# Environmental Sustainability QI Toolkit

OVERVIEW AND RECOMMENDATIONS

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# Acknowledgements

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# Objectives

- Overview environmental sustainability in anesthesia
- Discuss selection of anesthetic agent
- Discuss management of fresh gas flow
- Review ASPIRE sustainability measures

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# **Section I:**
# Overview of Environmental Sustainability in Anesthesia

(Watts, 2018)

# Climate Crisis and Impact on Health

- The climate change crisis is the **largest and most profound threat to global health** ever described (Watts, 2018).
- 2022 IPCC (Intergovernmental Panel on Climate Change) Report indicates high confidence that climate change is adversely impacting multiple facets of human health, including (IPCC, 2022):
    - The spread of infectious disease
    - Malnutrition
    - Mental health
    - Displacement of peoples/communities

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# Urgency of Climate Change

- Global surface temperature has increased by 0.2°C per decade over the last 30 years (Hansen, 2006).
- The U.N. Climate Report notes that we are on a pathway to more than **double** the 1.5°C limit set by climate scientists.

"It's now or never, if we want to limit global warming to 1.5°C; without immediate and deep emissions reductions across all sectors, it will be impossible"

Jim Skea, Co-Chair of IPCC Working Group III (Rich, 2022)

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# Environmental Impact of Healthcare

Healthcare emissions are a drop in the bucket, right?

- The U.S. health care sector contributes nearly **10%** of GHG emissions per year (Pichler, 2019).
- If the U.S. health care sector were a country, it would rank **13th** in GHG emissions (Eckelman, 2016).
- If global healthcare were a country, it would be the **fifth largest** carbon emitter on the planet (Budd, 2019).

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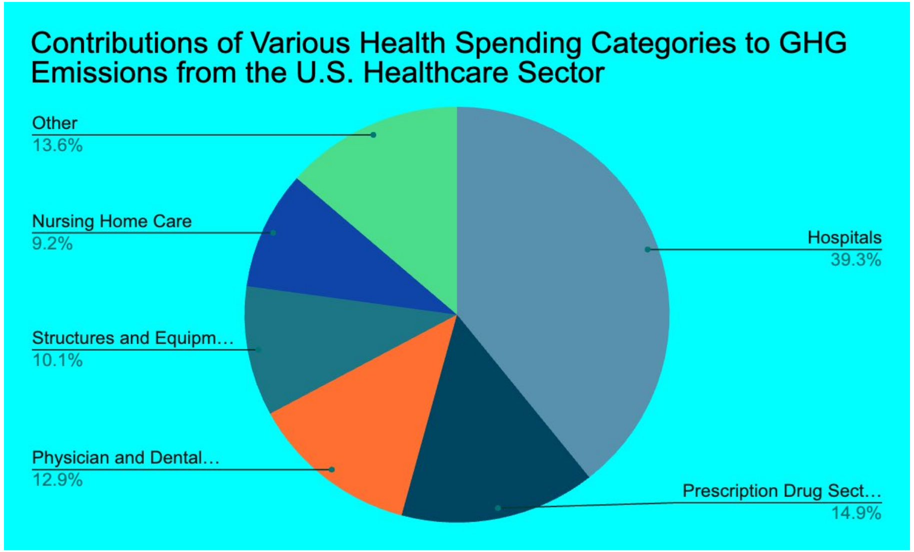
# Environmental Impact of U.S. Healthcare System

From a 2007 JAMA Study, the U.S. Healthcare Sector annually contributes approximately (Chung, 2009)

- **8%** of all greenhouse gas emissions
- **7%** of all carbon dioxide emissions

Within the U.S. Healthcare Sector

- **Hospitals** make up the largest contributor of greenhouse gases, followed by prescription drugs, physician and dental services, structures and equipment, and nursing home care.

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# Environmental Impact of U.S. Healthcare System (cont.)

The U.S. healthcare sector is also responsible for significant fractions of national air pollution emissions and impacts, including:

- Acid rain (12%), greenhouse gas emissions (10%), smog formation (10%) criteria air pollutants (9%), stratospheric ozone depletion (1%), and carcinogenic and non-carcinogenic air toxics (1–2%) (Eckelman, 2016).

This is attributable to approximately 123,000 to 381,000 DALYs (Disability-Adjusted Life Years) in future health damages (Eckelman, 2018).

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# Environmental Impact of Anesthesia

- Anesthetic gases play a significant role in this contribution.
- From the American Society of Anesthesiologists (Devlin-Hegedus, 2022).
  - Inhaled anesthetics account for **5% of acute hospital $CO_2$-equivalent emissions** and **50% of perioperative department emissions** in high-income countries.
  - Overall, inhaled anesthetic agents are estimated to be responsible for approximately **0.01% to 0.1% of the total global carbon dioxide equivalent emissions** per year.
  - Based on recent research and atmospheric sampling of volatile anesthetics, this accumulation has been and is still currently increasing.

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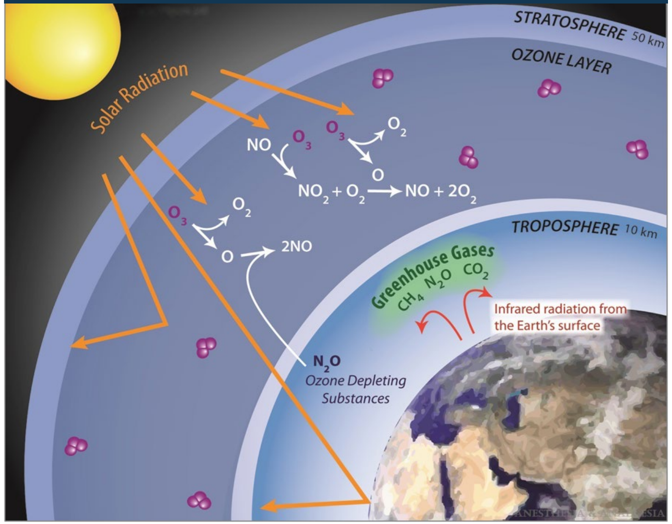
# GHGs and the Greenhouse Effect

- Greenhouse gases, or GHGs, warm our planet by absorbing/re-radiating the infrared radiation emitted from Earth's surface (US EPA, 2016).

- Common GHGs include:
  - $CO_2$
  - Methane
  - Nitrous Oxide
  - Fluorinated Gases

Summary of the Greenhouse Effect

*(Ishizawa, 2011)*




Overview of U.S. Greenhouse Gas Emissions in 2020

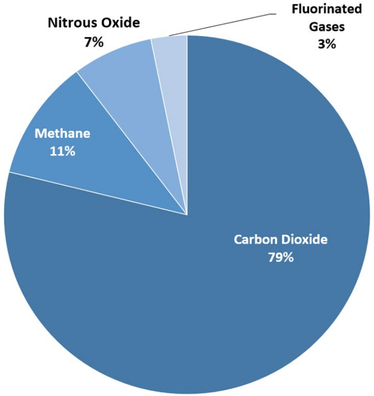



Image adapted from U.S. Environmental Protection Agency Website (EPA, 2022)

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# Global Warming Potential

- **Global Warming Potential (GWP)**: A measure of how much energy the emissions of 1 ton of a given greenhouse gas will absorb (over a given period of time) relative to the emissions of 1 ton of carbon dioxide (US EPA, 2016).
  - The larger the GWP, the more that a given greenhouse gas warms the Earth compared to $CO_2$.
- GWP is constituted of two primary factors (McGain, 2020):
  - *Radiative Efficiency*: Ability to absorb energy
  - *Atmospheric Lifetime*: Estimate of molecular stability in the atmosphere

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# GWP for Select Greenhouse Gases

| Name | MW (g/mol) | Chemical Formula | Atm Lifetime (years) | GWP 20 | **GWP 100** |
|---|---|---|---|---|---|
| Carbon Dioxide | 44.01 | $CO_2$ | 5-200 | 1 | **1** |
| Common Inhaled Anesthetics | | | | | |
| Sevoflurane | 200.5 | $C_4H_3F_7O$ | 1.4 | 349 | 130, **144**, 210 |
| Isoflurane | 184.5 | $C_3H_2ClF_5O$ | 3.2 | 1401 | 510, **565** |
| Desflurane | 168.0 | $C_3H_2F_6O$ | 14 | 3714 | 1620, 2540, **2720** |
| Nitrous Oxide | 44.0 | $N_2O$ | 114 | 289 | 265, 273, **282**, 298, 300 |

