A VCR, high-efficiency, hydrogen-gasoline engine

The combination of a novel variable compression ratio system and hydrogen fueling presents an ideal solution for automotive decarbonization

The automotive sector is under mounting pressure to meet the European Union's stringent CO_2 targets: a fleet average of 49.5g/km by 2030 and zero emissions by 2035. With OEMs facing fines of €95 (US$98.5) for every gram of CO_2 exceeding the limits per vehicle, alternative solutions have become essential.

Although battery-electric vehicles were once expected to dominate the transition, slower-than-anticipated EV adoption, limitations in charging infrastructure and high production costs have spurred the search for viable alternatives. The Gomecsys VCR-H engine offers a flexible pathway by employing a variable compression ratio (VCR) powertrain capable of operating on both hydrogen and gasoline. This dual-fuel approach not only facilitates significant CO_2 reduction but also preserves performance, efficiency and cost-effectiveness. Moreover, Western OEMs face fierce competition from Chinese electric vehicles – which benefit from lower production costs and governmental control over critical minerals – making a diversified strategy indispensable.

THE VCR-H ENGINE CONCEPT

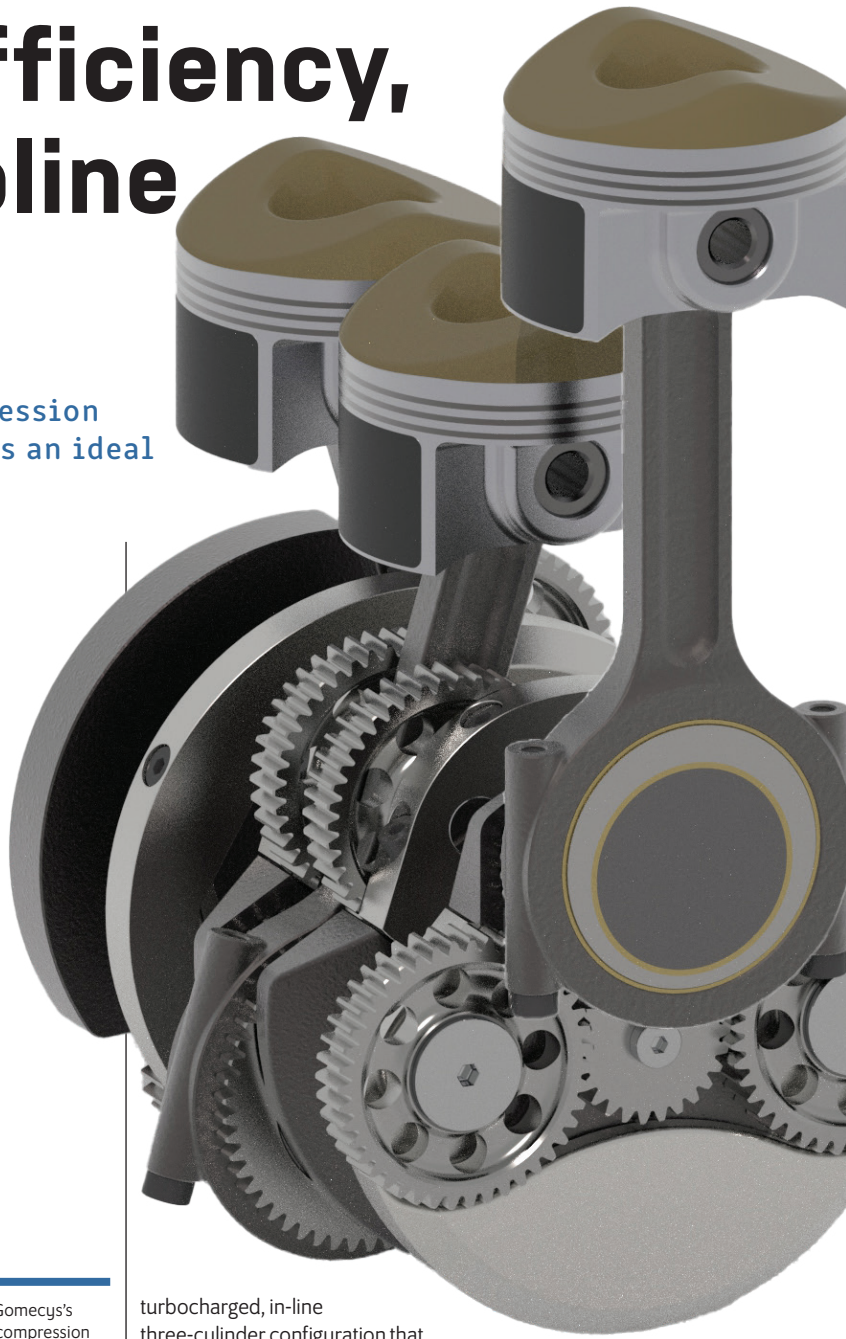
Gomecsys – a Dutch engineering company with extensive experience in developing VCR technology for combustion engines – upgraded its VCR system in 2024 for heavy-duty diesel applications. The upgrade uses a double gear drive for the eccentrics of each cylinder. This double gear drive also uses a larger sun gear, making the overall load capacity of the VCR gear three to four times stronger than previous versions.

