A STUDY ON THE REDUCTION OF THE CARBON FOOTPRINT IN THE USE OF PRESSURE GAS CYLINDERS

A comparison between the impact of WP 300 bars steel 50 liter and smart carbon cylinders 45 liters

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1. INTRODUCTION

This document presents the comparative study of greenhouse gases (GHG) emissions derived from the raw material production, manufacturing and transportation of the steel and the our smart carbon cylinder (from now on called SCC cylinder) for pressurized gases, such as hydrogen, helium, nitrogen, oxygen, argon and its mixes, etc.

Nowadays there is a global commitment to fight against climate change, which means a double challenge:

- Mitigation through the development of policies, technologies and measures that allow.
    - On the one hand, to limit and reduce the emissions of greenhouse gases.
    - On the other hand, to improve the capacity of gas absorption by the terrain.
- Adaptation, that is, anticipating the adverse effects of climate change and taking the appropriate measures to avoid or minimize the damage they may cause, adapting to the consequences that may come.

> The Carbon Footprint could be defined as an indicator that allows us to numerically value the amount of greenhouse gas emissions attributable to any human activity.

Overcoming this double challenge requires a new approach to the manufacturing procedures: our present model leads to either fragile systems or with a significant climatic and environmental impact. This effort towards a new productive model will open up new opportunities, such as the development of systems with low inputs or a wider use of renewable energies, which will support a new low-carbon economy.

So the Carbon Footprint could be defined as an indicator that allows us to numerically value the amount of greenhouse gas emissions attributable to any human activity. It is expressed in mass (grams, kilograms, tons...) of CO_2 equivalent. The CO_2 equivalent is considered as a unit that allows us to use a single reference to refer to all greenhouse gases through its Global Warming Potential. The global warming potential of a gas (GWP) reflects its relative capacity to increase the greenhouse effect compared to that of Carbon Dioxide.

2. GOALS AND SCOPE OF THE STUDY

OBJECTIVES OF ANALYSIS

Calculate the GHG emissions of the process of extraction of the required raw material for the manufacture of both steel and SCC cylinders.

Calculate the GHG emissions in the manufacturing process of both steel and SCC cylinders.

Calculate the GHG emissions throughout the life cycle of both steel and SCC cylinders.

Explain why the use of SCC cylinders is truly a positive contribution to the objectives of energyefficiency and climate protection.

3. WHAT IS THE CARBON FOOTPRINT?

The carbon footprint is the addition of all CO_2 emissions directly or indirectly caused by humans on the environment. It is measured from the extraction of raw materials to our daily habits, such as what means of transport we use or what energy consumption we make.

4. FACTORS TO CONSIDER

THE FACTORS TO TAKE INTO ACCOUNT FOR THIS CALCULATION ARE:

- THE RAW MATERIALS THAT GENERATE CO_2 EMISSIONS INTO THE ATMOSPHERE DURING THEIR EXTRACTION
- THE TRANSFORMATION OF THESE RAW MATERIALS TO OBTAIN THE FINAL PRODUCT
- TRANSPORTATION
- RECYCLING

4.1 EXTRACTION OF RAW MATERIALS

Following you will find a table of emissions of CO_2 Kg in the extraction of raw materials needed to manufacture WP 300 bars steel and and smart carbon cylinders.

MATERIALS	CARBON FOOTPRINT
1 Kg of ROUGH ALUMINUM	1.7 Kg of CO_2
1 Kg of CARBON FIBRE	12.5 Kg of CO_2
1 Kg of POLYURETHANE	3 Kg of CO_2
1 Kg of EPOXY RESIN	6.7 Kg of CO_2
1 Kg of UNPROTECTED POLYPROPYLENE	1.34 Kg of CO_2
1 Kg of ROUGH STEEL	2 Kg of CO_2

The raw material needed to manufacture a 50-liter steel cylinder weighing 68.5 Kg, as well as its carbon footprint, is:

MATERIALS	Kg MATERIALS	CARBON FOOTPRINT
ROUGH STEEL	68.5	137 Kg of CO_2
TOTAL	**68.5**	**137 Kg of CO_2**

The raw materials needed to manufacture a 50-liter carbon fibre cylinder weighing 25 Kg are:

MATERIALS	Kg MATERIALS	CARBON FOOTPRINT
ROUGH ALUMINIUM	11.4	19.38 Kg of CO_2
CARBON FIBRE	9.9	123.75 Kg of CO_2
POLYUTETHANE	2	6.00 Kg of CO_2
EPOXY RESIN	4.2	28.14 Kg of CO_2
POLYPROPYLENE	2.5	3.35 Kg of CO_2
TOTAL	**30**	**180.62 Kg of CO_2**

4.2 MANUFACTURING PROCESS

After accounting for the carbon footprint required to obtain the raw materials for the manufacture of these cylinders, we must also take into account the treatment and moulding of the raw material for the manufacturing of each cylinder. To test these processes we need to find the calorific value of each industrial process.

The data to consider are: Kg of the product, melting temperature and specific heat of the material. With these data we can obtain the calorific power needed to mould the material.

To obtain the calorific power needed, we need to use a fuel such as propane. We have estimated that in the process we are going to have a 40 % loss (reduction of calorific power) in the propane.

Required data from all raw materials:

	MELTING TEMP.	KILOGRAMS	SPECIFIC HEAT J / KGºC
ALUMINIUM	660	11.4	897
CARBON FIBRE	1 500	9.9	711
POLYPROPYLENE	220	2.5	1 880
STEEL	1 500	68.5	2 000

PROPANE	CALORIFIC POWER	CARBON FOOTPRINT
1 Kg	11 082 Kcal/Kg	2.94 Kg/CO_2

In the following table, we show the calorific value necessary for the treatment of both types of cylinders:

	B50 CYLINDERS				M x Ce x (T2-T1)	
SCC CYLINDER	KILOGRAMS	SPECIFIC HEAT	ROOM TEMP.	MELTING TEMP.	Q (JOULES)	Q (Kcal)
ALUMINIUM	11.4	897	25	660	6 493 383	1 551.95
CARBON FIBRE	9.9	711	25	1 500	10 382 377	2 481.44
POLYPROPYLENE	2.5	1 880	25	220	916 500	219.05
TOTAL SCC						**4 252.44**
STEEL CYLINDER	KILOGRAMS	SPECIFIC HEAT	ROOM TEMP.	MELTING TEMP.	Q (JOULES)	Q (Kcal)
TOTAL STEEL	68.5	2 000	25	1 500	202 075 000	**48 297.08**

Summary table of the calorific value required

B50 CYLINDER660	Q (Kcal)
SCC CYLINDER 45 LITERS	4 252.44
STEEL CYLINDER 50 LITERS	48 297.08

A 40 % energy loss of the propane in the manufacturing process has been assessed. In the following table we may observe the Kg of propane needed in both types of cylinder to obtain the calorific value and therefore its carbon footprint.

The carbon footprint of 1 Kg of Propane Gas has an emission factor of 2.94 Kg CO_2

	MxCex (T2-T1)		PROPANE Kg	PROPANE	EMISSION Kg CO_2
	Q (JOULES)	**Q (Kcal)**	**100%**	**140%**	**CO_2**
ALUMINUM	6 493 383	1 551.95	0.14	0.196	0.576
CARBON FIBRE	10 382 377	2 481.44	0.223	0.312	0.917
POLYPROPYLENE	916 500	219.05	0.019	0.026	0.076
TOTAL ALUMINUM		4 252.44	0.382	0.534	1.569
	MxCex (T2-T1)		**PROPANE Kg**	**PROPANE**	**EMISSION KG CO2**
	Q (JOULES)	**Q (Kcal)**	**100%**	**140%**	**CO_2**
TOTAL STEEL	202 075 000	48 297.08	4.358	6.101	17.93