GWP 20 and GWP 100: Global warming potential over a 20-year period and 100-year period, respectively
Multiple sources were used, as GWP 100 values are estimates and thus show variability in published literature
**Bolded** values represent those used by the MPOG SUS-02 measure
References: (Budd, 2019; Chung, 2009; US EPA, 2016; Ishizawa, 2011; EPA, 2022; McGain, 2020; Yasny, 2012)

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# Reducing Environmental Impact of Anesthesia

- Based on GWP values, **all** common inhaled anesthetics have a global warming potential significantly greater than that of carbon dioxide.
  - These gases are thus potent contributors to global warming, even in small concentrations.
- We can reduce this impact in **two primary ways**:
  - Selecting environmentally-safer anesthetic agents
  - Managing fresh gas flow

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# Section II:
# Managing Selection of Inhaled Anesthetic Agent

(Watts, 2018)

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# Environmental Impact of Inhaled Anesthetics

- Halogenated anesthetics (sevoflurane, isoflurane, and desflurane) and nitrous oxide are all recognized greenhouse gases (Yasny, 2012).
- Nitrous oxide presents additional environmental concerns:
  - In addition to being a greenhouse gas, it is also classified as an ozone-depleting agent (Yasny, 2012).
  - When nitrous oxide is used as a carrier gas along with a halogenated anesthetic, the impact of each gas on the environment is compounded (McGain, 2020; Axelrod, 2022).

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# Carbon Dioxide Equivalents

- The environmental impact of a specific inhaled anesthetic over a given time period can be standardized by converting the amount of the gas used to **carbon dioxide equivalents,** or "$CO_2$ (equiv)(Axelrod, 2022)"

- Calculating $CO_2$ equivalents can be done by multiplying the mass of the anesthetic agent used by its global warming potential (GWP).
  - Mass used is dependent on both the concentration of gas used and the fresh gas flow rate (see calculation on next slide).

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# Calculating $CO_2$ Equivalents

**Step 1:** Use concentration of gas used and fresh gas flow to calculate $\frac{moles\ of\ gas}{time}$, or **"A"**

(assuming standard temp and pressure)

$$\frac{Conc\ (\%) \times FGF\ (L/time)}{24\ L/mol} = A$$

**Step 2:** Convert moles of gas over time (A) to mass of anesthetic used in the given time period, or **"B"**

$$A \times Molecular\ Weight\ (\frac{grams}{mole}) \times time = B$$

**Step 3:** Convert mass used (B) to CO2 equivalents used in the given time period

$$B \times GWP_{100} = Number\ of\ Carbon\ Equivalents\ (CO_2 equiv)$$

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# Comparing $CO_2$ Equivalents for Common Anesthetics

| Anesthetic | FGF (L/min) | GWP(100) | $CO_2$ equiv (x100,000) | Equivalent auto miles driven per hour use of anesthetic (Axelrod, 2022) |
|---|---|---|---|---|
| Sevoflurane 2% | 2 | 144 | 2.9 | 8 |
| Isoflurane 1.2% | 2 | 565 | 6.2 | 18 |
| Isoflurane 1.2% | 1 | 565 | 3.1 | 9 |
| Desflurane 6% | 2 | 2720 | 137 | 400 |
| Desflurane 6% | 1 | 2720 | 68.5 | 200 |
| Nitrous Oxide 60% | 1 | 282 | 18.6 | 61 |

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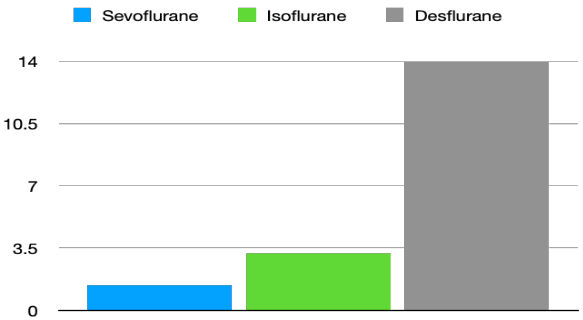
# Recommendation 1: Eliminate Desflurane

Under comparable conditions, desflurane has a significantly greater carbon footprint and thus larger impact on global warming than other halogenated anesthetics such as sevoflurane and isoflurane (McGain, 2020; Axelrod, 2022; Sherman, 2012; Ryan, 2010).

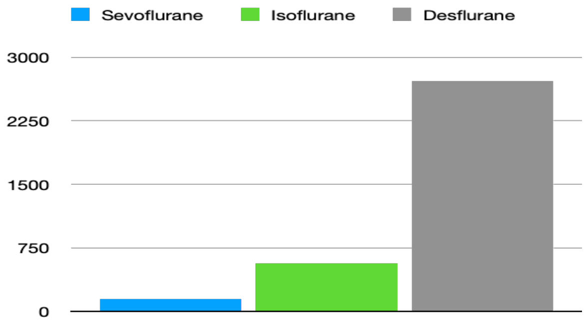
When looking at the full lifecycle of the drug (i.e. from resource extraction to disposal), it's estimated that desflurane accounts for the largest GHG emissions both in terms of anesthetic gas wasted during a procedure and other life cycle stages (Axelrod, 2022).

# Comparing the Environmental Impact of Common Inhaled Anesthetics

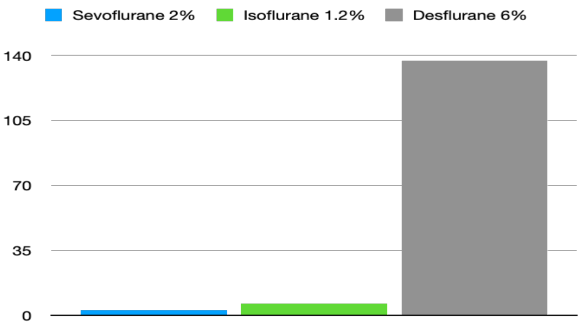
**Atm Lifetime (years)**



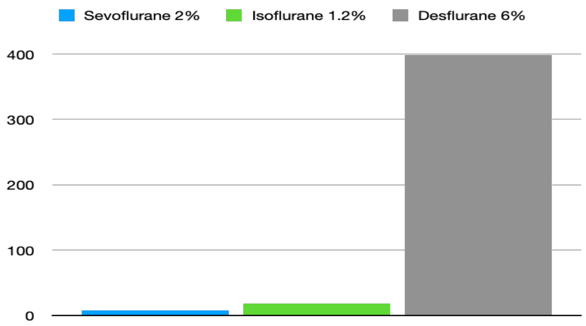

**Global Warming Potential (100)**




**$CO_2$ Equivalents (at 2 L/min)**




**Equivalent MPH Driven in a Car**

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# Eliminating Desflurane (cont.)

## Clinical Considerations

Research suggests negligible clinical differences between desflurane, sevoflurane, and isoflurane.

- There appears to be no significant difference in the quality of overall recovery between the 3 agents (see next slide) (White, 2009; Lopez, 2009).
- Home readiness, PONV, and airway irritation seem to be comparable between the 3 agents as well (Kurhekar, 2017; Gupta, 2004).

## Economic Considerations

Desflurane is significantly more expensive than sevoflurane and isoflurane (Moody, 2020).

- Total cost at 1 L/min:
  - Sevo: $2.14
  - Iso: $0.32
  - **Des: $10.32**
- Total cost at 2 L/min
  - Sevo: $4.28
  - Iso: $0.64
  - **Des: $20.64**

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# Eliminating Desflurane (cont.)

In comparison to sevoflurane and isoflurane, desflurane appears to show **no significant clinical advantage** in terms of the quality of overall recovery, home readiness, PONV, and post-op airway irritation.

- A study from the University of Texas Southwestern (n = 130) suggests that although desflurane may lead to a faster initial recovery, the difference in the quality of overall recovery between the 3 agents is negligible (White, 2009).
    - Other, more recent studies appear to support this finding (Lopez, 2009; Boggett, 2019).
- Studies from John Hopkins University (Kurhekar, 2017) and the Shri Sathya Sai Medical College (Gupta, 2004) suggest that home readiness and incidences of post-op nausea, vomiting, and airway irritation are comparable as well.

