Calculating Global Warming Footprint from Inhaled Anesthetics

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MPOG Sustainability Measures

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Reducing Environmental Impact of Anesthesia

All inhaled anesthetics agents have a global warming potential significantly greater than that of carbon dioxide.

These gases are potent contributors to global warming, even in small concentrations.

We can reduce this impact in two primary ways:

1. Selecting environmentally safer anesthetic agents
2. Managing our total fresh gas flows

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- SUS-01: Fresh Gas Flow, less than or equal to 3L/min
- SUS-02: Global Warming Footprint, Maintenance
- SUS-03: Global Warming Footprint, Induction
- SUS-04: Fresh Gas Flow, less than or equal to 2L/min
- SUS-05-Peds: Nitrous Avoided, Induction
- SUS-06-Peds: Low Fresh Gas Flow, Pediatric Induction
- SUS-07: Nitrous Oxide Avoided

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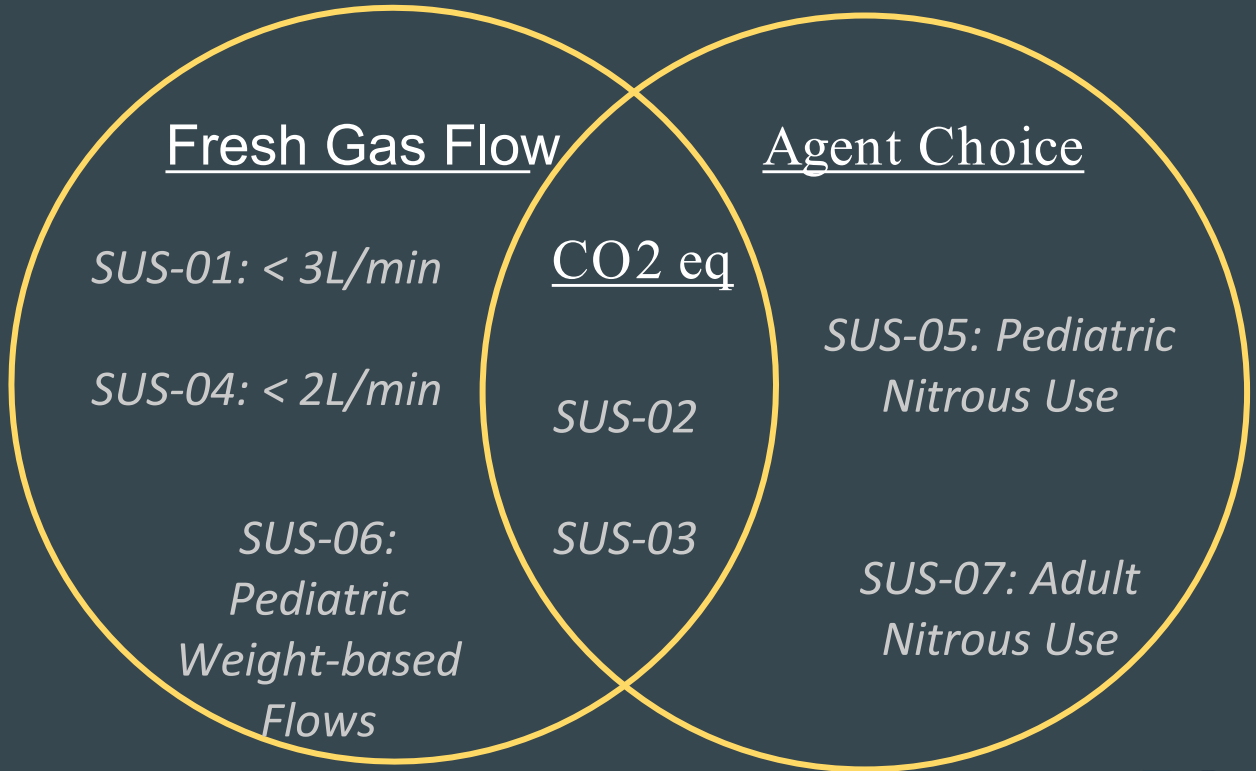
MPOG Sustainability Measures



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MPOG Sustainability Measure Time Periods

