Reducing the carbon footprint of anaesthetic gasses

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Overview

- Review of anaesthesia
- Atmospheric science
- Review of the agents used for inhalational anaesthesia
- Tools that might help reduce the CO_2e
- Systems and processes

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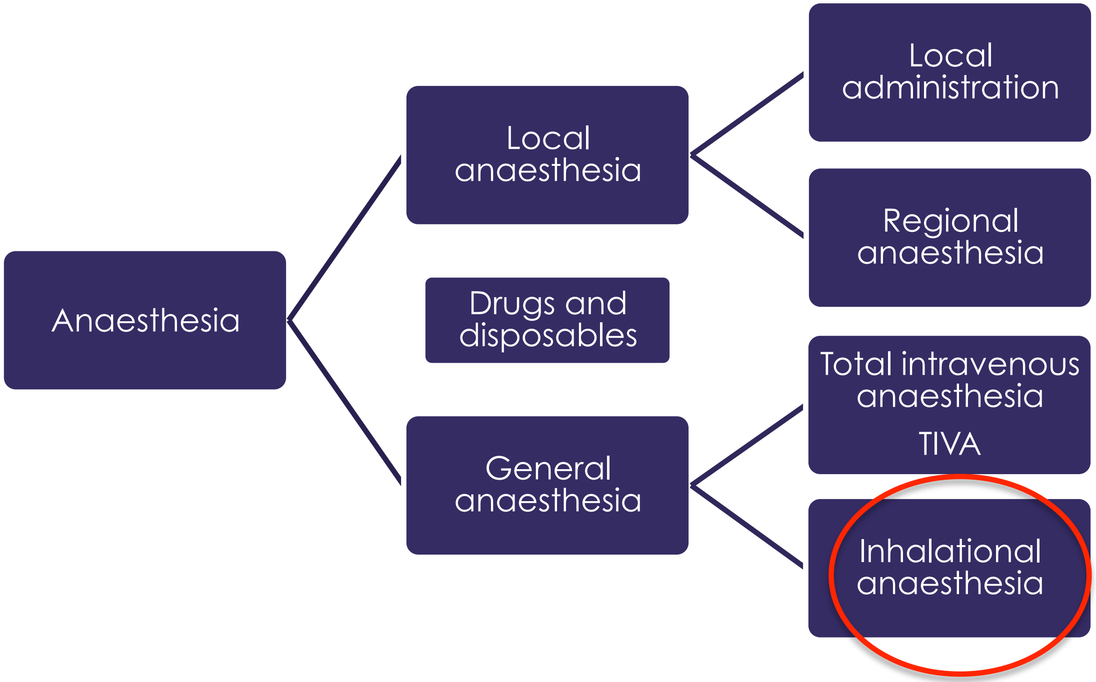
Overview of anaesthesia



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Practical components of anaesthesia

Sedation analgesia and relaxation

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Practical components of anaesthesia

Maintenance of homeostasis

Vascular access

Monitoring

Cardiovascular and respiratory control

Temperature control

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Fate of all of these components

- Disposables
  - Combustion
- Intravenous drugs
  - Metabolised
  - Unused residue combusted
- Packaging
  - Recycled
- Inhalational agents
  - Exhaled into the atmosphere unchanged

Combustion of1kg PVC produces 3kg CO_2

Combustion of 1kg paper 2.1-2.6 kg CO_2

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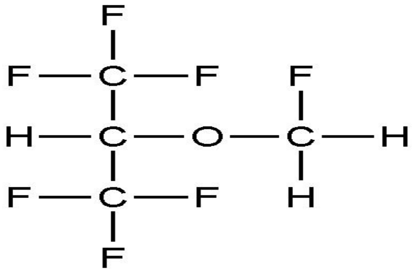
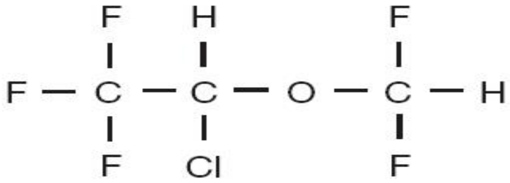
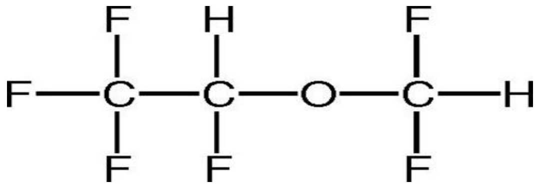
Inhalational anaesthetic agents



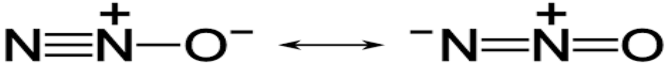
Sevoflurane
GWP 130
Bottle (250ml) 44kg CO_2e



Isoflurane
GWP 510
Bottle (250 ml)190 kg CO_2e



Desflurane
GWP 2540
Bottle (240 ml) 886 kg CO_2e



Nitrous oxide
GWP 310
Cylinder (3.4 kg) 1054 kg CO_2e

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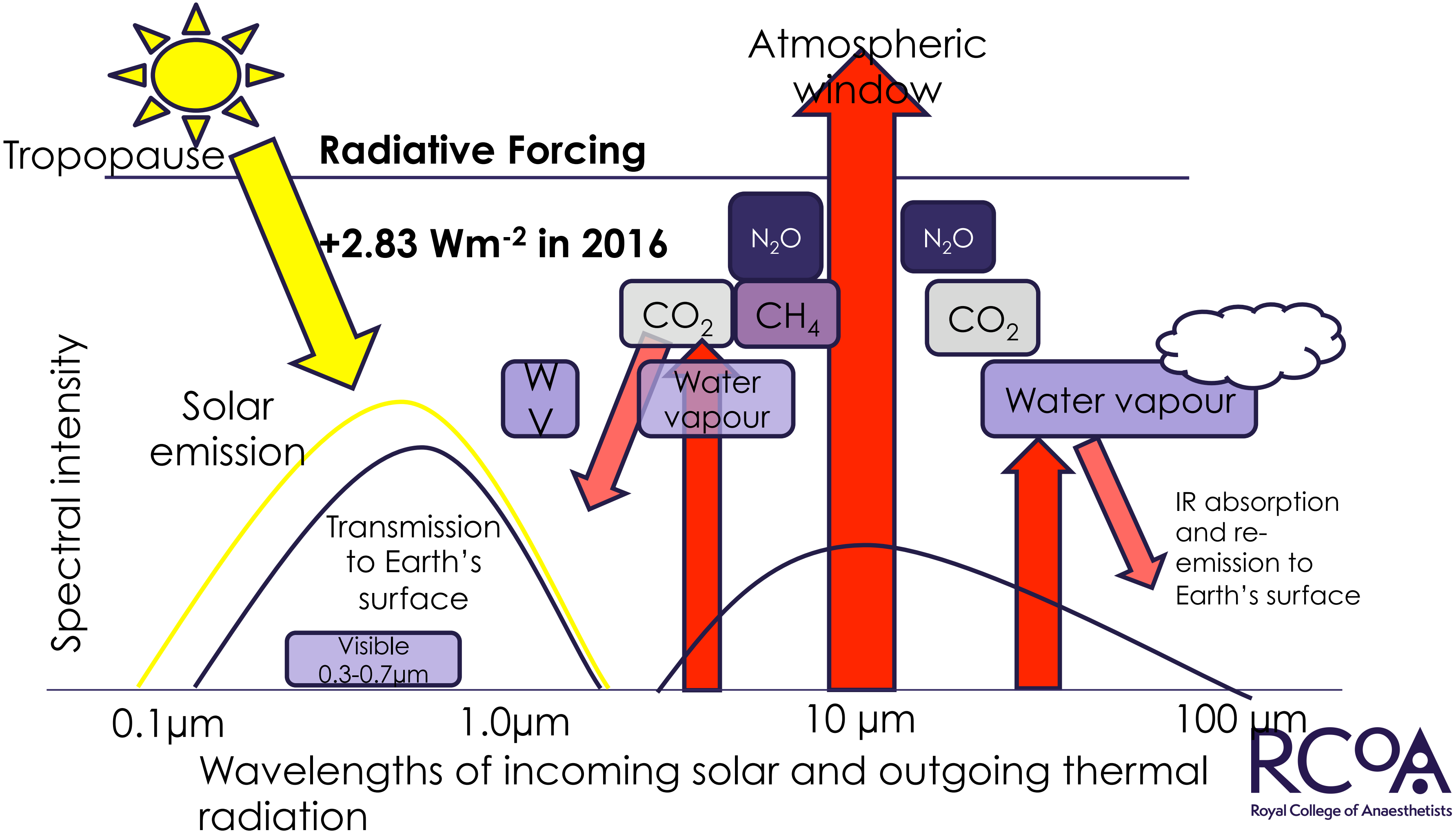