# Eliminating Desflurane (cont.)

- Desflurane has been eliminated at multiple institutions across the country, generating savings on the order of $100,000 to millions of dollars per year (Silva, 2021).
    - Some hospital systems that have significantly reduced or completely eliminated desflurane include Michigan Medicine, Stanford Medicine, UCSF Health, Cleveland Clinic, Boston Medical Center, Kaiser Permanente, Seattle Children's Hospital, and many more (Schowtzer, 2020; Zoghbi, 2022).
- The EU has formulated a proposal to ban, or at least severely restrict, the use of desflurane starting in January of 2026 (Hendrickx, 2022).
- The ASA Environmental Task Force formally recommends the avoidance of desflurane based on the ecological and economic benefits as well as the negligible clinical differences between halogenated anesthetics (Devlin-Hegedus, 2022; Axelrod, 2022).

# Recommendation 2: Reduce Nitrous Oxide

Estimated Atmospheric Lifetime of Nitrous Oxide ($N_2O$): **114 years**

- This value is approximately 8x that of desflurane, 35x that of isoflurane, and more than 100x that of sevoflurane.

Although nitrous oxide has a relatively lower global warming potential, it is used in a much higher concentration in comparison to halogenated anesthetics (Aranake, 2013).

| Anesthetic | Sevoflurane | Isoflurane | Desflurane | **Nitrous Oxide** |
|---|---|---|---|---|
| MAC | 2 | 1.15 | 6 | **105** |
| MAC-awake | 0.62 | 0.49 | 2.5 | **68** |

Values expressed as a percentage of 1 atmosphere

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# Reducing Nitrous Oxide (cont.)

In addition to being a potent greenhouse gas, nitrous oxide is also an **ozone-depleting agent**.

- Ozone Depleting Potential (or ODP): The ratio of the estimated impact on the ozone layer relative to CFC-11 (ODP = 1) (Velders, 2014).
- A study into the ozone-depleting effects of nitrous oxide by Dr. Ravi Ravishankara of Colorado State University poses nitrous oxide as “the single most important ozone depleting emission of the 21st century (Ravishankara, 2009).”

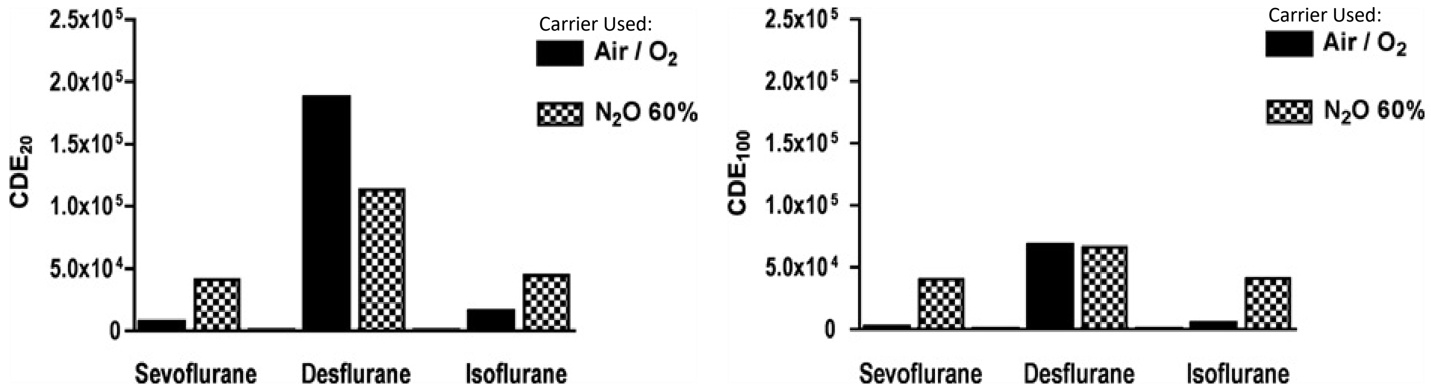
| Anesthetic Agent | ODP (Bosenberg, 2011; Kleeman, 1994) |
|---|---|
| Sevoflurane | 0 |
| Desflurane | 0 |
| Isoflurane | 0.01* |
| Nitrous Oxide | **0.017** |

* Although isoflurane has an ODP of 0.01, the tropospheric lifetime is short and its ozone-depleting effect is thus minimal (Branche, 2017)

# Reducing Nitrous Oxide (cont.)

Nitrous oxide can also **increase the carbon footprint** of both sevoflurane and isoflurane when nitrous is used as a carrier gas (relative to using medical air).

From a 2010 study from the Journal of Anesthesia and Analgesia (Ryan, 2010):




"CDEx": Carbon dioxide equivalents emitted over an x year period

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# Reducing Nitrous Oxide (cont.)

The American Society for Anesthesiologists recommends two primary methods of reducing nitrous oxide emissions in the operating room (Axelrod, 2022):

1. **Reserve** nitrous oxide for cases in which it is clearly preferred for clinical reasons.
2. **Decommission or avoid installing** centralized nitrous oxide and substitute portable tanks that can remain closed between uses.

   If logistically feasible, a switch to portable tanks has the potential to dramatically reduce nitrous leakage (Axelrod, 2022; Devlin-Hegedus, 2022).

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# Reducing Nitrous Oxide (cont.)

Study from the Providence Portland Medical Center (2016): Compared the nitrous oxide leak from both central and portable systems (Chesebro, 2022)

- *Central* Systems: Cryogenic containers (filled with liquid $N_2O$) and compressed gas cylinders (filled with gaseous $N_2O$)
- *Portable* Systems: Open or closed e-cylinders

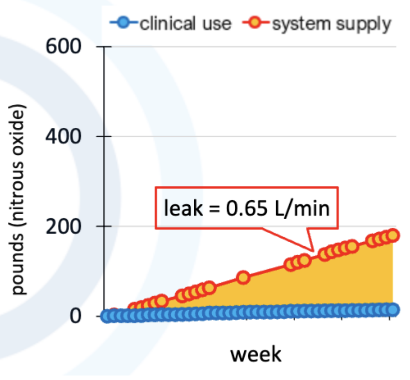
Results show a significant decrease in nitrous oxide leak (in comparison to clinical usage) in using either type of portable system vs. either type of central system.

# Reducing Nitrous Oxide (cont.)

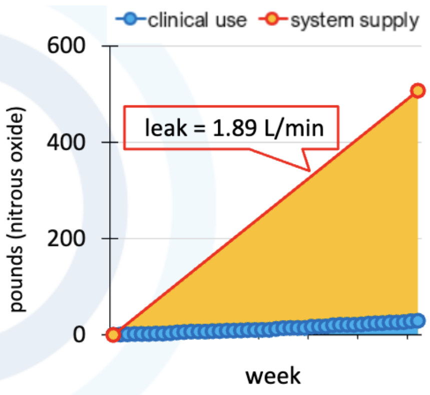
## Central Systems

## Portable Systems

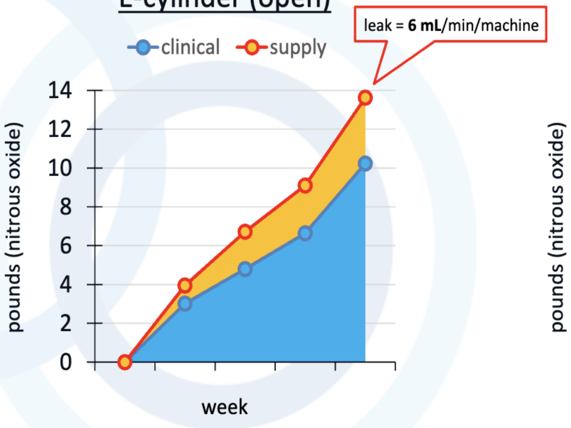
### Cryogenic



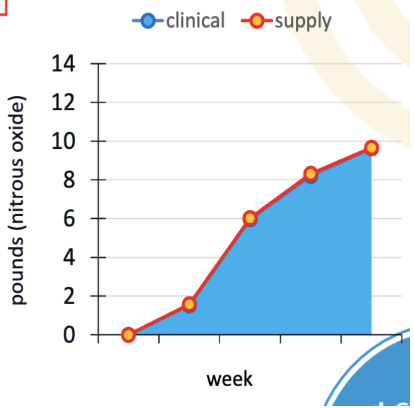

### Compressed




### E-cylinder (open)




### E-cylinder (closed)

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# Reducing Nitrous Oxide in Pediatric Anesthesia

For pediatric inhalational inductions, limit nitrous oxide use to only medically necessary cases.

Studies show a difference of < 10 seconds to loss of lash reflex when sevoflurane was used without $N_2O$ during single-breath vital capacity inductions (Lee, 2013).

For acceptance of mask induction and sevoflurane, distraction techniques such as conversation, electronic media, and premedication are effective (Gordon, 2020).

