CARBON DIOXIDE (CO_2)

What is CO_2? How is it formed? How is it recycled? What are its dangers? How are the amounts of CO_2 emitted by automobile engines calculated? How can we reduce CO_2 emissions related to car traffic? Here are some answers.

What is CO_2?

CO_2 is the chemical name of the carbon dioxide molecule. This molecule is composed of one carbon atom (chemical symbol C) and two oxygen atoms (chemical symbol O), hence its name.

What are the properties of CO_2?

CO_2 is a colorless, odorless and non-toxic gas that can dissolve in water. Its density is about 2 grams per liter, a density 1.5 times higher than that of air. From a chemical point of view, CO_2 belongs to the category of neutral gases, in other words it combines with only a very small number of elements.

These physicochemical properties and its sour taste make CO_2 a very useful product in the food industry, to keep fresh products packaged in a controlled atmosphere or to gasify drinks like mineral waters, juices and sodas.

Where the CO_2 comes from?

CO_2 is formed during any combustion of wood, coal, gas or hydrocarbon by reaction of carbon (C) with oxygen (O_2). Automotive fuels contain about 84% carbon (gasoline), about 87% (diesel), this reaction with oxygen of the air providing the energy needed to run the engine.

Note that CO_2 emissions are proportional to the amount of fuel consumption, and note that modern engine clean-up techniques (oxidation catalyst, reduction catalyst, particulate filter, etc.) do not reduce these emissions.

What happens to the CO_2?

Carbon dioxide is biodegradable, which means it recycles naturally. Green plants and especially trees, thanks to their leaves, capture the CO_2 present in the atmosphere to assimilate carbon, the main constituent of wood (carbon cycle), and release oxygen into the air (process of photosynthesis).

The CO_2 released over the oceans dissolves in seawater. Some of the marine CO_2 is captured by aquatic plants and phytoplankton that need carbon for their growth. The oxygen thus released maintains the underwater life. The other part of the marine CO_2 reacts with the calcium (chemical symbol Ca) present in the seawater to form calcium carbonate ($CaCO_3$) like the coral reef, the main constituent of the seabed.

What is the problem by CO_2?

Neither trees nor plants are now numerous enough on land or in the sea to absorb the huge amounts of CO_2 released into the atmosphere, because of the massive consumption of fossil energy all around the world (wood, coal, gas, oil).

This frenzy of energy consumption began in the mid-nineteenth century to increase sharply from the 50s with the development of the automobile, land transport, fluvial, maritime and air.

During the same period, forest areas have been declining throughout the world, mainly because of the exploitation of forest resources or massive deforestation in Africa, Asia and South America. In fact, regular analyzes of the concentration of the Earth's atmosphere in CO_2 show that it steadily increases.

Carbon dioxide being a gas more mass than air, it absorbs the infrared radiation emitted by the Earth, this is called the greenhouse effect. So, the CO_2 present in the Earth's atmosphere contributes to global warming, with all the consequences that could result in the medium or long term: melting glaciers, rising sea levels, climate changes, progression of deserts ...

How to calculate car's CO_2 emissions?

To inform general public, European manufacturers are now required to publish the amount of CO_2 released by cars. How are they calculated?

The European homologation needs a consumption test: each car passes on a bench that measures the amount of fuel required for a standard cycle with a total duration of 20 minutes. This cycle, driven by a computer program, is identical for all cars and restores the driving conditions in the city (urban cycle) and on the road (extra-urban cycle). The advantage of this procedure is to consider all car models equally.

The consumption thus measured, expressed in liters per 100 kilometers (symbol l / 100 km), is called *mixed consumption according to the European community standards*, not to be confused with real consumption, which depends on the condition of the car, on the routes taken and on the driver's way of driving.

Mixed consumption according to CE standards is then used as a calculation basis for CO_2 emissions, expressed in grams per kilometer traveled (g / km symbol). To do this, a simple rule of three is sufficient, since we know that a gasoline engine discharges about

2,400 grams of CO_2 per liter of gasoline consumed, a diesel engine about 2,700 grams per liter of diesel fuel consumed.

The calculation is to multiply by 24 the consumption of a gasoline engine expressed in liters per 100 kilometers, and by 27 that of a diesel engine, to express the CO_2 emissions in grams per kilometer traveled (*).

Example:

- a gasoline engine with a fuel consumption of 6 l / 100 km emits approximately 6 x 24 = 144 grams of CO_2 per kilometer driven;

- a diesel engine with a fuel consumption of 5 l / 100 km emits approximately 5 x 27 = 135 grams of CO_2 per kilometer driven.

Note this point: the CO_2 emissions mentioned on the homologation forms are only indicative. The real quantities depend on the condition of the car, its load, the route taken, the traffic conditions and, above all, the driving style of the driver! This means that, depending on your mood or motivation, any driver can do better ... or less well!

Consumption and CO_2 emissions ...

