Demonstration and validation of Direct Injection of CNG in vehicle engines and its environmental benefits

LAYMAN’S REPORT - 2018
LIFE DI-CNG factsheet

LIFE DI-CNG is co-financed by LIFE+, the financial instrument for the environment of the European Commission (LIFE13 ENV/LU/000460)

Duration: 2014-2018

Budget: € 7,969,959

Goal of the project:
Validation and industrialization of the DI-CNG injectors and demonstration of the DI-CNG technology potential and its environmental benefits

Decarbonization of the industry and the mobility sector is a major societal challenge for the 21st century. While many different sectors are impacted by it, this project focuses on road transport.

New vehicles sold in the year 2021 must emit less than 95g CO$_2$/km in average. For the year 2030, a further reduction of 37.5% is required. Other stringent regulations are on clean air, toxic emissions and particles. The automotive industry addresses these challenges by proliferating vehicle powertrain technologies and the energy sources. In this project, the use of compressed natural gas in adapted engines in passenger car is analysed. This energy source – powertrain technology combination is compared to best in class gasoline powered vehicles.

**Energy source**
The Compressed Natural Gas (CNG) is mainly composed of methane, CH$_4$. CH$_4$ has the highest hydrogen to carbon ratio of any fossil fuel and therefore offers the optimum composition. The graph “**Principle of Power-to-Gas technology and bio-methane as fuels for natural gas vehicles**” here below illustrates the ways to produce methane other than extracting it from gas fields.

![Principle of Power-to-Gas technology and bio-methane as fuels for natural gas vehicles](image-url)
2. LIFE DI-CNG PROJECT
   a. Project objectives
   In the course of the Life DI-CNG Project;
   • The novel injector for CNG direct injection is validated for performance and durability.
   • The injector is industrialized and built on a pilot manufacturing line.
   • The Energy source-powertrain technology combination is benchmarked for environmental and performance criteria.
   • The environmental impact of the Energy source-powertrain technology combination is quantified in a life cycle analysis.

b. Project activities
   The Delphi Technologies’ DI-CNG injector is developed from the early prototype stage to the final product going through several design iterations. The product validation which is done at the end of the development process confirms strong performances on gas flow and leakage and a robust behaviour during durability tests going up to 400 Million injector tip opening cycles.

A key criteria for the industrialization of the Di-CNG injector is the repeatability of all production steps. The different manufacturing processes are developed and demonstrated on manufacturing equipment. A pilot line is installed in the technical centre that enables the production of injectors in a high-volume production environment. The production is performed in batches and statistically analysed.
The benchmarking activities of the Energy source-powertrain technology combination were done in both engines and vehicles. Accomplishments obtained along with TU Vienna and Mahle are published in the MTZ journal. The results of the cooperation with vehicle manufacturers, that develop and demonstrate monovalent DI-CNG vehicles are published in the frame of the Horizon 2020 GasOn project (www.gason.eu).

A Life Cycle Assessment Study (LCA) is conducted with the Luxembourg Institute of Science and Technology (LIST). The LCA evaluates the carbon footprint over the entire supply chain and calculates the well to wheel (WtW) emissions reduction. This study includes injector manufacturing as well as generation, transport and storage of CNG or bio-methane. These results are used to evaluate the environmental as well as the socio-economic impact.

3. RESULTS

a. Expected results / obtained results

The Delphi Technologies DI-CNG injector operates with a solenoid actuation similar to Multec® gasoline direct injectors. Conversely to standard gasoline injectors, an outwardly opening valve design is used. The novel nozzle design reaches the required flow rates of up to 7g/s at 16 bar. In the course of the Life project several DI-CNG injector design iterations took place. A full performance and durability validation of the last design iteration was passed successfully and completed the injector development.

The installed pilot line served to build and quality control of batches of injectors. It allows simulation of single piece flow and large quantity production. In the last phase of the project more than 100 injectors of the final design iteration were build and quality checked. All process control parameters were set and respected.

The high knock resistance of natural gas allows for higher engine compression. A compression ratio of 13:1 is targeted. Due to the increase in pressure several engine components are modified in order to maintain engine robustness and wear resistance. The variable valve actuation is another asset to direct-injection, it increases the volumetric efficiency and boosts performance. The turbocharger is optimized such that it can provide sufficient boost pressure and torque at low engine speeds. The gas injector and gas supply system is specially made.

Engine development is traditionally done by the vehicle manufacturer. For this reason Delphi Technologies collaborates with several research partners to demonstrate the DI-CNG potential on engine and vehicle level. The results are summarized in the next table.
The project objectives for the DI-CNG Energy source - powertrain technology combination are:

- **25% CO₂ reduction** vs. comparable gasoline direct injection (GDI) engines.
- **>90% reduction of particulate matter** (compared to diesel engines).
- Performance and low-end torque comparable to gasoline direct injection engines.