Incorporate IV anesthetics, regional, and local techniques to reduce $N_2O$ use during maintenance or emergence.

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# Reducing Nitrous Oxide in Pediatric Anesthesia (cont.)

Nitrous oxide for mask induction: pros and cons

| Advantages | Disadvantages |
|---|---|
| Euphoria and ambivalence to presence of volatile anesthetic | Prohibits preoxygenation, predisposing to rapid desaturation in the event of laryngospasm, bronchospasm, or apnea |
| Stable hemodynamics overall (but potential risk of increased pulmonary pressure) | Significant delay to onset of clinical effect of euphoria |
| | Dysphoria common with high inspiratory fraction |
| | Does not speed mask induction |
| | Increases risk of postoperative nausea and vomiting |
| | Increases carbon footprint of the anesthetic |

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# Summary

- Commonly used inhaled anesthetic agents such as halogenated gases and nitrous oxide are greenhouse gases, with nitrous also being an ozone-depleting agent.

- The environmental impact of anesthetic gases can be compared by converting to $CO_2$ equivalents, which both factors in both the amount used in a given time and the global warming potential (or GWP).

- We can significantly decrease our carbon footprint in the O.R. by both eliminating desflurane and reducing nitrous oxide usage.

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# Recommendations

1. **Eliminating Desflurane**

   Problem: In comparison to other halogenated anesthetics, desflurane has a significantly greater impact on the environment in terms of atmospheric lifetime, GWP 20, GWP 100, and $CO_2$ equivalents produced.

   Recommendation: Completely eliminate desflurane from the operating room and elect for environmentally-safer alternatives such as sevoflurane or isoflurane.

1. **Reducing Nitrous Oxide**

   Problem: Nitrous oxide adversely affects the environment on its own both as a greenhouse gas and ozone-depleting agent as well as in conjunction with other anesthetics as a carrier.

   Recommendation: Only use nitrous oxide when clinical advantages are transparent and, if feasible, opt for portable cylinders over centralized nitrous oxide piping.

# **Section III:**
# Managing Fresh Gas Flow

(Watts, 2018)

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# Fresh Gas Flow and Waste

- When fresh gas flow exceeds a patient's needs in a circular anesthesia system, gases and vapors will enter the scavenging system and be vented into the atmosphere.

- Thus, the fresh gas flow rate is correlated to the amount of gas that enters the scavenging system and ultimately contaminates the ambient environment.

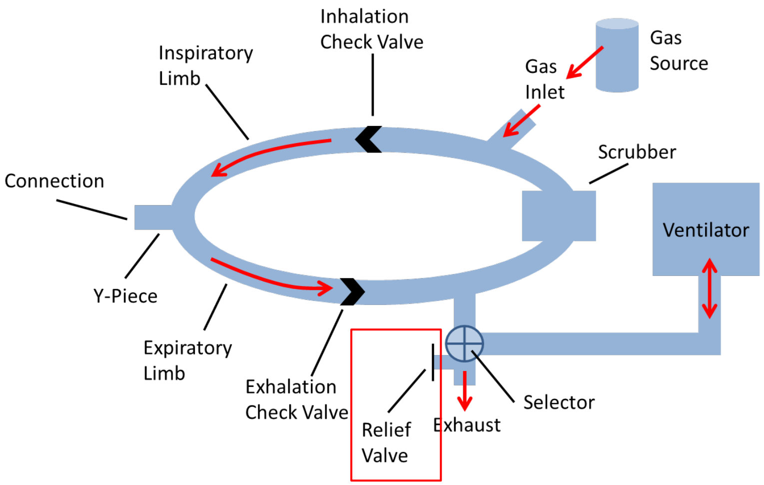


Image adapted from Pulse Physiology (Pulse Physiology, 2022)

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# Fresh Gas Flow and Waste (cont.)

- Since all anesthetic gases are greenhouse gases, high fresh gas flows of any inhaled anesthetic can lead to significant environmental contamination.
  - At high FGFs, it's estimated that more than 80% of delivered anesthetic is wasted (Kapoor, 2019).
- Although the impact of a single case is minimal, the effects are cumulative.
  - With an estimated worldwide volume of 200 to 300 million surgeries per year, the potential to decrease GHG emissions in the O.R. is considerable (Miller, 2022).

# Managing Fresh Gas Flow

- Regardless of the inhaled anesthetic agent used, managing fresh gas flow can reduce waste from circular anesthesia and decrease the overall carbon footprint of a surgical case.
- There are three primary ways to reduce fresh gas flow that minimize ecological impact without compromising patient care:
  1. Minimizing fresh gas flow during induction in pediatric patients
  2. Minimizing fresh gas flow during maintenance
  3. Turning the vaporizer up (and the FGF down) during intubation

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# Minimizing FGF during Pediatric Inductions

**The Society for Pediatric Anesthesia published guidelines for weight-based FGF during inhalation induction (Glensky, 2022):**

*Set FGF based on patient weight to exceed minute ventilation ($V_E$) in order to prevent rebreathing*

- Minute Ventilation (VE)= Vt x RR

Simplified calculation for FGF Induction:

- Set FGF to exceed minute ventilation (VE) for open circuit conditions:
  - **150 mL x weight (kg)**, where VE~120 ml/kg estimate based upon VCO2 from Brody's equation:
    - VCO2 = 5.56x(Wt in Kgs)^1.05
    - Approximation: VCO2 = 6 x Wt in Kgs
    - Fraction of CO2 in the alveolus
    - FACO2 ~ 0.05 at sea level
    - Minute Ventilation = VCO2/FACO2 ~ (6 x Wt in Kgs)/0.05 ~ 120 x Wt in Kgs
- Values on table calculated based on 150mL x Weight (kg)

**Induction:**

| | |
|---|---|
| <20kg | 3 lpm |
| 20-30kg | 4 lpm |
| 30-40kg | 5 lpm |
| >40kg | 6 lpm |

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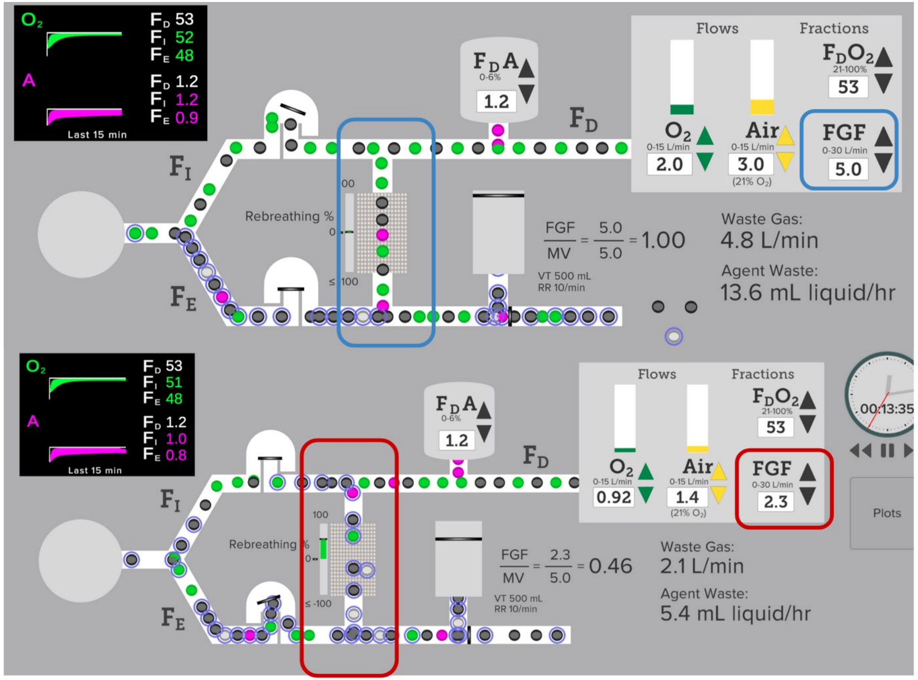
# Minimizing FGF during Pediatric Inductions (cont.)

**Setting induction FGF to exceed minute ventilation during induction prevents rebreathing and dilution of volatile concentration.**




*Simulation courtesy of "Low Flow Anesthesia" from the University of Florida Center for Safety, Simulation & Advanced Learning Technologies:*

- Top diagram: FGF >/= VE with no evidence of rebreathing.
- Bottom diagram: FGF<VE with evidence of rebreathing.

