# SPECTRUM

**Technology Highlights and R & D Activities at FEV**

**Issue 38, September 2008**


30 years FEV


## One World – One Dream

One World – One Dream! Under this motto, the world is looking to Beijing where the Olympic Games are featuring the world's best athletes in their pursuit to determine the best.

### SUMMARY



For the last seven years China has been preparing for this big event to demonstrate its capabilities and to welcome people from all over the world. Since FEV has witnessed the breath-taking development in this country for a long time, we know that China's evolution is not only about sports and architecture. China has become one of the biggest vehicle markets and has developed into a partner in an ever-expanding global automotive industry. Consequently, it's no surprise that new technologies are on their way to the customers in China.

**Similar to the athletes, the automotive world is also in the pursuit of One Dream:** It is the automotive world's dream to provide the best powertrain solution that would answer the questions of providing mobility that is sustainable, affordable and ecological. The Chinese government is committed to the idea that the answers to these questions provide advanced powertrain solutions. Therefore, the development of Hybrid Electric Vehicles (HEV) is strongly promoted and almost all of the car manufacturers are motivated to work on ambitious development programs. ▶

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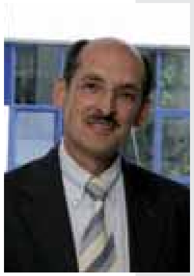
## Preface



Dear Spectrum reader,

Are we currently experiencing a paradigm shift in powertrain technology?

Persistently high oil prices combined with uncertainties about the problem of $CO_2$ emissions and the growing desire for mobility in emerging nations are having a significant impact on the assessment of present and future powertrain strategies. The widespread consensus among the general public that a conventional automobile represents the ideal solution is losing ground. Everyone now is talking about electric cars.

Development of electric cars over the next few years will change them from being a niche item into a standard production vehicle. This trend will be accelerated by politically-determined boundary conditions. This does not mean the end of the internal combustion engine, but it is indication that alternatives are gaining ground in some areas of applications.

FEV is well equipped for the future. We are leaders in the development of hybrid powertrains, including plug-in hybrids as a stage of this electrification process. A great deal of research and development is going into the optimization of the electric motor and the control technology, and into the integration of electric motors in the transmission. Combustion engines are being adapted to the new operating conditions by becoming a means to extend the vehicle's range. FEV is also engaged in the development of batteries. These technologies are among our many services which our satisfied customers use.

The reality of what is taking place here is not a paradigm shift, but rather it is a step-by-step development aimed at satisfying the worldwide desire for mobility.

Yours faithfully

Dr.-Ing. Ernst Scheid
Executive Vice President



▶ One of the most important car manufacturers in China is the ChangAn Automobile (Group) Co. Ltd., located in ChongQing. ChangAn started its HEV development years ago and after some conceptual work in early 2006 they decided to prepare for the regular production of HEV vehicles by the end of 2008.

The overall development targets were easy to define: realize a considerable improvement in fuel economy, improve driving performance (fun-to-drive) and meet the market's requirements for safety and reliability.

It has always been important to ChangAn to offer products to the Chinese market that the Chinese customers can afford. This is why one of the most challenging aspects of this development has become the integration of local suppliers for many of the HEV's components. For FEV this meant intensive communication and interaction with new players in the automotive market.

The development task started with a Concept Phase, where all of boundary conditions were taken into account. Key suppliers had to be nominated and the initial specifications for the main components and systems had to be issued. Simultaneously, cooperation was established between ChangAn's highly motivated engineering team and FEV's experienced specialists. Simulation work was started to establish a clear break-down of the development targets, with additional CAE work being performed to address critical issues, packaging design work had to be performed, specifications were worked out and relationships with the nominated suppliers were established.


The concept was agreed to include an Integrated Starter/Generator (ISG) and a 144V Nickel-Metal-Hydride (NiMH) battery that would enable the vehicle to apply stop-start functionality, regenerative braking and boosting during vehicle acceleration. The challenge was established to achieve a 20 % mileage gain, derived from the hybridization as well as from the downsizing of the engine. Due to the boosting capability of the HEV system, the established performance levels could be achieved with a 1.5L gasoline engine, instead of the larger displacement baseline power source.

