Evidence-Based Policy Report:
Reducing Environmental Emissions attributed to Piped Nitrous Oxide Products within NHS Hospitals

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Emailed V1 for review by members within the following organisations:
NHS Hard facilities Management England, Wales, Scotland and Northern Ireland
Association of Anaesthetists 2% task force and Royal College of Midwifery Subgroup
Royal Pharmaceutical Society, Great Britain circulation by Chief Scientist
Quality Control Pharmacists England via James McDade (QAS SE Scotland)
Centre for Sustainable Healthcare and Environmental Fellows England and Wales
NHS England and NHS Improvement Medicines Policy Unit and Greener NHS
NHS Lothian Nitrous oxide mitigation project team

GREEN: QA V2 Undertaken by Tim Horsfield 20/4/21 and additional amendment sent through by Hasina Begam 26/4/21

Final QA needed of highlighted text

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List of Abbreviations

AAGBI	Association of Anaesthetists of Great Britain and Ireland
BOC™	British Oxygen Company
CO_2e	Carbon dioxide equivalent
CSH	Centre for Sustainable Healthcare
DATCC	Diagnostics, Anaesthetics, Theatres and Critical Care
DMAIC	Define, Measure, Analyse, Improve and Control
EC	European Commission
ED	Emergency Department
GHG	Greenhouse Gas
GWP_{100}	Global Warming Potential over 100 years
HFM	Hard Facilities Management
HFS	Health Facilities Scotland
ICS	Integrated Care Systems
N_2O	Nitrous oxide
NHSEI	NHS England Improvement
NHSL	National Health Services Lothian
NHSS	National Health Services Scotland
NSS	National Services Scotland
OAA	Obstetric Anaesthetists Association
PPM	Planned Preventative Maintenance
QAS	Quality Assurance Specialist
QC	Quality Control
QI	Quality Improvement
RCOA	Royal College of Anaesthetists
RCT	Randomised controlled study
RIE	Royal Infirmary of Edinburgh
SFM	Soft Facilities Management
SJH	St John's Hospital
TIVA	Total Intravenous Anaesthesia
WGH	Western General Hospital

Executive Summary

Nitrous oxide is a potent greenhouse gas and dominant ozone depleting substance. Within healthcare it is used ubiquitously as an anaesthetic and analgesic agent by a variety of practitioners in a variety of settings. Emissions from nitrous oxide products from English NHS sites approximated 253 kilo tonnes in carbon dioxide equivalents ($ktCO_2e$) in 2019/20.

New research from Scotland has revealed that wastage within *piped* nitrous oxide systems is a significant problem. A small initial study in 2020 of three nitrous oxide piped systems all demonstrated varying degrees of waste to a total volume approximating 1.5 million litres per year.

Due to the significance of the findings, the mitigation methods applied by the Scottish team have been shared and disseminated across the UK and in the Republic of Ireland. This has led to a number of compelling case studies all demonstrating significant waste from piped nitrous oxide, including that of Entonox® manifolds. By 31 March 2021, 16 sites involved in the National Nitrous Oxide Project have identified nitrous oxide waste averaging 95% across nitrous oxide manifolds, suggesting England could achieve a reduction of 78,000 tCO_2e for these systems. Three sites have begun assessments on their Entonox® manifolds and have an estimated an average waste close to 60%, however these are exceptionally high emitting systems. It is perhaps too early to speculate about emission reductions for manifold Entonox®; a conservative estimate of a 25% reduction in waste would yield an emission savings of 34,000 tCO_2e for NHS England.

This report uses data analysis to enable strategic collaboration with trusts with high levels of nitrous oxide emissions and draws on cases studies to gain deeper insight into causes of waste and challenges in addressing wastage. This document presents structured guidance to enable NHS sites in England to reduced piped nitrous oxide product waste and provides links to resources. The report has been developed in consultation with NHS Hard Facilities Management and the Association of Anaesthetists, Royal College of Midwives, Royal College of Anaesthetists, The Royal Pharmaceutical Society, the Centre for Sustainable Healthcare, the Greener NHS programme and the Environmental Fellows for England and Wales.

A summary of the main recommendations are as follows:

1. Medical Gas Committees (MCGs) of each trust should establish multidisciplinary project teams to work towards zero emissions of anaesthetic gases at each acute site under their purview.

2. All acute sites with a piped nitrous oxide and Entonox® systems should undertake a waste review.

3. Estate teams and MGCs should immediately investigate nitrous oxide and Entonox® system waste.

4. Waste should be eliminated, and the leanest nitrous oxide supply should be introduced.

5. MGCs should conduct quarterly reviews of processes and practices to minimise waste, reducing reviews to biannual after 12 months.

Other:

6. New theatres should be built to have zero emissions and should avoid excessive system redundancy. Nitrous oxide piped systems should not be routinely introduced in new surgical suites.

INTRODUCTION

Within the NHS, anaesthetic gases are recognised as potent greenhouse gases, expired virtually unchanged by the body and account for approximately 2% of the NHS carbon footprint. The bulk of these emissions are made of nitrous oxide which has a 100-year global warming potential (GWP_{100}) of 298, is a significant ozone depleting substance and persists in the environment for approximately 131 years (IPCC, 2013). For the NHS to reach net zero, mitigating emissions from this agent will be essential.

Nitrous oxide products are often supplied through a remote bank of compressed gas cylinders known as a manifold. These piped systems account for most of the anaesthetic gas emissions within NHS sites. Based on BOC™ data summaries in 2019/20 manifold nitrous oxide and Entonox® made up close to 27% and 45% of these anaesthetic emissions for NHS England sites respectively.

The main supplier of these manifold cylinders across the four nations is BOC™ (Linde™ group). Within England an alternative medical gas cylinder supplier Air Liquide™ supplies approximately 15% of NHS sites. Entonox® will be used to describe a 50:50 nitrous oxide and oxygen gas mix in this document.

New evidence from Scotland strongly indicates that these piped systems are prone to significant wastage. By January 2021, NHS Lothian had interrogated five nitrous oxide manifolds in detail, and all examined exhibited waste to some extent. A total loss in manifold nitrous oxide of over 1.9 million litres in 2019/20 was estimated and a further 144,000 litres wasted through expired unused cylinders.

The Scottish team compared nitrous oxide manifold emissions of 38 acute sites against surgical intensity and expect that 34 sites will demonstrate waste to some extent[1]. Additionally, using the average amount of piped Entonox® in CO_2e per maternity as a benchmark, the team estimate that up to 16 of 21 Scottish sites are losing Entonox® within their piped infrastructure[2]. Adopting a similar approach is especially valuable for the NHS in England with its large population, allowing identification of high emission sites and targeting mitigation strategies accordingly. Application of NHSEI surgical and maternal CO_2e intensity analysis is considered within the implementation strategy.

The waste mitigation methodology developed in Scotland relies on the Lean Six Sigma DMAIC framework seeking to eliminate waste along to the entire supply chain (Chakera, 2020). With the support of The Nitrous Oxide Mitigation Project[3], this work has been steadfastly adopted and applied within acute sites across the UK and the Republic of Ireland. Within England alone 35 health trusts have committed to undertaking this project within the next 12 months. To date, 16 sites have reported on piped nitrous oxide waste as a result of poor stock management, system leaks and theft.

The Scottish research is recognised as a significant development by the Greener NHS programme. The Scottish waste elimination methods must be adapted and embedded within wider plans to mitigate anaesthetic gases within the rest of the UK. It is now deeply evident that waste within piped nitrous oxide systems is so significant and so polluting that hesitancy in elimination escalation and mitigation would be deeply negligent.

[1] Discussion of analysis, courtesy of NHS Lothian, A. Chakera and A. Grant
[2] Discussion of analysis, courtesy of NHS Lothian, A. Chakera and S. Cross
[3] The Nitrous Oxide Mitigation Project A. Chakera, A. Fennel-Wells and C. Allen

This policy brief considers emerging evidence from stakeholders, considers consumption data, provides recommendations and proposes an implementation strategy that can be adapted across NHS sites.

1 METHODS

Two years of NHSEI BOC™ returns data for nitrous oxide and Entonox® were reviewed alongside the prescribing dataset for volatiles agents and the carbon footprint of each of these agents was determined. Air Liquide™ data was not available at the time of analysis or on completion of the consultative draft.

Carbon intensity calculations for each trust were determined for manifold nitrous oxide and Entonox® NHS Trusts and Integrated Care Systems (ICS) using BOC™ nitrous oxide manifold cylinders had their emissions determined in carbon equivalents for 2019/20 and this was plotted against corresponding NHS Digital Data of Finished Consultant Episodes for 2019/20 against selected main speciality codes 100, 101, 110, 120, 130, 140, 150, 160, 170, 171 and 190 as a proxy for surgical admissions.

NHS Trusts and ICSs using Entonox® manifold cylinders had their emissions determined in $kgCO_2e$ for 2019/20; this was plotted against NHS Digital maternity statistics for 2019/20. Per delivery emissions were determined against total deliveries and total deliveries, less elective Caesarean sections (C-Sections).

The Scottish research was reviewed (Chakera, 2020) alongside case studies provide by the Nitrous Oxide Project Team. The cases studies included qualitative and quantitative information extracted by phone/digital interviews and email and information gathered on the: (i) BOC™ volume of returned cylinders in 2019/20, (ii) estimated usage of nitrous oxide and/or Entonox®, (iii) volume of waste, (iv) type of waste, (v) mitigation activities taken/planned and (vi) challenges encountered in the process. Site data was anonymised and tabulated.

Multidisciplinary stakeholders from across the UK were consulted. These included members from soft and hard facilities teams, quality control pharmacy services, cylinder suppliers, anaesthetic consultants and trainees, operating department practitioners, midwives and emergency department trainees and consultants.

Recommendations emerging from the evidence were assessed for implementation viability with key stakeholders.