	Measure Start	Measure End
SUS-01	Intubation	Extubation End
SUS-02	Intubation	Extubation End
SUS-03	Intubation	Induction End
SUS-04	Intubation	Extubation End
SUS-05-Peds	Induction Start	Intubation. If none, Induction End
SUS-06-Peds	Induction Start	Intubation. If none, Induction End
SUS-07	Anesthesia Start	Anesthesia End

Minimizing Fresh Gas Flow

Measures that focus on Fresh Gas Flow*

SUS-01

- Percentage of cases with mean fresh gas flow (FGF) ≤ 3L/min during administration of halogenated hydrocarbons and/or nitrous oxide.

SUS-04

- Percentage of cases with mean fresh gas flow (FGF) ≤ 2L/min during administration of halogenated hydrocarbons and/or nitrous oxide.

**FGF measures do not consider agent choice great starting place for sites to begin working on sustainability.*

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Minimizing Fresh Gas Flows during Maintenance of Anesthesia

Maintenance is defined as:

- Measure Start:
  - Intubation. If not available, then
  - Induction End.
- Measure End
  - Extubation Time. If not available, then
  - LMA Removal Time. If not available, then
  - Surgery End. If not available, then
  - Patient Out of Room. If not available, then
  - Anesthesia End.

Flow and gas values are considered artifact if inside the following ranges:

- Nitrous Oxide Flows: < 0.2 L/min
- Isoflurane Insp: < 0.3%
- Sevoflurane Insp: < 0.4%
- Desflurane Insp: < 1.2%
- Nitrous Oxide Insp: < 20%

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Calculating Mean Fresh Gas Flow (SUS-01 & SUS-04)

Step 1: Determine which minutes to include in the measure. Included minutes must meet **all** of the following criteria (see next slide for graphical representation):

A. Within the measure time bounds
   - Measure start (Induction start time)
   - Measure end (Patient Extubated)

B. Valid (non-artifact) Fresh Gas Flow value documented
   - Air, Oxygen, Nitrous Oxide (L/min)

C. Valid (non-artifact) Inhaled Agent value documented
   - Sevoflurane, Isoflurane, Desflurane, Nitrous Oxide

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Included Minute: All three criteria must align