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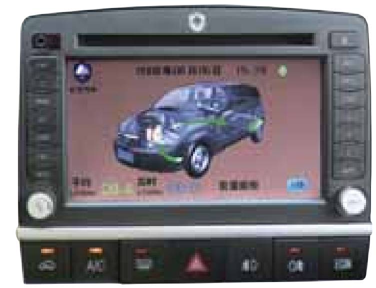
After this phase, a first set of A-sample vehicles was launched. The results were promising. All targets proved to be feasible and the further development steps were initiated without delay. For the next release, the focus was turned towards regular production-oriented aspects. The first step of this phase required a diagnostic concept to be defined and implemented. Again, this work must follow the boundary conditions of the Chinese market. Another new software module in the Hybrid Control Unit (HCU) was dedicated to an end-of-line test of the vehicle, which can be integrated into ChangAn's conventional vehicle assembly line.



B-sample vehicles, including these additional functionalities, were successfully tested under winter, summer and high altitude conditions during various developmental test trips. During the beginning of 2008, the idea to demonstrate the potential of ChangAn's HEV development during the August 2008 Beijing Olympic Games was established. A fleet of 25 vehicles were constructed and were ready for delivery in June to Beijing, where they started their public service as taxis. For the development program, this fleet is contributing considerably to the validation process.

Inside FEV, the project is integrated into a knowledge-based HEV networking program, which has qualified FEV as one of the most acknowledged engineering partners for Hybrid Technology. Projects like this have initiated a lot of internal efforts inside FEV. Within our internally funded research programs, we have ramped up new test facilities, which are exclusively dedicated to HEV development activities. Now, we are covering almost all aspects of hybridization from software to hardware and from tailored combustion engine layout through to the electric components, including the development of battery system that was recently presented in FEV Spectrum Issue 37.

We are proud having the opportunity to support ChangAn and the experience to provide our contribution to the Beijing Olympics. We are also quite pleased with the lessons-learned, which we have gathered during the last two years of cooperation with ChangAn in this exciting project.

By the end of August 2008, the athletes will enjoy their success or will be recovering for their next attempt in 2012. For FEV, the challenge is ongoing. If you want us be involved in your pursuit, let us know!

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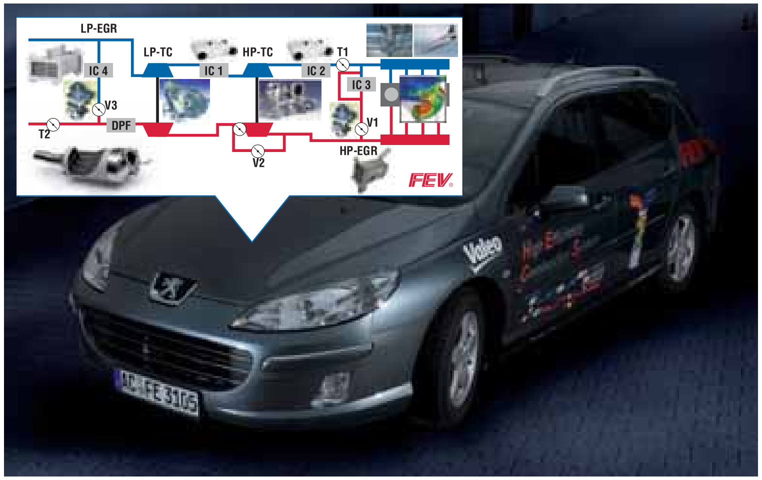


# Modern Diesel Engine Performance Potential with the Lowest Raw Emissions

Within the last couple of decades, the modern DI diesel engine has proven to be an economical and attractive alternative in the modern passenger car segment. This is attributable to its higher process efficiency and torque characteristics. The recent rise in consumer acceptance of the DI diesel engine is a result of improved drivability and acoustics, which has contributed to the reduction of fleet fuel consumption as a part of the ACEA voluntary commitment. This has been achieved by maintaining its traditionally low fuel consumption, while also fulfilling strict emission regulations. The combination of recent indications of climate change that are linked to the use of fossil fuels and the rising fuel prices, has brought fuel consumption into the limelight for the entire spectrum of manufacturers and their development teams.

To meet the continuously increasing demands resulting from this situation, the combustion system also needs to be redesigned. This measure is necessary, so that the disadvantages of exhaust aftertreatment systems (for example, DPF) can be minimized through significantly reduced engine-out emissions, thereby raising fuel efficiency. FEV analyzed all of the design parameters of the diesel combustion system in detail and evaluated them for future demands. The solution became the development of the FEV combustion system, **HECS** (**H**igh **E**fficiency **C**ombustion **S**ystem), which is designed and tailored for high EGR tolerance, combining low nitrogen oxide emissions with superior fuel efficiency, even under high part load conditions.