2 RESULTS

2.1 NHS ENGLAND ANAESTHETIC GAS CARBON FOOTPRINT

Figure 1 and Table 1 illustrate the carbon footprint of different anaesthetic gases in tCO_2e for NHS England sites for the years 2018/19 and 2019/20. The impact of piped nitrous oxide product is relatively stable over the two years conferring 222kt and 220 $ktCO_2e$, respectively. The slight decrease in use for 2019/2020 is possibly attributed the steep decrease in theatre activity late in March 2020 with suspension of many elective procedures to accommodate for a surge in Covid-19 cases.

In 2019/20 the carbon footprint of *piped* nitrous oxide products in NHS England sites was over 71%.

Figure 1. Breakdown of anaesthetic gas usage NHS England 2018/19 and 2019/20

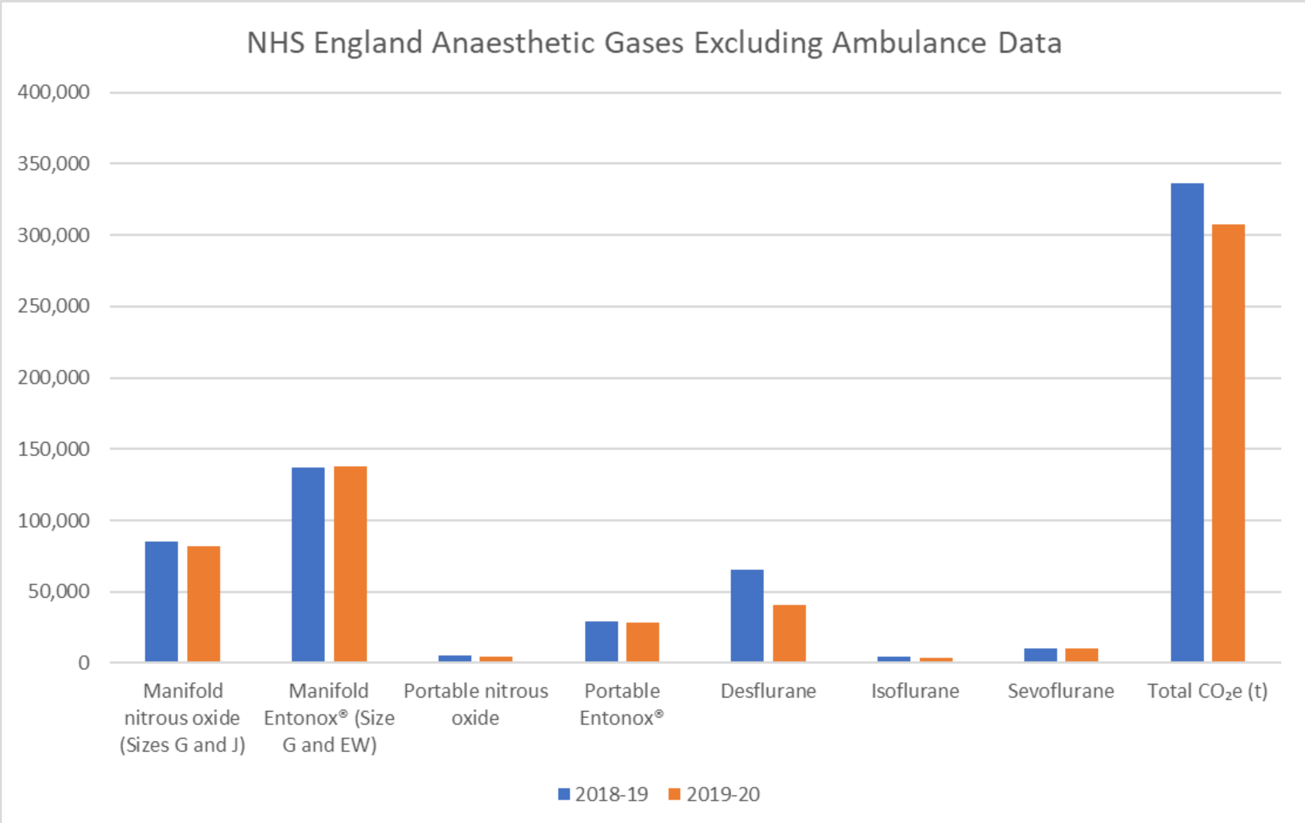

Table 1. NHS England 2018/19 and 2019/20 anaesthetic usage breakdown analysis

AGENT AND FORM OF SUPPLY	tCO_2e2018-19	tCO_2e 2019-20	% Change
Manifold nitrous oxide	85,358	82,277	-4%
Manifold Entonox®	137,225	137,669	0%
Portable nitrous oxide	5,293	5,130	-3%
Portable Entonox®	29,427	29,086	-1%
Desflurane	65,172	40,932	-37%
Isoflurane	4,313	3,452	-20%
Sevoflurane	10,165	10,106	-1%
Total CO_2e (t)	336,953	308,652	-8%

2.2 SURGICAL CARBON EMISSION INTENSITY FOR PIPED NITROUS OXIDE

A total of 139 NHS England Trusts and ICSs were reviewed as shown in Figure 2. The number of specified operations to total piped nitrous oxide emissions for 2019/20 was plotted in the scatter graph below. Closer inspection of the emissions data reveals that 13 NHS Trusts, or the top decile, account for 35% of all piped nitrous oxide emissions. These sites also have higher than average emissions per surgical episode (average 17 kgCO_2e per surgical episode). A total of 27 trusts fall within the top quintile for piped nitrous oxide emissions and account for 52% of total emissions. These trusts would benefit from granular analysis to identify which sites are the highest emitters. It is worth noting that, within the top quintile, five trusts have lower than the national average nitrous oxide emissions per surgical episode. However, as these are large trusts, nitrous oxide waste mitigation is advisable, as Scottish sites with lower-than-average emissions per surgical episode have identified significant volumes of waste[4]. Of the nine trusts that have zero surgical spells only one is an acute trust and it possible that surgical data has not been transferred. Of the remaining two are community and six are Mental Health and Learning Disability trusts the value of the nitrous oxide manifold will need to be reviewed.

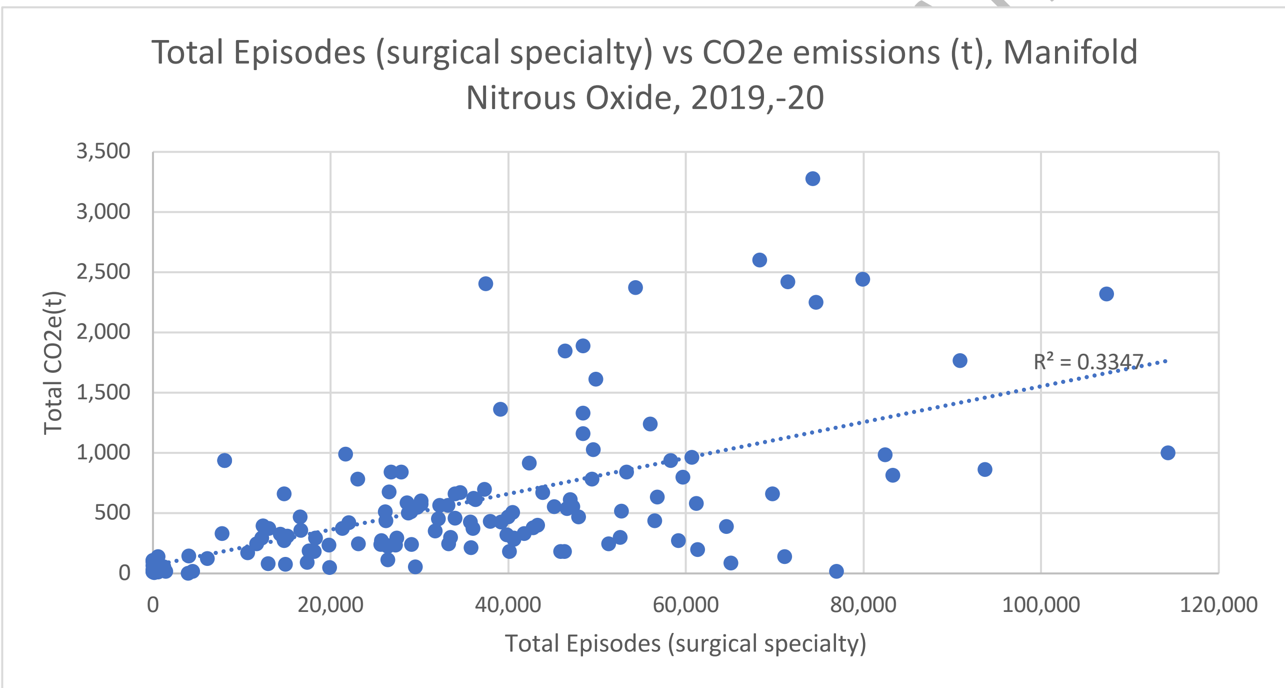

Figure 2 Surgical Episode Analysis[5]

2.3 CARBON EMISSION INTENSITY PER DELIVERY FOR PIPED ENTONOX®

[4] Royal Infirmary of Edinburgh, St John's hospital and the Golden Jubilee identified manifold waste to the magnitude of 97%, 82% and 100% despite having manifold nitrous oxide emissions levels per elective surgical case within operating theatres (Public Health Scotland) that fell below the Scottish national average. Data analysis, A. Chakera, unpublished abstract

[5] Average per surgical episode 17 kgCO_2e. Average per trust 588 tCO_{2e}. Median 423t CO_2e. Range 5-3,278 tCO_2e

In Figures 3 and 4 below, 108 NHS England site Entonox® manifolds emissions are reviewed against the total number of deliveries and deliveries less C- sections, respectively.

In Figure 3, the first decile of the highest emitting trusts account for 23% of the total emissions attributed to manifold Entonox® with the top quintile accounting for 40% of total piped Entonox® emissions. The top quintile accounts for 22 trusts, of which 16 have demonstrated higher than average emissions per delivery with one health trust demonstrating emissions per delivery three times higher than the national average. Once again 16 out of 22 sites within the top quintile demonstrate emissions above the national average and three of the health trusts emissions jumped to three times the national average once C-sections were removed.

