A PROTOTYPE OF CNG CARTRIDGES POWERED SCOOTER: A SOLUTION FOR A SUSTAINABLE MOBILITY INTO CITY CENTERS

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1. BACKGROUND

Gaseous fuels such as CNG, biomethane, Hythane®, could represent performing and efficient alternatives to oil-derived fuels, not only for heavy duty trucks, buses, light vehicles fleets but also for 2-wheel vehicles which are nowadays massively present in city-centers.
However, the transports and sustainable mobility markets will be addressable by these gaseous fuels only if they are available to the maximum of customers. This availability often means that at a country/territory scale refueling stations (private or public) needs to be built, forming a dense network.
But, within few years, refueling GNG vehicles into city-centers, could be (is already) problematic, as for security reasons, refueling stations will be (are already) banned from city centers.
The Research & Innovation Division of GDF SUEZ has decided **to think differently the refueling of CNG vehicles** (and especially 2-wheel vehicles) by developing a system of CNG cartridges that could be easily replaced when empty, without needing any access to a refueling station.
An innovative fast "plug-in" connecting system has been developed and a first demonstration of the potential offered by CNG cartridges concept has been done with a prototype of CNG cartridges powered scooter.

2. AIMS

The concept is very simple. Based on the current CNG composite cylinders technologies, the idea was to develop small CNG cartridges made of composite materials in order to store (and provide to customers) few litres of gaseous fuel. The use of composite materials for these cartridges allows an easy manipulation by customers (minimum total weight). The innovative fast "plug-in" connecting system ensures an easy connection/disconnection of the cartridge on the vehicle and under entire safe/secure conditions.

The innovation comes **not only from the technical aspects** (cartridges + « plug-in » connecting system) but also from **the new way of approaching the gaseous fuels**

distribution within urban areas, allowing the use of such gaseous fuels on market segments which have not been addressed yet massively (2-wheel vehicles, forklifts, etc.).

Thus, the CNG cartridge system open the way to possible new business. Why not thinking about a cartridges market. The full organisation of the **gaseous fuel cartridges « life cycle » - filling / distribution / empty cartridges collection / refuelling** could be integrated, as a **new service offer,** with high added value, in addition to the current CNG offers from several players.

Then, the objectives of this project were twofold :

- To imagine and set-up an **innovative way to distribute CNG/biomethane**, without requiring the installation of filling-stations **into city centres**;

- To demonstrate **the CO_2 and pollutants emissions reduction** offered by CNG **on a category o vehicles massively present into city centres**: 2-wheel vehicles.

3. METHODS

The work has been split into 3 major tasks:

- Conception and **development of the CNG/biomethane cartridge** with its **fast "plug-in" connection**;
- **Integration of the CNG cartridge into a scooter** (2 -wheel vehicle) and **modification of its engine** to run on CNG/biomethane;
- Evaluation of **the CO_2 and pollutants emissions** to demonstrate the benefits of CNG/biomethane on a scooter running into city-center.

3.1 Development of the CNG/biomethane cartridge with its fast "plug-in" connection

In order to facilitate the use of the CNG/biomethane cartridge, GDF SUEZ has established a list of specifications. To comply with the safety regulations, some specifications are based on the European ECE R110 regulation which exists for CNG vehicles and equipments. Thus, the cartridge and fast « plug-in » connection specifications are the following ones :

- Cartridge with a fast « plug-in » / « plug-out » connection system ;
- Light cartridge and an ergonomic system for an easy and safe manipulation;
- Maximal weight of the cartridge and its connection system : 9kg ;
- « Exclusivity » of the « plug-in » connecting system with a specific shape to avoid any misconnection and to ensure the use of the proper cartridge with the proper connection;
- Operating CNG/biomethane equivalent pressure: 200 bars at 15°C;
- Safety CNG/biomethane pressure: 350 bars;

- “Plug-in » / « Plug-out » connecting system complying with the ECE R110 regulation (no gas leak at the disconnection, integration of a thermal fuse on the connecting system, etc.);
- Operating temperatures for the full system (cartridge + connecting system) : – 40°C to +65°C;
- Durability for the full system (cartridge + connecting system): minimum of 3000 cycles (connection/disconnection).

