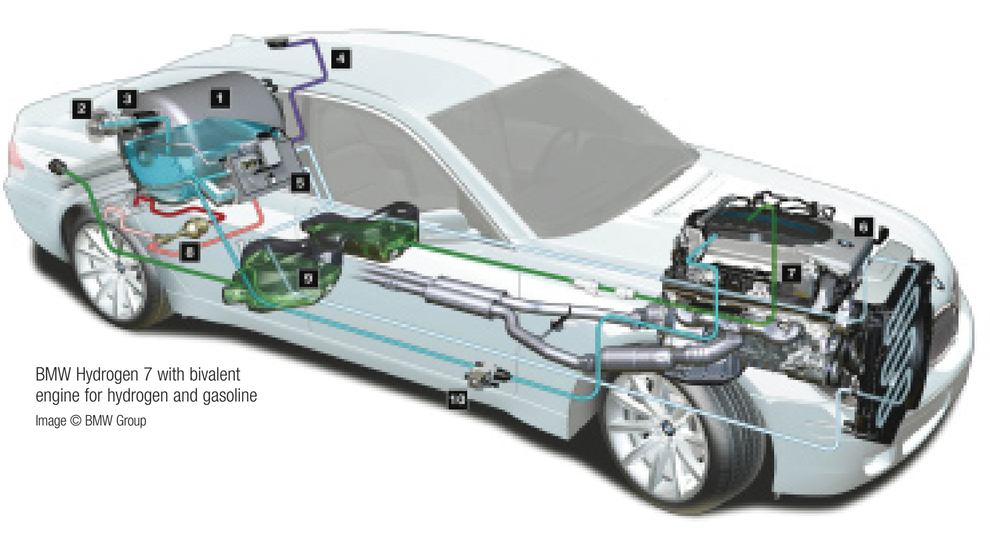
The **Future** of **Fuel**

A European research project is developing internal combustion engines powered by hydrogen.

By Jorge Ferreira, ANSYS, Inc.

Commercially available reserves of fossil fuels are fast running out, and the influence of harmful automobile emissions on the global climate is an ongoing debate. For these and other reasons, researchers and developers have been involved in investigating alternative fuels for the automotive industry. Fuel cells and electric cars are possible alternatives to today's cars and trucks, which are powered by fossil fuels; however, these technologies face some disadvantages, such as limited power dynamics and unsatisfactory power–weight ratios. As another alternative, the internal combustion (IC) engine itself offers many promising solutions if it is fueled by hydrogen. One benefit of hydrogen is that it can be produced from water and a renewable energy source, such as solar power. The main emission that results from this type of process is water vapor, making hydrogen a positive alternative fuel that has the potential for reducing carbon dioxide emissions.

Using trial runs and miniature models, many truck and automobile manufacturers, including BMW, MAN and Ford, have examined what can be done with alternative fuels. The research to date has been conducted mostly on bivalent systems — engines that can use two types of fuels — with most experiments using fossil fuels and hydrogen. The BMW Hydrogen 7™ luxury performance automobile is capable of running on either hydrogen or gasoline. Such mixed use of fossil fuels and hydrogen has the advantage of extending the range of today's cars as compared to pure hydrogen-fueled cars. However, a number of disadvantages arise when using one engine design for multiple and very different fuels. The engine is not optimized for hydrogen nor for gasoline or diesel consumption, meaning that efficiency cannot be optimized. When compared to gasoline and diesel, hydrogen has a good deal of variation in physical attributes, such as density, evaporative characteristics and combustion behavior. As these types of factors have a direct effect on engine performance, it is clear that if hydrogen were



BMW Hydrogen 7 with bivalent engine for hydrogen and gasoline
Image © BMW Group

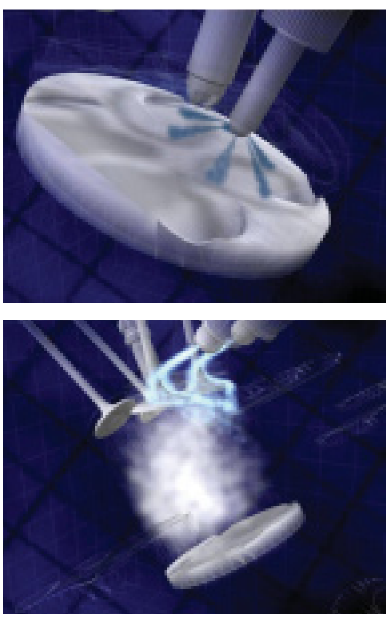
1 LH_2 Fuel Tank
2 LH_2 Tank Cover
3 LH_2 Tank Coupling
4 Safety Line to Blow Valve
5 Auxiliary Units Capsule containing Heat Exchanger for H_2 and Control Unit of the Tank
6 Bivalent Internal Combustion Engine (H_2/Gasoline)
7 Intake Manifold with H_2-Rail
8 Boil-Off-Management-System (BMS)
9 Gasoline Tank
10 Pressure Control Valve

- GH_2 Feed Line
- Boil-Off Pipe
- Safety Blow-Valve Feed Line
- Exhaust Pipe BMS
- Air Inlet BMS
- Water Cooling Cycle
- Gasoline Pipe

used to replace gasoline or diesel fuel in an engine designed for those fuels, there would be a loss of fuel efficiency and engine effectiveness.