Reporting on Entonox® manifold wastage to date is limited to sites with exceptionally high emissions. Opportunities for how to identify Entonox® manifold wastage is explored further within the evidence section.

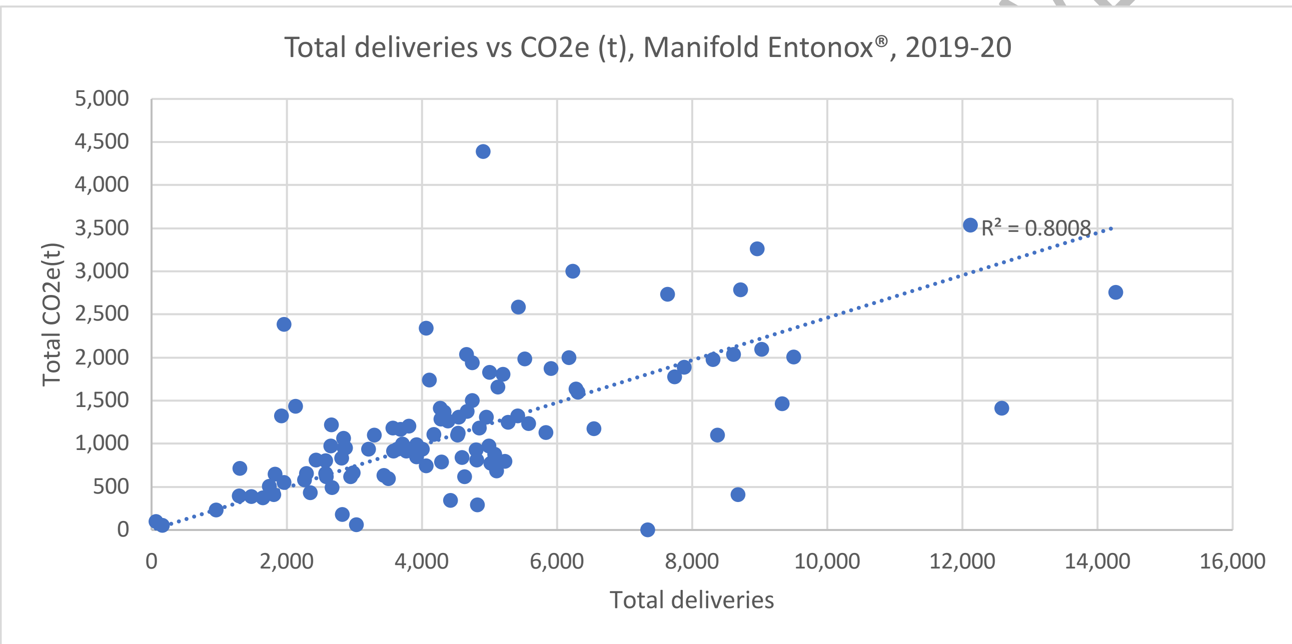

Figure 3. Manifold Entonox® Per Maternity NHS England Trust Level Analysis[6]

[6] Average per delivery 264 $kgCO_2e$. Average per delivery less elective C-sections 305 $kgCO_2$. Average CO_2e per trust 1,215 tCO_2e. Median 1,082 tCO_2e. Range 1-4,394 tCO_2e

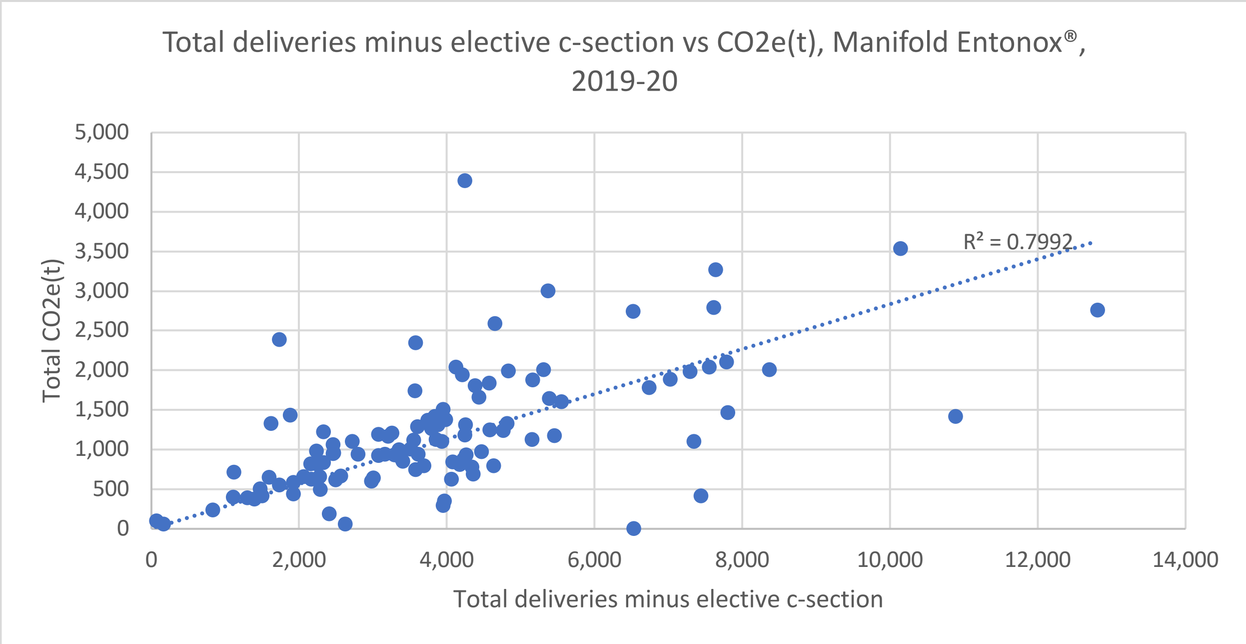

Figure 4 Manifold ***Entonox® Per Maternity less Elective section NHS England Trust Level Analysis***

2.4 CASE STUDIES

The following two tables summarise the interviews and discussions hosted with sites already engaged with the National Nitrous Oxide Project. It must be noted that many sites are in the midst of nitrous oxide and Entonox® investigations and there will be more conclusive evidence gathered over the next few months. The early evidence, however, is insightful and the most notable challenge to progressing the waste mitigation project was site capacity. Additionally, whilst many sites have identified system waste by assessing or estimating clinical use, they have not necessarily assessed the system waste with the utmost due diligence to establish the root causes for this waste. Detailed system waste assessments can be very useful as it can highlight problems around cylinder management, including security, stock control and medical gas contracts (Chakera, 2020). Such information can be valuable, especially when developing a lean implementation framework. This theory is expanded within the evidence and implementation strategy.

Table 2. Nitrous Oxide Manifold Waste Reviewed Against 2019/20 BOC™ Data[7]

Case Study Code	BOC™ Volume Returned in Litres 2019/20	Estimate of Annual Clinical Use (based on 2019/20 activity)	Estimated Volume of Waste	Type of Waste Identified or Suspected	Mitigation Actions Completed or Planned	Challenges
S1	792,000	4,000	788,000	Expired stock, overprovision, leaks	Decommissioning, reduce supply	Soft facilities training
S2	864,000	18,200	845,800	System leak	Planned manifold decommission	PFI hard FM communication
S3	432,000	75,000	357,000	Expired stock, system leak	Remove surplus piped work	Pressure drop test difficult to arrange
S4	234,000	0	234,000	Small leak	Decommissioned	Access to theatres

[7] Supplied by courtesy of The Nitrous Oxide Mitigation Project, A. Chakera, A. Fennell-Wells and C. Allen. Volume of waste excludes expired stock found on premises during waste investigations

S5	486,000	40,000	446,000	System leak	Decommission and move to leaner supply	Estate capacity
S6	1,592,000	60,000	1,532,000	System leak	Unsure	Estate capacity
S7	819,000	114,000	705,000	System leak	Unsure	PFI hard FM communication
S8	630,000	40,000	590,000	System leak	Unsure	Not communicated
W1	297,000	0	297,000	Expiring stock	Query redundant manifold	Estate capacity
W2	1,071,000	50,000	1,021,000	System leak Query Theft	In progress	Estate capacity
R1	1,197,000	100,000	1,097,000	System leak	4 leaks repaired	Estate access to theatres
E1	2,178,000	125,000	2,053,000	System leak	Pressure drop test	Estate capacity
E2	1,062,000	0	1,062,000	System leak	Unplugged anaesthetic machines, estates to decommission	Estate capacity
E3	261,000	6,000	255,000	System leak	Unplugged anaesthetic machines less 2 maternity theatres. Leak test to be performed	Estate capacity
E4	1,206,000	0	1,206,000	System leak	Unplugged anaesthetic machines, leak test to be performed or straight to decommissioning	Estate capacity
E5	1,322,000	45,000	1,277,000	Theft System leaks	Improved security. Anaesthetists to assess clinical use	In progress
Total Volume	14,443,000	683,200	13,771,800			
		Percentage Waste Observed	95%			

Table 3. Entonox® Manifold Waste Review Against BOC™ 2019/20 Data [8]

Case Study Code	BOC™ N_20 Volume Returned in Litres 2019/20	Estimate of Clinical Use 2019/20 Based on Scottish Benchmark	Estimated Volume of Waste	Type of Waste Identified or Suspected	Mitigation Actions Completed or Planned	Challenges
S3	1,634,556	1,343,743	246,813	System leak	Estates have agreed to arrange a pressure drop test	Labour unit and estates joint capacity
W2	8,200,000	2,871,732	5,328,268	System leak Query Theft	Estates have agreed to arrange a pressure drop test	Estate capacity
E5	7,927,500	2,912,941	5,014,559	Unknown	Estates have agreed to arrange a pressure drop test	Labour unit and estates joint capacity
Total Volume	17,762,056	7,172,416	10,589,640			
		Estimated Percentage Waste	60%			

[8] Ibid

3 SCOPE AND LIMITATIONS

This report considers different aspects of piped nitrous oxide and Entonox® supply. It weighs the environmental, infrastructural and social cost implications; within the evidence section it reviews its clinical application, causes of system wastage, challenges around management processes, and training and data management. Finally, it draws on this evidence to crystallise recommendations to mitigate this waste and inform an implementation strategy.

