200 BAR in a Lightweight Construction Tank

New Production Practices are Geared Towards Making Natural Gas Vehicles More Competitive

By Gundolf Kopp, Roland Schöll and Julia Förster

Why is there still only a small number of environmentally friendly natural gas vehicles? The answer is simple: Natural gas vehicles are more expensive than conventional vehicles. It costs manufacturers between 1,000 and 2,500 Euros to integrate the high-pressure tanks designed for natural gas compressed at 200 bar into vehicles. Engineers at the DLR Institute of Vehicle Concepts' Department for Lightweight and Hybrid Design Methods are working with new materials, production methods and many partners from the industry in order to create a cheaper and lighter solution.

Using natural gas as a fuel for combustion engines is not a new idea at all. The first combustion engines in the 19th century were already based on the principle of stationary gas engines. This principle is still used today in block heating stations. The advantages of gas combustion engines? Low CO_2 emissions and lower sulfur dioxide, soot and other particulate emissions compared to combustion engines that burn liquid fuels.

If we were already able to use natural gas to a greater degree in transport today, the advantages would be plentiful. Not only would it reduce CO_2 emissions, but it would also prolong the availability of fossil fuels and additionally be a pacemaker technology that could advance the utilization of renewable energies. This last aspect is owed to the fact that the properties of compressed natural gas (CNG) are very similar to those of alternative energies such as biogas or hydrogen.

Natural gas could basically replace conventional fossil fuels such as petrol or diesel. According to a study conducted by the consulting firm Roland Berger, the total fleet of natural gas vehicles in Germany will increase to 360,000 by the year 2010. However, in spite of the potential for development that the study predicts for natural gas vehicles and despite the obvious advantages for the environment, only very few natural gas vehicles have been produced and sold to date. This is just as much true for Germany as for the rest of the world.

It is partly a monetary issue which is causing only such a small amount of natural gas vehicles to be on the road today. Many people are deterred from buying a natural gas vehicle because of its higher price. The more difficult storage of compressed gaseous fuels in high-pressure tanks causes an increase in production costs of 1,000 to 2,500 Euros per vehicle compared to conventional cars.

The core issue can be easily described: If the gas is left at ambient pressure, it will fill a volume which is approximately one thousand times larger than the volume of a liquid fuel that delivers the same amount of energy. There are thus no alternatives to liquefying or compressing the gases at a high pressure. Since our entire gas supply is based upon gaseous natural gas, the high-pressure approach is much more promising in practice and is already a reality at gas stations that store and offer gas at a pressure of 200 bar. But still, the volume requirement of natural gas is two to three times higher when compared to liquid fuels with the same energy content.

This relationship characterizes the starting point or even the starting line of the DLR project "DLR-Gas-Tank." The goal is to reduce the disadvantages of the increased volume requirement: Compared to the conventional steel gas tank, the mass of the tank is to be reduced by 30 percent and the space requirements for packaging are to be reduced by 35% in relation to the same filling volume. The production costs should be reduced by up to 25 percent. A total of nine project partners, of which six

Driving lighter for less CO_2

Since the year 2005, the German Aerospace Center (DLR), the Fraunhofer Gesellschaft and the University of Karlsruhe have been closely cooperating in the area of lightweight vehicle construction within the research alliance "Competence Center for Lightweight Vehicle Construction" with a focus on fiber compound materials. The research alliance has set itself the goal of significantly reducing the energy consumption of a vehicle and the associated CO_2 emissions by reducing drive resistances. This also represents an obligatory research theme for Volkswagen.

The Institute of Vehicle Concepts is therefore coordinating the DLR's activities in the field of transport in Stuttgart and is also involved in the Volkswagen coordinated EU project "Super Light Car." This project researches into and evaluates innovative construction methods and vehicle concepts, for example, vehicles with highly integrated and cost-effective magnesium constructions.

