Reducing Greenhouse Gas Emissions: Modifying Nitrous Oxide Delivery at Stanford

Eric P. Kraybill, David Chen, Saadat Khan, Praveen Kalra

Submitted to: JMIR Perioperative Medicine
on: August 09, 2024

Table of Contents

Reducing Greenhouse Gas Emissions: Modifying Nitrous Oxide Delivery at Stanford

Eric P. Kraybill[1] BS; David Chen[1] MD; Saadat Khan[1] MEng; Praveen Kalra[1] MBBSMD

[1]Stanford Hospital Stanford US

Corresponding Author:
Saadat Khan MEng
Stanford Hospital
Department of Anesthesia; 300 Pasteur Drive, Suite H3580
Stanford
US

Abstract

Background: Reducing greenhouse gas emissions is a priority that must be addressed to prevent the negative impacts of climate change. Inhalational anesthetic agents are a major source of potent greenhouse gases, and reducing their emissions is a goal that can be readily addressed. Nitrous oxide (N2O) has a prolonged environmental half-life combined with a low clinical potency, leading to relatively large amounts of N2O being stored in cryogenic tanks and H cylinders for use, thus increasing the chance of pollution through leaks. Building on the results of previous studies, Stanford Health Care (SHC) N2O emissions were analyzed at two campuses and targeted for waste reduction as a precursor to system wide reductions.

Objective: To determine the extent of N2O pollution at SHC. Subsequently, to determine if using E-cylinders for storage and delivery of N2O at the point of care in its ambulatory surgery centers could reduce emissions within SHC's system.

Methods: Phase 1: Total Palo Alto, CA SHC N2O purchase data for CY2022 was collected and compared (volume and cost) to total Palo Alto clinical delivery data using Epic electronic health record.

Phase 2: A pilot study was conducted in the 8 operating rooms of SHC campus A (Redwood City). The central N2O pipelines were disconnected, and E-cylinders were used in each operating room. E-cylinders were weighed before and after use on a weekly basis for comparison to Epic N2O delivery data over a 5-week period.

Phase 3: After successful implementation, the same methodology was applied to Campus B, one of three facilities in Palo Alto.

Results: Phase 1: Total N2O purchased in 2022 was 8,217,449 liters (33,201.8 lbs.), at a total cost of $63,298. Of this, only 780,882.2 liters (9.5%) of N2O was delivered to patients, with 7,436,566.8 liters (90.5%) or $57,285 worth lost or wasted.

Phase 2: Total weight of N2O use from E-cylinders was 7.4 lbs (1lb N2O = 247.5L) or 1,831.5 liters at campus A. Epic data showed total N2O volume delivered was 1,839.3 liters (7.4 lbs).

Phase 3: Total weight of N2O use from E-cylinders was 10.4 lbs or 2,574 Liters at campus B (confirming reliability within error propagation margins). Epic data showed total N2O volume delivered was 2840.3 liters (11.5 lbs).

Over Phase 2 and 3, total use for campuses A and B was less than the volume of 3 E-cylinders (1 E-cylinder = 1590 liters).

Conclusions: Converting N2O delivery from centralized storage to point-of-care E-cylinders dramatically reduced waste and expense with no detriment to patient care. The results of this study provide strong evidence for analyzing N2O storage in healthcare systems that rely on centralized storage as well as consideration of E-cylinder implementation to reduce emissions. The reduction in N2O waste will help meet SHC's goal of Scope 1 and 2 emissions reduction by 50% before 2030.

(JMIR Preprints 09/08/2024:64921)
DOI: https://doi.org/10.2196/preprints.64921

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Reducing Greenhouse Gas Emissions: Modifying Nitrous Oxide Delivery at Stanford

Eric P. Kraybill, BS[1]; David Chen, MD[1]; Saadat Khan, MEng[2]; Praveen Kalra, MD[1]

1. Department of Anesthesiology, Stanford University School of Medicine, Stanford, CA, USA
2. Sustainability Program Office, Stanford Health Care, Stanford, CA, USA

We declare no conflicts of interest.