This report does not delve deeply into the site management of portable nitrous oxide and Entonox® cylinders or volatile mitigation. Within the implementation plan it encourages each site to first eliminate waste and then risk assess the validity of different types of technologies that may mitigate anaesthetic gases further. It does not endorse one technology over another. Additionally, it does not advocate one specific clinical treatment approach, but it does comment on trends in clinical practice and opportunities for clinicians to minimise waste.

Whilst the lead investigator has consulted broadly, time constraints and stakeholder commitments within the ongoing stresses of pandemic management have limited these consultations. Additionally, whilst lessons have been shared by participants contributing to the National Nitrous Oxide Mitigation Project, their narratives, whilst informative, are still emerging. It is accepted that we will learn more and that these further lessons will need to be shared in future updates.

4 THE COST OF PIPED NITROUS OXIDE AND ENTONOX®

4.1 INFRASTRUCTURE COSTS

Nitrous oxide, when compared to other pharmaceutical agents, is relatively inexpensive. A large health board or trust with a mix of NHS facilities serving a population between 800,000-1,000,000 people can expect to incur an annual cost of nitrous oxide and Entonox® agent and cylinder rental charges in the order of £45,000-50,000[9], with manifold nitrous oxide products costing just over two-third of this sum. The cost will vary depending on the nature of the contract negotiated with the medical gas supplier.

The cost of upkeep of manifolds is the main challenge. Contract costs for external medical gas contractors for annual inspections to meet Planned Preventative Maintenance (PPM) requirements is £4,000-6,000, the replacement of ageing manifolds £6,000-10,000 and the installation of new manifolds with associated piped infrastructure around £45,000. This infrastructure will need the oversight of a trained and authorised person and an authorised engineer, all of which will have an impact on costs. NHS Lothian has taken the decision to decommission rather than refurbish an aging, leaking manifold and is planning to decommission a second manifold. Decommissioning service charges are low at around £150 per manifold but driving considerable maintenance savings as such clinical necessity of the manifold should be verified[10].

[9] Health board and trust financial information is confidential. These figures are extrapolated estimates
[10] Personal communication, NHS Lothian hard FM authorised persons, Western General and St John's Hospital, NHS Lothian

Within NHS Lothian, a new suite of 11 theatres under development will not have a piped supply of nitrous oxide, primarily as a move towards green anaesthetic practice and in recognition that the use of the agent is relatively low and thus limits the justification of installation[11].

4.2 NITROUS OXIDE CATALYTIC DESTRUCTION TECHNOLOGIES

Whilst exploration of green technologies is not the focus of this report, it is advised that all sites risk assess the validity of different forms of green technologies prior to investing. Several Nordic manufacturers offer slightly different technologies which capture exhaled nitrous oxide which later splits nitrous oxide via catalytic conversion into nitrogen and oxygen. These technologies can potentially remove the need for traditional scavenging systems; however, within the piped medical gas systems their benefits are diminished if the nitrous oxide or Entonox® is lost before it reaches the patient. As such it is imperative to have waste prevention and monitoring processes within each site even if these technologies are introduced.

Sites that have considered installing these technologies have learned that costs will vary depending on baseline infrastructure. For example, a 10-room delivery suite supplying piped Entonox® without a pre-existing scavenging system will require the introduction of further piped infrastructure prior the instalment of centralised catalytic destruction unit with its associated consumables costing the site up to £200,000[12]. These technologies have a place but given the sizable outlay, sites should determine true clinical necessity of piped nitrous oxide infrastructure prior to investment.

4.3 SOCIAL COST OF NITROUS OXIDE

At present there is no unified approach to quantifying the social cost of anaesthetic gases. The BEIS Green Book non-traded value of CO_2e tonnes can be used to understand this social impact. In 2021 the central scenario valuation was £70.43 per tCO_2e. Using this lens, the social impact cost of BOC™ nitrous oxide products in the NHS in England (excluding ambulance services) approximates £18,000,000 per annum.

Welsh Environmental Fellow, Amarantha Fennell-Wells, has undertaken a speculative analysis of the financial cost waste versus the social cost for a relatively busy health trust based on three years of clinical piped nitrous oxide and Entonox® consumption assuming wastage at around at 80% and 70% respectively. These waste values are hypothetical and do not correlate with any trust waste directly but illustrates the larger impact of the social cost of this waste versus its material cost.

[11] Personal communication, A. Goddard, clinical reference group Short Stay Elective Centre, St John's Hospital, NHS Lothian
[12] Personal communication, S. Cross, Consultant Anaesthetist, and C. Lawson, authorised person St John's Hospital, NHS Lothian

Table 4. Financial and Social Cost of Piped Nitrous Oxide[13]

Nitrous Oxide Products	Total volume of Nitrous Oxide (L)	Hypothetical Waste in System (%)	Hypothetical Wastage (L)	tCO_2e Est. *GWP N_2O = 298*	Financial Cost of Waste Est. (£)	Social Cost Est. (£) *£70.43/Tonne*
Manifold Nitrous Oxide	5,418,000	80	4,334,400	2,363.72	£28,800	£166,477
Manifold Entonox®	45,565,000	70	31,895,500	17,393.89	£83,932	£1,255,052
TOTAL Manifold Consumption	50,983,000	-	18,003,900	19,758	£103,362	£1,391,529

5 THE EVIDENCE

5.1 CLINICAL USE OF PIPED NITROUS OXIDE AND ENTONOX®

5.1.1 Nitrous Oxide

Most piped nitrous oxide outlets are found in theatres. It is entirely feasible that an acute site might have multiple theatres that never use nitrous oxide. Additionally, there may be nitrous oxide outlets outside of theatres, but their clinical usage has been found to be low or negligible. Outlets may be found in emergency departments, but use is low or negligible with practitioners relying largely on Entonox® cylinders [14] [15] [16]. It is highly unusual for emergency departments to rely on nitrous oxide and demand for such a supply should be supported by an anaesthetic gas mitigation strategy[17].

Within theatres, anaesthetic use of nitrous oxide has steadily declined in the last 20-30 years, mainly because its use as carrier gas with a volatile anaesthetic agent has greatly diminished (Martindale, 2016). This, alongside the expansion of total intravenous, regional and local anaesthesia (Yoshimura and Ushijima, 2005, Yasny and White, 2012) efficiencies in anaesthetic technique, alongside a move to sustainable anaesthetic practice has driven nitrous oxide usage down. Practitioners who have continued to use the more environmentally deleterious volatile desflurane (with a high GWP_{100} of 2,540) are more likely to use nitrous oxide as a carrier, which will reduce the amount of desflurane needed to achieve adequate anaesthesia thus reducing the overall carbon footprint of the delivered anaesthetic (Hu et al., 2021).

[13] A. Fennell-Wells derived figures based on BOC report of different health boards/trusts, sources have been anonymised. Utilising the non-traded price of carbon has been cautiously recommended by Paul Watkiss of Paul Watkiss and Associates
[14] Royal Infirmary of Edinburgh Manifold Audit, Schematic Review and Clinical Assessment, July-September 2020
[15] St John's Hospital, Manifold Audit, Schematics Review and Clinical Assessment, October-February 2020
[16] Cardiff and Vale, Manifold Audit, Schematics Review and Clinical Assessment, February-March 2020
[17] Michael Ralph, Principal Engineer, NHEI, March 2021

However, it is unlikely that this emission saving feature is the motivating factor behind its use for this group of practitioners[18].

As an agent, nitrous oxide remains of value to many anaesthetists within paediatrics, obstetric emergencies requiring a general anaesthetic, dental surgery and colorectal cases although it's use in these areas is reducing (Chakera, 2020). A survey undertaken at one acute site in NHS Lothian demonstrated that anaesthetists have no preference for how this agent is supplied, allowing consideration of removal of piped provision for portable cylinders[19].

The Scottish research has highlighted the importance of annually assessing clinical use of nitrous oxide with appropriate due diligence[20] and choosing the leanest form of supply.

5.1.1.1 CASE STUDIES: Clinical Usage

SE Scotland

A General Hospital with a surgical case load circa 17,000 per annum including obstetric, paediatric and dental anaesthesia with desflurane making up 14% of the total number of volatile bottles issued from pharmacy. The ED department uses portable Entonox® cylinders with a demand valve for sedation and analgesia and no other nitrous oxide supply. Annual clinical use of piped nitrous oxide was quantified at <75,000 litres per annum with a manifold consumption of 432,000 litres per annum.

Outcome: This site has removed piped nitrous oxide supply clinical areas where use of this agent is redundant to reduce the chance of a leak. The site is in the process of conducting 'pressure drop tests' to assess further losses in system.

W Scotland

At a Surgical Specialist Hospital, new theatres were being developed. A senior estates' manager and authorised person questioned the supply of nitrous oxide piped into these theatres and ascertained that there was no requirement. He then questioned its use in the existing suite of theatres. Speaking with anaesthetists across specialties, he confirmed zero clinical use, indicating that a slow leak was present. He inserted blanking plugs as an interim step to ensure there was no clinical need and later decommissioned the system eliminating future waste volume of circa 234,000 litres.

5.1.2 Entonox®

The bulk of piped Entonox® will supply delivery suites. Occasionally, piped supply may be present within ED, endoscopy or colonoscopy departments but it is more likely that these areas rely on portable Entonox® cylinders. In acute sites Entonox® for delivery suites is often delivered via a remote manifold, but usage is via a demand valve that only delivers agent when a mother inspires.