Summary of the carbon footprint. Extraction raw material + manufacturing of cylinders:

SCC CYLINDER	
MATERIALS	**Kg CO_2**
EXTRACTION RAW MATERIALS	180.62
MANUFACTURING OF SCC MATERIALS	1.56
TOTAL	**182.18 Kg CO_2**

STEEL CYLINDER	
MATERIALS	**KG CO_2**
STEEL	137
STEEL MANUFACTURING	17.93
TOTAL	**154.93 Kg CO_2**

With these results it can be stated that the manufacture of a SCC cylinder produces **17.58% more CO_2** than the manufacture of a steel cylinder.

4.3 TRANSPORTATION

Let us check the savings in transportation using a 300 bars SCC cylinder 45 liter versus a steel cylinder 50 liter.
We take into account the following data:

- The CO_2 emissions considering an average value for transportation of goods by road is 50 gr. of CO_2 per Km and Ton of weight.
- We will consider a distance of 150 Km for our calculation.

	STELL CYLINDER 50 LITER	SMART CARBON CYLINDER 45 LITER
PRODUCT	20.6 KG of oxygen	18.54 KG of oxygen
	15.45 KG of nitrogen	13.90 KG of nitrogen
	25.56 KG of argon	23.01 KG of argon

CASE 1:

We will start by comparing the CO_2 footprint in the round trip of a single cylinder, in both cases.
Single Cylinder (14 Tn. Freight Truck) Delivery of a full cylinder with oxygen + collection of an empty one back to the plant.

SINGLE STEEL CYLINDER

Outbound trip full cylinder = 68.5 Kg +20.6 Kg = 89.10 Kg // 150 Km x 0.089 Tm x 50 gr. = 668.25 gr.
CO_2 Inbound trip empty cylinder = 68.5 Kg // 150 Km x 0.068 Tm x 50 gr. = 513.75 gr. CO_2
Total 1 182 gr. of CO_2 = 1.082 Kg of CO2 // Ratio CO_2 x Kg of gas delivered 1 082/20.6 Kg = 57.37 gr. CO_2

SINGLE SCC CYLINDER

Outbound trip full cylinder = 30 +18.54 Kg = 48.54 Kg // 150 Km x 0.048 Tm x 50 gr. = 364.05 gr. CO_2
Inbound trip empty cylinder = 30 Kg // 150 Km x 0.03 Tm x 50 gr. = 225 gr. CO_2
Total 589.5 gr. of CO_2 = 0.5895 Kg of CO_2 // Ratio CO_2 x Kg of gas delivered 589.50/18.54 Kg = 31.77 gr. CO_2

CONCLUSION:
USING SCC CYLINDERS FOR GAS TRANSPORTATION REDUCES CO_2 EMISSIONS BY A 44.62% COMPARED TO THE STEEL CYLINDER.

B50 CYLINDER	REDUCES CO_2
OXYGEN	- 44.62 %
NITROGEN	- 46.12 %
ARGON	- 43.28 %

4.3 TRANSPORTATION

CASE 2:

Delivering a single cylinder is not frequent, so we will consider a more usual example: the delivery of a whole freight truck. Freight Truck 24 tons of payload (dimensions 13.40 x 2.50 m.)