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# Recommendation 1: Reducing FGF During Maintenance

- During induction or emergence, it may be necessary to use high fresh gas flow when a rapid change in the concentration of anesthetic gas is required.
- However, the maintenance generally relies on a *steady* concentration of gas.
- Thus, the maintenance phase is an opportunity to lower the fresh gas flow to meet the patients needs, allowing for fewer GHG emissions without compromising clinical care.

# Literature-Defined Flow Rates (Hönemann, 2013)

| Metabolic Fresh Gas Flow | Minimal Fresh Gas Flow | Low Fresh Gas Flow | High Fresh Gas Flow |
|---|---|---|---|
| 0.35 L/min | 0.5 L/min | 1 L/min | 2-6 L/min |

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# Minimizing Fresh Gas Flow During Maintenance

- The minimum safe fresh gas flow supplies both enough oxygen and anesthetic to satisfy patient consumption *plus* additional gas to compensate for leaks in the circuit and/or via a sidestream gas analyzer (Axelrod, 2022).
- The patient oxygen uptake is correlated with **body mass** (Feldman, 2012) and is conventionally calculated via two different formulas:

| Brody's Formula (Hönemann, 2023) | Linear Formula (Feldman, 2012) |
|---|---|
| $VO_2 = 10 \cdot m^{3/4}$ | $VO_2 = 5m$ |

Key:

- "VO2": Volume of oxygen consumed by the patient per min
- "m": Patient mass (in kg)

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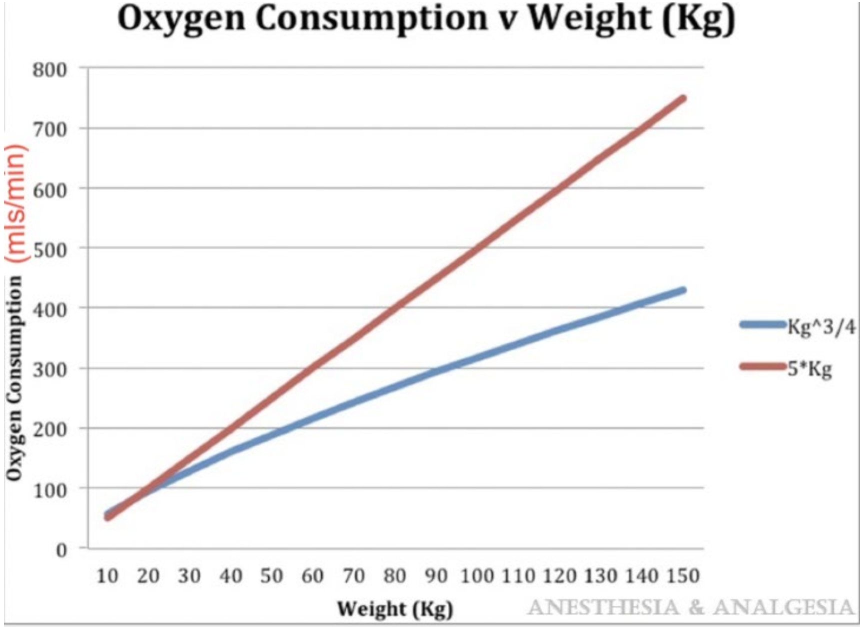
# Minimizing Fresh Gas Flow During Maintenance (cont.)

- This graph depicts the correlation between weight and oxygen consumption using Brody's formula (blue) and the linear formula (red).
- Although Brody's formula typically yields a more accurate estimate (Pulse Physiology Engine, 2022), the linear formula is both more simple to calculate and overestimates the oxygen consumption, creating a margin of safety.

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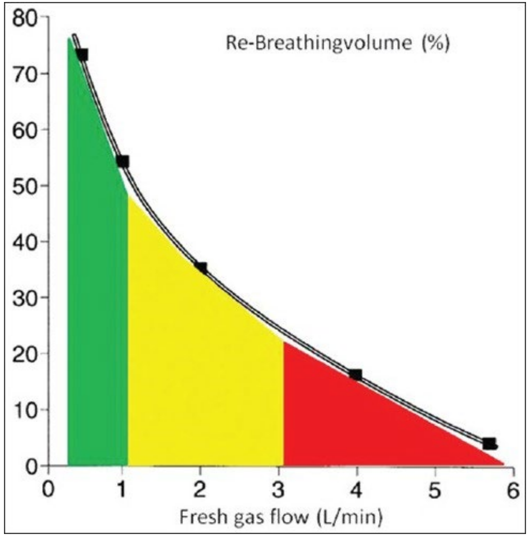
# Benefits of Minimizing FGF During Maintenance: Ecological

Minimizing fresh gas flow during maintenance is a safe and effective way to thwart waste anesthetic gases, or “WAGs.”

- WAGs are gases that escape from a circular anesthesia system into the outdoor atmosphere, virtually unmetabolized and unregulated (McGain, 2020).
- Lower Fresh Gas Flow → Larger Re-Breathed Volume → Smaller WAG Volume Emitted into the Atmosphere



# Benefits of Minimizing FGF During Maintenance (cont.)

## Clinical Considerations

- Prior research indicates that minimizing FGF during the maintenance phase can also…
    - Increase heat and moisture content in the lungs (Kleemann, 1994; Nunn, 2008)
    - Increase mucociliary clearance and help maintain a steady body temperature (Aldrete, 1981)
    - Help providers detect small leaks in the circuit and adjust accordingly (CSSALT, 2022)

## Economic Considerations

- Reduction of anesthetic gas consumption results in significant institutional savings (Watts, 2018).
- "Low-flow anesthesia is a simple but highly effective method of cost minimisation that can be applied to a large number of patients without any compromise in patient care or safety (Suttner, 2000)"

# Concerns of Minimizing FGF During Maintenance

- ***Inadequate Oxygen Delivery***
  - As the fresh gas flow is lowered, the amount of exhaled gas (with a higher carbon dioxide concentration) returned to the patient increases (Feldman, 2022).
  - This can lead to inadvertent low inspired concentration and hypoxemia.
- ***Inadequate Anesthetic Agent Delivery***
  - A decrease FGF risks an inadequate anesthetic concentration, especially during early procedural stages in which there is significant uptake of anesthetic from the lungs (Axelrod, 2022; Feldman, 2022.
- ***Wasted Emissions***
  - Lowering FGF still results in significant WAG emission (unlike a true closed circuit in which fresh gas flow directly equates what is consumed by the patient) (Sherman, 2012).
- ***Toxicity Associated with $CO_2$ Absorbents***
  - As FGF decreases, a higher concentration of $CO_2$ absorbent is required.
  - Depending on the absorbent used, the risk of toxicity from Compound A and/or carbon monoxide production may increase as well (Feldman, 2021; Branche, 2017).

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# Safely Minimizing FGF: Setting a Buffer

Once minimum FGF is calculated, the utilized FGF can be set **slightly above** this value to reduce the risk of inadequate oxygen/anesthetic delivery.

Even a small reduction in FGF can make a significant ecological difference.

- Assuming 500 cases over 35 years, reducing the maintenance flow of isoflurane from 2 liters/min to 1 liter/min prevents an estimated 18,900 liters from entering the atmosphere (Feldman, 2012).

The ASA recommends total oxygen flow to be **20% greater** than oxygen consumption.

Courses such as the University of Florida's "Low Flow Anesthesia" can educate on how to set a flow buffer and balance ecological impact with clinical safety(CSSALT, 2022).