[18] Anaesthetic usage survey, NHS Lothian and NE England comparative discussion, A. Chakera and C. Allen
[19] Western General Hospital Anaesthetist Survey on Nitrous Oxide Use and Supply, June 2020
[20] Case Study S2. A suite of 16 adult theatres with zero desflurane usage and surgical specialities, excluding obstetric, paediatric and dental cases, will use less than 6,500 litres. Case Study S3. A suite of 12 theatres with persistent desflurane usage and supporting obstetric, paediatric and dental cases will use up to 75,000 litres of nitrous oxide per year

Delivery suite staff often express anxiety that Entonox® might be taken away from mothers and they can be slow adopters of waste mitigation efforts. This is gradually changing with obstetric anaesthetists and midwives increasingly understanding the problem of Entonox® waste, not only through the manifold, but also through the early return of part-used portable cylinders which are vented by the supplier prior to refill. Waste mitigation needed to be advocated by the RCM, OAA and RCoA and embedded into professional practice.

It is challenging to undertake clinical usage assessments of this agent and benchmarking against normative usage is advised to infer a piped systems' integrity. Within Scotland, averaging acute sites' use of maternal Entonox® derives a value of 298 kgCO_2e per maternity[21] [22].

5.1.2.1 CASE STUDY: Benchmarking Entonox®

England

The Head of Sustainability in a Hospital in Central England observed year-on-year increases in Entonox® consumption. He spoke with the Scottish mitigation lead and they calculated consumption at around 880 kgCO_2e per maternity via their Entonox® manifold. They benchmarked this value against the Scottish average of 298 kgCO_2e per maternity which indicated there was waste within the system.

Outcome: The estate team are undertaking a detailed investigation with the Head of Sustainability and have adapted the Scottish mitigation methodology to help identify the source of waste.

5.2 SYSTEM WASTAGE

Wastage was a prominent feature in all of the reporting sites.

The Department of Health and Social Care Health Technical Memorandum Medical Gas Pipeline Systems Part B: Operational management document (HTM 02-01)[23] articulates the roles and responsibilities when managing and testing this infrastructure within NHS facilities. However, it has been found that acute sites varied greatly in their application of this guidance and that vague practices, confusion over roles and lack of awareness of responsibilities within the HTM all contributed to system wastage[24] (Chakera, 2020).

The HTM expressly requires that hard and soft facilities establish a schedule of maintenance that minimises waste through poor stock control or leaks.

In this review it was observed that some sites did not assign and maintain annual training of designated porters to carry out the changes in medical gas cylinders[25]. Some estates leads did not ensure compliance of the contractors when conducting the agreed Planned Preventive Maintenance (PPM) schedules or the

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[21] Manifold Entonox in CO_2e /Number of maternities = 298 kgCO_2e per maternity 2019/20 data
[22] Manifold Entonox in CO_2e /Number of maternities – Elective CS = 360 kg CO_2e per maternity 2019/20 data
[23] HTM responsibility has moved from DOHSC to NHSEI
[24] The Nitrous Oxide Mitigation Project, A. Chakera, A. Fennell-Wells and C. Allen
[25] Scotland Site 1, Manifold A. Audit, Schematic Review and Clinical Assessment, March-August 2020

adequacy of such schedules[26]. Generally, it was noted that facilities teams were often stretched with too few trained authorised persons with capacity to manage piped medical gases to the HTM standards.

5.2.1 Ineffective Stock Management

The overprovision of cylinders, poor stock rotation and holding on to surplus or empty cylinders will incur unnecessary supplier rental charges. Expired and part-used stock under present EC legislation is vented directly to the environment by the medical gas supplier before refilling and should be considered part of the acute site's emissions (EC, 2010). Sensible nitrous oxide provision is determined by establishing true clinical usage and aligning supply accordingly and this should be assessed annually. Stock rotation involves ensuring that the oldest cylinder stock is used first, which includes integrating the emergency reserves into the main cylinder bank. This should be a standard part of medical gas management training and good process should be in place to ensure sound stock management.

5.2.1.1 CASE STUDY: Stock Management

Scotland

In a City Hospital a pharmacist suspecting nitrous oxide cylinder mismanagement conducted an audit on a manifold supplying the hospital's 11 main theatres. The audit revealed expired stock on the left cylinder bank, in the emergency reserves and further expired and empty cylinders in the manifold room. There was no record of weekly manifold checks by soft facilities and the waste due to expired stock came to 108,000 litres. A qualitative clinical assessment of corresponding usage revealed that the anaesthetists used nitrous oxide in colorectal cases and rarely in other surgical specialities. Annual clinical usage was determined to be <12,000 litres per year but a single bank of four G-sized cylinders supplied 36,000 litres. This was surplus to clinical need.

Outcome: Estates arranged a reduction in manifold provision by 75% with a long-term plan to move towards portable cylinders by clinical teams when new anaesthetic machines are commissioned.

5.2.2 Poor Security

Poor cylinder security can result in theft. Good security involves not only keeping cylinders under lock and key, but judicious monitoring of use. This includes documenting cylinder movement and bank changes. The extent of theft is not fully understood[27] but nitrous oxide and Entonox® cylinders have a recreational drug value and are widely abused as a substance.

5.2.2.1 CASE STUDIES: Theft

Yorkshire

A number of acute sites experienced increased nitrous oxide cylinder theft during the spring of 2019. A single theft of five G-sized cylinders (45,000 litres) was tracked by police to a group operating out of Norfolk.

Outcome: Acute sites increased security features and physical barriers and have managed to mitigate this risk.

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[26] Scotland Site 2, Independent review of PFI subcontractor
[27] Communication, M. Ralph, Principal Engineer, NHSEI Estates, and G. Martini, Chief Scientist Royal Pharmaceutical Society

East England

External theft of cylinders was so significant that this site had increased it physical security. Still, there was an ongoing problem of high cylinder turnover and estates staff finding empty banks of cylinders that were previously full and no leaks were identified. This was a sprawling site, and a vehicle was used to move cylinders from storage to the manifold; it was eventually observed that this vehicle would leave the site transporting full cylinders and the team would return with empty cylinders so the theft would appear as usage and go undetected.

Outcome: This triggered a police investigation which confirmed the gas was being sold illicitly for recreational use. This highlighted the value of tighter stock control measures with staff handling traceability.

5.2.3 System Leaks

Leakages can occur anywhere within the piped system and their impact on wastage can be profound.

Leaks can occur at the connection of the cylinders to the manifold and at any outlet, especially if a flow valve is left in situ or deeper in the piped infrastructure. A small leak or a series of micro leaks to the volume of 1 litre a minute will yield a loss of 516,000 litres per year. The more extensive the piped system and the greater the number of outlets, the increase the risk of a small leak not being detected.

Systematic leak mitigation is highly varied across acute sites. The most diligent sites have their trained 'designated porters' to undertake manifold leak tests weekly and have identified leaks to the frequency of three times a year in their Entonox® manifolds alone[28].

Other sites do not routinely perform manifold leaks tests or claim to have devolved this responsibility to their piped medical gas subcontractors who visit annually[29]. This is insufficient and falls outside the guidance of the HTM as the checks should be done weekly or at the very least when manifold banks are changed.

Within estates, authorised persons are expected to ensure that both daily and weekly checks are sufficient to ensure waste is minimised and the systems are maintaining sufficient pressure. Estates should ensure that PPM arrangements with a designated contractor are appropriate for the piped system needs and are carried out. Outlets within theatres should be checked annually – however, these inspections are often excluded from PPM contracts or are simply not carried out as access to the theatres is challenging and this deficiency can detract from sufficient due diligence by estates teams[30].

Many NHS sites simply do not have sufficient authorised persons in place, hampering hard FM capacity. Additionally, the layering in of Private Finance Initiative (PFI) contractors can lead to confusion about service responsibilities for different parts of the piped system and has demonstrated delay in instigating waste reduction improvements[31].

5.2.3.1 CASE STUDIES: System Leaks

[28] Royal Infirmary of Edinburgh, Manifold Audit, Schematic Review and Clinical Assessment, July-September 2020
[29] Cardiff and Vale Manifold Audit, Schematic Review and Clinical Assessment, A Fennell-Wells, February 2021
[30] Paul Hogg, Senior Estates Manager, Golden Jubilee National Waiting Centre, March 2021
[31] Personal Communication with A. Grant, Royal Infirmary of Edinburgh, and E. Jack, Forth Valley, NHS Scotland, March 2021

Scotland

At a City hospital a designated porter escalated concerns over a notable increase in the frequency of bank changes of a nitrous oxide manifold. This manifold supplied neurology and the redundant ENT theatres. The manifold consumed 792,000 litres within ten months. A persistent outlet leak was finally identified and terminated, and the bank changes ceased.

Outcome: A qualitative survey of anaesthetic nitrous oxide usage within the site revealed negligible clinical use associated with this piped system and a decision was taken to decommission the ageing manifold.

Ireland

At a Regional Hospital, a trainee anaesthetist was perplexed at the amount of nitrous oxide consumption of ~1,197,000 litres per annum. This surprised colleagues as clinical usage was believed to be relatively low. He reached out to the Scottish mitigation lead who advised that, given that there were only 15 anaesthetic machines, the volume was indicative of system wastage and recommended urgent escalation to site leads and for estates to conduct investigation including a pressure drop test.

Outcome: In January 2021, estates conducted a weekend pressure drop test and at least three distinct leaks were identified and terminated. Cylinder turnover is being monitored and the team are also in the process of reassessing true clinical use predicted to <100,000 litres per year and intend to establish a leaner form of nitrous oxide supply.

5.2.4 Wastage Through System Design

There is a potential risk of waste with older anaesthetic machines that do not sound an alarm when the nitrous oxide continues running despite treatment having ended.

Of note is the inherent waste with the manifold system as a small amount of residual gas is always left in all medical gas cylinders to keep the system under positive pressure. When these part-filled cylinders are returned to the medical gas supplier in line with current European Commission legislation this gas is emitted directly to the environment prior to refilling (EC, 2010) and, as such, forms part of the hospitals' carbon footprint. If the system threshold pressure is set too high, it will trigger an earlier changing of cylinder banks thus increasing the amount of gas left in the cylinder. This unnecessary waste can be avoided as gauge pressure should be monitored as part of standardised daily and weekly estates audits. The Regional Technical Manager at BOC™ explains that only a small amount of residual gas should be returned to BOC™ (less than 5%) and modernised systems can allow for even lower pressure thresholds reducing this type of waste[32].