In order to properly take advantage of the characteristics of hydrogen as a fuel, a hydrogen-powered engine must be built from the ground up. This was the goal of the European Commission-funded Hydrogen Internal Combustion Engine (HyICE) research project, a three-year effort aimed at designing a clean automobile engine. This initiative led to the development of a hydrogen-powered IC engine that offers significant advantages in terms of cost and power as compared with other systems. The project team, co-ordinated by the BMW Research and Technology Group, comprised automobile manufacturers, automotive suppliers and two universities. Already, the group has shared its results and experiences with partners in the United States; in 2003, the United States and the European Union agreed to collaborate on speeding up the development of the hydrogen economy.

An important consideration for the project was the customization and improvement of appropriate simulation tools for the hydrogen-based combustion process, in order to support the future mass production of engines. ANSYS CFX computational fluid dynamics (CFD) software was selected as the main commercial CFD platform, because it already was employed by many of the project participants and because the software could be customized for the specific needs of the effort.

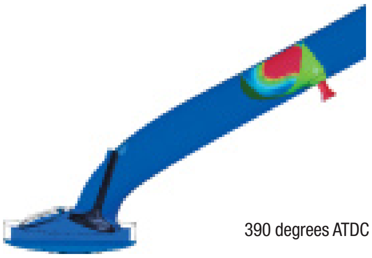


Two injection methods examined under the HyICE project: (top) direct injection of high-pressure hydrogen and (bottom) port injection using cryogenic hydrogen
Image © BMW Group

When designing the simulation model, special attention was paid to the specifics of hydrogen combustion. HyICE studied two different methods for fuel injection and, therefore, developed two different simulation models. For the cryogenic method, already in use as a bivalent solution, hydrogen was mixed with oxygen in the inlet port before it entered the cylinder, at which point it was compressed and ignited. In the direct injection method, hydrogen was injected directly and at high pressure into the cylinder and subsequently ignited. Hydrogen combustion is much faster than that of fossil fuels and occurs under higher pressures. Experts from ANSYS, Inc. implemented and tested different sets of models for their numerical stability and accuracy. These were compared with experimental data.

Because the ignition process takes only a few milliseconds to occur, the team developed a quasi-one-dimensional combustion/ignition model to simulate this behavior. A full 3-D simulation of the combustion process then was developed based on the solution provided by the ignition model.

The goal behind using CFD for the HyICE project was to accelerate the development process, though another goal focused on the design of a reliable and validated simulation solution for future development projects. These goals were achieved. The agreement of the simulation results with experimental data, especially in the areas of temperature and pressure distribution, was excellent. The extensions and modifications to the software made in the course of the HyICE project can be applied to conventional engines as well. ■



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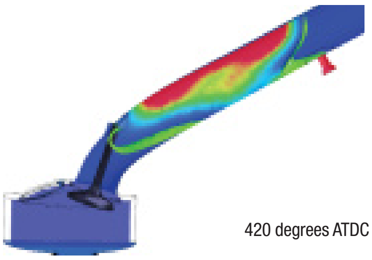

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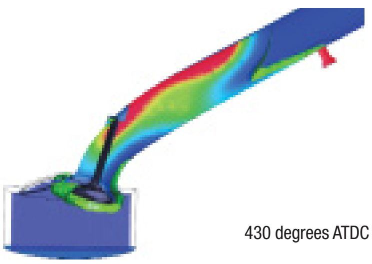

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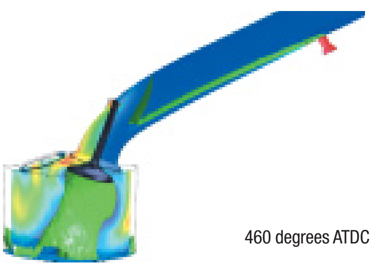

460 degrees ATDC

Cryogenic port injection plots show hydrogen mass fraction and motion of hydrogen as it flows into the cylinder during the intake stroke of the engine.
As the intake valve opens and the piston drops down away from the valves, the piston motion draws the fuel air mixture in through the intake port.