DLR scientists are working as development partner on strategies that enable the employment of the right material in the right place – multi-material design is the buzzword here. In this project, the depth of the research, which ranges from conceptual design through to simulation and the demonstration of concepts in suitable test environments, is a core competence feature.

Technically, multi-material design enables a 30 to 40 percent reduction of vehicle chassis weight with the same level of safety and comfort. When calculated in terms of a mid-sized vehicle, this weight reduction equates to a saving of 10 valuable grams of CO_2 emissions in the European driving cycle. In the customers' eyes, these advantages are even more appealing!

Dr. Martin Goede, Volkswagen head of the project "Super Light Car"

are from the industry and three from science, are working on the project which is funded as a lead project by the Ministry of Economic Affairs of the State of Baden-Württemberg. Its full name is "Innovative technologies for the creation of load-bearing lightweight construction elements made from short fiber enhanced thermoplastic with continuous filament strengthening using the example of a CNG tank (LLBT)."

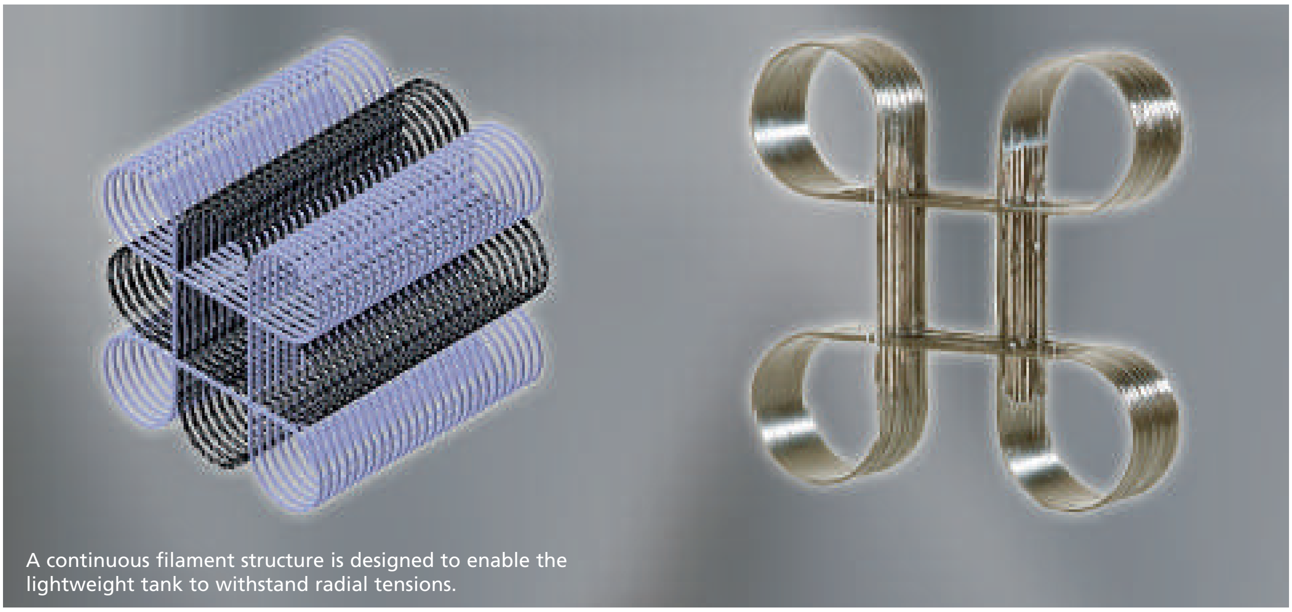
The basic body of current CNG tanks is made from steel. They are consequently heavier and can only be integrated with difficulty into the package of existing series production vehicles due to their classic gas-bottle resembling cylindrical shape. The weight problem can be solved using fiber-reinforced materials that are produced using the so-called wet winding method for fiber-reinforced thermosetting plastics. However, this production method leads to long cycle times and thus high manufacturing costs and does not solve the packaging problem.