Another source of waste is the early changing of cylinders, driven by designated porter concerns of diminishing system pressure overnight or over the weekend and being called in to change a bank[33]. This concern is unwarranted as the HTM allows for 48 hours before an exhausted bank of cylinders must be changed allowing for weekday management.

5.2.5 Clinical Wastage

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[32] Peter Henrys, Regional Technical Manager, BOC™, March 2021
[33] Michael Ralph, NHSEI Principal Engineer, and Peter Henrys, Regional Technical Manager BOC™, March 2021

The literature cites the importance of the judicious fitting of masks and checking of anaesthetic circuitry by clinicians as well as initiating supply only once the mask is in place or removing the mask once treatment has ended (Yasny and White, 2012). Whilst this is a small component of waste it merits attention as nitrous oxide is such a potent greenhouse gas.

More concerning is the use of piped nitrous oxide in maternity theatres offered to a mother awaiting a neuraxial block ahead of an emergency C-section. These mothers will be given nitrous oxide (mixed with oxygen) via an anaesthetic machine as a convenient means to deliver an analgesic with the potency similar to Entonox®[34]. However, this is profoundly wasteful as it provides continuous high flows of nitrous oxide, increasing both occupational exposure and environmental pollution. The Royal Infirmary of Edinburgh is trying to eliminate this practice by introducing portable Entonox® fitted with a demand valve; this should be considered across all acute sites. Similarly, very few ED departments will use nitrous oxide via an anaesthetic machine[35] under high continuous flow to facilitate reduction of a dislocation. Some ED consultants question the clinical value of this delivery method given the waste of agent, advising that Entonox® with a demand valve provides a leaner, more sustainable option with comparable clinical outcomes[36].

5.3 CHALLENGES

Stakeholder discussions and a review of different cases studies revealed that that there were a number of barriers to progressing waste mitigation and sites should be aware of these challenges and be prepared to overcome them.

5.3.1 Ownership and Leadership

The scrutiny of medical gas management falls under the remit of a trust's Medical Gas Committee (MGC). Whilst MGCs are considered advisory, across the UK during the Covid-19 pandemic many established operational working groups to develop oxygen resilience strategies. Nitrous oxide is a medicine and whilst it is not supplied directly by pharmacy its safe and appropriate supply must be embedded into the scrutiny of pharmacy services. Chief Pharmacists must be active on the MGCs and steward nitrous oxide mitigation activities. Lastly, the Chief Executives of NHS Trusts need to ensure a functioning and well represented MGC to ensure safe and sustainable management of these agents.

5.3.2 Soft Facilities and Designated Porters

The maintenance of training of designated porters is varied across acute sites. Under the HTM only specially trained and designated porters should undertake the changing of piped medical gas cylinders. At some sites no training had been provided to these porters in years and was evident in the lack of manifold logbooks and maintenance schedules. MGCs, as part of their oversight, should ensure this training is undertaken and a schedule of training is reviewed by the MGC.

5.3.3 Nitrous Oxide and Entonox® Data

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[34] F. Pearson, South Tees Hospital NHS Foundation Trust. S. Morrison, NHS Lothian, A. Fennell-Wells, Cardiff and Vale. Personal communication, 9 February-31 March 2021

[35] Michael Ralph, NHSEI Principal Engineer

[36] Confidential Discussion Emergency Department consultants and trainee

Acute sites varied in their approach to collecting this information with some relying on pharmacy electronic records and others relying on estates records. Both approaches are flawed as both pharmacy and estates[37] documentation is often lacking correct and complete entries[38] (Chakera, 2020). Ideally, organisations should examine supplier returns details and compare this to usage at the manifold. Pharmacy services should take stewardship at a site level to ensure that the project team has access to supplier cylinder monthly data and assist in interpreting this data.

5.3.4 Cylinder Management

Pharmacy, estates and porters are all engaged in the process of procuring, storing and distributing cylinders and the arrangement is not always cohesive. This should be sympathetically reviewed to eliminate confusion around areas of responsibility and when and how to report problems along different parts of the supply chain. This will help the stock management of cylinders, eliminate expired cylinder stock being found in inappropriate areas[39] and the untidy and unsafe housing of cylinders[40]. Sites that have struggled with cylinder management have benefited from 'process mapping' with a trained quality improvement facilitator to help improve their management of cylinders and communication between stakeholders (Chakera, 2020).

5.3.5 Health and Safety

Nitrous oxide is a medicine and a hazardous substance regulated by COSHH. There are significant occupational health advantages to reducing or removing unwarranted nitrous oxide supply and mitigating waste through leaks.

Occupational exposure is associated with immediate and chronic adverse physiological effects: decreased cognition and manual dexterity; vitamin B12 deficiency; increased risk of miscarriage and adverse prenatal development (IrwinTrinh and Yao, 2009). Research from the late 1990s and early 2000s showed that anaesthetic recovery rooms, delivery suites and radiology units exceeded nitrous oxide limits. Monitored midwives regularly exceeded occupational levels both during expiration, and within urine samples; and dental clinics without adequate ventilation and scavenging were regularly exceeding safe nitrous oxide exposure levels (Henderson et al., 2003, Henderson and Matthews, 1999).

6 RECOMMENDATIONS AND IMPLEMENTATION STRATEGY

In this section, the proposed recommendations and implementation strategy have been informed directly by the Scottish research and developed further through examination of the evidence shared by stakeholders engaged with the National Nitrous Oxide Project.

In NHS Lothian, the waste mitigation work has led to the decision to decommission several nitrous oxide manifolds as clinical use was so low and used by only a few anaesthetists that it became difficult to justify

[37] NHEI Natasha Calendar, Pharmacy Fellow Medicine Policy Unit, February 2021, and NHEI ERIC data analytics team, March 2021
[38] National Nitrous Oxide Project Case Studies, A. Chakera, A. Fennell-Wells and C. Allen
[39] J. Harrold, Procurement Lead, NHS Lothian, 27 May 2020
[40] D. Millar, Account Manager BOC™, 11 June 2020

supply. Additionally, across the UK new elective theatre suites across are not routinely being built with a nitrous oxide supply[41]. With this in mind NHSE Trusts should be mindful that decommissioning nitrous oxide manifolds may be the most prudent and cost-effective step in the journey toward zero emissions.

The validity of the recommendations and implementation strategy were discussed directly with senior estate engineers and are intended to remove excessive redundancy within these piped systems as well as reduce supply chain wastage within acute sites. The last subsection outlines a strategic collaborative framework for NHEI to support sites with exceptionally high nitrous oxide emissions to implement the proposed waste reduction strategy.

6.1 RECOMMENDATIONS

1. MGCs of each health trust and ICS should establish multidisciplinary project teams to work toward net-zero emissions of nitrous oxide at each acute site under their advisement.

2. All acute sites with a piped nitrous oxide and Entonox® systems should undertake a waste review[42].
   - Nitrous oxide usage should be established by undertaking qualitative and/or quantitative assessment of clinical administration within theatres and other areas and compare this to total volume consumed.
   - Review supplier cylinder returns data[43] to calculate volume consumed.
   - Determine Entonox® in CO_2e per delivery and benchmark this against the national mean (average) values for a maternity unit.

3. Estates teams and MGCs should immediately investigate system waste.

Estates teams should investigate:
- Stock management and security.
- System leaks at manifold, from outlets or piped infrastructure.
- System design: pressure set too high.

MGCs should:
- Support above actions.
- Consider the validity of all manifolds
- Review wasteful clinical practices including leaving flow valves in situ and failing to terminate nitrous oxide through anaesthetic machines.

4. The leanest nitrous oxide supply should be introduced:

   - Address stock management and security issues.
   - Decommission redundant manifolds

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[41] Exemplars. North Bristol NHS Trust, NHS Lothian, NHS Highland and NHS National Waiting Times Centre.
[42] The Nitrous Oxide Mitigation Project, A. Chakera, A. Fennel-Wells and C. Allen

[43] RCoA Stipulates the use of returns data to establish a consistent metric across all sites and refers to the cylinders returned to the medical gas supplier. All cylinders returned should be treated as exhausted and incorporated into the NHS sites carbon footprint as any residual gas returned to the medical gas supplier under currently legislation will be expunged prior to refilling.

- Repair leaks and remove superfluous piped infrastructure.
- Explore leaner supply options such as:
  - introducing smaller cylinders to the back of anaesthetic machines; or an
  - ambulatory cylinder supply with associated catalytic cracking unit.
- Manifolds may benefit from the introduction of flow meters.

5. MGCs should undertake quarterly reviews of processes and practices to minimise waste reducing to biannual after 12 months.
   - Ensuring greener clinical practices are established across <u>all</u> specialties using anaesthetic gases.
   - Consideration of green technologies such as nitrous oxide cracking technologies for manifold Entonox®.

NEW BUILDS

6. New theatres should be built to have zero emissions and should avoid excessive system redundancy. Nitrous oxide piped systems should not be routinely introduced in new surgical suites.

6.2 NHS TRUSTS AND SITE LEVEL IMPLEMENTATION STRATEGY

This report recognises the value of leadership from MGCs in developing and executing an implementation plan to mitigate wastage from these systems. It is expected that, at a trust level, chairs of MGCs should act on the findings of this report and call an Extraordinary General Meeting to establish mitigation project teams across all acute sites under their purview. Nitrous oxide is a potent greenhouse gas, and it is essential for MGCs to respond to this national guidance with haste. Mitigation of this waste should be embedded in acute site plans to achieve zero emissions of all anaesthetic gases.