**The following are the primary elements of this optimized combustion system layout:**

- Optimization of mixture formation (fuel injection and swirl)
- Improved cylinder filling with optimized gas exchange (boosting, manifold layout and flow losses)
- Highly capable boosting system, in conjunction with a combined high pressure and low pressure EGR system
- Adjustment of the combustion chamber (geometry and compression ratio) to the air and fuel system capabilities
- Intensified cooling (Air and EGR)
- Implementation of a high performance glow plug system

The information gathered from the process analysis forms the foundation for the design of an in-house prototype engine. A commercially available 1.6L, 4-cylinder engine, with optimized components and subsystems, serves as the platform for this project (title figure). The appropriate application of the technology packages, permits the replacement of an equally powerful 2.2L 4-cylinder engine motor with the modified 1.6L aggregate that is fitted with two-stage exhaust gas turbocharging, thereby achieving maximal fuel saving.

The careful layout of the combustion chamber geometry, with the aid of modern CFD tools ensures an ideal air utilization even within the nominal speed range. The realization of air-fuel ratios of nearly 1.1 at engine speeds above 3500 rpm is proof of the significant improvement over the state-of-art. In comparison to the larger base engine, an improvement in low end torque is possible through the combination of carefully laid out process parameters, such as charge motion, spray pattern and piston bowl shape. In addition, flexible multiple injection and two-stage turbocharging also improve low end torque, in spite of the reduction in engine capacity. Improving the gas exchange and significantly lowering charge temperatures leads to a shift toward leaner air-fuel ratios. Substantially increased EGR rates result, which permit a major reduction in untreated emissions.

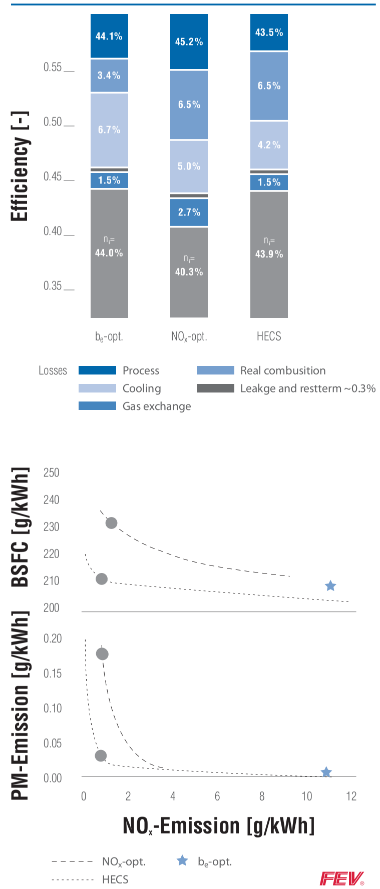


*Fig. 1: Emission Performance and Efficiency of the HECS Engine (Part Load Point @ ~2300 rpm)*

The improved $NO_x$/be trade-off can then be targeted separately from an improvement in the $NO_x$/PM trade-off. (s. Fig. 1).

The lowest possible $NO_x$ emissions can be obtained through the integration of a new, model-based control concept and the subsequent linking of these structures to innovative approaches to control combustion, with the help of an integrated pressure sensor and glow plug, allowing a near ideal configuration of combustion parameters. In addition, the considerably improved PM emissions guarantee longer regeneration intervals for the DPF, contributing to a further rise in fuel efficiency for everyday operation.

For the purpose of a complete analysis of the potential of diesel drivetrains, the improvements discussed thus far could be combined with developments in other areas. Therefore, the following aspects are of particular interest:

- Optimization of the mechanics and loss reduction (friction)
- Hybrid Development (start/stop, regeneration, power boost function)
- Vehicle improvements (weight, air and rolling resistance)
- Drivetrain optimization (losses in the gearbox and transmission ratios)

The HECS concept, in conjunction with the other technology concepts that are mentioned, could help realize a 40 % reduction in fuel consumption for a mid-sized car (vehicle class: 1590 kg/3500 lbs.) and result in the same or possibly even improved driving comfort.

We are working on a variety of projects to provide further increases in fuel efficiency and reduced emissions for diesel engines, in order to facilitate the customer's individual mobility. Apart from innovative concept vehicles and demonstrator vehicles, we are working on a variety of production development programs for the worldwide automotive market. We look forward to assisting you in achieving your goals.