Step 1a: Raw Data

Step 1b: Remove Measurements Outside Measure Duration

Step 1c: Remove Flow Measurements Outside Pollutant Intervals

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EXAMPLE CASE

	Pollutants						Flows						Total Fresh Gas Flow (L/min)
Measure time period	Sevoflurane Insp %			Nitrous oxide (L/min)			Oxygen (L/min)			Air (L/min)			
1051 - Measure start: Induction start	9/29/2023 10:51	Sevoflurane Insp %	3.1										
1052	9/29/2023 10:52	Sevoflurane Insp %	1.5										
1053	9/29/2023 10:53	Sevoflurane Insp %	3.1			0			0	9/29/2023 10:53	Flows Air (L/min)	1	1
1054	9/29/2023 10:54	Sevoflurane Insp %	2.4			0			0	9/29/2023 10:54	Flows Air (L/min)	1	1
1055	9/29/2023 10:55	Sevoflurane Insp %	2.3			0			0	9/29/2023 10:55	Flows Air (L/min)	1	1
1056	9/29/2023 10:56	Sevoflurane Insp %	2.4			0			0	9/29/2023 10:56	Flows Air (L/min)	1	1
1057	9/29/2023 10:57	Sevoflurane Insp %	2.4			0			0	9/29/2023 10:57	Flows Air (L/min)	1	1
1058	9/29/2023 10:58	Sevoflurane Insp %	2.5			0	9/29/2023 10:58	Flows Oxygen (L/Min)	0.9	9/29/2023 10:58	Flows Air (L/min)	1	1.9
1059	9/29/2023 10:59	Sevoflurane Insp %	2.2			0	9/29/2023 10:59	Flows Oxygen (L/Min)	0.9	9/29/2023 10:59	Flows Air (L/min)	1	1.9
1100	9/29/2023 11:00	Sevoflurane Insp %	2.2			0	9/29/2023 11:00	Flows Oxygen (L/Min)	0.9	9/29/2023 11:00	Flows Air (L/min)	1	1.9
1101	9/29/2023 11:01	Sevoflurane Insp %	2.2			0	9/29/2023 11:01	Flows Oxygen (L/Min)	0.9	9/29/2023 11:01	Flows Air (L/min)	1	1.9
1102	9/29/2023 11:02	Sevoflurane Insp %	1.8			0	9/29/2023 11:02	Flows Oxygen (L/Min)	0.9	9/29/2023 11:02	Flows Air (L/min)	1	1.9
1103	9/29/2023 11:03	Sevoflurane Insp %	1.8			0	9/29/2023 11:03	Flows Oxygen (L/Min)	0.9	9/29/2023 11:03	Flows Air (L/min)	1	1.9
1104	9/29/2023 11:04	Sevoflurane Insp %	1.6			0	9/29/2023 11:04	Flows Oxygen (L/Min)	0.9	9/29/2023 11:04	Flows Air (L/min)	1	1.9
1105	9/29/2023 11:05	Sevoflurane Insp %	1.7			0	9/29/2023 11:05	Flows Oxygen (L/Min)	0.9	9/29/2023 11:05	Flows Air (L/min)	1	1.9
1106	9/29/2023 11:06	Sevoflurane Insp %	1.8			0	9/29/2023 11:06	Flows Oxygen (L/Min)	0.9	9/29/2023 11:06	Flows Air (L/min)	1	1.9
1107	9/29/2023 11:07	Sevoflurane Insp %	1.9			0	9/29/2023 11:07	Flows Oxygen (L/Min)	0.9	9/29/2023 11:07	Flows Air (L/min)	1	1.9
1108	9/29/2023 11:08	Sevoflurane Insp %	1.9			0	9/29/2023 11:08	Flows Oxygen (L/Min)	1	9/29/2023 11:08	Flows Air (L/min)	1	2

*Copied and pasted minute to minute gas and flows from Case Viewer into Excel.

*Does not assess gas choice.

Step 2: Sum the gas flows to obtain the total fresh gas flow for each minute.

Time	Pollutants: Sevoflurane (%) & Nitrous Oxide (L/min)		Flows: Oxygen (L/min) & Air (L/min)			Total Fresh Gas Flow
1149	0.8	1	+ 1	+	0	= 2

Nitrous Oxide (L/min) + Oxygen (L/min) + Air (L/min) = Total Fresh Gas Flow

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Steps 3 & 4: Calculate the average FGF

Step 3: Sum the total fresh gas flow for each minute

Step 4: Divide the total by the number of included minutes (65)

Total Fresh Gas Flow (L/min)
1
1
1
1
1
1.9
1.9
1.9
1.9
1.9
1.9
1.9
1.9

For this case:

- Average gas flow of 2.08 for this case. What happened?
- At end of case, Oxygen flows were 14.9 L/min + Nitrous Oxide flows at 1 L/min = 15.9 L/min for a single minute of the case.

*This case passed SUS-01 but flagged SUS-04.

SUS-01 and SUS-04 Calculations Overview

- Determine measure time period:
  - Measure start (Induction start time): 1051 → Measure end (Patient Extubated): 1156
  - Measure time period = 65 minutes

- Determine which minutes to include: 62
  - SUS 01, 04 Fresh Gas Flow (O_2, Air, N_2O) running

- Sum of total flows for each included minute

- Take the average of the flows for the included minute
  - Add up flows for all included minutes and divide by the total number of include minutes.
  - Average is used instead of median to account for minutes of high flows during the case and to get an average of flow use per case..

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SUS-06-Peds: Low Fresh Gas Flow, Pediatric Induction

- Percentage of pediatric patients with a mean fresh gas flow (FGF) less than or equal to established weight-based threshold during induction.
- Weight-based thresholds based on Society for Pediatric Anesthesia (SPA) Recommendations:

Weight (kg)	Mean FGF
< 20	≤ 3 L/min
20 - 30	≤ 4 L/min
30 - 40	≤ 5 L/min
> 40	≤ 6 L/min

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Global Warming Footprint (SUS-02 & SUS-03)

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SUS-02: Global Warming Footprint (Maintenance)

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 = 2.83kg CO_2/hr

or

Total CO_2 eq is less than 2.83kg CO_2

…for the maintenance period of anesthesia.