The Lean Six Sigma five-step DMAIC cycle (Stonemetz et al., 2011) has been used to frame an implementation plan (Chakera, 2020)[44]. A template of six DMAIC cycles approximating two to three years of mitigation can be found in Appendix A1, an analytical manifold audit and clinical assessment sheet can be found in Appendix A2 and qualitative survey template to establish clinical use of nitrous oxide can be found in Appendix A3. It is imperative that acute sites form a multidisciplinary team and develop their own plan to achieve net zero emissions of these agents.

6.2.1 DMAIC Overview

6.2.1.1 DEFINE: Establish Project Teams and Objectives

The MGC should establish acute site project teams to work toward the total mitigation of anaesthetic gases with an immediate focus on piped nitrous oxide products. Multidisciplinary teams must be formed with senior representation from hard and soft FM management, medical physics, pharmacy and specialties that administer nitrous oxide products: anaesthetics, maternity units, emergency department practitioners and endoscopy all should be engaged and educated on the imperative to work toward achieving zero emissions of these agents.

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[44] The Nitrous Oxide Mitigation Project, A. Chakera, A. Fennel-Wells and C. Allen

6.2.1.2 MEASURE: Quantify Waste

Nitrous oxide waste is calculated determining by total volume of system turnover less actual volume of clinical usage over the same timeframe ideally per annum.

NITROUS OXIDE WASTE = Volume Turnover at Manifold – Volume of Clinical Usage

Entonox® volume waste can be estimated by multiplying the total volume consumed at manifold by the acute sites relative Entonox® waste ratio[45]. The waste ratio is determined by establishing the average emissions of Entonox® in kg CO_2e per delivery at the hospital (μ_H) and subtracting the national average[46] emissions of Entonox® in kg CO_2e per delivery (μ_N) calculation and dividing a positive differential by μ_H.

ENTONOX® WASTE = Volume Turnover at Manifold x $[(\mu_H - \mu_N)/ \mu_H]$

6.2.1.3 ANALYSE: Identify Clinical Areas Being Serviced by Each Manifold and Types of Waste

Project teams may benefit from using decision tree analysis at this step in the cycle (Chakera, 2020).

Review piped schematics and establish the number and location of outlets for nitrous oxide and Entonox®, identify areas of persistent clinical use and areas of negligible or zero clinical usage. Ascertain if alternative forms of nitrous oxide supply are being used such as portable Entonox® in these or other areas.

Systematically assess types of waste by reviewing stock management and security, checking for system leaks and reviewing if the pressure of the piped system are cylinders being returned to soon. Additionally, assess if there is clinical mismanagement of nitrous oxide including the administration of continuous flow of piped nitrous oxide where Entonox® on a demand valve would suffice; or if flow valves have been left in outlets or if older anaesthetic machines are inadvertently left on.

6.2.1.4 IMPROVE: Establish Root Causes and Apply Least Wasteful Solution

Clinical areas of zero or negligible clinical usage; estates and clinical leads to work toward terminating any superfluous supply of nitrous oxide as far up the supply chain as feasible and possibly decommission manifold(s).

Areas of consistent clinical usage, across all clinical areas but where cylinder turnover is greater, suggests waste in the system. Therefore, estates must investigate and, should no resolution be forthcoming, the leak should be escalated to their NHS authorised medical gas engineer.

Where stock is expiring on the manifold, but consistent clinical usage is documented, the manifold requires reduced cylinder provision. Pharmacy, estates and clinical leads should agree a sensible provision and reduce cylinder bank size and cylinder stock levels. Alternatively, the manifold can be decommissioned, and a portable supply of nitrous oxide might be preferable and should be explored.

6.2.1.5 CONTROL: Maintain Improvements and Work Towards Further Nitrous Oxide Mitigation

[45] To be eventually superseded with a delivery baseline derived from Entonox® manifold pressure drop tests at multiple NHS sites
[46] NHSE the emission of Entonox® = 264 kgCO_2e per delivery

Nitrous oxide and Entonox® supply and use involves many stakeholders, all of which are responsible for its complete mitigation. Deeper and complex problems associated with process can be aided by undertaking *process mapping* with a skilled quality improvement facilitator (Chakera, 2020).

6.3 NHSEI STRATEGIC COLLABORATION

The Greener NHS programme recognises that all sites have been under persistent operational duress during the last 15 months and this has impacted all areas of service. To facilitate national waste reduction efforts, the Greener NHS programme will apply data analytics to identify the trusts with the greatest amount nitrous oxide emissions and work with these trusts' sustainability leads to ensure that they are afforded the capacity to achieve the proposed waste reduction implementation plan. This is outlined in Table 7 below.

Table 5. NHEI Strategic Targeted Collaboration

PROCESS	PEOPLE	TOOLS/TECHNOLOGY
MISSION: i) Reduce system waste in nitrous oxide manifolds. ii) Reduce system waste in Entonox® manifolds. Establish Key Performance Indicators for both nitrous oxide and Entonox® manifolds: • Top decile emitters to complete primary DMAIC cycle by Q2 2021/22. • Top quintile emitters to complete primary DMAIC cycle by Q4 2021/22. Ensure strategic targeting and recruitment of these sites. Establish NHS Trust reporting structure.	NHS England Improvement Greener NHS Programme. NHSEI Data analytics Greener NHS Deputy Director of Engagement NHSEI National Communication and Greener NHS Communication Teams NHSEI Heads of Hard FM, Soft FM and Sustainability NHSEI Pharmacy and Medicines Optimisation Team	Provide site level data on nitrous oxide products on Future NHS platform and ensure NHS trusts have site level access. Provide strategic analysis identifying top decile and quintile emitters of manifold nitrous oxide and Entonox®. Reporting should be digitised potentially via ERIC structures
Issue national communiqué to NHS Trusts to undertake this waste mitigation activity.	CC. Chief Executives of NHS England Trusts and Sustainability leads	Provide: Synthesis e-Brief with recommendations and implementation plan. Top quintile emitters to get additional correspondence from NHSEI
Facilitate trust level engagement, education and stewardship.	Sustainability and Quality Improvement leads. Recruitment of top decile emitters.	NHSEI to host (record) educative webinar utilising Future NHS platform and <u>ensure</u> attendance of top decile emitters.
Educate on: MDT formation, metric collection, analysis, Improvements and maintaining and continuing improvements.	Chair of Medical Gas Committees. Director Hard FM and Soft FM. Chief Pharmacist Clinical directors of anaesthetics, emergency medicine, maternity services and GI medicine/endoscopy.	Synthesis e-brief with recommendations and implementation plan. Additional resources: National Nitrous Oxide Mitigation Project.

7 FUTURE-PROOFING: NATIONAL POLICY

Whilst this report examines opportunities for acute sites to minimise piped nitrous oxide and Entonox® waste, key amendments to national policy can also aid nitrous oxide mitigation. The UK is now in a position to reframe European Commission policy which presently stipulates the complete expungement of medical gases of all returned cylinders directly into the environment by the supplier prior to refilling (EC, 2010). DEFRA and the MHRA should work together to prohibit direct venting nitrous oxide and consider the application of catalytic cracking technology prior to venting and or direct top of cylinders.

The HTM governing the requirements of piped medical gases is now due for review is ownership is transferring from the DOHSC to NHSEI. The over-specification of piped nitrous oxide is under scrutiny by senior medical gas engineers and quality control pharmacists. Potential HTM modifications include minimising excessive nitrous oxide redundancy within the piped supply specification, obligatory annual waste investigations and limiting the introduction of piped nitrous oxide into new builds. Additionally, the revised HTM will need to embed zero emission objectives and consider how green technologies might act as an alternative to gas scavenging.

These national discussions are still in development. However, acute sites should be mindful of these legislative and guidance changes that take us toward zero emissions, as legislative changes may be associated with punitive measures to ensure trusts and health boards exercise due diligence in mitigating these Scope 1 emissions.

Consideration as to how NHSEI may be able to strategically influence these policy areas is outlined in Table 8.

Table 6. Strategic Framework to Influence National Policy

PROCESS	PEOPLE	TOOLS/TECHNOLOGY
Mission: i) Work with DEFRA to counter EC legislation enforcing medical gas supplier venting of returned medical gas to the environment prior to refilling. Policy revision: • Returned cylinders containing nitrous oxide should never be vented directly to the environment. • The medical gas industry can introduce catalytic destruction of nitrous oxide into nitrogen and oxygen prior to venting and or negotiate legislative changes to permit topping up these cylinders.	DEFRA NHEI Greener NHS Programme AAGBI 2% taskforce	Nitrous oxide catalytic cracking technologies for industry (used in Nordic nations by Linde™).
Mission ii) Introduce zero emission criteria to the Department of Health and Social Care Hospital Technical Memorandum Part B management of piped medical gases. Policy revision: • Amend over-specification of piped nitrous oxide and Entonox®. • Limit outlets and piped network to areas of true clinical use. • Assess impact of different green technologies that capture anaesthetic agents and their potential impact on the necessity of traditional anaesthetic gas scavenging systems.	NHS 4-Nation Hard and Soft Facilities Management NHEI Greener NHS Programme NHS 4 Nation Quality Control Pharmacists Medical Physics /Medical Engineers Royal College of Midwives	TO BE DISCUSSED: This is a complex laborious piece of work traditionally undertaken by hard FM leads reporting back to the Department of Health and Social Care NHEI Greener NHS programme should consider what resources they could offer NHSEI Hard FM.

8 CONCLUSIONS

This report advises that the waste of nitrous oxide products though piped manifold systems is of significant concern and that all NHS sites utilising a manifold system prioritise a waste management review.

This is emerging work and ongoing revision will be needed to continue to reduce emissions from all nitrous oxide products. The report recognises that greater understanding is needed to improve stock security and traceability of cylinders, as well as a deeper understanding of the risk and benefits of various leaner supplies of nitrous oxide within different clinical settings.

Whilst exploration of novel green technologies was not included within the scope of the report, it must be stressed that the benefits of nitrous oxide catalytic cracking technology will only be fully realised if waste is completely mitigated within the supply system prior to reaching a patient. The value of investing in this technology has merit for labour units and Entonox® mitigation, but within theatres the benefit may be limited as many anaesthetic specialities have discontinued their use of nitrous oxide.