Several technologies of CNG/biomethane cylinders were available. However, the selected technology was **type-4 CNG cylinders** made of composite materials with a polyethylene membrane (light materials). The total volume of the CNG cylinder/cartridge is 6.8 liters (water) for a total empty weight of 4kg. The selected CNG/biomethane cylinder as cartridge is presented in the Figure 1 below.

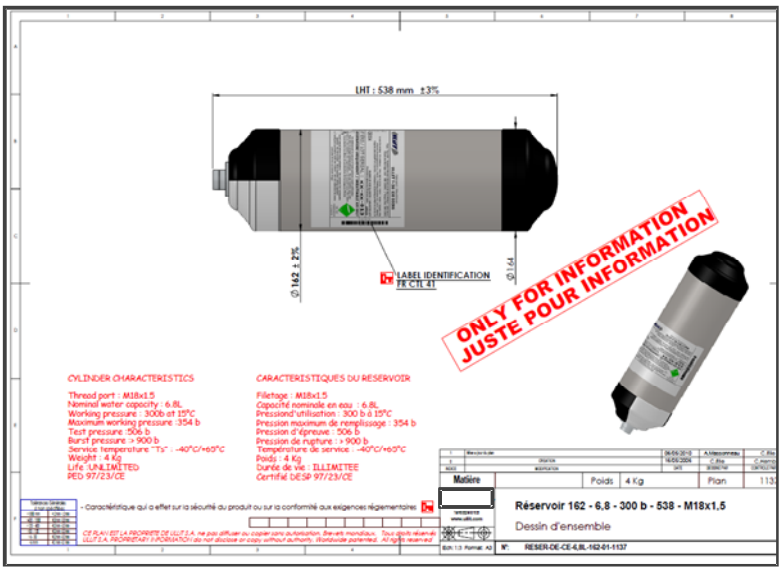

Figure 1 : Selected type-4 CNG cylinder.

In addition, the fast « plug-in » / « plug-out » connecting system of the cartridge has been co-developed by GDF SUEZ and STÄUBLI, a French company lead er on high pressure connecting systems. After the design, conception and test of 3 different technical solutions, the selected fast « plug-in » / « plug-out » connection system is the one presented in the Figure 2. This fast “plug-in” / “plug-out” connecting system is patented.

In order to comply with the safety regulations, a thermal fuse (110°C) has been integrated into the connecting system. In addition, to protect the head of the cartridge and the connecting system from any shock, a specific protection head has been developed, integrating also a dedicated handle for an easy manipulation / use of the cartridge. This protective head, presented in the Figure 2 (bottom right hand side) has been also patented.