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## FEV Spray-guided Turbocharged Vehicle – Reducing $CO_2$ Emissions

Spark ignition engine downsizing, when used in conjunction with the turbocharging, is currently considered to be a promising method for reducing $CO_2$ emissions. Using this concept, FEV has developed a new, highly efficient drivetrain to demonstrate fuel consumption reductions and driveability in a vehicle based on the Ford Focus ST. The newly designed 1.8L turbocharged gasoline engine incorporates infinitely variable intake and outlet control timing and direct fuel injection in a central location with piezo injectors. In addition, this engine uses a prototype FEV engine control system, with software that was developed and adapted entirely by FEV. The vehicle features a 160 kW engine with a maximum mean effective pressure of 22.4 bar. The CMD port plays a major part in depicting the required volumetric efficiency and the desired charging movement. The cooling of the cylinder head, in particular the injectors and spark plugs, was optimized using CAE design. Tests of the stratified combustion process on the engine testbed revealed potential fuel consumption reduction to about 310 g/kWh at an operating point of 2,000 rpm, 2 bar.

During the first stage, a new electrohydraulically actuated hybrid transmission with seven forward gears and one reverse gear and a single dry starting clutch will be integrated. The electric motor of the hybrid is directly connected to the gear set of the transmission. Utilizing the special gear set layout, the electric motor can provide boost during a change of gears, so that there is no interruption in traction. Therefore, the transmission system combines the advantages of a double clutch controlled gear change (gear change without an interruption in traction) with the efficient, cost-effective design of an automated manual transmission system. Additionally, the transmission provides a purely electric drive system and the operation of an air-conditioning compressor during the start/stop phases. Compared to the vehicle on which it is based with a 2.5L turbocharged engine and a manual six-speed transmission, computer simulations show a savings in fuel consumption for the downsizing concept with a 1.8L turbocharged engine and shift operation of 26 % and for a hybrid drivetrain a 34 % savings, which also offers improved performance.

One other alternative is through the use of CAI (Controlled Auto Ignition), which incorporates a process developed by FEV for controlled compression ignition. Due to the very low untreated emissions, CAI also makes it possible to avoid the complex aftertreatment of $NO_x$ emissions, while at the same time achieving a similar potential reduction in fuel consumption to that obtained with a stratified lean-burn operation.

Furthermore, the vehicle serves to demonstrate a variety of future transmission technologies for reducing $CO_2$, such as stratified engine operation ($\lambda > 1$), power EGR, various turbocharging techniques and ethanol operation. It also allows for the demonstration of the optimization of exhaust emission treatment concepts, such as $NO_x$ adsorber catalytic converters and SCR. The projected tests for $NO_x$ reduction using SCR provides a low-consumption alternative to $NO_x$ adsorber catalytic converter technology. The central injector position also provides the potential to fulfil the strict SULEV emission standards in $\lambda = 1$ operation, without additional exhaust emission treatment procedures.


*Fig. 1: Prototype Vehicle for Demonstrating Different $CO_2$ Reduction Technologies*

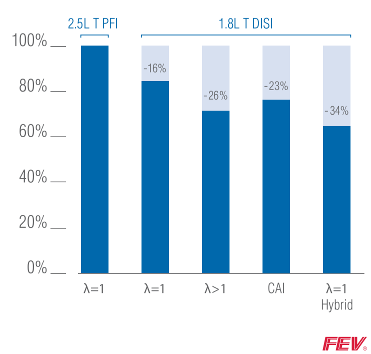


*Fig. 2: Potential $CO_2$ Reduction Values of the SGT Demonstrator Vehicle*

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## FEV Durability Test Center (DTC)

Following a 13 month period of construction, the FEV Durability Test Center had an initial start-up in July 2008, with 19 operational test benches. In October 2008 the remaining test benches that provide temperature and powertrain tests, which were a part of the initial start-up phase, will be ready for operation.

Brehna's modern test field architecture (s. Fig. 1) has allowed for the ramp-up of engine durability tests with special fuels (E85) and high power engines with more than 300 kW rated power have been operated in a full continuous mode. During separate tests, critical components from similar high performance engines were tested for mechanical functionality, using comprehensive measurement and analysis techniques. The efficient operation of tests are run at an average of more than 22 hours a day by approximately 90 experienced and trained employees in the test field and in the control room (s. Fig. 2).