The Scottish lean methodology for eliminating this waste is strongly recommended and it is observed that the success of mitigation efforts is largely driven by the collaboration of all stakeholders and establishing quality data. To this end NHSEI can support trusts by dispersing a mitigation briefing to all NHS Trusts Chief Executives, sustainability leads and chairs of each trusts' MGC. NHEI can champion this work by establishing quality data flows that can be accessed by all NHSE sites; hosting educational webinars and ensuring additional support to trusts with exceptionally high emissions.

9 Appendices

Appendix A1 Lean Six Sigma DMAIC Framework Exemplar (6 Cycles)

	Cycle 1	Cycle 2	Cycle 3
DEFINE	N_2O Manifold A. audit and clinical use assessment. MDT: Pharmacist, Hard/Soft FM, anaesthetists x3	N_2O Manifold A. audit and clinical use assessment. MDT: Pharmacist, Hard/Soft FM, anaesthetists x3	N_2O Manifold A. audit and clinical use assessment. MDT: Pharmacist, Hard/Soft FM, anaesthetists x3
MEASURE AND OBSERVATIONS	Manifold turnover 48 x 9,000LPM. Expired stock on emergency reserves. Manifold services 10 theatres plus ITU. Estimated clinical use: 750,000 LPA. No logbooks, leak tests not performed.	Manifold turnover based on 2 months analysis 4 x 9,000 = 36,000. Clinical use 6,000L for 2 months. Logbooks presented and maintained. Leak tests at manifolds outstanding and theatre outlets not checked as part of PPM.	Manifold turnover based on 3 months analysis. No returned cylinders. Expired stock still in situ. Logbooks presented and maintained. Leak test performed at last bank change. Clinical use estimated 11,000L for 3 months.
ANALYSE	Waste magnitude 431,925 (plus 18,000L expired stock.	Waste magnitude: 30,000 (expired stock still in situ). Leak suspected, pressure, drop test needed.	Waste magnitude reduced, cannot determine exact residual volume left in bank of cylinders.
IMPROVE	Remove surplus pipework. Introduce logbooks and leak tests.	2 pendant leaks identified and repaired.	Address minimising clinical usage in theatres.
CONTROL	Revise practices and agree to review data in 2 months.	MDT agree to review practice and data in 3 months.	Review PPM contract ensure annual outlet checks MDT agree to review data in 6 months.

	Cycle 4	Cycle 5	Cycle 6
DEFINE	N_2O Manifold A. audit and clinical use assessment. MDT: Pharmacist, Hard/Soft FM, anaesthetists x3	N_2O Manifold A. audit and clinical use assessment. MDT: Pharmacist, Hard/Soft FM, anaesthetists x3	N_2O Manifold A. audit and clinical use assessment. MDT: Pharmacist, Hard/Soft FM, anaesthetists x3
MEASURE and observations	Manifold turnover N_2O 4 x 9,000L in 6 months. Expired stock still in situ. Estimated clinical use 30,000 litres in 6 months. Desflurane use 10% of volatile bottles issued from pharmacy. Logbooks maintained. Leak tests conducted at bank changes only.	No returned manifold cylinders to BOC™ for 6-month period. Expired stock still. Clinical use 6,000L for 6 months. Logbooks presented. No recent manifold leaks tests. PPM now includes outlet inspection. Desflurane <5% of volatile bottles issued from pharmacy.	No returned manifold cylinders for 12 months. Expired stock still in situ. Logbooks presented. Leak test only performed at last bank change. Clinical use estimated <4,000L in last 6 months. Desflurane removed of theatre stock lists.
ANALYSE	Waste magnitude 6,000 litres.	Waste magnitude low (in situ).	Waste magnitude reduced, cannot determine with accuracy what is left in bank of cylinders. Is the manifold warranted with expensive maintenance contract or is a portable supply more suitable?
IMPROVE	Increase frequency of leak tests. Address clinical behaviours leaving in flow metres. Educate to reduce anaesthetic N_2O use and desflurane use.	Increase frequency of leak tests. Address clinical behaviours leaving in flow metres. Educated to reduce anaesthetic N_2O use and desflurane use. Speak to medical physics and medical devices committee about trialling volatile capture technology.	Trial volatile capture technology.
CONTROL	MDT agree to review in 6 months.	MDT agree to review practice and data in 6 months.	Escalate discussion to clinical leads.

Appendix A2 Manifold Audit and Clinical Assessment Analytics Sheet

Nitrous Oxide and Entonox® Audit and Analytics Sheet				Doc	Audit Sheet	Version	1.0	Updated	N/A
Hospital Name:				National Project lead: Alifia Chakera, NHS Lothian					
Date of Review Start:		Date Review End:		Queries contact: thenitrousoxideproject@gmail.com					
Clinical Audit Lead:				Pharmacy Lead:					
Anaesthetic Lead:				Facilities Lead:					
BOC™ regional contact:									

Key N_2O G cylinder = 9,000L N_2O J cylinder = 18,000L Entonox® G = 5000L Entonox® EW= 16,275L **Tip: take a photo of each manifold**	Manifold management Audit			Corresponding Piped Schematics	Audit Clinical Usage (use secondary spreadsheet if needed)	
	Stock Management (rotation, provision)	Bank Changes: Review logbook (photocopy) or question porter or security team Calculate: Volume per month and per year	Leak tests Evidence: Yes/No Frequency	Identify location of outlets corresponding to manifold, review schematics and conduct visual inspection	Qualitative Survey Frequency per month and area used	Quantitative Interrogation (extract from anaesthetic machine data logs) Calculate: Volume per month and per year
Manifold name: Type: Arrangement:						
Manifold name: Type: Arrangement:						
Manifold name: Type: Arrangement:						

Appendix A3 Template Qualitative Survey, Courtesy of Cardiff and Vale University Hospital Board, 2021[47]

Survey Regarding Nitrous Oxide Use in Anaesthetics

<u>Introductory page</u>

Thank you for participating in this 5-minute. Your answers will help to assess the efficiency of CAVUHB's nitrous oxide infrastructure.

When answering questions about usage please think back to pre-COVID

<u>Survey Pages</u>

What anaesthetics grade are you?

- ☐ CT1-3
- ☐ ST3-4
- ☐ ST5-7
- ☐ Consultant

In which area(s) do you work? (Please select all that apply.)

- ☐ UHL – Cardiac
- ☐ UHL – CAVOC
- ☐ UHL – General
- ☐ UHW – Dental Hospital
- ☐ UHW – Main Theatres
- ☐ UHW – Obstetrics
- ☐ UHW – Paediatrics (Children's Hospital for Wales)
- ☐ UHW – SSSU
- ☐ UHW – Theatre 8 (Ophthalmic Outpatients)
- ☐ Velindre Cancer Centre Hospital, Whitchurch
- ☐ Other
    - o Please specify

How often do you use nitrous oxide for INDUCTION of anaesthesia?

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ A few times a year
- ☐ Once a year
- ☐ Never
- ☐ Other

In which specialties would you do this?

- ☐ UHL – Cardiac
- ☐ UHL – CAVOC
- ☐ UHL – General
- ☐ UHW – Dental Hospital
- ☐ UHW – Main Theatres
- ☐ UHW – Obstetrics

47 **Authors:** Fennell-Wells, A; Saitch, H; Oliver, C; Agombar, D; Brennan F

- ☐ UHW – Paediatrics (Children's Hospital for Wales)
- ☐ UHW – SSSU
- ☐ UHW – Theatre 8 (Ophthalmic Outpatients)
- ☐ Velindre Cancer Centre Hospital, Whitchurch
- ☐ Other

How often do you use nitrous oxide for MAINTENANCE of anaesthesia?

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ A few times a year
- ☐ Once a year
- ☐ Never
- ☐ Other

In which specialties would you do this?

- ☐ UHL – Cardiac
- ☐ UHL – CAVOC
- ☐ UHL – General
- ☐ UHW – Dental Hospital
- ☐ UHW – Main Theatres
- ☐ UHW – Obstetrics
- ☐ UHW – Paediatrics (Children's Hospital for Wales)
- ☐ UHW – SSSU
- ☐ UHW – Theatre 8 (Ophthalmic Outpatients)
- ☐ Velindre Cancer Centre Hospital, Whitchurch
- ☐ Other

Please give us more information on the types of cases where you would use nitrous oxide. *For example: patient request, patient co-operation, specific procedure etc.*

[Free text]

Do you use nitrous oxide for ANALGESIA as part of your clinical SEDATION practice?

- ☐ Yes
- ☐ No

Are there any other indications for use of nitrous oxide beyond induction and maintenance of anaesthesia in ANAESTHETICS? (Please describe.)

[Free text]

What is your opinion on the role of nitrous oxide in anaesthesia today?

- ☐ Essential (there are no alternatives)
- ☐ Important (there are alternatives, but it is the best option in some situations)
- ☐ Useful (there are alternatives which can replace its role)
- ☐ Redundant (no longer necessary due to better alternatives and harmful potential)
- ☐ Unsure

Would you like to add any thoughts on nitrous oxide in anaesthesia?

[Free text]

Appendix A4 Cylinder description, corresponding volume and mass of nitrous oxide in each cylinder type provide courtesy of BOC™

Product	Cylinder Size	Cylinder Total Gas Volume (litres)	Cylinder Total Nitrous Volume (litres)	Nominal Nitrous Weight (kg)
Nitrous Oxide	D	900	900	1.67
	E	1 800	1 800	3.37
	F	3 600	3 600	6.50
	G	9 000	9 000	16.50
	J	18 000	18 000	33.50
	CD	440	220	0.42
Entonox	D	500	250	0.47
	F	2000	1000	1.86
	G	5000	2500	4.65
	EA	350	175	0.33
	ED	700	350	0.65
	EX	3500	1750	3.26
	EW	16275	8138	15.15
	HX	2200	1100	2.06

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