Co-corresponding Authors: Praveen Kalra, MD, pkalra@stanford.edu;
Saadat Khan, MEng, saadatkhan@stanfordhealthcare.org

Abstract

Background

Reducing greenhouse gas emissions is a priority that must be addressed to prevent the negative impacts of climate change. Inhalational anesthetic agents are a major source of potent greenhouse gases, and reducing their emissions is a goal that can be readily addressed. Nitrous oxide (N_2O) has a prolonged environmental half-life combined with a low clinical potency, leading to relatively large amounts of N_2O being stored in cryogenic tanks and H cylinders for use, thus increasing the chance of pollution through leaks. Building on the results of previous studies, Stanford Health Care (SHC) N_2O emissions were analyzed at two campuses and targeted for waste reduction as a precursor to system wide reductions.

Objectives

To determine the extent of N_2O pollution at SHC. Subsequently, to determine if using E-cylinders for storage and delivery of N_2O at the point of care in its ambulatory surgery centers could reduce emissions within SHC's system.

Methods

Phase 1: Total Palo Alto, CA SHC N_2O purchase data for CY2022 was collected and compared (volume and cost) to total Palo Alto clinical delivery data using Epic electronic health record.

Phase 2: A pilot study was conducted in the 8 operating rooms of SHC campus A (Redwood City). The central N_2O pipelines were disconnected, and E-cylinders were used in each operating room. E-cylinders were weighed before and after use on a weekly basis for comparison to Epic N_2O delivery data over a 5-week period.

Phase 3: After successful implementation, the same methodology was applied to Campus B, one of three facilities in Palo Alto.

Results

Phase 1: Total N_2O purchased in 2022 was 8,217,449 liters (33,201.8 lbs.), at a total cost of $63,298. Of this, only 780,882.2 liters (9.5%) of N_2O was delivered to patients, with 7,436,566.8 liters (90.5%) or $57,285 worth lost or wasted.

Phase 2: Total weight of N_2O use from E-cylinders was 7.4 lbs (1lb N2O = 247.5L) or 1,831.5 liters at campus A. Epic data showed total N_2O volume delivered was 1,839.3 liters (7.4 lbs).

Phase 3: Total weight of N_2O use from E-cylinders was 10.4 lbs or 2,574 Liters at campus B (confirming reliability within error propagation margins). Epic data showed total N_2O volume delivered was 2840.3 liters (11.5 lbs).

Over Phase 2 and 3, total use for campuses A and B was less than the volume of 3 E-cylinders (1 E-cylinder = 1590 liters).

Conclusions

Converting N_2O delivery from centralized storage to point-of-care E-cylinders dramatically reduced waste and expense with no detriment to patient care. The results of this study provide strong evidence for analyzing N_2O storage in healthcare systems that rely on centralized storage as well as consideration of E-cylinder implementation to reduce emissions. The reduction in N_2O waste will help meet SHC's goal of Scope 1 and 2 emissions reduction by 50% before 2030.

Introduction

Reducing greenhouse gas (GHG) emissions is a priority that must be addressed to reduce climate change and its negative impacts on Earth and its inhabitants. The U.S. Environmental Protection Agency (EPA) classifies GHG emissions into different categories, with Scope 1 emissions defined as direct GHG emissions from sources that are controlled by organizations, including healthcare systems, and Scope 2 emissions being indirect GHG emissions associated with the purchase of electricity, heat, steam, or cooling [1]. Stanford Health Care (SHC) has signed on to the U.S. Department of Health and Human Services' pledge to reduce its Scope 1 and 2 emissions by 50% by the year 2030 [2]. Within the medical sector, inhalational anesthetic gases that are directly released into the atmosphere are a major source of potent GHGs. Thus, there is a fertile opportunity to reduce GHGs by reducing the emission of anesthetic gases [3]. By collecting annual emissions data within the SHC system, improvements to sustainability and infrastructure could be explored.

Global warming potential (GWP) represents the energy a gas is able to absorb relative to carbon dioxide, with a larger GWP representing increased planetary warming [4]. The environmental impacts of two inhaled anesthetic gases are particularly relevant: desflurane, a volatile halogenated agent with particularly high GWP of 2540, and nitrous oxide (N_2O) with lower GWP of 265 but used in much higher concentrations than other anesthetic gases, and with prolonged half-life and lasting environmental consequences [5]. Further, because of its low clinical potency, large amounts of N_2O must be stored for use, increasing the chance of pollution through leaks. Centrally piped cryogenic liquid, centrally piped gas, and portable E-cylinders are the standard options for delivering N_2O [6]. Miles of pipes and innumerable valves in centrally piped systems lead to an abundance of leaks contributing to excessive loss and waste [6]. While desflurane has already been discontinued from routine clinical use at SHC, we aimed to determine the degree to which N_2O emissions could be reduced and waste prevented, building on prior studies highlighting the waste of N_2O in other institutions [7].