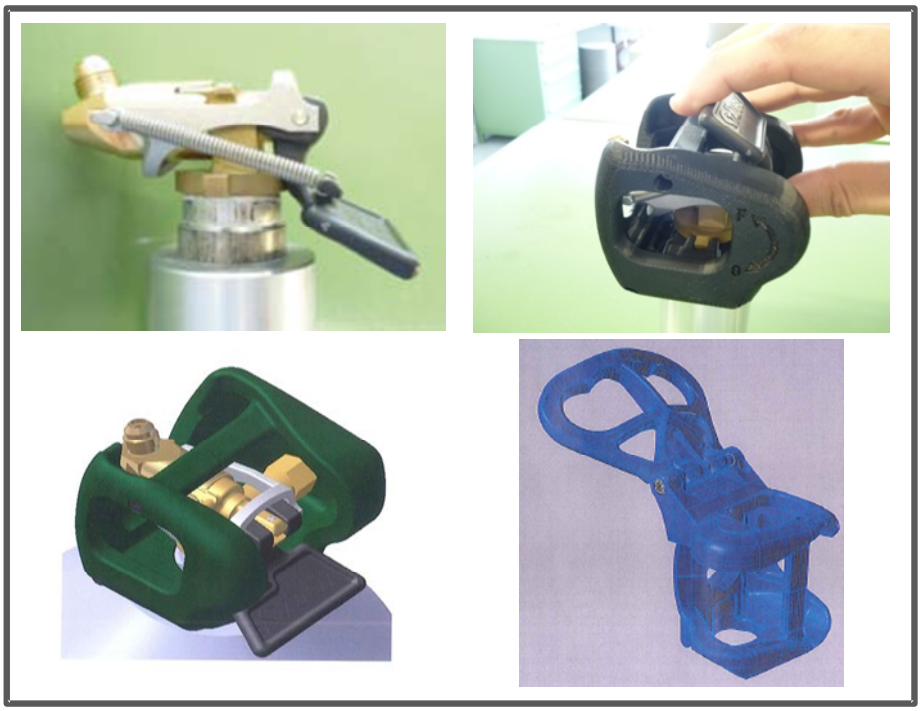

Figure 2 : Fast “plug-in” / “plug-out” connecting system co-developed by GDF SUEZ and STÄUBLI and the cartridge protective head with handle.

Finally, the complete cartridge system with the CNG/biomethane cylinder, its fast « plug-in » / « plug-out » connection and its protective head with the handle is presented in the Figure 3 below.

Figure 3 : The complete CNG/biomethane cartridge

3.2 Development of the scooter prototype powered by CNG/biomethane cartridges

3.2.1. *The original gasoline scooter:*

The original gasoline scooter benefits from large wheels for a better stability and allowing a « sportive » drive in city centers (urban areas) and semi-urban areas. The engine is a 4-stroke engine of 125 cm³ with liquid cooling system and electronic injection. This scooter benefits also from the ABS to optimize the braking efficiency. The space available under the saddle allows the storage of two helmets. Some of the characteristics of the original scooter are summarized below:

- Rigid frame compatible with a sportive drive
- Large wheels 15 inches at the front and 14 inches at the rear
- 4-stroke engine of 125 cm³ with electronic injection and liquid cooling system
- ABS for a better control of the brakes
- Brakes with disks at the front and at the rear
- Space under the saddle to store 2 helmets
- Large gloves compartment
- Autonomy: 300 km.

The original gasoline scooter is presented in the Figure 4 below.

Figure 4 : The original scooter before its modifications

All the modifications applied to the original gasoline scooter have been **conducted with an industrial approach**, envisaging a potential large scale production of the GNG cartridges powered scooter.

3.2.2. ***The CNG cartridge integration onto the scooter :***

The original under-saddle cavity has been removed to allow the complete integration of the CNG cartridge in a **new dedicated under-saddle cavity**. This new under-saddle cavity has been co-developed by GDF SUEZ and the France Craft company, based on the following specifications:

- A raise of 3 cm to allow the integration of the cartridge without blocking the closing of the saddle,
- A dedicated cradle for an easy position of the cartridge with a secure blocking system,
- A guiding system for the high pressure line connecting the cartridge to the gas pressure regulator,
- A sufficient space to access to the cartridge and its connection system.

Several specific moulds have been developed to manufacture the new under-saddle cavity made of resin. These moulds are presented in Figure 5.

Figure 1 : Cartridge position into the cavity and moulds for the new cavity.

The Figure 6 presents a simulation of the cartridge positioned into the under-saddle cavity and a picture of the new cavity made of resin.