USING STEEL CYLINDERS:

240 cylinders with cages, each cylinder contains 20.6 Kg of oxygen
240 cylinders x 89.10 Kg + 20 cages x 130 Kg = 23 984 Kg
240 cylinders x 68.5 Kg + 20 cages x 130 Kg = 19 040 Kg
Total 43 024 Kg to deliver 4 944 Kg of product

Outbound trip full cylinder = 150 Km x 23.98 Tn x 50 gr. = 179 850 gr. CO_2
Inbound trip empty cylinder = 150 Km x 19.04 Tn x 50 gr. = 142 800 gr. CO_2
Total 322 650 gr. of CO_2 // Ratio CO_2 x Kg of product 322 650 gr./4 944 Kg = 65 26 gr. CO_2

USING SCC CYLINDERS:

465 cylinders, 31 pallets of 15 cylinders each, each cylinder carries 18.54 Kg of oxygen
465 cylinders x 48.54 Kg + 31 pallet x 25 Kg = 23 346 Kg
495 cylinders x 30 Kg + 31 pallet x 25 Kg = 14 725 Kg
Total 38 071 Kg to deliver 8 621 Kg of product

Outbound trip full cylinder = 150 Km x 23.34 Tn x 50 gr. = 175 050 gr. CO_2
Inbound trip empty cylinder = 150 Km x 14.72 Tn x 50 gr. = 110 400 gr. CO_2
Total: 285 450 gr. of CO_2 // Ratio CO_2 x Kg of product 285 400 gr./ 8 621 Kg = 33.111 gr. CO_2

CONCLUSION:
USING SCC CYLINDERS FOR GAS TRANSPORTATION REDUCES CO_2 EMISSIONS BY A 49.26% COMPARED TO THE STEEL CYLINDER.

CYLINDER 40/50 LITER	REDUCES CO_2
OXYGEN	- 49.26 %
NITROGEN	- 50.69 %
ARGON	- 47.94 %

LAYOUT OF CYLINDERS IN A 24 TN FREIGHT TRUCK

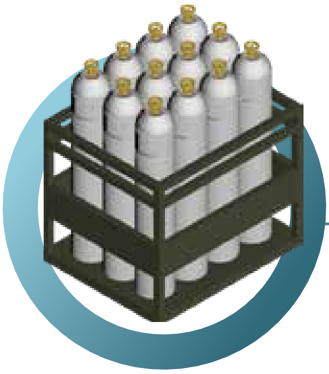
Weight is important, but let us consider dimensions and space too.
A freight truck of 24 tons, dimensions of the cargo space: 13.4 x 2.50 meters.

USING STEEL CYLINDERS:

Transportation of these cylinders requires metal cages with dimensions of 850 x 1080 mm, each cage has a capacity of 12 cylinders. Each cage with the 12 cylinders filled with gas weighs 1 199 Kg. Considering that the maximum weight allowed by the freight truck is 24 Tons, only 20 cages (23 980 Kg) can be carried. Also, we must keep in mind the space, keeping the necessary distances in the freight truck cargo space, we may fit 2 rows of 15 cages in each, for a maximum of 30 cages (35 970 Kg). Due to this reason, the truck can only carry 20 cages (240 cylinders).

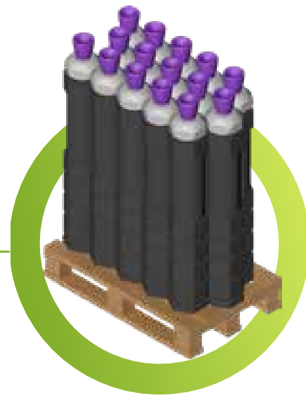
USING SCC CYLINDERS:

Standard 800 x 1200 euro pallets are used, 15 cylinders fit in each pallet. Keeping the necessary distances, 33 pallets (465 SCC cylinders) fit in each cargo space. Each pallet with 15 filled cylinders weighs 753.10 Kg, that is, 31 filled pallets weigh 23 346 Kg.
Although space allows us to fit 33 pallets, the weight limit of 24 tons permits us to charge just 31 pallets.



Steel cylinders must travel in cages, so they need more space in the truck.

The cylinders can be carryed on standart european pallets.
15 SCC cylinders per pallet.