Methods

Phase 1:

To begin investigating N_2O emissions, purchase data (volume and cost) was collected and compared to total use data (clinical delivery) using the Epic SlicerDicer tool, part of the Epic electronic health record (EHR) [8]. Epic yearly clinical use data for N_2O is available per clinical service in the SHC Operating Rooms. Gas losses in the system can be estimated by comparing documented gas delivery at the point of care with the volume of N_2O purchased. Initial data analysis revealed a drastic amount of lost N_2O, leading us to perform a pilot study (Phase 2, E-cylinder implementation) to enable remediation aimed at reducing N_2O emissions.

Phase 2:

Using the Institute for Healthcare Improvement framework of “Plan, Do, Study, Act” for performance improvement [9], a pilot study was conducted in the 8 operating rooms of the SHC campus in Redwood City, CA (Campus A). E-cylinder canisters were deployed in each operating room and all central N_2O pipelines were disconnected. EHR documentation of gas delivered in liters (volume) was compared to measured E-cylinder weight. To verify use and track N_2O leaving each tank, the E-cylinders were weighed before and after use on a weekly basis with the difference in weight converted to volume (liters). Since the measured pressure remains the same as long as liquid remains in the cylinders, pressure differences cannot be used for measuring N_2O flow until only gas is left (at which point the pressure drop correlates with the amount of gas being removed) [10]. By using the conversion of 1lb of N_2O = 247.5 Liters [6], the volume of N_2O dispensed could be calculated. Total calculated volume leaving the E-cylinders based on measured weight was compared to total volume delivered according to Epic data.

Phase 3: Following the results of phase 2, a secondary study was conducted in 16 operating rooms at Blake Wilbur Drive Palo Alto, CA (Campus B). Phase 3 utilized the same methodology as phase 2 over a three-week period.

Results

Phase 1:

According to the Stanford Medicine Sustainability Program Office [2], the annual Palo Alto SHC 2022 Scope 1 emissions were 19,374 $MTCO_2e$ (metric ton of CO_2 equivalent, the standard unit for comparing different greenhouse gases to quantify their environmental impact and GWP) of which medical gases (including N_2O, carbon dioxide, sevoflurane, and isoflurane) represented 4,862 $MTCO_2e$. N_2O contributed 4,590 $MTCO_2e$ of the medical gases. Thus, medical gases account for 25.1% of all SHC Scope 1 Emissions, and N_2O alone accounts for 94.4% of those emissions (or 23.7% of the total).

Annual clinical usage of N_2O in 2022 per Epic data (Table 1) was 780,882.2 liters (3,155.1 lbs), with the greatest use being for orthopedic surgery, general surgery, and neurosurgery cases. However, the total amount of N_2O purchased was 8,217,449 liters (33,201.8 lbs), at a total cost of $63,298. Thus, only 9.5% of the total purchased N_2O was actually delivered to patients, and 90.5% (or $57,285 worth) was wasted.

With this data indicating a loss of greater than 90% between storage tanks and clinical use, a highly inefficient storage and pipeline system was recognized. The proposed solution (for Phase 2 of the study) was to decommission the storage tanks and pipelines and switch to portable E-cylinders that stored and delivered N_2O at the point of care.

Phase 2:

The change in weight of the E-cylinders indicated that N_2O use at campus A totaled 7.4 lbs, or a volume of 1,831.5 Liters, over the 5-week study period. Epic data showed total N_2O volume delivered to be 1,839.3 liters calculated to 7.4 lbs (consistent with the measured 7.4 lbs). Using the standard of 1 E-Cylinder = 1590L or 6.4lbs [11], total use equaled 1.16 E-cylinders.

Phase 3:

The E-cylinder change in weight indicated that N_2O use at Campus B totaled 10.4 lbs, or 2,574 Liters, over the 3-week data collection period. Epic data showed total N_2O volume delivered to be 2,840.3 liters calculated to 11.5 lbs (compared to the measured 10.4 lbs, which would be equivalent to 1.63 E-cylinders) [11].