Atmospheric window
Tropopause
Radiative Forcing
+2.83 Wm-2 in 2016
N2O
N2O
CO2
CH4
CO2
W V
Water vapour
Water vapour
Solar emission
Transmission to Earth's surface
Visible 0.3-0.7µm
IR absorption and re-emission to Earth's surface
Spectral intensity
0.1µm
1.0µm
10 µm
100 µm
Wavelengths of incoming solar and outgoing thermal radiation
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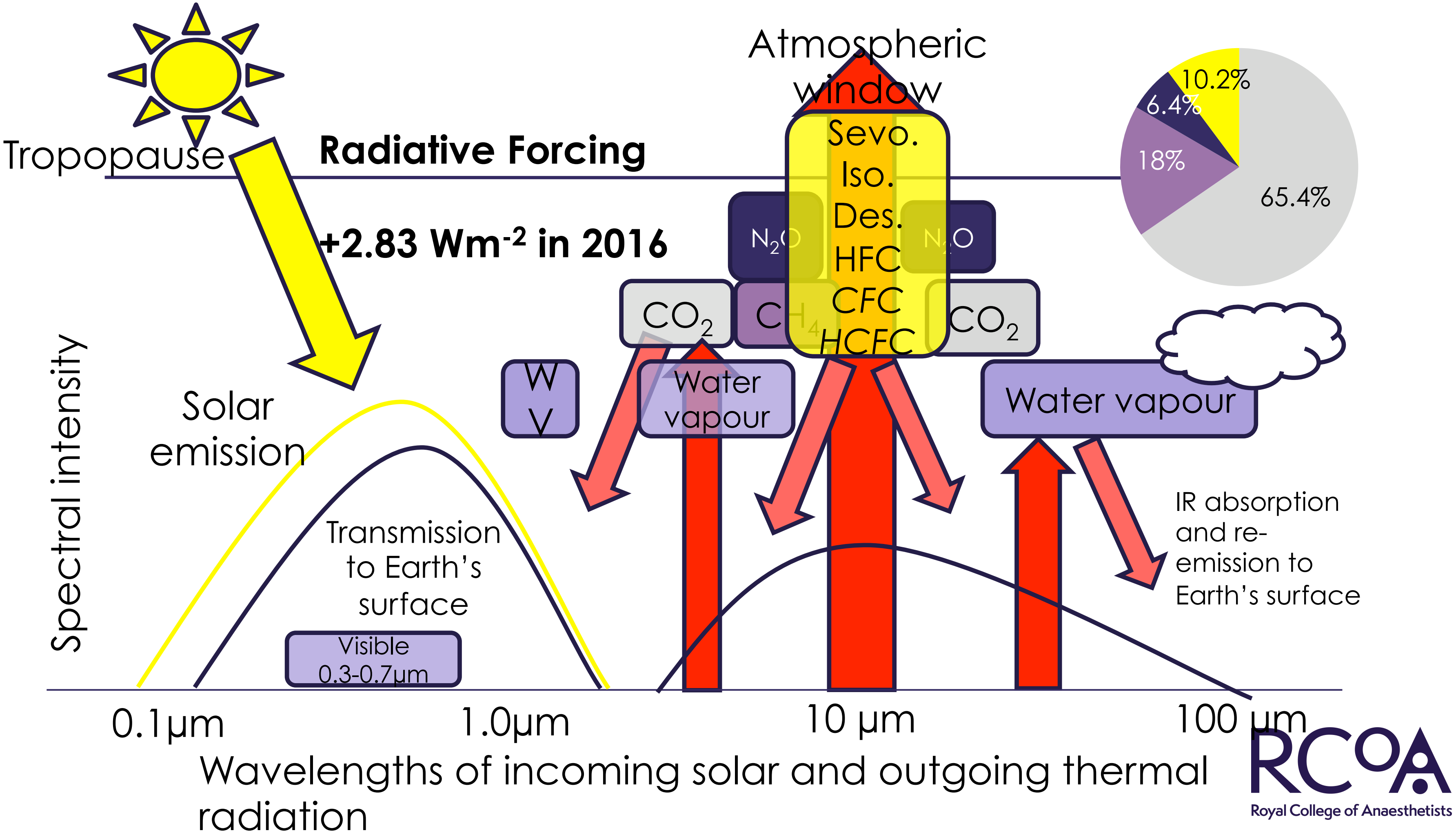

Tropopause
Radiative Forcing
+2.83 Wm-2 in 2016
Atmospheric window
Sevo.
Iso.
Des.
HFC
CFC
HCFC
N2O
N2O
CO2
CH4
CO2
W V
Water vapour
Water vapour
10.2%
6.4%
18%
65.4%
Solar emission
Transmission to Earth's surface
Visible 0.3-0.7μm
IR absorption and re-emission to Earth's surface
Spectral intensity
0.1μm
1.0μm
10 μm
100 μm
Wavelengths of incoming solar and outgoing thermal radiation
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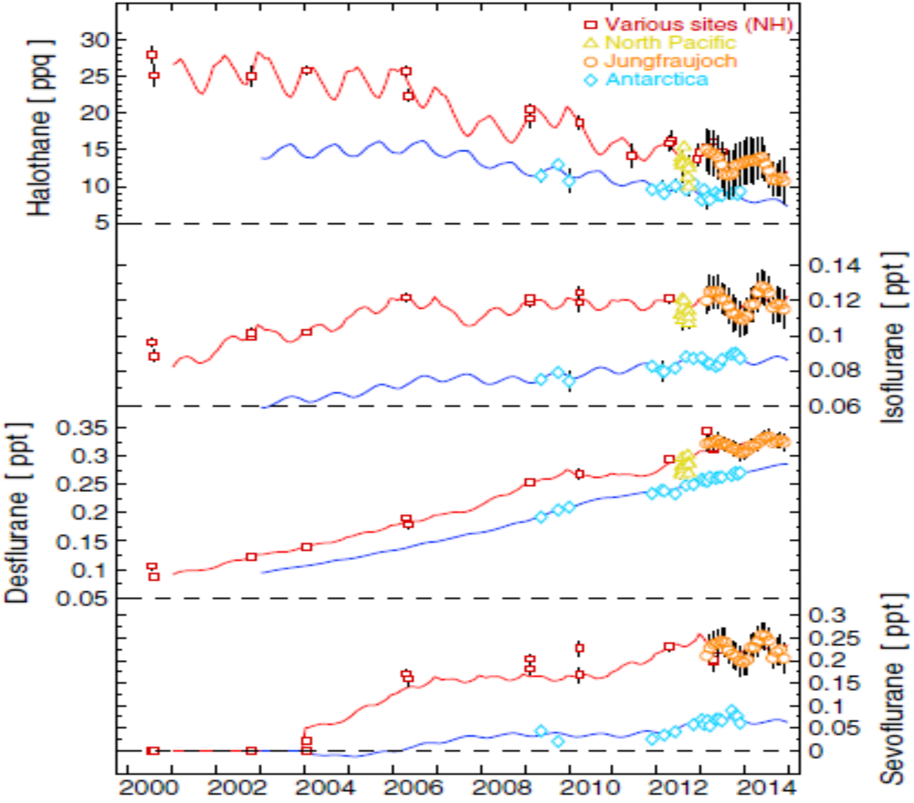
Inhalational anaesthetic agents

	IR absorption range (μm)	Tropospheric lifetime (yr)	GWP $_{100}$	CO_2e Kg (container)	MAC_{40}
Sevoflurane	7-10 μm	1.1	130	44 (250ml)	1.8
Isoflurane	7.5-9.5μm	3.2	510	190 (250ml)	1.2
Desflurane	7.5-9.5 μm	14	2540	886 (240ml)	6.6
Nitrous oxide	4.5, 7.6, 12.5 μm	110	310	1054 (size E)	104

Sulbaek Andersen et al Anesth and Analg 2012; 114: 1081-5 Br J Anaesth 2010; 105: 760-6