**The new FEV Durability Test Center:**

- Usage of vehicle-original exhaust system incl. aftertreatment for longitudinal and transversal installation
- Legislative approval and technical compliance with environmental regulations for usage of special/future fuels (ethanol and methanol blends, biodiesel, …)
- Control room operating concept
- Fully continuous operation (365 days/year, 7 days/week, 24 h/day)
- Complete and through-going ressource planning (availability, maintainance demand, …)

**… for maximum efficiency in durability testing**

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## Boosting the Future: FEV Turbocharger Testbench

One of the main challenges of powertrain development is the reduction of $CO_2$ emissions. Downsizing in combination with boosting is a key technology to achieve future fuel efficiency targets for both diesel as well as gasoline engines.

In order to achieve similar or even better performance and drivability with a downsized engine, turbocharger matching and optimization are an integral part of today's engine development process. With its new hot gas turbocharger testbench, FEV adds an important tool to the complete optimization process of turbocharged engines from concept layout to testbench optimization and validation.

The testbench concept is based on a proven design, but additional features cover more advanced measurement tasks.

**Main test bench spesifications:**

- Mass flow range from 0.01 kg/sec to 1 kg/sec (Compact passenger cars to heavy-duty vehicles)
- High temperature capability up to 1200 °C
- High turbine expansion ratios up to 5
- Twin scroll turbine measurements with variation of the entry pressure ratio
- Separate control of the compressor flow to enlarge the turbine measurement range
- Fully automated data acquisition

The flexible testbench set-up allows for the generation of turbocharger maps according to all of the state-of-the-art boundary conditions, either for single-stage or multi-stage turbocharger systems. For new and advanced layouts of turbocharger system components, the direct link to CFD analysis and engine testing at FEV allows for a deep understanding of the interaction between engine and turbocharger systems.

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# Electric Vehicles – Plug-Ins with and without Range-Extender

The electrification of cars is rapidly moving forward. At the end of this evolution seems to be all-electric vehicles, which eliminate the local vehicle exhaust emissions, and the prime power supply is through re-charge over the electricity grid (plug-ins).

Previous attempts to develop and market electric vehicles were not very successful. One of the reasons was the limited available range of those vehicles. However, new battery technology reduce this issue, and offer a substantial increase in electric range. But, even today's battery technology will not provide the same vehicle drive range than a conventional gasoline-fueled vehicle. In order to overcome this hurdle in a step towards the all-electric vehicle, a Range-Extender electric vehicle provides the benefits of partial local zero emissions, combined with the advantage of a "normal" vehicle driving range. In this combination, an internal combustion engine serves as additional power source, should the battery power not be sufficient to drive the vehicle (s. Fig. 1).

This push for pure electric or range-extender electric vehicles is particularly present in the US. Presently, tax incentives of up to US$ 7.000 per vehicle are being discussed.

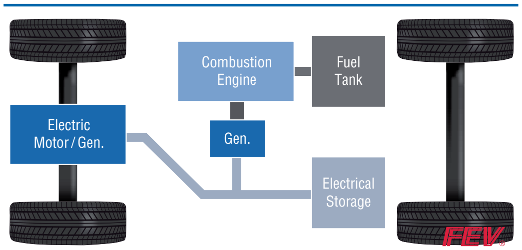


*Fig. 1: Range-Extender PHEV Concept*

Under these boundary conditions, the development of electric vehicles, either as pure electric or as range-extended vehicles with plug-in capability, has gained a tremendous momentum.
FEV has built and developed several such demonstrator vehicles for various customers. As this is new technology (batteries, electric motors, controls, etc.), no benchmark information exists, and no prior automotive experience can be utilized. Even completely new development processes and test equipment needs to be utilized. As an example, the electric traction motor needs to be tested and verified on a special test rig. In order to develop the traction motor system and its controls to the highest degree on such a test rig, it is necessary to include battery emulation capabilities, but also have the capability for the test rig to simulate regeneration. Based on the work done on such test rigs at FEV, the actual vehicle calibration time could be reduced to a few days, rather than weeks or months. Figure 2 shows one of FEV's electric motor test rigs.

With this new technology come completely new technical issues and challenges. For example, the complexity of the cooling system(s) increases significantly, the vehicle might now have up to 6 cooling circuits. Another technical challenge is the operating strategy of the combustion engine in case of the Range-Extended Electric Vehicle. As the engine has no mechanical connection to the wheels, only the generator demand determines the engine operating condition. The engine operating strategy is the subject of current optimization work, but depends on the actual vehicle and its customer drive cycle.

Based on experience with various vehicles at FEV, the plug-in capability has been demonstrated, with all-electric drive ranges in excess of 40 miles. Presently, several development programs with various customers are on-going. The next few months will see a lot of valuable information coming from such demonstrator vehicles.


*Fig. 2: FEV Electric Motor Test Rig*

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