Discussion

Results from phase 1 corroborate findings from previous studies in the United Kingdom and Portland, Oregon, USA [12, 13] that reveal excessive waste from centralized storage of N_2O and pipe systems for delivery. Phases 2 and 3 of this study, from two different SHC campuses, demonstrate the efficient and cost-effective elimination of waste through substitution of E-cylinders with storage and delivery at the point of care. In phases 2 and 3, avoidable N_2O emissions were almost completely eliminated (Figure 1). The discrepancy between actual weighed N_2O and Epic reported use for campus A was 7.8 L, or <0.1 lb. Campus B had a greater discrepancy with the difference in actual weighed N_2O and Epic reported use being 266.3 L, or 1.1 lbs. The amount of gas delivered according to the EHR was greater than the amount actually measured at the source, potentially accounted for by limited precision of the scales used to weigh the E-cylinders (only to 0.1 lb increments), or accidental reconnection of nitrous oxide pipelines in one operating room during phase 3. This issue was detected after one week and immediately rectified.

E-cylinders provide an efficient and effective solution, but they hold limitations. E-cylinders must be stored properly to ensure they don't present a catalyst in the event of a fire [14]. However, no policy implementation is required as E-cylinders are already in use in operating rooms and costs associated with storage can be offset by the N_2O saved. Ready accessibility, lower cost, reduced supply chain issues, and efficiency of E-cylinders far outweigh the above disadvantages.

Limitations of this study include the fact that real-world use and waste may vary from our experimental conditions, likely incurring greater losses. If e-cylinder valves are accidentally left open, losses may simulate those from centralized pipelines until the valve is closed [6] or the E-cylinder is emptied. Purchase amount of N_2O would need to be greater than the amount used in our example (Table 1), to provide surplus in the E-cylinders as well as spare E-cylinders. Prospective estimates of volume when making a purchase order would likely exceed actual use. Documented (in Epic) and scale measurement are both susceptible to human error.

Conclusion

Converting the delivery of N_2O from centralized storage to point-of-care E-cylinders has dramatically reduced waste and expense with no detriment to patient care. Stanford's pledge to reduce Scope 1 and Scope 2 emissions by 50% can be achieved and even surpassed if this practice is changed in all SHC locations. The introduction of E-cylinders will provide a non-disruptive means for immediately decreasing emissions while continuing to provide optimal anesthetic care. Pilot studies throughout Stanford's campuses continue, with the goal of removing the centralized N_2O system and switching to E-cylinders at other sites, thereby significantly reducing anesthetic GHG emissions. Efforts to reduce GHG emissions may begin locally but have applications globally. Reducing the anesthetic carbon footprint of healthcare organizations is necessary for our planet and can begin with the reduction in wasteful emissions.

Acknowledgements

Eric P. Kraybill: data analysis, drafting and editing manuscript. David Chen: data analysis, editing manuscript. Saadat Khan: data collection and analysis. Praveen Kalra: concept, data collection and analysis, editing manuscript. We would like to acknowledge the Stanford Sustainability Planning Office for their support throughout the project.

Conflicts of Interest

The authors have no conflicts of interest to declare.

Abbreviations

EPA – Environmental Protection Agency
GWP – Global Warming Potential
N_2O – Nitrous Oxide
SHC – Stanford Healthcare

References

1. US EPA O. Scope 1 and Scope 2 Inventory Guidance. Published December 14, 2020. https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance

2. Stanford Medicine. Sustainability Program Office. Our Sustainability Commitment. https://stanfordhealthcare.org/sustainability-program-office/sustainability-program-office/what-we-do/our-sustainability-commitment.html

3. Chesebro B, Mason A. Nitrous Oxide: Climate-Smart Anesthesia 201 | Cleanmed 2022. https://www.youtube.com/watch?v=KRBajNxKo4A

4. US EPA O. Understanding Global Warming Potentials. Published January 12, 2016. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

5. Gadani H, Vyas A. Anesthetic gases and global warming: Potentials, prevention and future of anesthesia. *Anesth Essays Res*. 2011;5(1):5-10. doi:10.4103/0259-1162.84171

6. Practice Greenhealth. Collaborating to prevent Nitrous Oxide waste in medical gas systems | Practice Greenhealth. https://practicegreenhealth.org/tools-and-resources/collaborating-prevent-nitrous-oxide-waste-medical-gas-systems

7. Seglenieks R, Wong A, Pearson F, McGain F. Discrepancy between procurement and clinical use of nitrous oxide: waste not, want not. *British Journal of Anaesthesia*.