Atmospheric concentration of inhalational anaesthetic agents



Vollmer et al 2015

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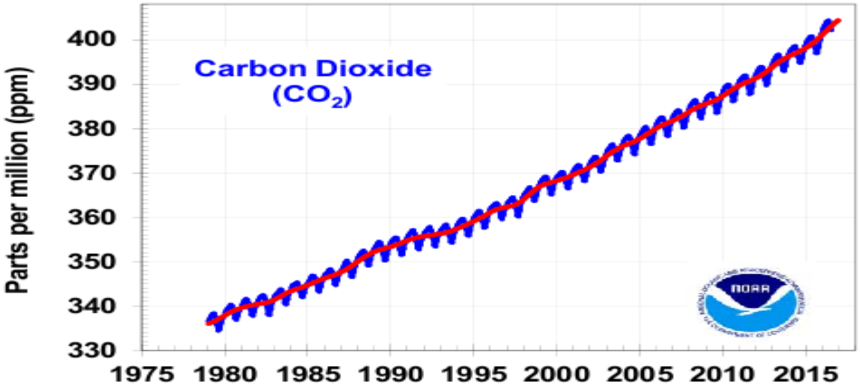
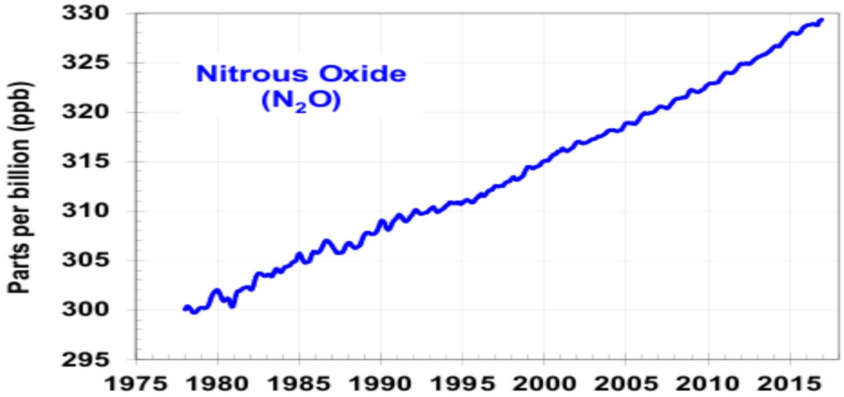
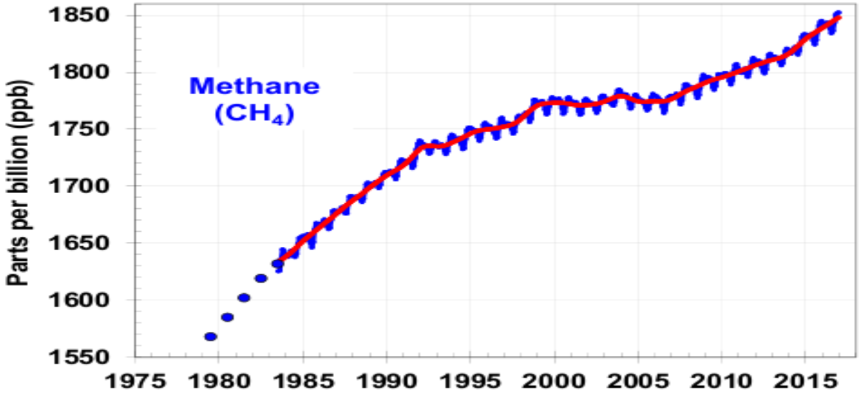
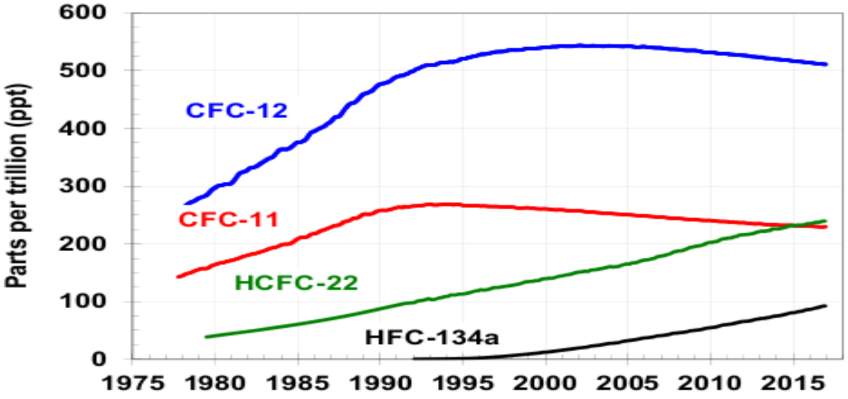
Atmospheric concentrations of major GHGs

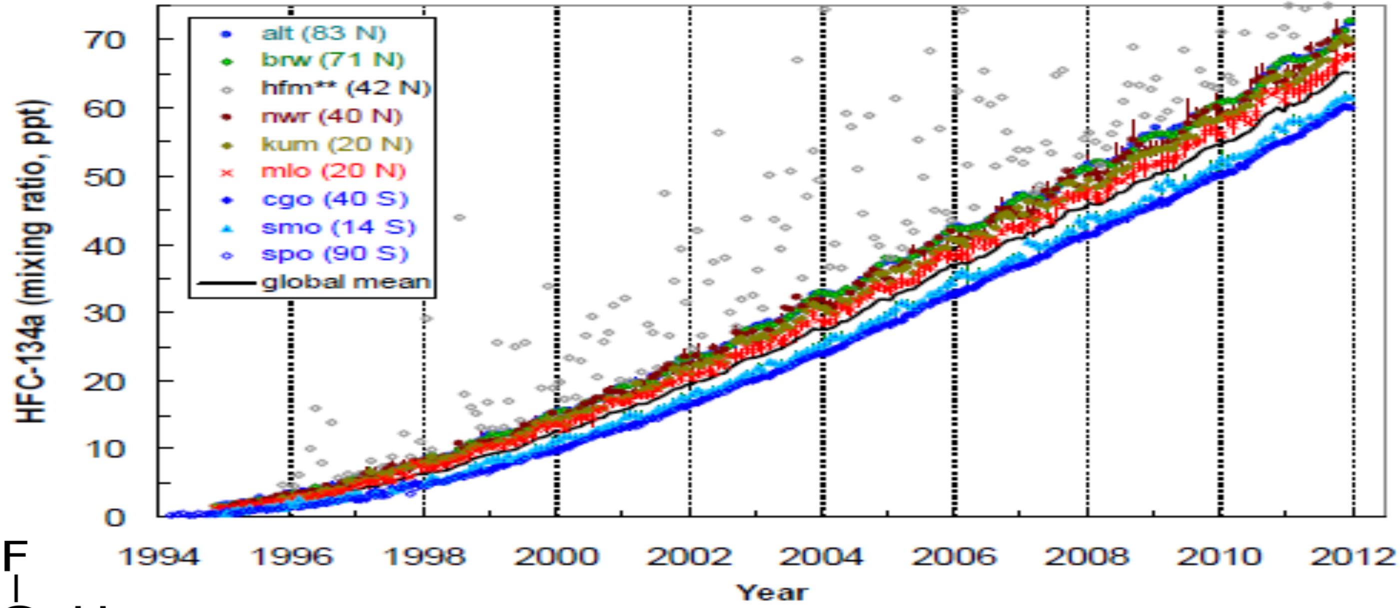


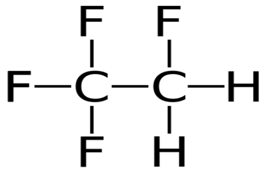






Atmospheric concentration HFC-134a





HFCs in the atmosphere, concentrations emissions and impacts. Montzka SA

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Peculiar aspects of inhalational anaesthesia

Volatile substituted ethers

Liquids at room temperature

Vapourised and added to the anaesthetic breathing circuit in a concentration from 1-8%

Carrier gas mixture is oxygen/air or oxygen/N_2O 30%/70%

Depth of anaesthesia depends on the exhaled partial pressure (concentration)

Exhaled unchanged recycled via CO_2 absorber and/or scavenged into the atmosphere

Most of the CO_2e of procurement is in disposal of the agent

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ET Isoflurane

Fresh gas flow

Patient's minute ventilation

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Scope for choice in anaesthesia

- General anaesthesia vs regional anaesthesia
- Carrier gas oxygen enriched air or O_2/N_2O
- Inhalational agents
  - The type
  - The fresh gas flow "low flow anaesthesia"
  - Added intravenous analgesics or sedatives

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Sustainable Development Unit
Working across the NHS, Public Health and Social Care system

Carbon Footprint update for NHS in England 2012

Appendix 1 – Overview of major changes for the 2012 update

To maintain alignment with the latest methods and information available a number of changes have been included in the 2012 update:

Update	2012 ($MtCO_2e$)	%
Healthcare services commissioned from outside the NHS are now included	2.3	9%
Carbon intensity factors for goods and services updated	0.9	4%
Meter Dose Inhalers (MDIs) now included	1.4	6%
Anaesthetic gases now included	0.6	2%
Total	5.2	21%

Carbon footprint update 2013 Sustainable Development Unit NHS

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Sustainable Development Unit
Working across the NHS, Public Health and Social Care system

Carbon Footprint from Anaesthetic gas use

Conclusion

These results give total emissions for anaesthetic gases including Nitrous Oxide of an additional 2.5% (0.56 $MtCO_2e$) of NHS carbon footprint for England.

The majority of anaesthesia is in an acute setting. This is 5% of organisation footprint of acute organisations[18] (0.56 $MtCO_2e$ of 10.4 $MtCO_2e$). For acute organisations this is comparable with half the emissions from gas used for building energy use[19] (1.17 $MtCO_2e$) and would add around 15% to 25% on the building energy use carbon footprint (2.47 $MtCO_2e$)

Measuring, monitoring and reporting carbon dioxide equivalent emissions, from inhaled anaesthetics, is crucial for reducing emissions.

http://www.sduhealth.org.uk/documents/publications/Anaesthetic_gases_research_v1.pdf

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EudraLex
The Rules Governing Medicinal Products in the European Union

Volume 4

Good Manufacturing Practice

Medicinal Products for Human and Veterinary Use

Annex 6

Manufacture of Medicinal Gases

32. Cylinders that have been returned for refilling should be prepared with care in order to minimise the risks of contamination, in line with the procedures defined in the Marketing Authorisation. These procedures, which should include evacuation and/or purging operations, should be validated.