The project partners are thus approaching the new tank structure in very different ways. They have drawn up a system that is based upon individual honeycombs which can vary in length and diameter and can thus be integrated more easily into the existing vehicle package. Vehicle developers hence have more liberty in creating new chassis concepts, the packaging can be more easily optimized and the weight of the car can be reduced. This is an important step toward considerably reducing energy consumption and CO_2 emissions from cars.

However, this system cannot be realized using either the currently employed winding techniques or any other conventional method of compound material technology. Instead, the engineers want to produce the tanks from short fiber strengthened plastics using a die-casting production method. This can achieve lighter components and thus more cost-effective series production. There is one catch, however: So far, no sufficient failure criterion exists for a short fiber strengthened plastic, especially not for multi-axle loads like the ones exerted in a high pressure tank. In other words, there is no reliable knowledge that describes in what way this new plastic needs to be created in order for it to fulfill all requirements safely.

The engineers are provided with this knowledge from a test unit which is being tested under a double-axis load and different temperatures at the Fraunhofer Institute for Mechanics of Materials (FhG-IWM) in Freiburg.

An important issue is optimizing the orientation of the short fibers in the plastic. Their orientation depends on the die-casting production process, which needs to be controlled accordingly. The tank also requires a further



A continuous filament structure is designed to enable the lightweight tank to withstand radial tensions.

component. For gas pressure tanks, the tensions in the circumferential direction are much stronger than in the longitudinal direction and the short fiber strengthened thermoplastics cannot withstand these tensions on their own. They are to receive help from carbon fibers that are manufactured as continuous filaments in a loop shape and that are integrated into the honeycomb structure of the tank.

The continuous filament structure will be able to withstand the exerted circumferential tensions. Using the test subjects, the DLR engineers participating in the project and their partners have already been able to prove that this continuous filament structure can in principle be manufactured.

The conditions for a "new" tank are thus not that bad at all. The project partners are now using the test items to analyze how the honeycombs can be created using the die-casting method and how continuous filaments and short fiber reinforced thermoplastics connect to each other. This is an essential issue because of the requirements with regard to load transmissions between the two components. Several simulations and experimental analyses are still required with regard to the issue of how the short fiber orientation and the continuous filament strengthened elements can be optimally adjusted towards each other.

The road to success in finding the solutions is, obviously, rather long and slippery. In today's day and age, however, it is only such roads which lead to the development of true innovations. At the finishing line, we will be rewarded with new possibilities and new vehicle concepts, DLR technologies for alternative fuels and the vehicle of the future.

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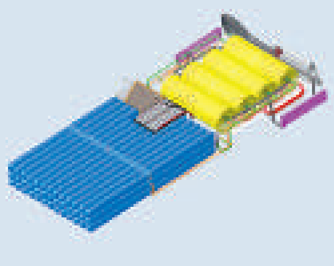
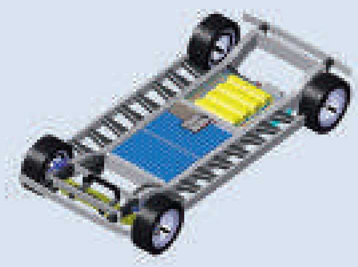
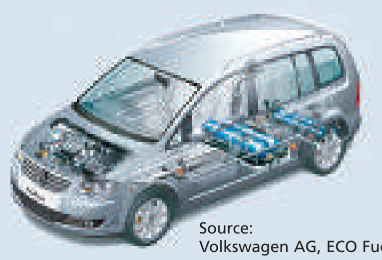


Package-optimized drive train module with DLR gas tank structure (blue) and free-piston linear generators (yellow)



Integrated drive train module with a safety bottom structure and lateral fiber compound crash elements (black)



Source:
Volkswagen AG, ECO Fuel

Contemporary series production car by Volkswagen with conventional steel bottles for storing CNG (Compressed Natural Gas)