2022;128(1):e32-e34. doi:10.1016/j.bja.2021.10.021

8. Epic Systems Corporation. Our Software | Epic. https://www.epic.com/software/

9. How to Improve: Model for Improvement | Institute for Healthcare Improvement. https://www.ihi.org/resources/how-to-improve

10. Themes UFO. Medical Gases: Storage and Supply. Anesthesia Key. Published August 12, 2019. https://aneskey.com/medical-gases-storage-and-supply-2/

11. Rose G, McLarney JT. Pneumatic Systems. In: *Anesthesia Equipment Simplified*. McGraw-Hill Education; 2014. https://accessanesthesiology.mhmedical.com/content.aspx?bookid=871&sectionid=51860168

12. Devlin-Hegedus JA, McGain F, Harris RD, Sherman JD. Action guidance for addressing pollution from inhalational anaesthetics. *Anaesthesia*. 2022;77(9):1023-1029. doi:10.1111/anae.15785

13. Sherman JD. It's Time Hospitals Abandon Nitrous Oxide Pipes. *ASA Monitor*. 2024;Vol. 88(33). https://pubs.asahq.org/monitor/article/88/2/33/139724/It-s-Time-Hospitals-Abandon-Nitrous-Oxide-Pipes

14. National Oceanic and Atmospheric Administration. NITROUS OXIDE | CAMEO Chemicals | NOAA. https://cameochemicals.noaa.gov/chemical/8909#:~:text=It%20is%20noncombustible%20but%20it,to%20rupture%20violently%20and%20rocket-

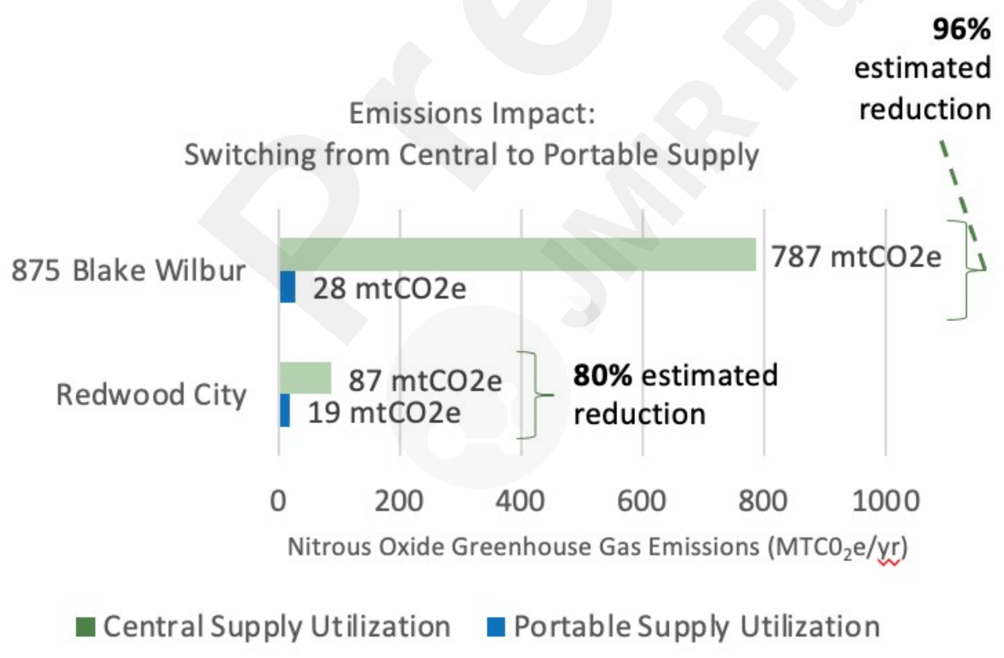

Figure 1: Reduction in N_2O emissions per metric tons of CO2 equivalents by switching from original Central Supply to Portable Supply E-cylinder storage.

	Amount Purchased (liters)	Cost (USD)	Amount Used (liters)	Amount Lost as Waste (liters)
Centralized System	8,217,449	$63,298	780,882.2	7,436,566.8
E-Cylinders	780,882.2*	$6,015	780,882.2	0**

Table 1: Annualized data comparing Centralized N2O system to hypothetical E-cylinders for SHC (all campuses). *Amount needed to purchase with zero surplus based on use data under experimental conditions **Annualized E-cylinder data is extrapolated from experimental conditions; real world conditions may vary.

Supplementary Files

Figures

Reduction in N2O emissions per metric tons of CO2 equivalents by switching from original Central Supply to Portable Supply E-cylinder storage.