Calculating the CO_2e of anaesthetics

Nitrous oxide cylinders

- Cylinder return data
- Cylinder volumes and temperature
  - Cylinders expressed in terms of numbers of litres of uncompressed gas at 15C
- Universal gas equation number of moles (PV=nRT)
- MWt $N_2$0 44; calculate the mass of nitrous oxide
- GWP = 310

Entonox®

- 50:50 nitrous oxide : oxygen

Inhalational agents

- – Number of bottles x volume x density x GWP

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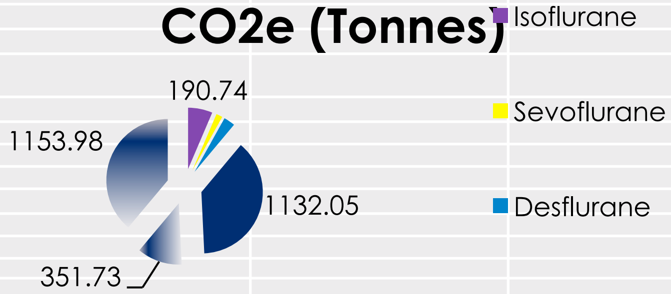
Anaesthetic agent CO_2e calculator

Usage	
Agent	Number of bottles issued from pharmacy
Isoflurane	1000
Sevoflurane	1000
Desflurane	100
Anaesthetic Nitrous oxide	Number of returned cylinders
Size E	30
Size F	30
Size G	200
Size J	0
Mobile Entnox Nitrous oxide	
Entonox EA	0
ENTONOX SIZE CD	10
ENTONOX SIZE D	2
ENTONOX SIZE ED	150
ENTONOX SIZE EX	200
ENTONOX SIZE F	200
ENTONOX SIZE HX	4
Maternity Manifold N2O	
ENTONOX SIZE G	800

CO2e		
	CO_2e (Tonnes)	Percent of total CO_2e
Isoflurane	191	6
Sevoflurane	49	2
Desflurane	89	3
Anaesthetic N_2O	1132	38
Portable Equanox N_2O	352	12
Maternity Manifold Entonox N_2O	1154	39
TOTAL	2967	100



http://www.sduhealth.org.uk/resources/default.aspx?q=anaesthetic+

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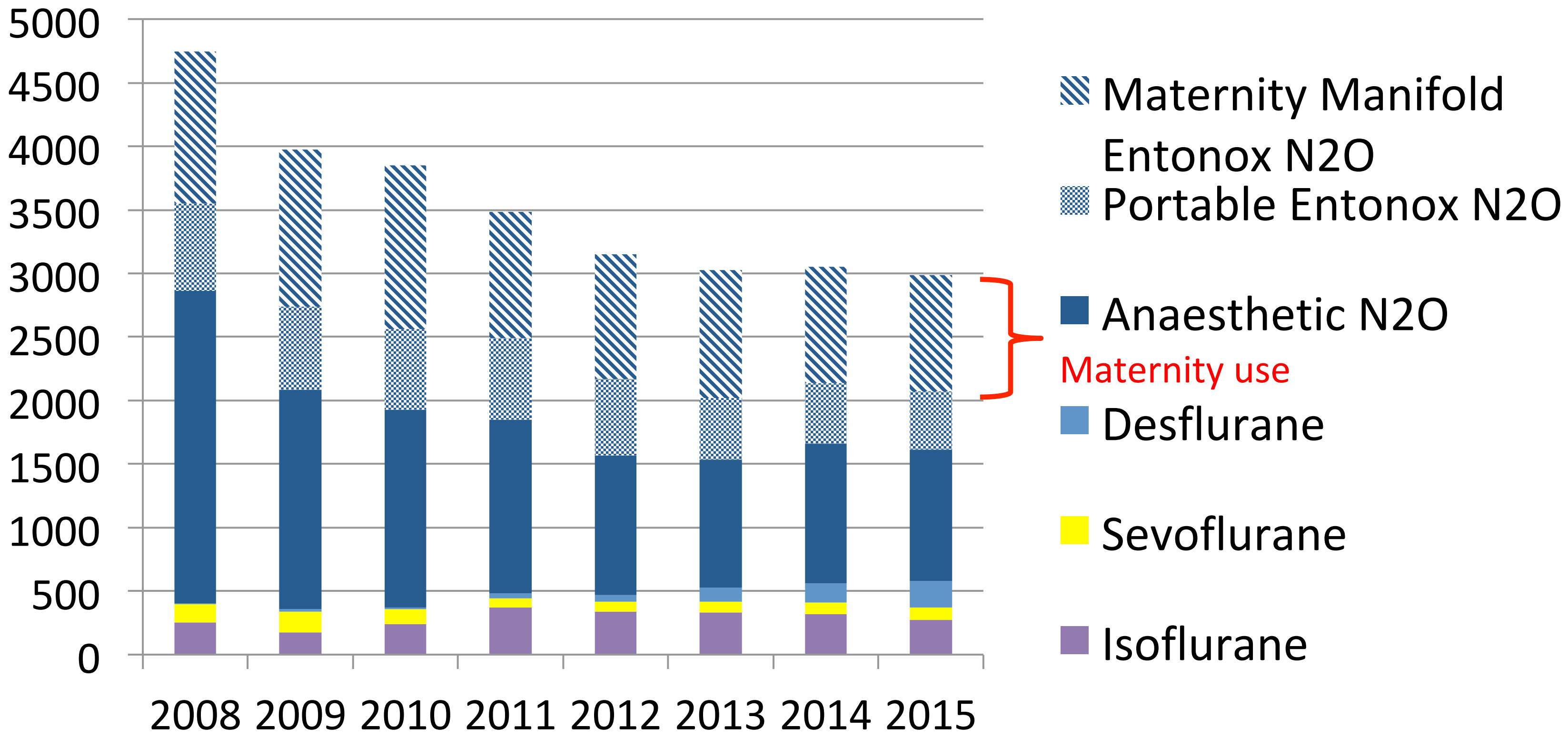
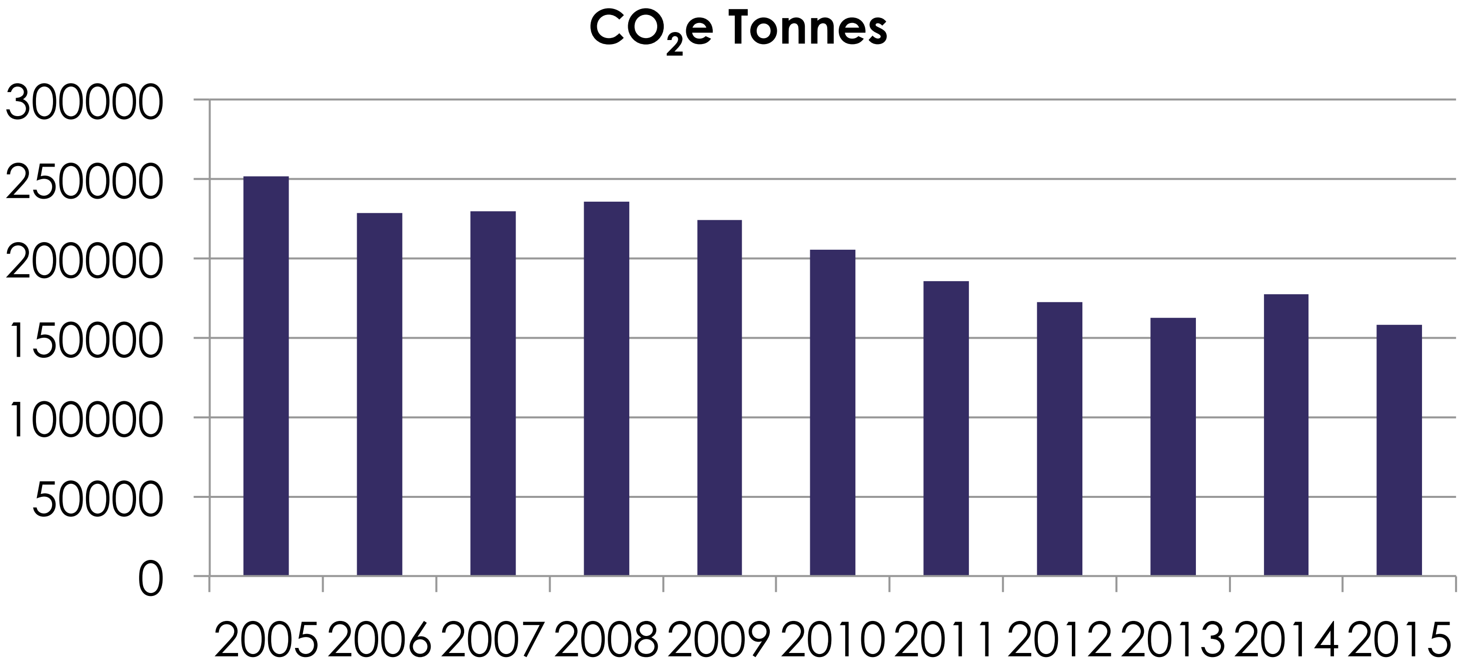
UHS CO_2e (T) of anaesthetic vapour use



http://bja.oxfordjournals.org/forum/topic/brjana_el%3B13932

UK medical gas supplier N_2O CO_2e



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Accounting for the change of CO_2e

Less general anaesthesia and more regional and local anaesthesia

Move away from nitrous oxide/oxygen to oxygen enriched air

Low flow anaesthesia

- Lower fresh gas flow
- Greater intraoperative recycling of exhaled agents
- Less wastage

Still a residual use of nitrous oxide

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Annual data

- Way of plotting trends
- Historical data
- Not contemporaneous
- Unlikely that it will change behaviour
- Might provide feedback