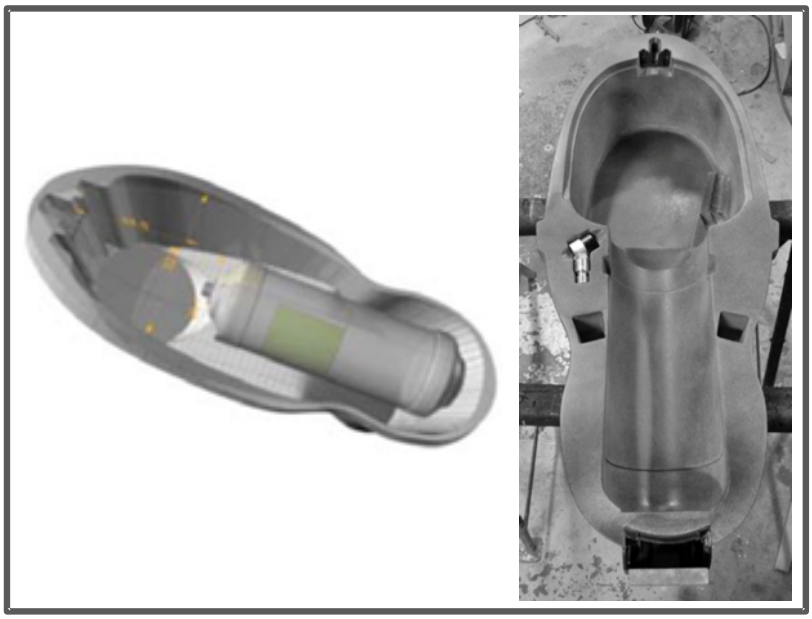

Figure 2 : under-saddle cavity with the cartridge and new cavity made of resin

3.2.3. <u>The original gasoline engine modifications:</u>

Modifications applied to the original gasoline engine has been done in collaboration with the company RM GAZ. These modifications have been conducted in 2 phases :

- Installation of the different gas elements and gas injection system on the original gasoline engine : gas pressure regulator, specific gas pipe for the injector
- Adjustment of the engine cartography

After some tests on the bench, a first optimisation of the engine cartography has been done.

An electronic box has been added to modify the ignition advance. Then, the scooter has been tested on the bench to finely tune the optimisations (ignition times, ignition advance, etc.).

The modified scooter is bi-fuel. It runs not only on CNG but also on gasoline (the gasoline part has not been modified). A switch on the handlebars allows the automatic change between the gasoline mode to the CNG mode (and reverse).

Cold start is automatically made on the gasoline mode. Once the engine temperature reaches 20°C, the scooter switch to its CNG mode. When the remaining CNG pressure into the cartridge is not sufficient, the gasoline mode is automatically switched on.

4. <u>RESULTS</u>

A picture of the scooter prototype powered with CNG cartridges is presented in Figure 7.

Figure 7: Prototype of scooter powered with CNG cartridges

In August 2011, the scooter prototype powered with CNG cartridges has been tested at UTAC to measure its emissions (CO_2, pollutants). With an engine of 125 cm^3, for its homologation, tests have to be conducted following 6 urban cycles. However, this prototype has been tested for each fuel (gasoline and CNG) following 6 urban cycles and 1 extra-urban cycle.

The following figures (Figures 8 to 11) present the emissions measured on the scooter for the different fuels (CNG and gasoline).