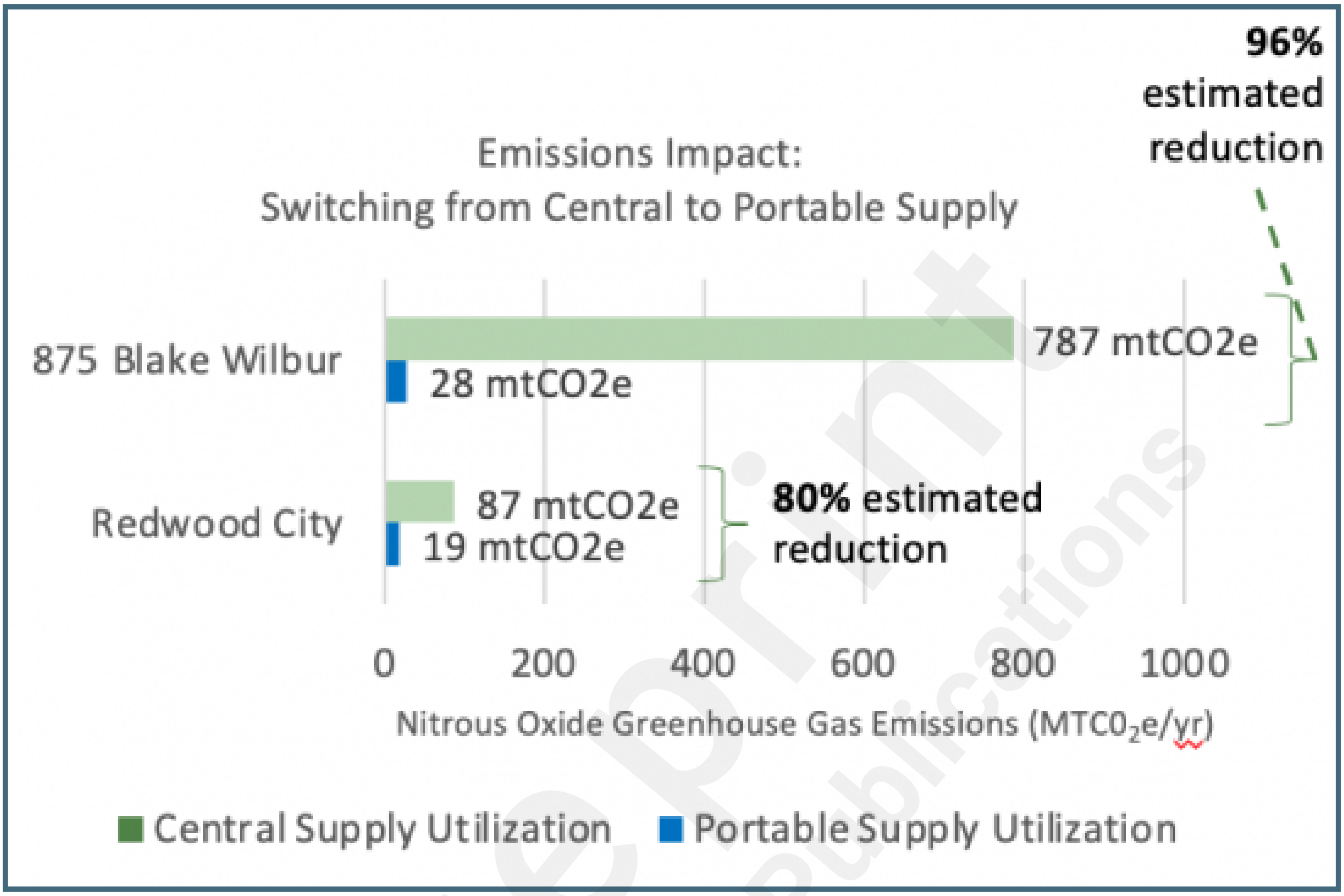

Table 1: Annualized data comparing Centralized N2O system to hypothetical E-cylinders for SHC (all campuses). *Amount needed to purchase with zero surplus based on use data under experimental conditions **Annualized E-cylinder data is extrapolated from experimental conditions; real world conditions may vary.

	Amount Purchased (liters)	Cost (USD)	Amount Used (liters)	Amount Lost as Waste (liters)
Centralized System	8,217,449	$63,298	780,882.2	7,436,566.8
E-Cylinders	780,882.2*	$6,015	780,882.2	0**