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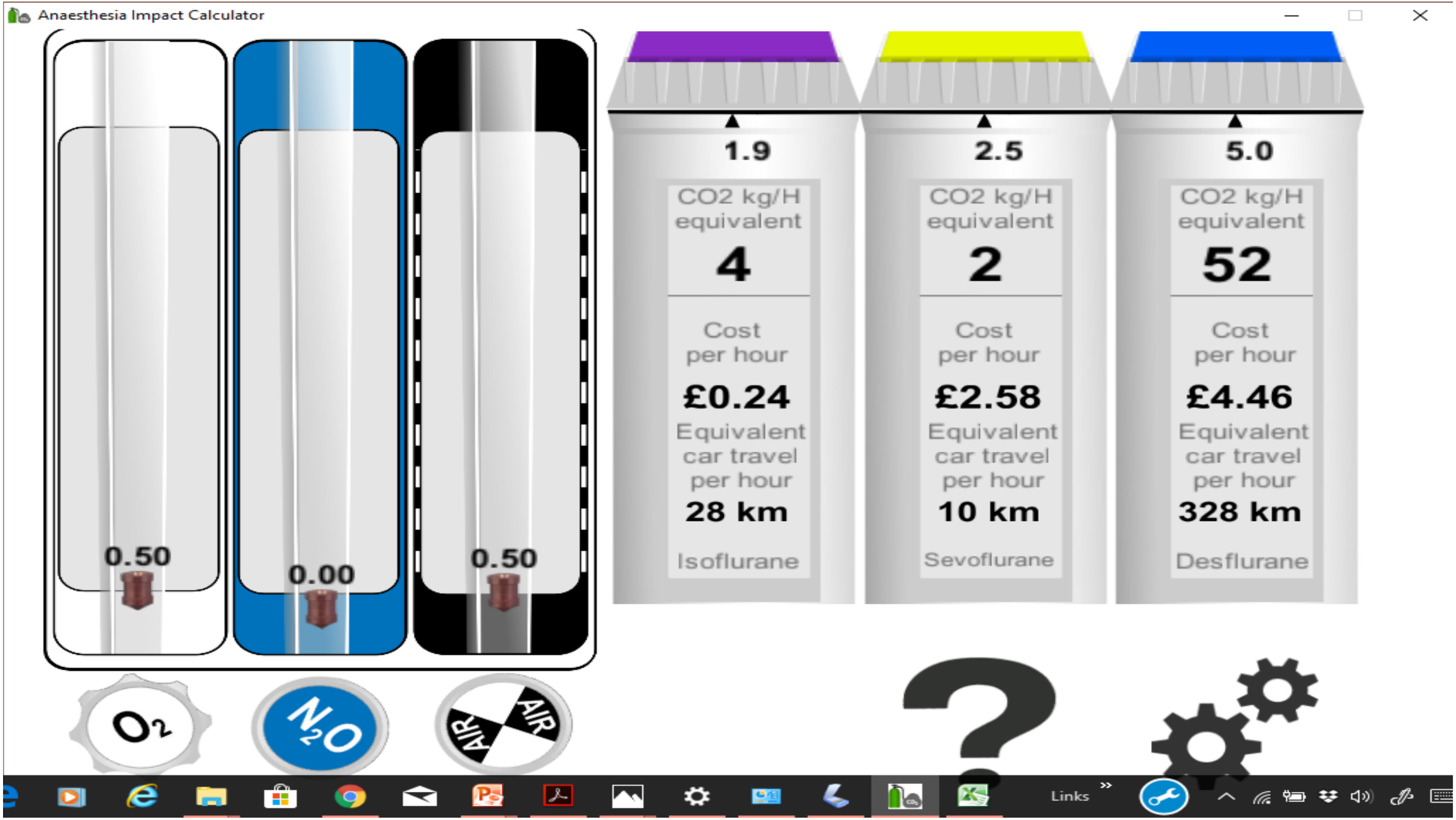
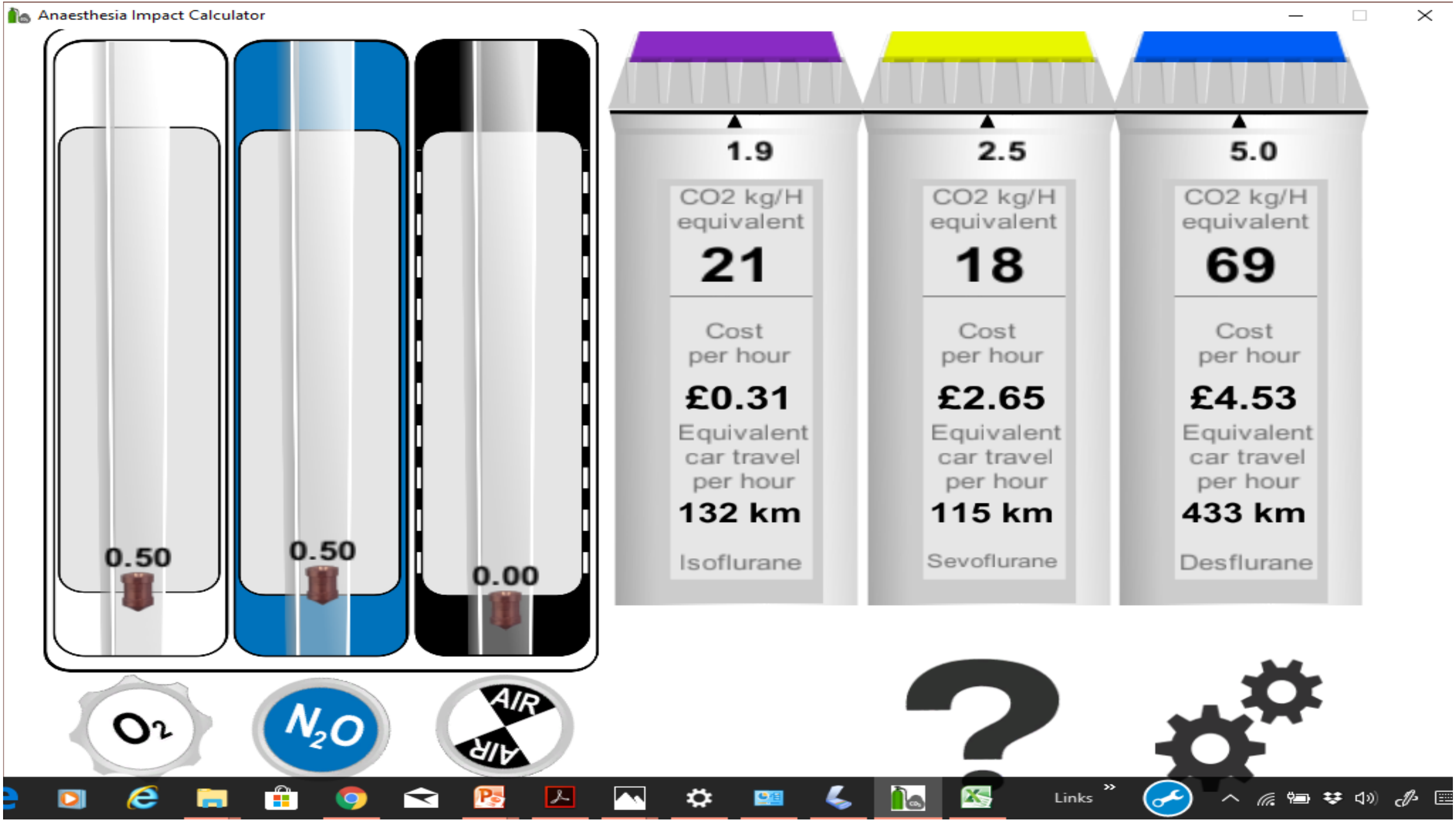
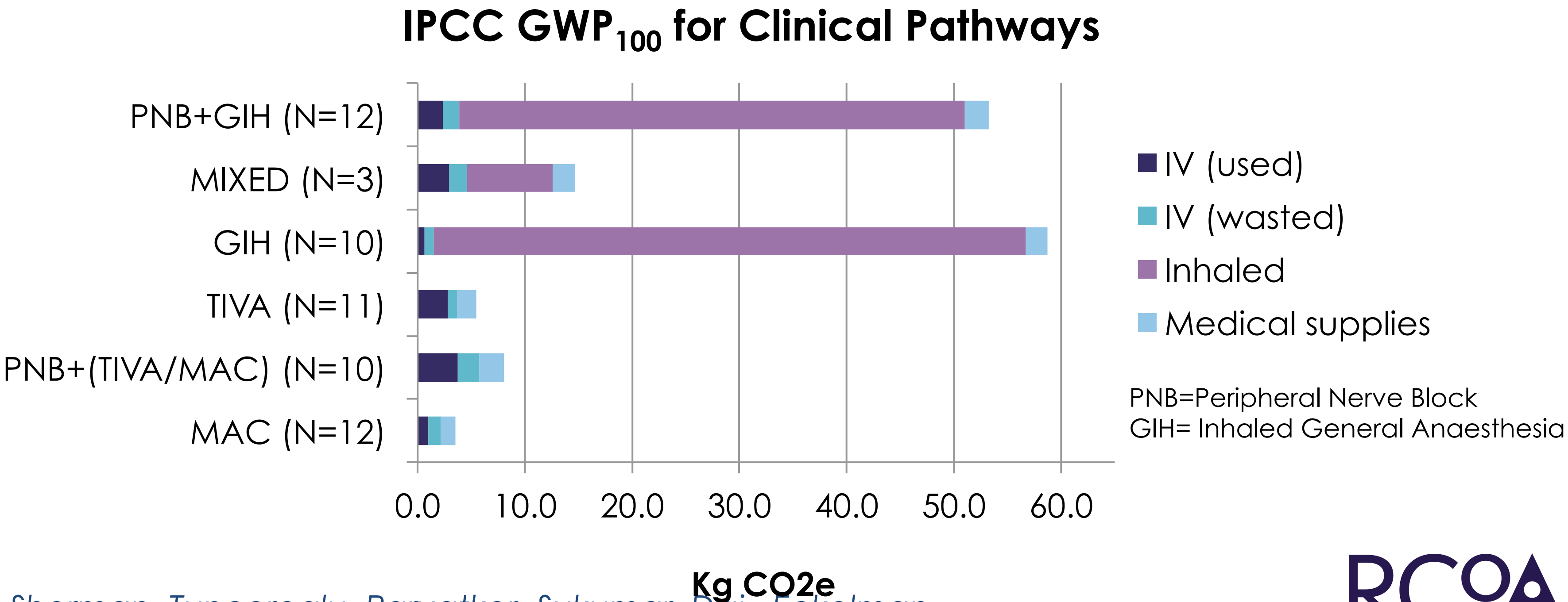
Real time CO_2e calculator