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Maintenance period of Anesthesia for SUB-02

Maintenance is defined as:

- Measure Start:
  - Intubation. If not available, then
  - Induction End.
- Measure End
  - Extubation Time. If not available, then
  - LMA Removal Time. If not available, then
  - Surgery End. If not available, then
  - Patient Out of Room. If not available, then
  - Anesthesia End.

Of Note: Flow and gas values are considered artifact if inside the following ranges:

- Nitrous Oxide Flows: < 0.2 L/min
- Isoflurane Insp: < 0.3%
- Sevoflurane Insp: < 0.4%
- Desflurane Insp: < 1.2%
- Nitrous Oxide Insp: < 20%

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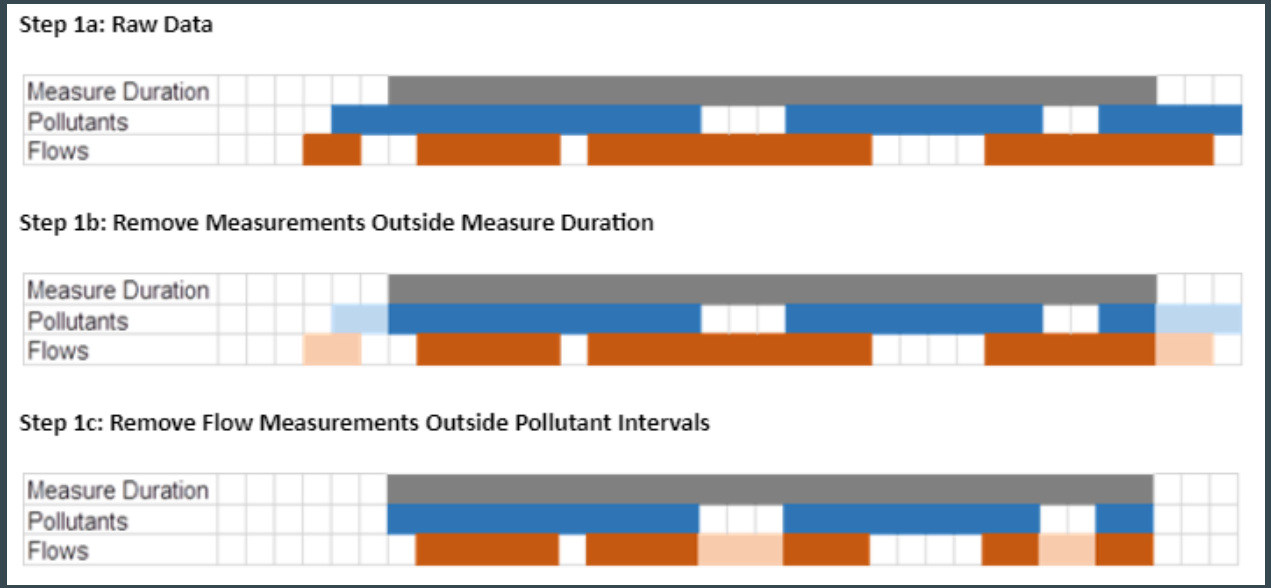
Step 1: Calculating Fresh Gas Flow for SUR

- Determine included minutes for the measure where FGF values and Inhaled agent values are documented within the bounds of the measure time period
- Sum the gas flows to obtain total FGF for each minute



Step 2: Calculate CO_2 eq for each inhaled agent for each minute.

*If multiple agents are running for a single minute, calculate the CO_2 for each agent, then add CO_2 eq. from each agent together to calculate total CO_2 eq for the minute.