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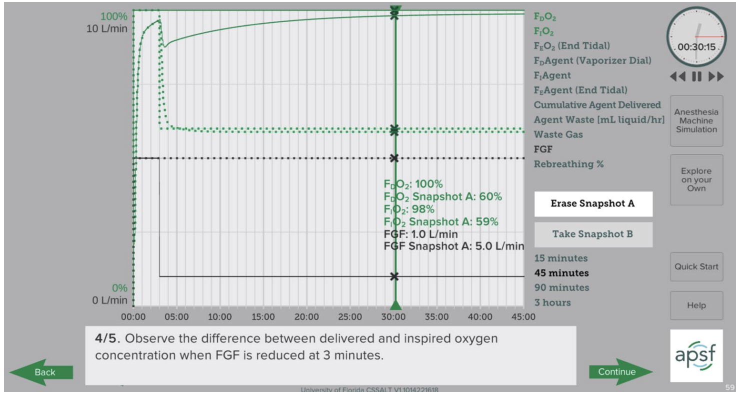
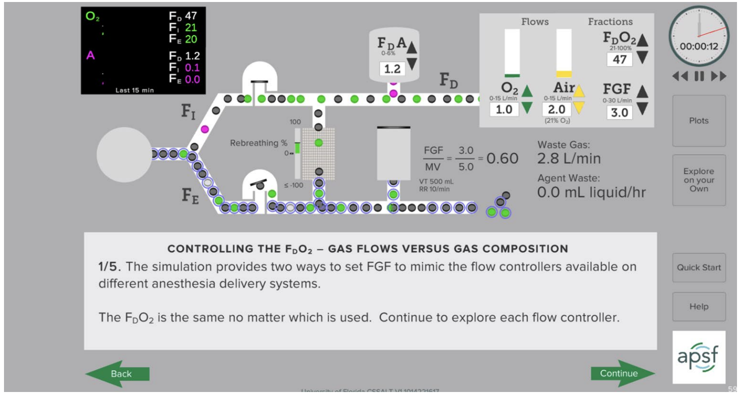
# Safely Minimizing FGF: Setting a Buffer

“Low Flow Anesthesia” from the University of Florida Center for Safety, Simulation & Advanced Learning Technologies

https://simulation.health.ufl.edu/education-training/apsf-technology-education-initiative/low-flow-anesthesia/

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# Safely Minimizing FGF: Monitoring

Monitoring gas and anesthetic concentrations by the provider throughout the maintenance phase is **essential** for reducing the risks of hypercapnia/hypoxia and inadequate anesthetic delivery (Axelrod, 2022; Honemann, 2013; Feldman, 2012; Feldman 2022; Garg, 2012).

Inspired/expired carbon dioxide, oxygen, and anesthetic agent concentration should be consistently observed and fresh gas flow should be adjusted accordingly.

- *Note:* Managing inspired anesthetic concentration may be more challenging since uptake of anesthetic falls exponentially over time (Feldman, 2022).

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# Safely Minimizing FGF: $CO_2$ Absorbent Choice

- Although some $CO_2$ absorbents present the possibility of toxicity when mixed with anesthetic gas, it's suggested that choosing absorbents containing no potassium chloride and less than 2% sodium chloride would eliminate this risk (Feldman, 2022).
    - In absorbents containing KOH and NaOH, the strong base can react with sevoflurane or desflurane to produce Compound A or carbon monoxide, respectively.
    - Without these bases present, however, Compound A and carbon monoxide production are no longer a concern, eliminating the risk of toxicity.
- Thus, these $CO_2$ absorbent formulations can be used safely to minimize anesthetic waste by allowing the reduction of fresh gas flow during the maintenance phase without the risk of toxic gas production.

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# Intubation: Vaporizer vs. FGF

Common Misconception: Turning off the vaporizer while turning on fresh gas flow during intubation prevents pollution of the operating room by the anesthetic agent.

Rather, the anesthetic vapor that has accumulated in the circuit during mask ventilation is washed into the room by fresh gas flow (Axelrod, 2022; Feldman, 2012; Scott, 2005).

Thus, room contamination is **not** avoided and vapor in the circuit is wasted.

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# Recommendation 2: Vaporizer On/FGF Off During Intubation

**Alternate Strategy:** Leave the vaporizer on and turn the fresh gas flow off during the intubation process.

- This could mean temporarily switching FGF off or using the 60-second “pause flow” feature on your anesthesia machine during intubation
- This practice would completely eliminate the discharge of the anesthetic gas mixture into the O.R. environment during intubation (Scott, 2005).
- In the absence of fresh gas flow, none of the anesthetic vapor is washed into the room and the reservoir that has built up in the circuit is preserved (Axelrod, 2022).

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# Vaporizer On/FGF Off During Intubation: Benefits

**Ecological**

- No environmental contamination during intubation (Feldman, 2012)
- A lower FGF can be used to maintain the circuit concentration subsequent to intubation (Feldman, 1999)

**Economic**

- Higher alveolar concentration can be achieved at the same vapor cost (Feldman, 1999)
- Additional cost savings when FGF is kept paused or off immediately after intubation

**Clinical**

- A greater alveolar concentration speeds up induction (Feldman, 1999)
- Would also prevent a fall in concentration within the circuit, thus reducing the likelihood of awareness post-intubation (Scott, 2005)

# Vaporizer On/FGF Off During Intubation: Other Considerations

- Note: Pausing or turning off the fresh gas flow during intubation may **not** be appropriate for all cases.
  - In the event of difficult airway, fresh gas flow may need to be turned back on to continue mask ventilation (Axelrod, 2022; Feldman, 2012).
- Each practitioner should make a decision about their own comfort level with airway management and fresh gas flow changes.

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# Summary

- Circular anesthetic systems allow leaks of anesthetic vapor into the ambient environment through the scavenging system.
- Managing fresh gas by both reducing FGF during maintenance and turning FGF off during intubation when clinically appropriate can help minimize this waste while also providing both economic and clinical benefits.

# Recommendations

1. **Minimizing Fresh Gas Flow During Maintenance**

- Using minimum fresh gas flow that still satisfies the patient's anesthetic and oxygen needs provides ecological, economical, and clinical benefits.
- To ensure adequate anesthetic and oxygen concentrations, a buffer should be set that overestimates minimum FGF and both gas and anesthetic concentrations should be monitored throughout the case.

1. **Turning Off Fresh Gas Flow During Intubation**

- Keeping the vaporizer on and turning the FGF off during mask intubation does not contaminate the operating room but actually provides numerous ecological and non-ecological advantages.
- However, this technique may not be appropriate for all procedures and should ultimately be a provider-led decision.

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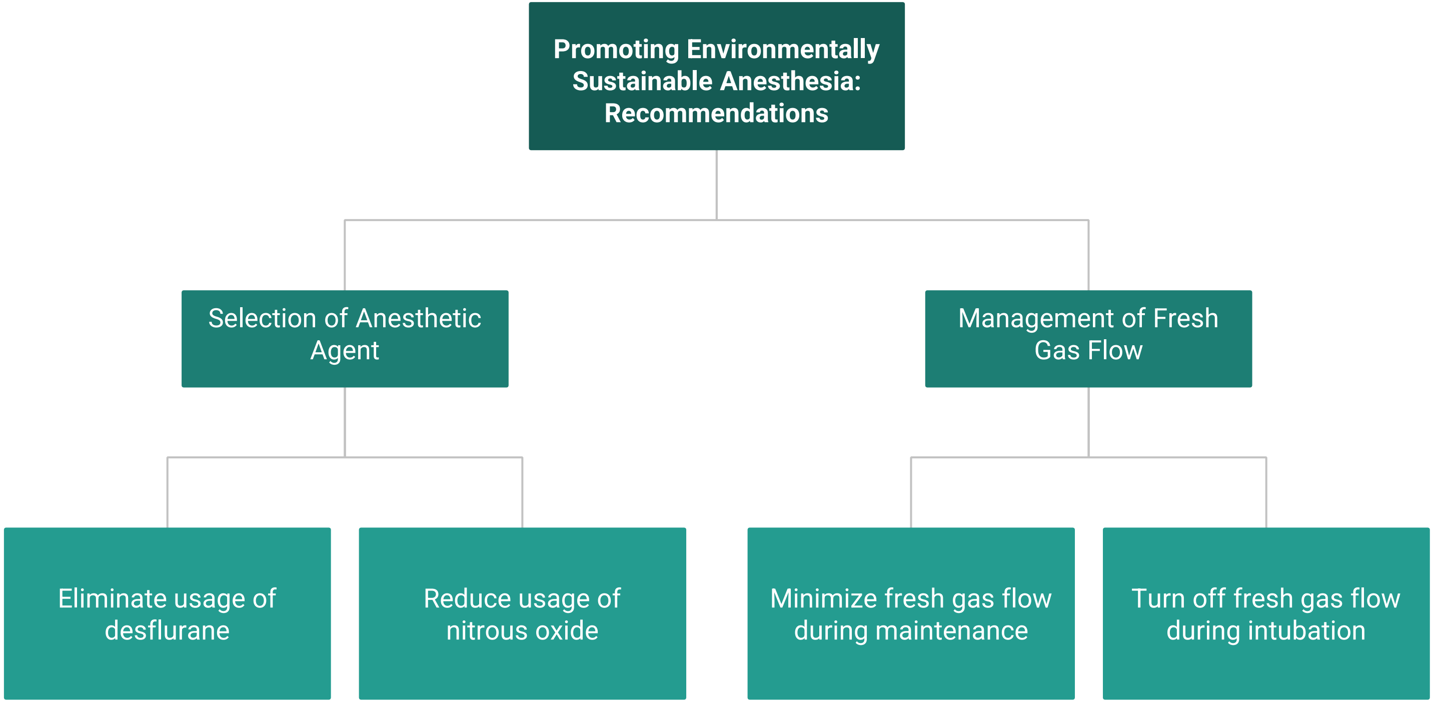