Here is a table that shows the amounts of CO_2 emitted according to the engine and the consumption of the car:

CO_2	**4** l/100 km	**5** l/100 km	**6** l/100 km	**7** l/100 km	**8** l/100 km	**9** l/100 km	**10** l/100 km
GASOLINE	96 g/km	120 g/km	144 g/km	168 g/km	192 g/km	216 g/km	240 g/km
DIESEL	108 g/km	135 g/km	162 g/km	189 g/km	216 g/km	243 g/km	270 g/km

Annual carbon footprint ...

Countries that have signed the Kyoto Protocol on the Environment (1997) are invited to make their annual carbon footprint. This operation consists in calculating the quantities of CO_2 emitted into the atmosphere every year, based on the volumes of wood, coal, gas and oil consumed.

Each driver can do the same on an individual basis. For that, it is enough to note on a small notebook the quantity of fuel poured in the tank, as well as the corresponding mileage.

Example: a driver who traveled 100,000 kilometers in the year with 7,500 liters of diesel fuel consumed an average of 7.5 liters per 100 kilometers and emitted a total of more than 20 tons of CO_2 in the 'atmosphere.

Annual carbon balance

Here's what an annual carbon footprint looks like:

GASOLINE	**4** l/100 km	**5** l/100 km	**6** l/100 km	**7** l/100 km	**8** l/100 km	**9** l/100 km	**10** l/100 km
15,000 km/year	1.4 t	1.8 t	2.2 t	2.5 t	2.9 t	3.24 t	3.6 t
30,000 km/year	2.9 t	3.6 t	4.3 t	5 t	5.8 t	6.5 t	7.2 t
60,000 km/year	5.8 t	7.2 t	8.6 t	10.1 t	11.5 t	13 t	14.4 t
100,000 km/year	9.6 t	12 t	14.4 t	16.8 t	19.2 t	21.6 t	24 t

DIESEL	**4** l/100 km	**5** l/100 km	**6** l/100 km	**7** l/100 km	**8** l/100 km	**9** l/100 km	**10** l/100 km
15,000 km/year	1.6 t	2 t	2.4 t	2.8 t	3.2 t	3.7 t	4 t
30,000 km/tear	3.2 t	4 t	4.9 t	5.7 t	6.5 t	7.3 t	8.1 t
60,000 km/year	6.5 t	8.1 t	9.7 t	11.4 t	13 t	14.6 t	16.2 t
100,000 km/year	10.8 t	13.5 t	16.2 t	18.9 t	21.6 t	24.3 t	27 t

And the trucks? A modern articulated lorry consumes 33 liters of fuel per 100 kilometers. Scheduled to travel 150,000 kilometers per year, it will release about 135 tons of CO_2 into the atmosphere each year, more than 3 times its mass! ...

Taxing carbon emissions ...

As information and prevention campaigns often prove to be ineffective, governments that really want to reduce CO_2 emissions (they are committed to doing so) may have no choice but well-known methods of coercion:

- bonus-malus carbon on the purchase of a new car;
- carbon tax;
- emission quota per car;
- etc.

How to reduce CO_2 emissions?

All you need to do is use greener cars, reduce mileage when it's possible, or when it's not possible, reduce driving style fuel consumption.

The manufacturers will have to lighten the cars, improve their aerodynamic performances, as well as the efficiency of the engines. But on this last point, the biggest progress has been made and there is little miracle to wait.

Road planners will have to learn how to reduce or eliminate the causes of unnecessary slowdowns (roundabouts, traffic lights, stops) because that are greedy for fuel. The synchronization of traffic lights, for example, allows substantial savings in energy and pollution.

Drivers concerned about the environment will have to learn to drive in moderation, for example by avoiding powerful starts, unnecessary acceleration and hard braking.

Speed is another source of energy waste, and therefore unnecessary emissions of CO_2 into the atmosphere:

- a car traveling at 130 km/h (80 mph) instead of 110 km/h (70 mph) increases consumption by about 20%, which is the same increase of CO_2 emitted.

- a modern truck traveling at 90 km/h (55 mph) instead of 80 km/h (50 mph) increases consumption by about 10%, which represents nearly 10 kilograms of CO_2 unnecessarily emitted into the atmosphere every 100 km, nearly 16 kilograms of CO_2 unnecessarily emitted into the atmosphere every 100 miles (**).

Therefore, one of the solutions could be to reduce the maximum speeds allowed on the motorways, for example to 110 km/h (70 mph) for cars and 80 km/h (50 mph) for trucks.