<table>
<thead>
<tr>
<th>Project partner</th>
<th>Configuration</th>
<th>Compared to</th>
<th>Test type</th>
<th>Test criteria</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAHLE</td>
<td>1.2l DI-CNG engine with variable turbo geometry</td>
<td>Gasoline 1.4l GDI</td>
<td>engine test</td>
<td>CO₂</td>
<td>-23 - 36%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vehicle test</td>
<td>particles</td>
<td>Not tested</td>
</tr>
<tr>
<td></td>
<td>ultra-light weight DI-CNG demonstration vehicle</td>
<td>ultra-light weight demonstration vehicle with GDI engine</td>
<td>vehicle test</td>
<td>CO₂</td>
<td>-31%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vehicle test</td>
<td>particles</td>
<td>Not tested</td>
</tr>
<tr>
<td>CULT project</td>
<td></td>
<td></td>
<td>vehicle test</td>
<td>power/torque</td>
<td>Comparable</td>
</tr>
<tr>
<td>Vehicle manufacturer (not named)</td>
<td>monovalent 1l DI-CNG engine in a mid range vehicle</td>
<td>0.9l CNG port fuel injection engine in the same mid range vehicle</td>
<td>engine test</td>
<td>CO₂</td>
<td>-17.50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vehicle test</td>
<td>particles</td>
<td>90% below limit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>vehicle test</td>
<td>power/torque</td>
<td>Improved</td>
</tr>
</tbody>
</table>

*These development vehicle and engine test results demonstrate the potential of the DI-CNG technology: they meet the project objectives*
b. Environmental impact

In the previous chapter the vehicle emissions (called tank to wheel emissions) were analysed to demonstrate the environmental benefits of the technology. The LCA analyses allows a larger view of emissions as it includes the energy supply path (called well to tank) and the environmental impact generated by manufacturing and recycling of the vehicle.

The graph here above shows the well-to-wheel CO_2 footprint. It is calculated for DI-CNG vehicles powered by natural gas or bio-methane and compared to a GDI application. A further reduction of WtW emissions can be expected when using “e-gas”. The calculation based on TtW emissions leads to the conclusion that annual CO_2 savings of 600-700 kTon CO_2 can be achieved for a fleet of 1 million NGVs with an annual mileage of 20,000km. The environmental impact strongly depends on the growth of NGV market. Furthermore it is closely coupled to the use of bio-methane instead of natural gas.

The LCA study revealed that the production process of the injector has a reduced environmental impact compared to a gasoline injector. In particular:

- 22% Electrical energy savings during injector assembly.
- 7% less GHG emissions generated by the lower consumption of electrical energy.
- No consumption of Stoddard during the injector assembly.
c. **Socio-economic impact**

The deployment and acceptance of alternative energy sources and powertrain technologies may be driven by social efforts for decarbonisation. In order to gain large public acceptance, those alternative technologies must meet the legal requirements while being equally comfortable and affordable than established technologies based on fossil energy sources. They need to offer significant CO₂ and GHG reduction, low levels of pollutants - to avoid city bans-, and ultimately be powered by fuels made from renewables respectively renewable energy.

Natural gas combustion generates very low levels of particulates. Further development of DI-CNG engine calibration and strategies for fast heating of catalytic converter is required to ensure that NOₓ, CO and hydrocarbon specifications are met. In that case DI-CNG vehicles can reduce the local pollution. Such DI-CNG vehicles don’t need to be banned from urban areas that are impacted by bad air quality.

The major hurdle for monovalent DI-CNG vehicles remains the lack of fuelling infrastructure. The DI-CNG engines are optimized for operation on methane gas. The on board gas tanks are designed for an autonomy of more than 500 km. The regulatory framework work for deployment of CNG fuelling infrastructure and production of bio-methane appears not appropriate to support a strong growth scenario for NGVs.

---

4. **TRANSFERABILITY OF PROJECT’S RESULTS**

The Life DI-CNG project achieved:

- **Industrialization and validation of the DI-CNG injector.**
- **Demonstration of the system being compliant to post 2020 CO₂ requirements and toxic emission regulations.**
- **Demonstration of a net positive effect on the carbon footprint over lifetime.**

These are major prerequisites for a potential market uptake. All efforts made during the project led towards product readiness and identified obstacles of technical nature; in the gas filling station net in Europe and in the large scale deployment of the powertrain technology.

All project results will be applied to make the DI-CNG technology a “clean and green” alternative to current powertrains in road transport.