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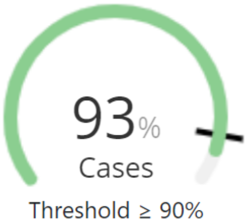
# Section IV:
# MPOG QI Measures

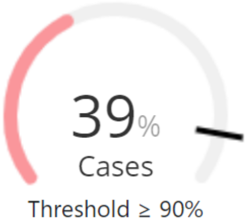
(Watts, 2018)

# MPOG: Sustainability Dashboard (sample)

SUS-01
Fresh Gas Flow, less than or equal to 3L/min

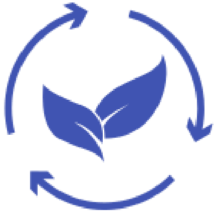



SUS-02
Global Warming Footprint, Maintenance



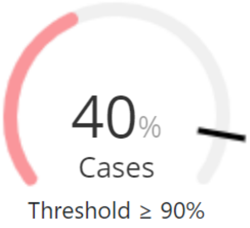

SUS-03
Global Warming Footprint, Induction

6.81 kg $CO_2$/case

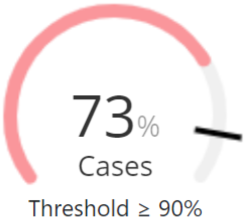


MPOG Average: 6.70 kg $CO_2$/case

SUS-04
Fresh Gas Flow, less than or equal to 2L/min




SUS-05-Peds
Nitrous Avoided, Induction

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# SUS-01: Mean Fresh Gas Flow ≤ 3L/min

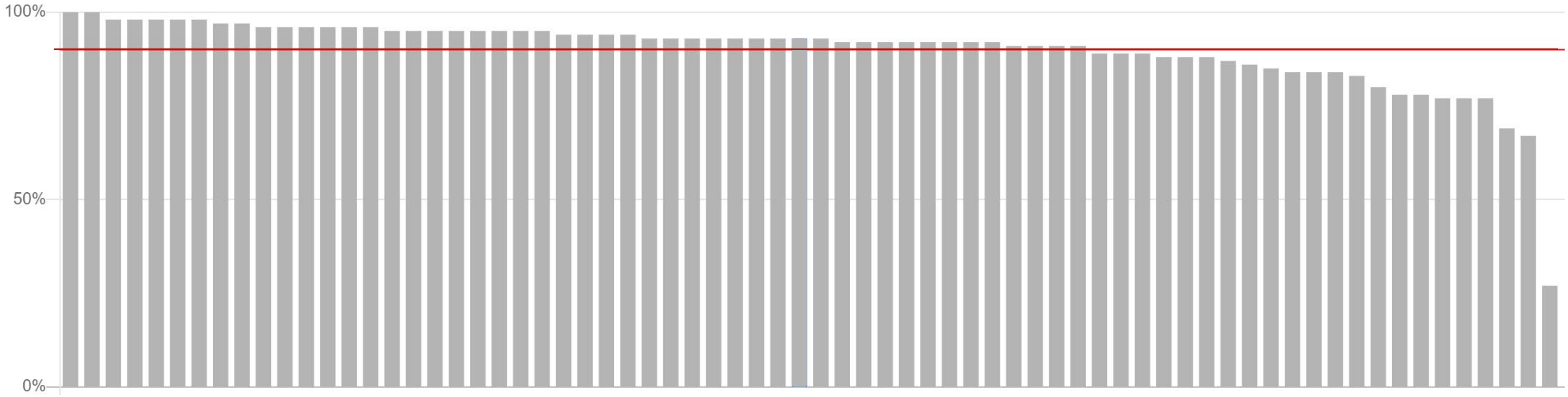
**Description:** Percentage of cases with mean fresh gas flow (FGF) equal to, or less than **3L/min,** during administration of halogenated hydrocarbons and/or nitrous oxide.

**Inclusion Criteria:**

- Cases with an ETT or LMA as determined by Anesthesia Technique: General value_codes 1,2,3,6 (Feldman, 2022)
- Patients administered halogenated hydrocarbons and/or nitrous oxide, for greater than or equal to 30 minutes from placement of the airway device to removal of the airway device.

**Success:** Mean FGF equal to, or less than 3L/minute when inspired halogenated hydrocarbons is > 0.2%, or nitrous oxide FGF > 0.2 L/min, during the maintenance period of anesthesia.

# SUS-01: Percentage Passed Across MPOG Sites



# SUS-02: Global Warming Footprint (Maintenance)

**Description:** Percentage of cases where carbon dioxide equivalents ($CO_2$ eq) normalized by hour for cases receiving halogenated agents and/or nitrous oxide is less than $CO_2$ eq of 2% sevoflurane at 2L FGF = 2.83 kg $CO_2$/hr during the maintenance period of anesthesia.

**Inclusion Criteria:**

- Cases with an ETT or LMA as determined by MPOG phenotype Anesthesia Technique: General (value codes 1,2,3,6) (Feldman, 2022).
- Cases where halogenated hydrocarbons and/or nitrous oxide were administered during the maintenance phase of anesthesia.

**Success:** Mean efficiency less than or equal to carbon dioxide equivalents of 2% sevoflurane at 2L FGF = **2.83 kg $CO_2$/hr.**

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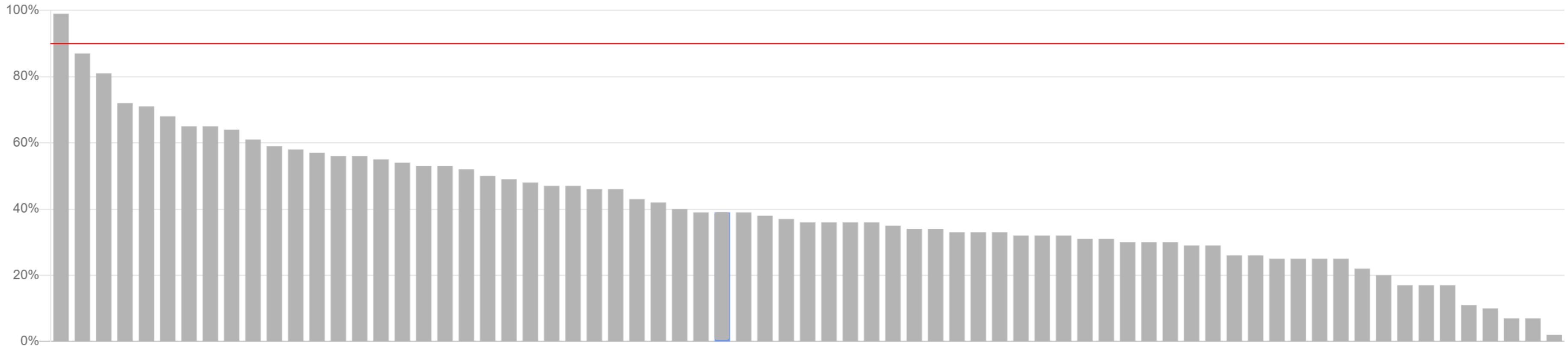
# SUS-02: Percentage Passed Across MPOG Sites



# SUS-03: Global Warming Footprint (Induction)

**Description:** Total carbon dioxide equivalents per induction for cases where halogenated agents and/or nitrous oxide was administered during the induction period of anesthesia

**Inclusion Criteria:**

- Cases with an ETT or LMA (Feldman, 2022)
- Cases where halogenated hydrocarbons and/or nitrous oxide were administered during the maintenance phase of anesthesia.