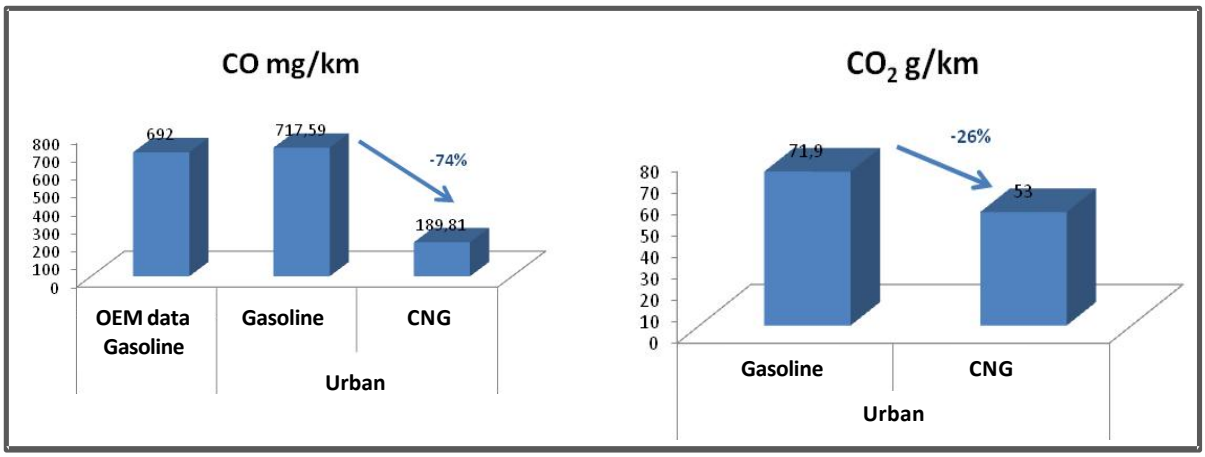

Figure 8 : CO and CO_2 emissions of the scooter in gasoline and CNG modes following urban cycles.

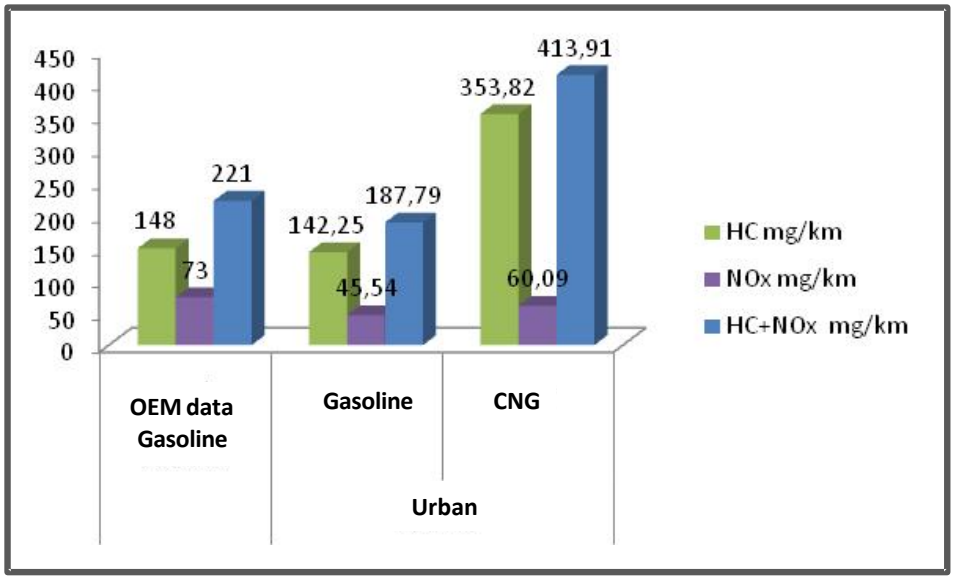

Figure 9 : NOx and HC emissions of the scooter in gasoline and CNG modes following urban cycle

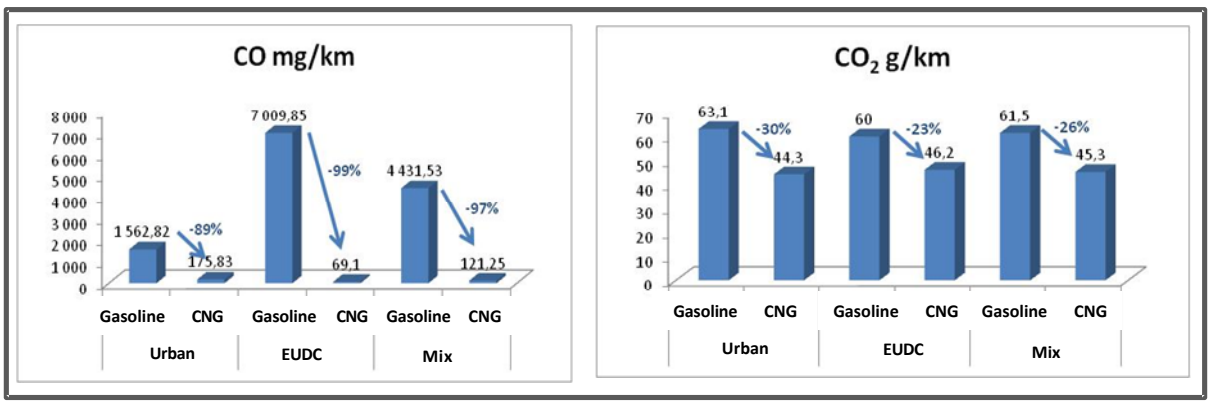

Figure 10 : CO and CO_2 emissions of the scooter in gasoline and CNG modes following urban, extra-urban and mix cycles.