- Know the fresh gas flow (litres per min) and the vapouriser setting (%)
- Assume that inhaled agent behaves as ideal gas
- Know the temperature and the GWP of each agent
- Calculate the mass of agent used from the volume
- Mass used x GWP = CO_2e
- Know the unit cost then calculate the cost per hour of the inhalational component of anaesthesia


Anaesthesia Impact Calculator
0.50
0.00
0.50
O2
N2O
AIR
AIR
1.9
CO2 kg/H equivalent
4
Cost per hour
£0.24
Equivalent car travel per hour
28 km
Isoflurane
2.5
CO2 kg/H equivalent
2
Cost per hour
£2.58
Equivalent car travel per hour
10 km
Sevoflurane
5.0
CO2 kg/H equivalent
52
Cost per hour
£4.46
Equivalent car travel per hour
328 km
Desflurane
Links


Anaesthesia Impact Calculator
0.50
0.50
0.00
O2
N2O
AIR
AIR
1.9
CO2 kg/H equivalent
21
Cost per hour
£0.31
Equivalent car travel per hour
132 km
Isoflurane
2.5
CO2 kg/H equivalent
18
Cost per hour
£2.65
Equivalent car travel per hour
115 km
Sevoflurane
5.0
CO2 kg/H equivalent
69
Cost per hour
£4.53
Equivalent car travel per hour
433 km
Desflurane
?
Links

CO_2e of different forms of anaesthesia



Sherman, Tunceroglu, Parvatker, Sukumar, Dai , Eckelman

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The bigger picture

- Travel for staff and patients
- Devices; single use or reusable?
- HVAC and AGSS
- Plug-in electrical devices
  - Patient warming
- Recycling

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The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems

Andrea J MacNeill, Robert Lillywhite, Carl J Brown

Summary

Background Climate change is a major global public health priority. The delivery of health-care services generates considerable greenhouse gas emissions. Operating theatres are a resource-intensive subsector of health care, with high energy demands, consumable throughput, and waste volumes. The environmental impacts of these activities are generally accepted as necessary for the provision of quality care, but have not been examined in detail. In this study, we estimate the carbon footprint of operating theatres in hospitals in three health systems.

Methods Surgical suites at three academic quaternary-care hospitals were studied over a 1-year period in Canada (Vancouver General Hospital, VGH), the USA (University of Minnesota Medical Center, UMMC), and the UK (John Radcliffe Hospital, JRH). Greenhouse gas emissions were estimated using primary activity data and applicable emissions factors, and reported according to the Greenhouse Gas Protocol.

Findings Site greenhouse gas evaluations were done between Jan 1 and Dec 31, 2011. The surgical suites studied were found to have annual carbon footprints of 5 187 936 kg of CO_2 equivalents (CO_2e) at JRH, 4 181 864 kg of CO_2e at UMMC, and 3 218 907 kg of CO_2e at VGH. On a per unit area basis, JRH had the lowest carbon intensity at 1702 kg CO_2e/m^2, compared with 1951 kg CO_2e/m^2 at VGH and 2284 kg CO_2e/m^2 at UMMC. Based on case volumes at all three sites, VGH had the lowest carbon intensity per operation at 146 kg CO_2e per case compared with 173 kg CO_2e per case at JRH and 232 kg CO_2e per case at UMMC. Anaesthetic gases and energy consumption were the largest sources of greenhouse gas emissions. Preferential use of desflurane resulted in a ten-fold difference in anaesthetic gas emissions between hospitals. Theatres were found to be three to six times more energy-intense than the hospital as a whole, primarily due to heating, ventilation, and air conditioning requirements. Overall, the carbon footprint of surgery in the three countries studied is estimated to be 9·7 million tonnes of CO_2e per year.

Interpretation Operating theatres are an appreciable source of greenhouse gas emissions. Emissions reduction strategies including avoidance of desflurane and occupancy-based ventilation have the potential to lessen the climate impact of surgical services without compromising patient safety.

Funding None.

Lancet Planet Health 2017; 1: e381–88

See **Comment** page e357

Division of General Surgery, University of British Columbia, Vancouver, Canada (A J MacNeill MD, Prof C J Brown MD); Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, UK (A J MacNeill); and School of Life Sciences, University of Warwick, Warwick, UK (R Lillywhite)

Correspondence to: Dr Andrea J MacNeill, Division of General Surgery, Vancouver General Hospital, 950 West 10th Avenue, Vancouver, BC, V5Z 1M9, Canada andrea.macneill@vch.ca

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	Volume purchased (L/year)			CO_2e (kg/year)		
	VGH	UMMC	JRH	VGH	UMMC	JRH
Desflurane	535·7	532·8	0	1 983 073	1 972 412	0
Isoflurane	34·2	176·4	222	26 297	135 636	170 314
Sevoflurane	132	115·5	217	24 907	21 793	40 898
Total	..	..	..	2 034 277	2 129 841	211 212

CO_2e calculated using 100-year Global Warming Potential (GWP_{100}) values of 2540 for desflurane, 510 for isoflurane, and 130 for sevoflurane.[8] VGH=Vancouver General Hospital. CO_2e=CO_2 equivalents. UMMC=University of Minnesota Medical Center. JRH=John Radcliffe Hospital.

