, Leslie K. The safety of nitrous oxide: glass half-full or half-empty? Br J Anaesth [Internet]. 2024 May [cited 2024 Jul 31];133(6):1358–62. Available from: https://pubmed.ncbi.nlm.nih.gov/38816332/
51. Myles PS, Leslie K, Chan MTV, Forbes A, Paech MJ, Peyton P, et al. Avoidance of nitrous oxide for patients undergoing major surgery: a randomized controlled trial. Anesthesiology [Internet]. 2007 [cited 2025 Feb 7];107(2):221–31. Available from: https://pubmed.ncbi.nlm.nih.gov/17667565/
52. Myles PS, Leslie K, Chan MTV, Forbes A, Peyton PJ, Paech MJ, et al. The safety of addition of nitrous oxide to general anaesthesia in at-risk patients having major non-cardiac surgery (ENIGMA-II): a randomised, single-blind trial. Lancet [Internet]. 2014 Oct 18 [cited 2025 Feb 7];384(9952):1446–54. Available from: https://pubmed.ncbi.nlm.nih.gov/25142708/
53. McGain F, Bishop JR, Elliot-Jones LM, Story DA, Imberger GLL. A survey of the choice of general anaesthetic agents in Australia and New Zealand. Anaesth Intensive Care. 2019 May 1;47(3):235–41.
54. Husum B, Stenqvist O, Alahuhta S, Sigurdsson GH, Dale O. Current use of nitrous oxide in public hospitals in Scandinavian countries. Acta Anaesthesiol Scand [Internet]. 2013 Oct [cited 2025 Mar 13];57(9):1131–7. Available from: https://pubmed.ncbi.nlm.nih.gov/23889322/
55. Chakera A. Evidence-Based Policy Report: Reducing Environmental Emissions attributed to Piped Nitrous Oxide Products within NHS Hospitals. 2021;
56. Smith E, Mitchell C. The importance of tackling leaks in nitrous oxide pipes. ANZCA Bulletin [Internet]. 2023 [cited 2024 Apr 6];(1):58–9. Available from: https://issuu.com/anzca1992/docs/anzca_bulletin_autumn_2023_issuu
57. Marx T, Fröba G, Bäder S, Villwock J, Georgieff M. Diffusion of anaesthetic gases through different polymers. Acta Anaesthesiol Scand [Internet]. 1996 Feb 1 [cited 2025 Jan 23];40(2):275–81. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1399-6576.1996.tb04432.x
58. Metro North Health. TPCH anaesthetists make a clinical sustainable switch for a greener future | Metro North Health [Internet]. 2024 Apr [cited 2024 Dec 2]. Available from: https://metronorth.health.qld.gov.au/news/switch-for-a-greener-future
59. National Green Theatres Programme. National Green Theatres Programme Decommission of Nitrous Oxide Manifolds-Opportunity for Change. 2023 May.
60. Rossaint R, Coburn M, Jantzen JP. Should we Still use Nitrous Oxide in our Clinical Practice? No! Turk J Anaesthesiol Reanim [Internet]. 2017 Feb 1 [cited 2025 Jan 23];45(1):3. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC5367722/
61. Chief Health Officer. Bankstown-Lidcombe Hospital Medical Gases Incident: Final Report. 2016.
62. PS54(A)BP Position statement on the minimum safety requirements for anaesthesia machines and workstations for clinical practice Short title: Anaesthesia machine safety BP [Internet]. 2021. Available from: www.anzca.edu.au
63. Sinclair CM, Thadsad MK, Barker I. Modern anaesthetic machines. Continuing Education in Anaesthesia, Critical Care and Pain [Internet]. 2006 Apr 1 [cited 2024 Dec 2];6(2):75–8. Available from: http://www.bjaed.org/article/S1743181617303979/fulltext
64. Datex-Ohmeda. Aisys Anesthesia Machine Technical Reference Manual. Madison, Wisonsin: Datex-Ohmea; 2008.
65. Paul J. The CIG Medishield "Bassoon" active scavenging interface. Anaesth Intensive Care. 1993 Apr;21(2):251–2.
66. Australian Standards CH-009. AS 4332:2004 The storage and handling of gases in cylinders [Internet]. 2004 Apr [cited 2025 Jan 29]. Available from: https://store.standards.org.au/reader/as-4332-2004?preview=1
67. Al-Shaikh B, Stacey S. Medical gas supply. In: Essentials of Equipment in Anaesthesia, Critical Care and Peri-Operative Medicine [Internet]. Sixth. Elsevier; 2024 [cited 2025 Jan 23]. p. 1–19. Available from: https://www-clinicalkey-com-au.ezproxy.anzca.edu.au/#!/content/book/3-s2.0-B9780702071959000019
68. Dahling S, Wennerhed FM. Nordic Know-How 2020 [Internet]. Malmo; 2020 [cited 2025 Mar 6]. Available from: https://nordicshc.org/images/Nordic_know-how_2020_Nitrous_Oxide_2.pdf
69. Ek M, Tjus K. Destruction of Medical N2O in Sweden. In: Liu G, editor. Greenhouse Gases - Capturing, Utilization and Reduction [Internet]. InTech; 2012 [cited 2025 Mar 6]. Available from: www.intechopen.com
70. McGarrigle C, Hartigan S, Duffy O, Tan T. Perspectives on sustainable practices in the use of nitrous oxide for labour analgesia: A patient and staff survey. Eur J Anaesthesiol. 2024 Jul 1;41(7):473–9.
71. Gordon DW, Chatterjee D, McGain F. It's time to stop using nitrous oxide for pediatric mask induction. Pediatric Anesthesia [Internet]. 2024 Feb 1 [cited 2025 Mar 6];34(2):104–7. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/pan.14778
72. Jephcott C, Grummet J, Nguyen N, Spruyt O. A review of the safety and efficacy of inhaled methoxyflurane as an analgesic for outpatient procedures. Br J Anaesth [Internet]. 2018 May 1 [cited 2025 Jan 23];120(5):1040–8. Available from: http://www.bjanaesthesia.org/article/S0007091218300394/fulltext
73. Liu Y, Lee-Archer P, Sheridan NicoleM, Seglenieks R, McGain F, Eley VictoriaA. Nitrous Oxide Use in Australian Health Care: Strategies to Reduce the Climate Impact. Anesth Analg [Internet]. 2023;137(4):819–29. Available from: https://libkey.io/10.1213/ANE.0000000000006620

74. Anwari JS, Khalil L, Terkawi AS. Efficacy of the methoxyflurane as bridging analgesia during epidural placement in laboring parturient. Saudi J Anaesth [Internet]. 2015 Oct 1 [cited 2025 Jan 23];9(4):370–5. Available from: https://journals.lww.com/sjan/fulltext/2015/09040/efficacy_of_the_methoxyflurane_as_bridging.7.aspx
75. Wong A, Gynther A, Li C, Rounds M, Lee JH, Krieser D, et al. Quantitative nitrous oxide usage by different specialties and current patterns of use in a single hospital. Br J Anaesth [Internet]. 2022 Sep 1 [cited 2023 Feb 20];129(3):e59–60. Available from: http://www.bjanaesthesia.org/article/S0007091222002616/fulltext
76. National Transport Commission. Executive summary: Carbon Dioxide Emissions Intensity for New Australian Light Vehicles 2022 [Internet]. Melbourne; 2023 Dec [cited 2025 Mar 6]. Available from: www.ntc.gov.au