In the VCR-H concept, Gomecsys uses an eccentric with 3mm eccentricity, which results in a variation in TDC of 6mm, permitting variable use of all compression ratios between 24:1 and 10:1. The bore and stroke of the demonstrator engine is 84 x 98mm but the VCR system can be integrated in any I3 engine already in mass production.

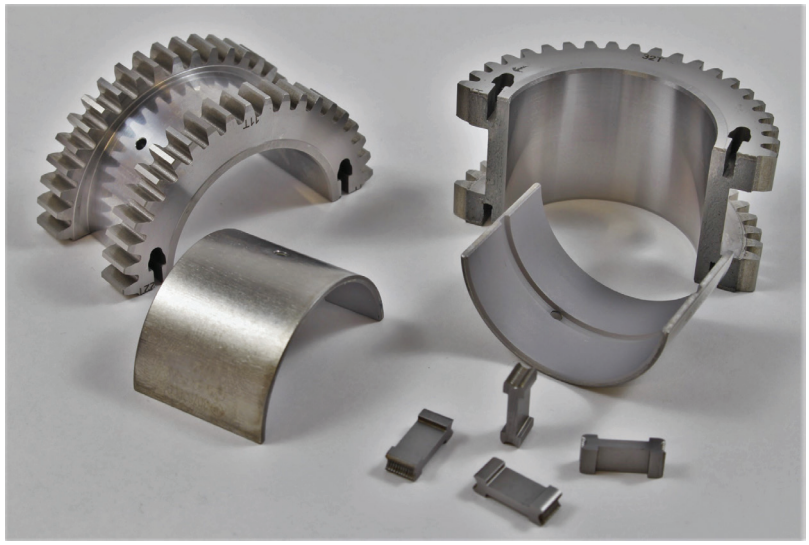
During initial testing with 100% hydrogen, engineers at Gomecsys were impressed by the four times faster flame speed than could be achieved with gasoline, which enables lean-mixture operation. In practical terms, when operating at Lambda 2, an engine fueled with hydrogen exhibits zero CO, zero hydrocarbons, almost zero NO_x and, most notably, zero CO_2 emissions.

The innovative design of the VCR-H engine features a turbocharged, in-line three-cylinder configuration that employs a diesel-like combustion process using high-pressure direct injection of hydrogen at a high compression ratio of 24:1 to 18:1 during part-load conditions, thereby significantly enhancing efficiency. At higher loads, the engine transitions to using gasoline port injection with compression ratios ranging between 13:1 and 10:1. A blend of hydrogen and gasoline is also available during part-load operation, with compression ratios adjusted between 18:1 and 13:1.

An in-house-developed hydraulic VCR actuator ensures that the shift from 24:1 to 10:1 compression ratio goes smoothly and in just 0.15 seconds. This flexibility enables the engine to meet regulatory



Above: Gomecys's variable compression ratio engine has been adapted and proven for use with hydrogen



demands while reducing the need for larger hydrogen storage, all while leveraging existing gasoline infrastructure.