***Table 1:* Annual greenhouse gas emissions from volatile anaesthetics**

Nitrous oxide use at all three centres minimal

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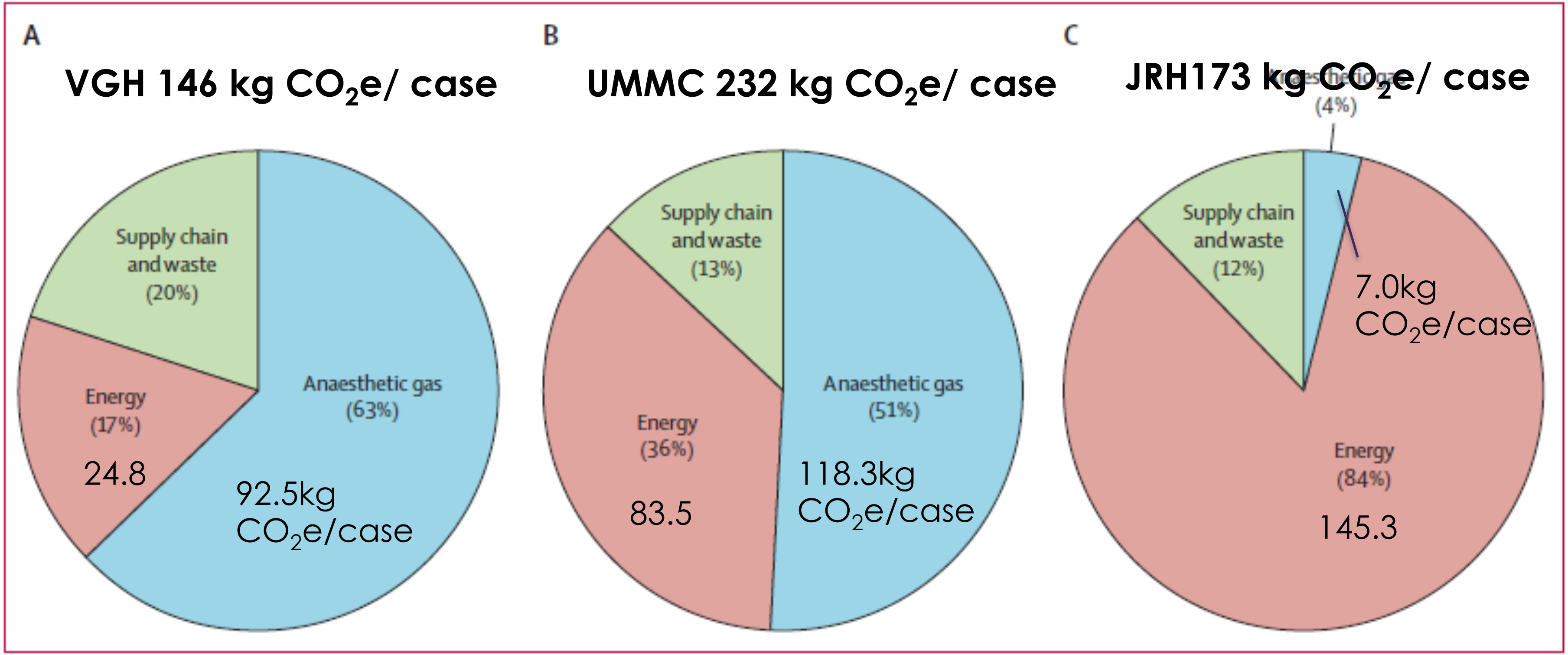
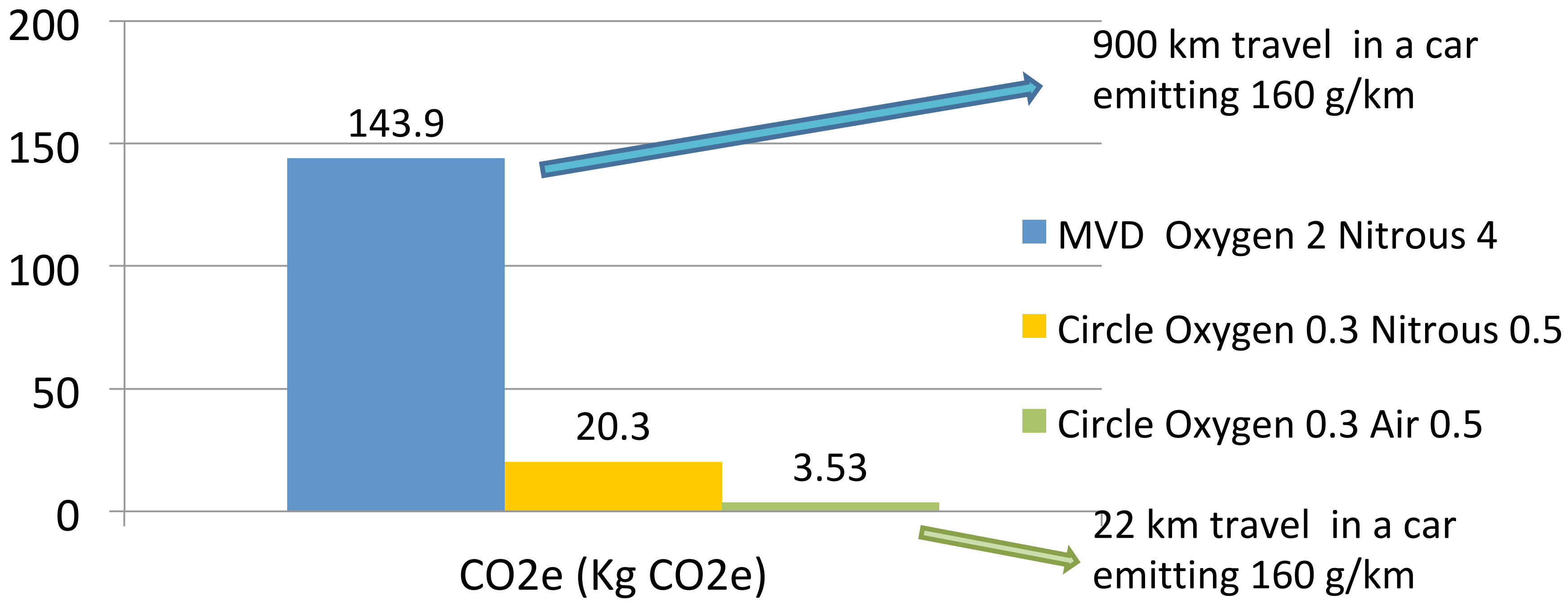


Figure 2: Relative contribution of scopes 1, 2, and 3 to the carbon footprint of operating theatres at (A) Vancouver General Hospital, (B) University of Minnesota Medical Center, and (C) John Radcliffe Hospital

Anaesthetic gas=scope 1. Energy=scope 2. Supply chain and waste=scope 3.

An hour's anaesthesia related CO_2e

Change in clinical practice from1985 to 2018



End tidal control

GE Aisys CS²

- Vapour use adjusted to achieve the desired Et_{agent}
- Reduces vapour use
- Displays the cost
- Reduces cost; £51k pa
  - Benefit at 3-4 years
- Values for cost are very similar to those obtained from the free app
- App provides CO_2e

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Systems and processes

Protecting resources, promoting value: a doctor's guide to cutting waste in clinical care

November 2014

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Guidelines for the Provision of Anaesthesia Services (GPAS)

ACSA
Anaesthesia Clinical Services Accreditation
Royal College of Anaesthetists
ACCREDITATION

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Operating rooms

- The overall impact of anaesthesia is small on a global scale compared with other GHGs
- ORs 188 T CO_2e per OR per year
- The proportion of the CO_2e of health care delivery attributable to anaesthesia is significant
- Nitrous oxide and desflurane have the highest GWPs
- There is scope for informed choice of practice

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Anaesthesia practice

- All forms of anaesthesia require both drugs and disposables
- For general anaesthesia inhalational anaesthesia has a larger CO_2e than total intravenous anaesthesia (TIVA)
- Inhalational anaesthesia low flow anaesthesia should be the standard of practice both financially and environmentally
- Recognise the role of the anaesthesia machine manufacturers
- Reducing or eliminating the use of nitrous oxide is the largest single contribution one can make
- The Impact Calculator quantifies the magnitude of the change in practice
- Need systems and processes in place

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Measurement tools

Annual carbon footprint of anaesthetic agents and nitrous oxide

http://www.sduhealth.org.uk/documents/publications/_carbon_hotspot_anaesthetic_gases_Feb_2014.xlsx

Smart phone app to calculate the real-time CO_2e of inhalational anaesthesia

- iOS search Anesthetic Impact Calculator
  - Sleekwater Software / Kevin Scott
- Android search Anaesthetic Impact Calculator
  - Sleekwater Software / Kevin Scott

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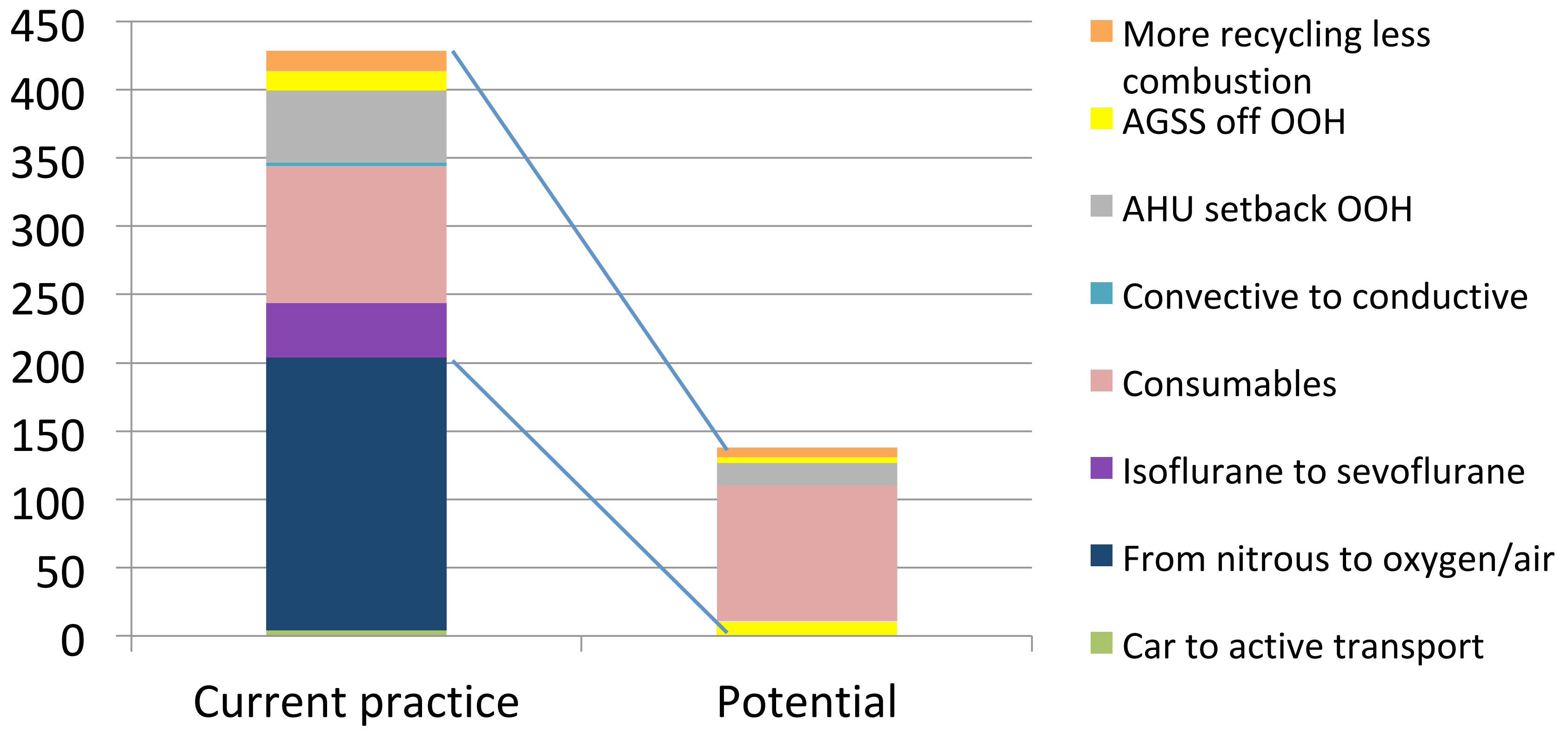
Any questions?