	Pollutants: Sevoflurane (%) & Nitrous Oxide (L/min)		Flows: Oxygen (L/min) & Air (L/min)		Total Fresh Gas Flow
1149	0.8	1	1	0	2

Pollutants				
	Sevoflurane %	CO2 eq	Nitrous Oxide L/min	CO2 eq
1149	0.8	0.0189	1	0.5085

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SevoIso/Desflurane: Calculation & Reference Table

*** CO_2 eq for Sevoflurane, Isoflurane or Desflurane (%):**

1. Convert agent % → mLs of agent/min: (FGF (l/min) x 1,000 x agent %) / 100
2. Convert mls/min → moles: agent mL / 24,400
3. Convert moles → mass: (agent moles x MW of agent) / 1,000
4. Convert mass → CO_2 equivalents: agent mass x GWP of agent

Agent	Global Warming Potential[100]	Atmospheric Lifetime (years)	Molecular Weight (g/mol)
Isoflurane[12]	565	3.2	184.5
Sevoflurane[11]	144	1.1	200
Desflurane[12]	2540	14	169
Nitrous Oxide[13]	282*	114	44

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SUS-02 Example Case: Calculate CO_2 eq. for each minute

Sevoflurane + Nitrous Oxide running

	Pollutants: Sevoflurane (%) & Nitrous Oxide (L/min)		Flows: Oxygen (L/min) & Air (L/min)		Total Fresh Gas Flow
1144	1.8	0.8	1.2	1	3

Sevoflurane CO_2 equivalents:

1) Convert % agent → mLs of agent:

$(3*1{,}000*1.8)/100 = 54$

1) Convert mLs/min to moles: $54/24{,}400 = 0.002213$
2) Convert moles to mass: $(0.002213 * 200) / 1{,}000 = 4.43 * 10^{-4}$
3) Convert mass to CO_2 eq: $4.43x10^{-4} * 144 = 0.0637$

Nitrous Oxide: Calculation and Reference Table

** **CO_2 eq For Nitrous Oxide:**

For cases with documented Nitrous Oxide % but Nitrous Oxide flow is not reported, then use Nitrous Oxide % and FGF:

- Divide Nitrous Oxide % / 100 = **N**
- Convert **N** → mLs/min: (FGF (l/min) x 1,000 x **N**)
- Convert mls/min → moles: **N mL** / 24,400
- Convert moles → mass: (**N moles** x MW of agent) / 1,000
- Convert mass → CO_2 equivalents: **N mass** x GWP of agent

For cases with both valid Nitrous Oxide % and Nitrous Oxide flows reported, only Nitrous Oxide flow values will be considered (N2O values reported as % will be ignored):

1. Convert Nitrous Oxide (l/min) → mols/min: Nitrous Oxide / 24.4 = **Nmol**
2. Convert Nmol → N20 mass (kg/min): (**Nmol** *44) / 1,000
3. Convert Nmass → CO_2 equivalents: **Nmass** * GWP

Agent	Global Warming Potential[100]	Atmospheric Lifetime (years)	Molecular Weight (g/mol)
Isoflurane[12]	565	3.2	184.5
Sevoflurane[11]	144	1.1	200
Desflurane[12]	2540	14	169
Nitrous Oxide[13]	282*	114	44

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Example: Calculate CO_2eq of Nitrous Oxide

Since Nitrous Oxide is reported as flows (L/min), use second equation (steps 1-3) for calculation:

1144: Nitrous oxide flow was 0.8 L/min

1. 0.8 / 24.4 = 0.0328
2. (0.0328 * 44) / 1,000 = 0.0014432
3. 0.014432 * 282 = 0.407 CO_2 eq

For cases with both valid Nitrous Oxide % and Nitrous Oxide flows reported, only Nitrous Oxide flows will be considered (N2O values reported as % will be ignored):

1. Convert Nitrous Oxide (l/min) → mols/min: Nitrous Oxide / 24.4 = **Nmol**
2. Convert Nmol → N20 mass (kg/min): (**Nmol** *44) / 1,000
3. Convert Nmass → CO_2 equivalents: **Nmass** * GWP

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Example: Nitrous Oxide calculation if reported as Insp % (instead of L/min)

Nitrous Oxide Insp %: 35.2%

- 35.2 / 100 = 0.352
- 2.2 * 1000 * 0.352 = 774.4
- 774.4 / 24,400 = 0.0317377049
- (0.0317377049 * 44) / 100 = 0.0139645902
- 0.0139645902 * 282 = 3.938 CO_2 eq