TRUCK OF 24 TONS	STELL CYLINDER 50 LITER	SMART CARBON CYLINDER 45 LITER
OXIGEN	20 cages (240 cylinders)	31 cages (465 cylinders)
NITROGEN	21 cages (252 cylinders)	33 cages (495 cylinders)
ARGON	19 cages (228 cylinders)	29 cages (435 cylinders)

4.4 RECYCLING

We must keep in mind that more **than 95% of all SCC materials can be recycled.** Aluminum is a totally recyclable material that does not lose its properties, moreover, recycling aluminum saves 95% of the energy needed to produce new aluminum.
Polypropylene is 100% recyclable which makes it a versatile material in reprocessing, allowing us to obtain products that fulfill an equivalent functional promise to the initial application or giving them a greater impact destination.

5. REDUCTION OF THE CARBON FOOTPRINT WITH THE SCC CYLINDER

HOW MUCH CO_2 CAN A TREE ABSORB?

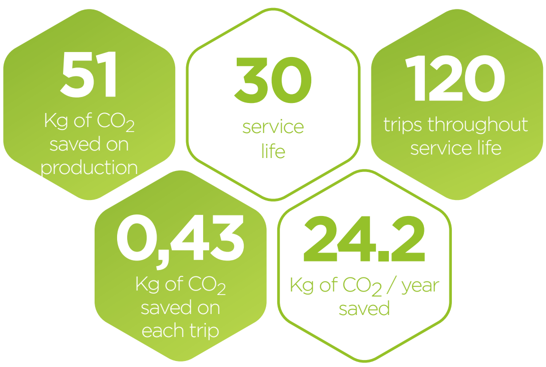
It can be stated that figures vary between 10 Kg and 30 Kg of CO_2 per year. For calculation purposes, it is recommended to take 15 Kg of CO_2 as a reference.

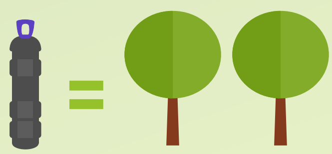
SCC cylinder service life: 30 years
One 50-litres SCC cylinder has an average rotation of 4 times to the year, meaning it is filled, delivered and collected 4 times a year.

1º In the manufacturing process there is a saving of:
Steel Cylinder = 154.93 Kg of CO_2
BIC Cylinder = 182.18 Kg of CO_2
The difference is – 27.25 Kg of CO_2 per cylinder.

2º In the transportation of a SCC cylinder:
Considering a service life of 30 years and a rotation of 4 times a year, 120 round trips are made in the life of each cylinder.
On each round trip there is a saving of 0.429 Kg of CO_2 per cylinder
So for 120 trips, the economy is: 0.429 Kg of CO2 x 120 = 51.48 Kg of CO_2

CONCLUSION:
TOTAL SAVING OF CO_2= 51.84 KG – 27.25 KG = 24.23 KG OF CO_2. AS IF WE HAD SEEDED 1.6 TREES.





Using SCC cylinders implies a reduction of the carbon footprint equivalent to the seeding of more than one tree all over the life of each BIC cylinder.

6. CONCLUSIONS

After the present study and the analysis of the results, we can state that, although in the manufacturing process of the SCC the data are similar to those of the steel cylinder, there is a **significant reduction of 56% in the carbon footprint in the transportation process**, that grows up to 60% when considering the full load of a 24 Tn freight truck.

The reason for this economy are:

- Its lower weight, almost three times lighter than steel cylinders.
- Its hexagonal shape, which allows using pallets instead of cages, so we have more space to carry almost twice as many cylinders in a 24 Tn freight truck.

We may come to the conclusion that the "carbon balance" for smart carbon cylinders (SCC) shows that its use implies a **reduction of the carbon footprint equivalent to the seeding of more than one tree** all over the life of each SCC cylinder.

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CARBOTAINER S.L.

Pº Independencia, 8 dpdo. 2ª Planta | 50004 – Zaragoza (Spain)
Telephone: 976 141 749

www.carbotainer.com
info@carbotainer.es

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