	Energy (MWh/year)			CO_2e (kg/year)		
	VGH	UMMC	JRH	VGH	UMMC	JRH
Heating	2518	2204	6971	514 340	610 702	2 283 426
Cooling	66	357	1312	1523	195 629	787 149
Ventilation	449	1062	2045	10 317	581 938	1 104 386
Lighting*	236	177	313	5423	96 959	169 189
Plug-loads	113	56	..	2591	30 535	..
Total	3382	3856	10 641	534 194	1 515 763	4 344 150

CO_2e=CO_2 equivalents. VGH=Vancouver General Hospital. UMMC=University of Minnesota Medical Center. JRH=John Radcliffe Hospital. *At VGH and UMMC, theatre submetering included plug-loads and surgical spotlights, but not overhead lighting; overhead lighting is reported separately based on lighting audits; at JRH, all lighting was captured in theatre submetering, hence only one value is reported for both lighting and plug-loads.

Table 2: **Annual operating theatre energy requirements and greenhouse gas emissions**

A day's anaesthesia related CO_2e (kg)



Guidelines for the Provision of Anaesthesia Services

- Work with estates to minimise energy use
  - Including AGSS and OR ventilation and lighting
- Reduce resource use
  - Low flow anaesthesia
    - Avoid nitrous oxide within reason
    - Desflurane low flow as a matter of course
    - TIVA
  - Minimise drug and disposable wastage
- Recycling to avoid combustion of waste or landfill

GPAS 2016 Further steps

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Choosing Wisely

1. **Day surgery** should be considered the default for most surgical procedures (except complex procedures)

2. Patients do **not need to come into hospital the day before surgery** if they have had the appropriate preoperative assessment and preparation

3. Most patients **do not need routine preoperative tests** before minor or intermediate surgery.

4. For many patients the chance of harm after an operation may be reduced if they **improve fitness, stop smoking, reduce alcohol intake** and in some cases **reduce weight** in the weeks or months before their surgery.

http://www.choosingwisely.co.uk/i-am-a-clinician/recommendations/#1476651640539-f279ec69-9e40

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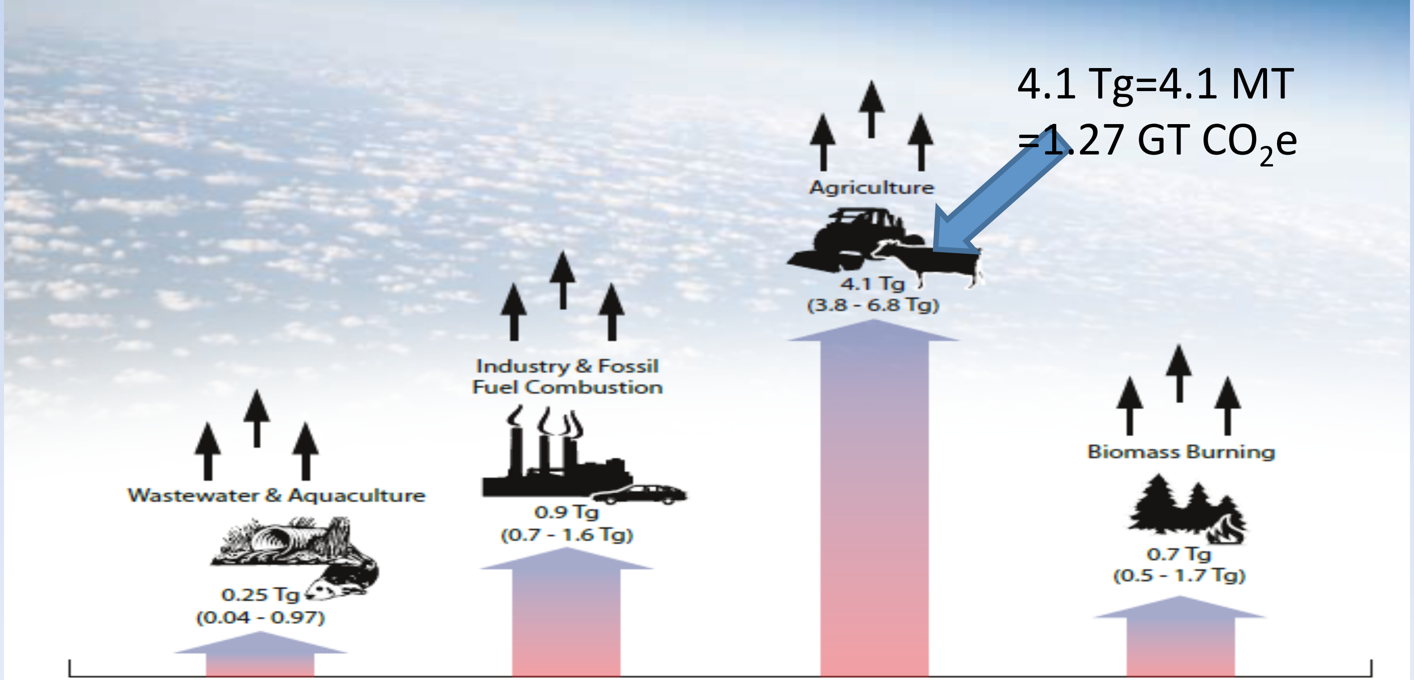
Drawing Down N_2O

To Protect Climate and the Ozone Layer

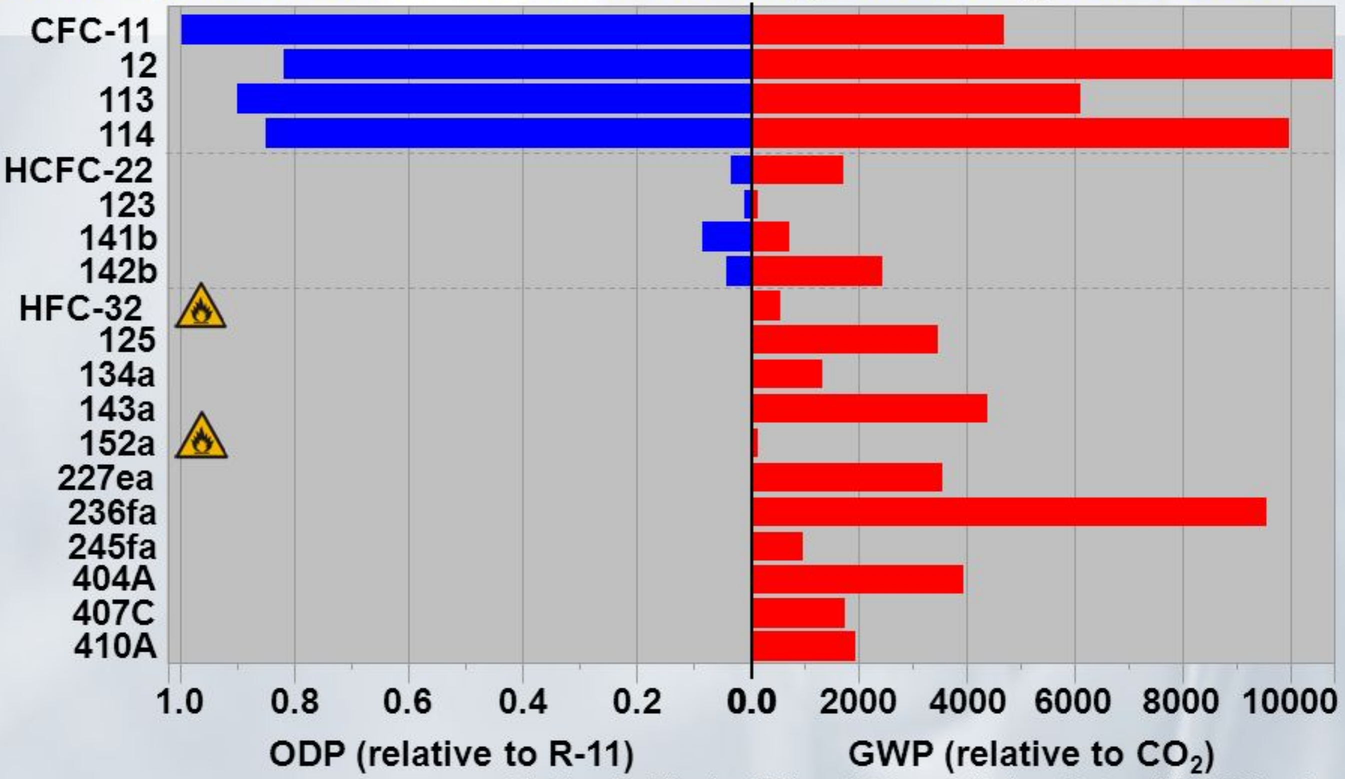
A UNEP Synthesis Report

Figure ES.1 Current anthropogenic N_2O emission sources and estimates of their contributions



http://www.unep.org/pdf/UNEPN2Oreport.pdf

Ozone Depletion Potential & Global Warming - *Balancing ODP vs GWP*



J. M. Calm and G. C. Hourahan, “Refrigerant Data Summary,” Engineered Systems, 18(11):74-88, November 2001 (based on 1998 WMO and 2001 IPCC assessments). © JMC 2001