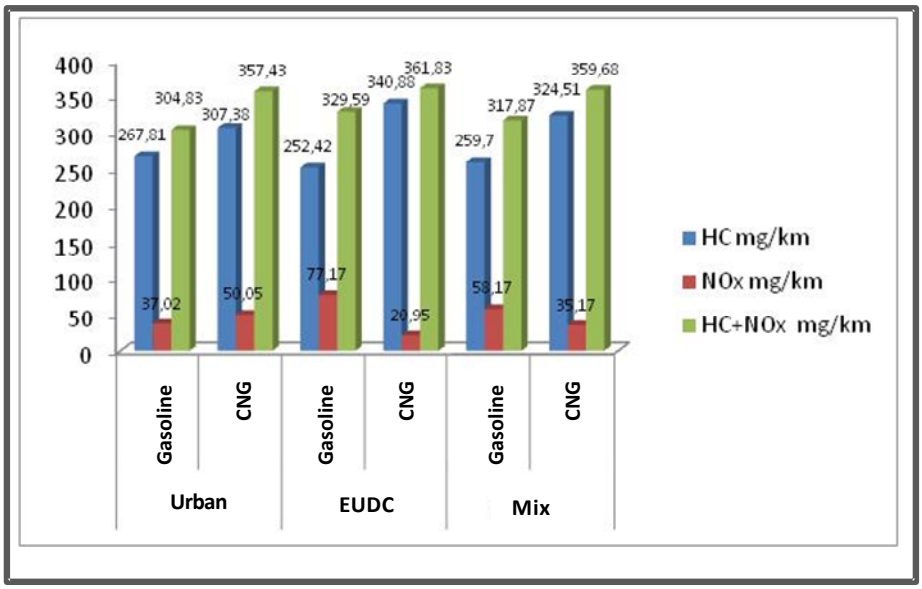

Figure 3 : NOx and HC emissions of the scooter in gasoline and CNG modes following urban, extra-urban and mix cycles.

The performances obtained with the scooter powered with CNG cartridges are already exceptional regarding the emissions reductions and the energy consumption, and the global system presents a real optimization potential :

- Very high reduction of CO_2 emissions: 45g CO_2/km on a mix normalized[1] cycle (**which represents -26% of CO_2 vs. gasoline scooter**) ;
- High reduction of the NOx emissions: 35mg NOx/km on a mix normalized[1] cycle (**which represents – 39% of NOx vs. gasoline scooter**) ;
- Very low energy consumption of 2,58m^3 de CNG/100km[1] giving an **autonomy of more than 55km on CNG**[2] to which is added the autonomy of **300km on gasoline** making this scooter an **perfect mobility tool for urban/extra-urban areas.**
- High **optimization potential** via the electronic engine cartography which has to be optimized for CNG..

[1] : *Measurements conducted in august 2011 at UTAC (France) on normalized cycles :urban, extra-urban et mix (cold and hot starts).*
[2] : *Autonomy measurements conducted under real driving conditions in urban and extra-urban areas in July and August 2011.*

5. CONCLUSIONS

This prototype of scooter powered with CNG cartridges, developed by GDF SUEZ, offers an immediate and adapted answer for a sustainable mobility in urban and extra-urban areas. This vehicles, with its low emissions levels, benefits from **an innovative CNG refueling system via fast "plug-in" / "plug-out" cartridges**. This new refueling system facilitates the

use of CNG as a fuel into city-centers where the installation of refueling stations is not often easy.

Following this first demonstration, new vehicles such as forklifts, mini-trucks could be developed with the same CNG cartridges system.

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