Global Warming Potential (GWP)

It measures the contribution to the greenhouse effect of ONE gram of a certain gas, with respect to ONE gram of CO_2.

- The term of comparison is the MASS of the gas
- The GWP is adimensional

	R134a	HFO-1234ze	CO_2	$i\text{-}C_4H_{10}$	SF_6	GWP	CO_2e (g/l)
STD	95.2			4.5	0.3	1485	6824
ECO2		35	60	4	1	476	1522
ECO3		25	69	5	1	527	1519
Density (g/l)	4.68	5.26	1.98	2.69	6.61		
GWP	1430	7	1	3	22800		

Ex.: 1 g of $C_2H_2F_4$ (TFE) contributes to the greenhouse effect as 1430 g of CO_2

Global Warming Potential (GWP)

The GWP of a certain gas depends on the time frame considered. Here and in the following we will refer to the GWP over 100 years. For all tables and calculations we use (here and in the paper) the GWP reported in:

✓Council of European Union, Regulation (EU) No. 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC), No. 842/2006, text with EEA relevance (2014), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R0517

GWP of gas mixtures

Each component of the gas mixtures <u>contributes independently</u>:

- One has to take ONE gram of the gas mixture, figure out how many fractions of grams of the various gaseous components are present, and add up their GWP.
- Equivalent to computing the weighted average of the GWP of the various components, with their weights being their fractions in MASS.

GWP of gas mixtures (2)

At the LHC experiments we usually express percentages in the gas mixtures in VOLUME.

➢ Therefore, if one wants to compute the GWP of a gas mixture, first has to compute the percentages in MASS and then compute the GWP of the mixture.

➢ Gas densities are needed.

Percentages in VOLUME

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GWP of gas mixtures (3)

We used the gas densities from:

NIST Chemistry WebBook, the NIST Standard Reference Database Number 69, https://webbook.nist.gov/chemistry/", retreived on April 2, 2023

at STP = (1013 hPa, T=273.15K = 0°C), since Bronkhorts mass-flowmeters operate this way.

Note: gas densities depend on T and p conditions, and that is the reason why GWP refers to units of MASS.

GWP of gas mixtures (4)

So, ONE liter of “standard” gas mixture contains:

- 0.952 liters of TFE $\times$ 4.68 g/l = 4.046 g
- 0.045 liters of isobutane $\times$ 2.69 g/l = 0.1129 g
- 0.003 liters of SF6 $\times$ 6.61 g/l = 0,01851 g

For a total mass of 4.17746 g

$$\mathrm{GWP(STD)} = \frac{4.046 \times 1430 + 0.1129 \times 3 + 0.01851 \times 22800}{4.117746} = 1485$$

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GWP of gas mixtures (5)

The GWP of ECO2 and ECO3 are, roughly, a factor THREE less than GWP of standard mixture:

- injecting into the atmosphere <u>three GRAMS of ECO2 or ECO3</u> contribute to the greehouse effect, more or less, as <u>one GRAM of STD mixture</u>.

Why the CO_2 equivalent?

Generally, at the LHC experiments, we do not want to compare equal amounts in MASS of various gas mixtures, but equal amounts in VOLUME.

Basically we want to answer the question: if the inject into the atmosphere 1 LITER of ECO2 or ECO3, we will contribute more or less with respect to injecting one LITER of STD mixture? How much more or less?

This is a consequence of the fact that RPCs are operated with (roughly) fixed fractions of gas volume exchanges.

→ We inject into the atmosphere fixed amount (in volume) of gas

Why the CO_2 equivalent?

While GWP is an intensive quantity, CO_2 equivalent is an extensive quantity.

It expresses the contribution to the greenhouse effect of a certain amount of gas: how many grams of CO_2 we should inject into the atmosphere to contribute to the greenhouse effect like the amount of gas chosen?

If this amount of gas is 1 g, CO_2e coincides, <u>only numerically</u>, with the GWP:

- 1 g of CO_2 has a CO_2e = 1 g
- 1 g of TFE has a CO_2e = 1430 g

BUT:

- 1 kg of TFE has a CO_2e = 1430000 g
- 1 liter of CO_2 has a CO_2e = 1.9763 g

Why the CO2 equivalent?

In one LITER of STD gas mixture, we have:

- 4.45 g of TFE $\times$ 1430 = 6371 g CO2e per liter
- 0.1209 g of isobutane $\times$ 3 = 0.3628 g of CO2e per liter
- 0.01984 g of SF6 $\times$ 22800 = 452 g of CO2e per liter

For a total CO2e = 6824 g/l of STD gas mixture.

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Why the CO2 equivalent?

The CO_2e of one LITER of ECO2 or ECO3 is about 4.5 less than the CO2e of one LITER of STD mixture.

By multiplying the CO2e of one liter of gas mixture (whatever) by the total number of liters injected into the atmosphere by the LHC experiments, we have an absolute number of the contribution to the greenhouse effect, that can be directly compared to the contributions from other sources (e.g. heating, cars, etc.).

For instance: 2000 liters/h of STD mixture coming from RPCs of the LHC experiments (numbers completely invented) correspond to:
2000 l/h * 24 h * 365 d * 6824 g/l = 120.000 tons of CO_2e per year.
- Is this much?

Cumulative CO_2 Emissions per Year (as of 2019)

1. China	10.49 billion tons of CO_2
2. USA	5.26 billion tons of CO_2
3. India	2.63 billion tons of CO_2
4. Russia	1.68 billion tons of CO_2
...	
7. Germany	711 million tons of CO_2
18. Italy	340 million tons of CO_2
20. France	316 million tons of CO_2
50. Austria	68 million tons of CO_2
71. Switzerland	**37 million tons of CO_2**

It is about 0.34% of the total emissions of CO_2e in Switzerland