(*) *For the physicist, the nuance between measurement and calculation is fundamental: fuel consumption is measured, CO_2 emissions are calculated.*

(**) *One mile = 1.609 kilometers, one kilometer = 0.620 mile. Characteristics of the truck: frontal surface 10 m²; drag coefficient 0.9; mass 40 t; chassis mounted on 12 wheels and tires generating a rolling resistance assumed to be independent of the speed; engine efficiency assumed equal to ½ and independent of the rotation speed.*

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SOME CHEMICAL RÉACTIONS

Atoms molar mass (kg.kmol^{-1}):

hydrogen (**H**): 1
carbon (**C**): 12
nitrogen (**N**): 14
oxygen (**O**): 16

Molecules density (kg.m^{-3} at 273 K and 1,013 hPa):

nitrogen (N_2): 1.25
oxygen (O_2): 1.43
carbon dioxide (CO_2): 1.96
water (H_2O): 1,000
diesel fuel: 845
gasoline: 760
LPG: 550

Chemical formula of pure air (*rares gases considered as nitrogen*)**:**

mass: oxygen (O_2) 23 %; nitrogen (N_2) 77 %

- molar mass of oxygen: 16 x 2 = 32 kg
- molar mass of one kilomole of oxygen: (32 / 23) x 100 = 139 kg
- mass of nitrogen: 139 – 32 = 107 kg
- molar mass of nitrogen: 14 x 2 = 28 kg
- nitrogen index: 107 / 28 = **3.8**

chemical formula: $O_2 + 3.8\ N_2$

Diesel fuel formula:

mass: carbon (**C**) 87 %; hydrogen (**H**) 13 %

carbon index: 87 / 12 = **7.25**; hydrogen index: 13 / 1 = **13**

chemical formula: $C_{7.25}H_{13}$

Gasoline formula:

mass: carbon (**C**) 84 %; hydrogen (**H**) 16 %

carbon index: 84 / 12 = **7**; hydrogen index: 16 / 1 = **16**

chemical formula: C_7H_{16}

LPG chemical formula:

LPG mass: butane (C_4H_{10}) 50 %; propane (C_3H_8) 50 %

chemical formula: $C_{3.5}H_9$

Diesel fuel combustion:

$$C_{7.25}H_{13} + 10.5\ O_2 + (10.5 \times 3.8)\ N_2 \rightarrow 7.25\ CO_2 + 6.5\ H_2O + 40\ N_2$$

$C_{7.25}H_{13}$: diesel fuel
O_2: oxygen
N_2: nitrogen
CO_2: carbon dioxide
H_2O: water

By referring to the molar mass of each element of this reaction, one obtains the following proportions:

1 kg of diesel fuel + 3.36 kg of oxygen + 11.2 kg of nitrogen
$\rightarrow$
3.19 kg of CO_2 + 1.17 kg of water + 11.2 kg of nitrogen

By referring to the density of each body involved in this reaction, one obtains the following proportions:

1 liter of diesel fuel + 1,985 liters of oxygen + 7,570 liters of nitrogen
$\rightarrow$
1,375 liters of CO_2 + 1 liter of water + 7,570 liters of nitrogen

Gasoline combustion:

$$C_7H_{16} + 11\ O_2 + (11 \times 3.8)\ N_2 \rightarrow 7\ CO_2 + 8\ H_2O + 42\ N_2$$

C_7H_{16}: gasoline
O_2: oxygen
N_2: nitrogen
CO_2: carbone dioxide
H_2O: water

By referring to the molar mass of each element of this reaction, one obtains the following proportions:

1 kg of gasoline + 3.52 kg of oxygen + 11.76 kg of nitrogen
→
3.08 kg of CO_2 + 1.44 kg of water + 11.76 kg of nitrogen

By referring to the density of each body involved in this reaction, one obtains the following proportions:

1 liter of gasoline + 1,870 liters of oxygen + 7,150 liters of nitrogen
→
1,195 liters of CO_2 + 1.1 liter of water + 7,150 liters of nitrogen

LPG combustion:

$$C_{3.5}H_9 + 5.75\ O_2 + (5.75 \times 3.8)\ N_2 \rightarrow 3.5\ CO_2 + 4.5\ H_2O + 22\ N_2$$

$C_{3.5}H_9$: LPG
O_2: oxygen
N_2: nitrogen
CO_2: carbon dioxyde
H_2O: water

By referring to the molar mass of each element of this reaction, one obtains the following proportions:

1 kg of LPG + 3.6 kg of oxygen + 12 kg of nitrogen
→
3 kg of CO_2 + 1.6 kg of water + 12 kg of nitrogen

By referring to the density of each body involved in this reaction, one obtains the following proportions:

1 liter of LPG + 1,390 liters of oxygen + 5,320 liters of nitrogen
→
850 liters of CO_2 + 0.875 liter of water + 5,320 liters of nitrogen

Total energy produced by fuel combustion:

Diesel: **44.3 $MJ.kg^{-1}$** (**37.4 $MJ.l^{-1}$**)

Gasoline: **46.9 $MJ.kg^{-1}$** (**35.6 $MJ.l^{-1}$**)

LPG: **48.7 $MJ.kg^{-1}$** (**26.8 $MJ.l^{-1}$**)

Net energy produced by fuel combustion:

Diesel: **41.7 MJ.kg^{-1}** (**35.2 MJ.l^{-1}**)

Gasoline: **43.7 MJ.kg^{-1}** (**33.2 MJ.l^{-1}**)

LPG: **45.1 MJ.kg^{-1}** (**24.8 MJ.l^{-1}**)

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