**Success:** *Not applicable - informational measure.*

Carbon dioxide equivalents reported as kilograms of carbon dioxide equivalents per case
Emissions data are also converted to other meaningful equivalencies & reported as:

Miles driven by an average gasoline-powered passenger vehicle
Gallons of gasoline consumed

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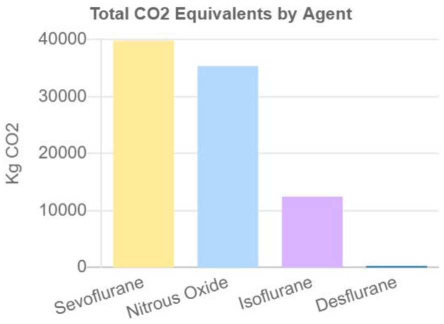
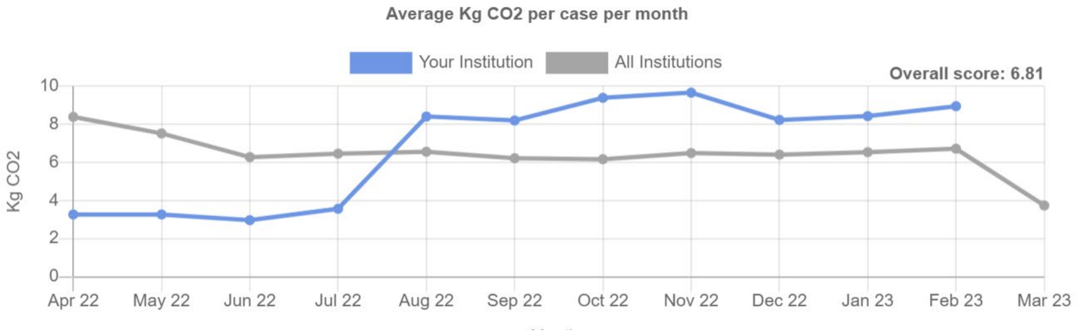
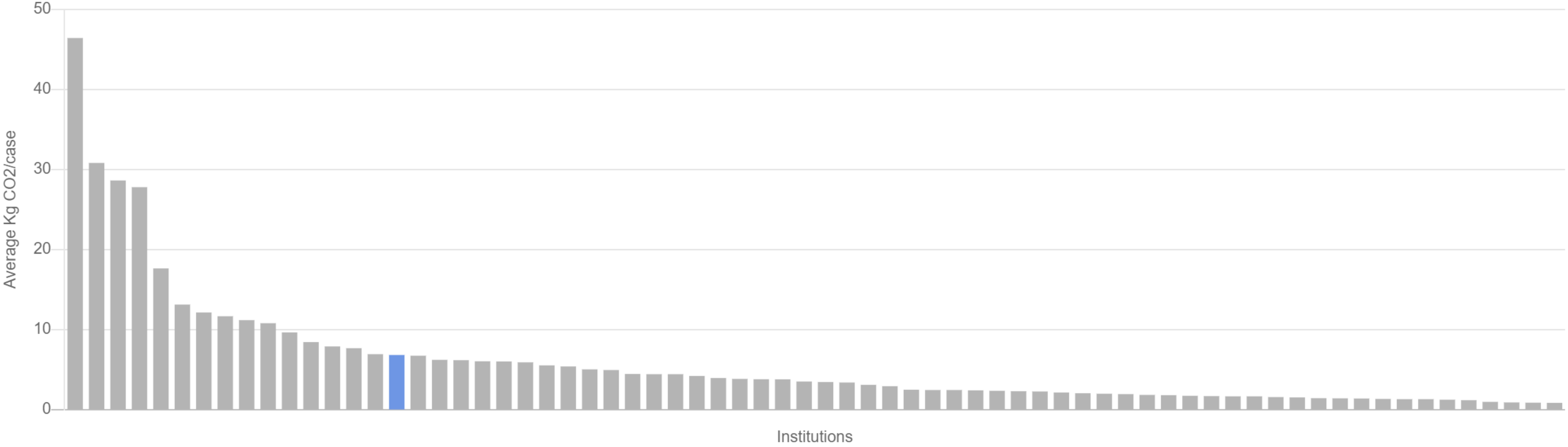
# SUS-03: Average CO2 eq (Induction) Across MPOG Sites



# SUS-04: Fresh Gas Flow ≤ 2L/min

**Description:** Percentage of cases with mean fresh gas flow (FGF) equal to, or less than **2L/min**, during administration of halogenated hydrocarbons and/or nitrous oxide.

**Inclusion Criteria:**

- Cases with an ETT or LMA as determined by Anesthesia Technique: General value_codes 1,2,3,6 (Feldman, 2022).
- Patients administered halogenated hydrocarbons and/or nitrous oxide, for greater than or equal to 30 minutes from placement of the airway device to removal of the airway device.

**Success:** Mean FGF equal to, or less than 2L/minute when inspired halogenated hydrocarbons is >0.2%, or nitrous oxide FGF >0.2L/min, during the maintenance period of anesthesia.

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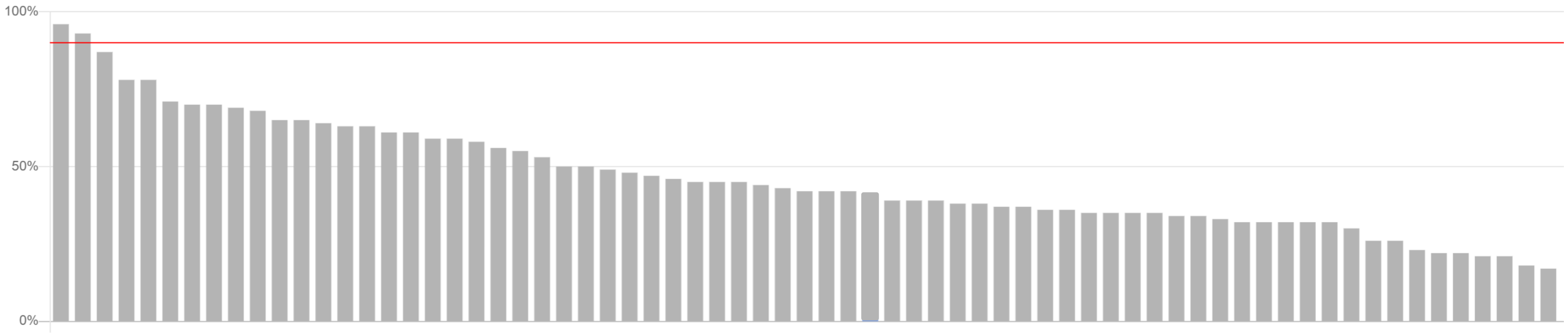
# SUS-04: Percentage Passed Across MPOG Sites



# SUS-05-Peds: Nitrous Avoided During Induction (Pediatrics)

Description: Percentage of pediatric cases where nitrous oxide gas was avoided during induction of anesthesia.

**Inclusion Criteria:**

- Patients < 18yo who undergo general anesthesia as defined by Anesthesia Technique: General (Feldman, 2022).

**Success:** Nitrous oxide was not administered during the induction period of anesthesia.

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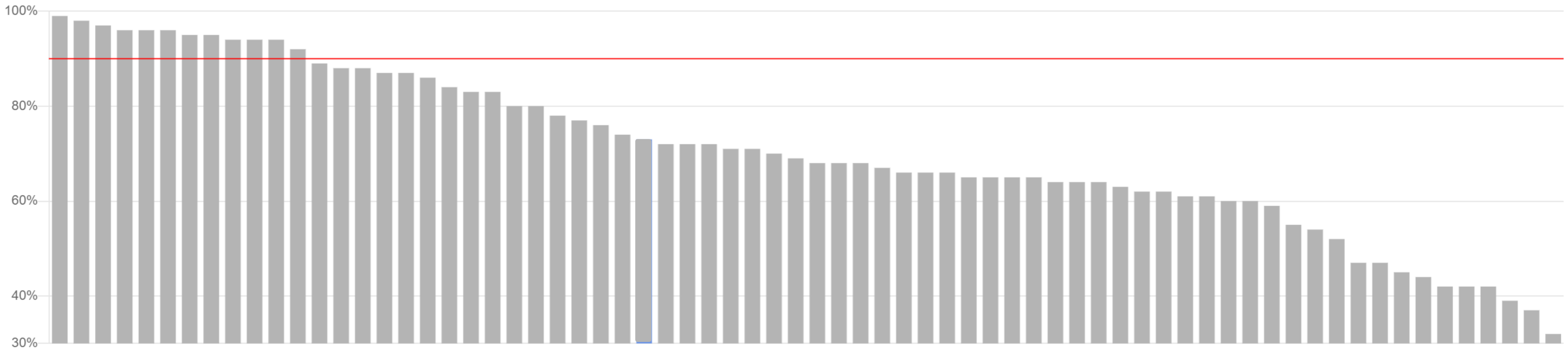
# SUS-05: Percentage Passed Across MPOG Sites

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