For cases with documented Nitrous Oxide % but Nitrous Oxide flow is not reported, then use Nitrous Oxide % and FGF:

- Divide Nitrous Oxide % / 100 = **N**
- Convert **N** → mLs/min: (FGF (l/min) x 1,000 x **N**)
- Convert mls/min → moles: **N mL** / 24,400
- Convert moles → mass: (**N moles** x MW of agent) / 1,000
- Convert mass → CO_2 equivalents: **N mass** x GWP of agent

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Step 3: Determining Mean CO_2eq per hour for the case (reported as kg CO_2/hr)

*Total CO2 eq is calculated by determining the pollutant total for the time period and dividing by total minutes between Intubation and Extubation Time.

1. Calculate CO_2 eq for each included minute of Sevoflurane% /Desflurane %/Isoflurane %
2. Calculate CO_2 eq for each included minute of Nitrous Oxide % or Nitrous Oxide Flows (L/min)
3. Sum CO_2 eq
4. Divide by total of included minutes:
    a. Total CO_2 eq / Total # minutes = CO2 eq/min
5. Multiple Total CO_2 eq/min X 60 = Mean CO_2 eq/hr

1. Total CO_2 eq for Sevoflurane % = 2.598846451
2. Total CO_2 eq for Nitrous Oxide (L/min) = 5.390360656
3. 2.598846451 + 5.390360656 = 7.989207107
4. 7.989207107 / 62 = 0.128858179
5. 0.128858179 * 60 = 7.731490749

MEAN CO_2 eq/hr for case = 7.731 …FLAG

SUS-02 Threshold = Mean CO_2 of 2.83kg CO_2

Carbon dioxide equivalents for each inhaled agent: FGF constant at 2L/min

Agent used	% Insp	FGF	CO_2 eq./minute
Sevoflurane	2%	2 L/min	0.047
Isoflurane	1%	2 L/min	0.085
Desflurane	6%	2 L/min	2.111
Nitrous Oxide	50%	2 L/min	0.509

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SUS-03: Global Warming Footprint, Induction

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

Total CO_2 equivalents is calculated by determining the pollutant total for the time period and dividing by the total number of minutes between the induction period.

Induction period: Induction Start to Induction End

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SUS-03: Calculations

- Follows the same steps as SUS-02, but with a shorter measure time period being between Induction Start to Induction End

- Additional calculations for this measure:
  - Site average kg CO_2 = SUM ('Total CO_2 eq) / COUNT included cases
  - Average kg CO_2/min = SUM ('Total CO_2 eq) / SUM ('Total Included Minutes')

*There is no threshold for this measure.

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Agent Considerations: Avoiding Nitrous Oxide (SUS-05 & SUS-07)

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SUS-05-Peds: Nitrous Avoided, Induction

- Percentage of pediatric patients where nitrous oxide was avoided
- Nitrous oxide values will be assessed and considered artifact within the following ranges:
  - Nitrous Oxide Flows: < 0.2 L/min
  - Nitrous Oxide Insp %: < 20%

- Reducing nitrous oxide use will also decrease total carbon dioxide emissions for the case.

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SUS-07: Nitrous Oxide Avoidance - Adults

- Percentage of adult cases where nitrous oxide is avoided during anesthesia.
- Nitrous oxide values will be assessed and considered artifact within the following ranges:
  - Nitrous Oxide Flows: < 0.2 L/min
  - Nitrous Oxide Insp %: < 20%

- Reducing nitrous oxide use will also decrease total carbon dioxide emissions for the case.

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Measure Overview

	Measure Start:	Measure End:	Calculate Fresh Gas Flow	Calculate CO_2	Assesses Agent(s) Used
SUS-01	Intubation	Extubation End	√		
SUS-02	Intubation	Extubation End	√	√	
SUS-03	Intubation	Induction End	√	√	
SUS-04	Intubation	Extubation End	√		
SUS-05-Peds	Induction Start	Intubation			√
SUS-06-Peds	Induction Start	Intubation			√
SUS-07	Anesthesia Start	Anesthesia End			√

Questions or Light Bulb moment?

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