OPERATING MODES

In the first operating mode, the engine runs solely on hydrogen using a diesel-like diffusion combustion process at compression ratios between 24:1 and 18:1. This spark-assisted diffusion combustion mode is employed only during part-load conditions – up to 8 bar BMEP – when the hydrogen tank pressure exceeds 150 bar. In this setting, a high-pressure direct injection at 150 bar near top dead center enables ultra-lean combustion that yields zero CO, zero hydrocarbons and nearly zero NO_x emissions. In this part-load mode, the VCR-H concept beats a diesel engine at its own game, not only operating at higher compression ratios and with lower friction levels but also using the high pressure of hydrogen in the H_2 tank, because the H_2 is injected with 150 bar in TDC firing.

The second mode involves an average blending of 50% hydrogen and 50% gasoline under lean-burn spark-ignition conditions, with compression ratios set between 18:1 and 13:1 during part-load operation when hydrogen tank pressure is below 150 bar. Low-pressure hydrogen injection at 10 bar during the intake stroke ensure exhaust temperatures remain above 400°C for optimal three-way catalyst performance. This approach delivers around a 60% reduction in CO_2 emissions compared with a standard gasoline engine, and improves efficiency by roughly 20% over fixed compression ratio designs.

In this second mode, cold start and very low loads up to 1.5 bar BMEP is still performed with 100% hydrogen (lean); at higher part loads, the percentage of hydrogen is much lower than 50%.

In the third operating mode, the engine runs exclusively on gasoline using standard spark ignition at compression ratios from 13:1 to 10:1 under high-load conditions (8 to 20 bar BMEP). Turbocharging enhances power output; port injection, coupled with conventional three-way catalyst aftertreatment, results in an efficiency improvement of about 5% over traditional gasoline engines. During most drive cycles, high load efficiencies are not the biggest problem – it's part load that is used 90% of the time, representing 70% of the energy consumption.

KEY TECHNICAL FEATURES

The engine's variable compression ratio, is central to using diffusion combustion for hydrogen in part load operation, which is key to realizing a major improvement in part load efficiency, and low-cost port injected gasoline operation for full load, with only a three-way catalyst for meeting emission regulations.

Above: The heart of Gomecys's engine concept, the eccentric crankshaft gears and associated bearings

High-pressure direct hydrogen injection at 150 bar supports stable, spark-ignited diffusion combustion, and turbocharging ensures that peak power demands are met economically in gasoline mode.

CO_2 REDUCTION AND REGULATORY COMPLIANCE

Designed to align with the EU's stringent emissions standards, the VCR-H engine offers a practical solution for OEMs seeking to avoid heavy fines. Simulations based on the WLTP cycle for a 1,200kg vehicle equipped with a 1.5 liter three-cylinder turbocharged gasoline engine – which typically consumes 5.5 l/100km and emits 125 g/km of CO_2 – indicate that the VCR-H system can reduce CO_2 emissions to 46g/km, representing an approximately 63% reduction from 125g.

In the WLTP, hydrogen consumption is 0.7 kg/100km and gasoline consumption is 2.0 l/100km. Brake thermal efficiencies of roughly 30% in hydrogen part-load mode, 24% in the hydrogen-gasoline blend part-load mode and 40% in the gasoline high-load mode are achieved. When a high-pressure hydrogen pump is used in the hydrogen-only and gasoline modes, CO_2 emissions can be reduced further to 36g/km. With a 5kg, 120-liter, 700-bar hydrogen tank and a 16-liter gasoline tank, the system delivers an impressive range of 800km.

COMPETITIVE ADVANTAGES AND OUTLOOK

The VCR-H engine's ability to deliver zero-CO_2 emissions in hydrogen-only mode, along with a 63% reduction in the WLTP, positions it as a compelling alternative to meet tightening EU emissions standards. The technology avoids the substantial fines associated with CO_2 over-emission while using the existing gasoline infrastructure, making it an economically viable solution for OEMs. The engine's flexible dual-fuel operation supports a transitional strategy toward full zero-emission mobility without a complete shift to battery-electric vehicles. Future developments will focus on prototype testing, forging partnerships with OEMs and integrating the technology into commercial production. ⊙

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