# #79 SPECTRUM

## Dear readers,

In this issue of SPECTRUM, we put our focus on the wide range of services provided by FEV vehicle, our strong brand in the field of complete vehicle and component development.

On the following pages, we reveal interesting insights into future interior climate control systems and an interior concept that takes autonomous driving functions into account. We also take a close look at the development of vehicle attributes - a decisive factor for market success and customer acceptance in the context of global competition. This includes areas such as vehicle dynamics, aerodynamics and NVH, which are all covered in this issue of SPECTRUM.

In the area of off-highway vehicles, such as construction and agricultural machinery, $CO_2$ emission limits are expected to be introduced from around 2030. This will increase the pressure to further reduce $CO_2$ emissions. What needs to be considered here and how FEV can support your company with these challenges can be found in the chapter "Electrification off the road" from page 36. In another article, we explain methods for increasing capacity and efficiency while reducing costs in the rail industry, based on FEV's experience of more than 30 years in this field.

In addition, we present our approach to optimize engineering activities within the organization with the help of artificial intelligence (AI) and to ensure a uniform structure. This enables us to handle complex engineering tasks, creates time and cost benefits and allows us to achieve unprecedented levels of efficiency, accuracy and innovation for our customers.

Furthermore, we demonstrate how FEV can successfully meet the challenge of market introduction in a cost-efficient manner in the face of constantly changing global regulations.

We have also expanded the scope of our benchmarking services globally and present our activities combining detailed design, cost and material analysis with vehicle performance testing in a way that only FEV can do.

I wish you an exciting read about these and many other topics.

**Dr. Patrick Hupperich**
President and CEO of the
FEV Group

feel evolution

# CONTENT

The cabin air conditioning of modern battery electric vehicles (BEV) plays a particularly significant role in the development of thermal management solutions. In addition to customer expectations of interior comfort, this is primarily due to the considerable impact on the vehicle driving range. The challenge in the design of cabin conditioning systems therefore lies in resolving the conflict between electrical energy demands and thermal comfort.

For the further development of methods for cabin conditioning, FEV has built up a demonstrator vehicle and climate manikin for the assessment of thermal comfort in the interior, as part of an internal research project. The aim of the project is to be able to evaluate the performance of individual measures and develop operating strategies that enable efficient operation. In this article, the features of the demonstrator vehicle and the conceptual design of the climate manikin will be presented.

# #1
# More comfort with greater range – efficient ***interior climate control*** in battery electric vehicles

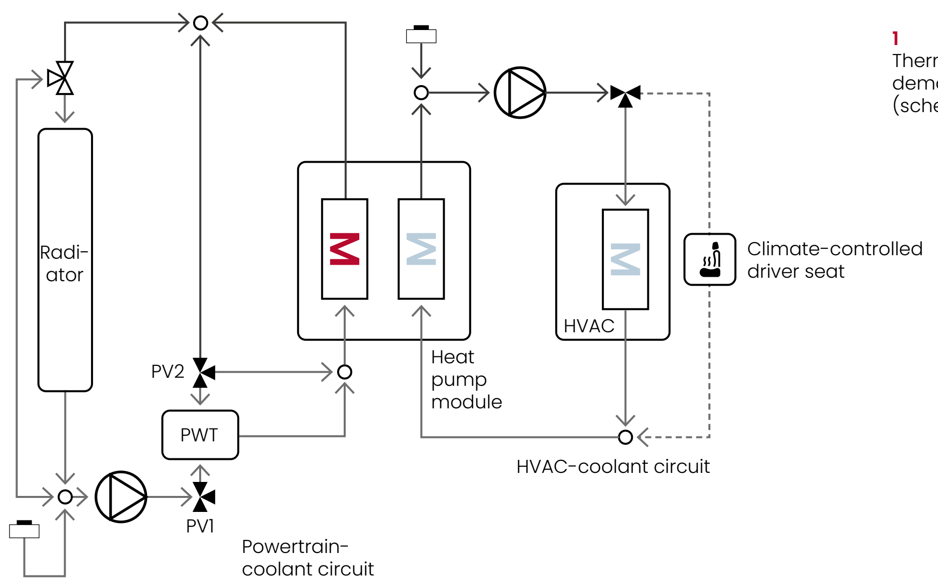
»Conditioning measures close to the body are one way of improving comfort in the interior in an energy-efficient manner.«

**Structure of the demonstrator vehicle**
An A-segment passenger vehicle was selected as the basis for the demonstrator vehicle. The main purpose of the demonstrator was to investigate the effect of different air conditioning measures on thermal comfort and energy efficiency under real operating conditions. The vehicle was equipped with a heat pump for air conditioning, radiant surfaces in the footwell area of the front row of seats, a steering wheel heater, a ventilated front passenger seat, and a driver's seat with coolant flowing through it.

As a first step, a heat pump module, operated with the refrigerant R1234yf and a 400V power supply, was integrated into the engine compartment of the vehicle. The various operating modes of the module enable active cooling and heating of the interior. Either the ambient air (fresh air mode) or the air drawn in from the cabin (recirculation mode) can be used for this via the HVAC (Heating, Ventilation and Air Conditioning) system. Figure 1 schematically shows the integration of the thermal system in the vehicle. The left part contains the powertrain circuit with radiator, drivetrain components (PWT), and the heat exchanger of the heat pump module. The two proportional valves (PV1 and PV2) distribute the coolant flow to the respective circuits, as required. This means that both the waste heat from the drivetrain components and the ambient air can be used for heat pump operation. This offers the potential to further increase the efficiency of the system. The right-hand side of the illustration shows the part of the thermal system that is connected to the heat exchanger in the HVAC. The included proportional valve (PV3) can selectively activate the fluidic seat conditioning in the driver's seat as desired.

In addition to the use of a heat pump, conditioning measures close to the body of the occupants are another way of improving comfort in the interior in an energy-efficient manner. Because of this, the driver and front passenger seats were each equipped with a different system. As previously indicated, the driver's seat was equipped with a fluidic seat conditioning unit. For this purpose, mats featuring capillary tubes were integrated into the backrest and seat surface of the driver's seat and then connected to the vehicle's thermal system. This enables seat conditioning regardless of the air temperature in the passenger compartment. Active seat ventilation is used for the front passenger seat. The air flow required for this is provided by a compact module that can be mounted under the seat. Integrated Peltier elements ensure that the air for seat conditioning can be heated or cooled as required. The design and configuration of the seat conditioning unit were determined in preliminary tests. Heating capacities of approx. 100W and cooling capacities of approximately 30W can be achieved. The efficiency of the system was determined with a maximum COP (coefficient of performance) of over 3. It provides information about the cooling/heating capacity through Peltier conditioning in relation to the electrical energy used. The COP of conventional electrical seat conditioning units for heating is less efficient and only below 1. The selected systems are to be further optimized and compared with the demonstrator in the future. Both variants are able to also cool the seat in contrast to a conventional seat heating system, which is a significant benefit.

As a further measure for cabin air conditioning, radiant heating surfaces were integrated in the driver and passenger areas. The infrared radiation emitted has a direct impact on the occupants' perception of the thermal environment, independent of the air temperature. When using radiant heating surfaces, the air temperature can be lowered without reducing thermal comfort. This allows additional energy to be saved during operation. Another advantage of this measure is that it has a much faster effect than air conditioning alone. Radiant heating surfaces with a




1
Thermal system of the demonstrator vehicle (schematic diagram).


2
FEV thermal manikin for determining the local equivalent temperature (left) and detailed view of the measuring points (right).

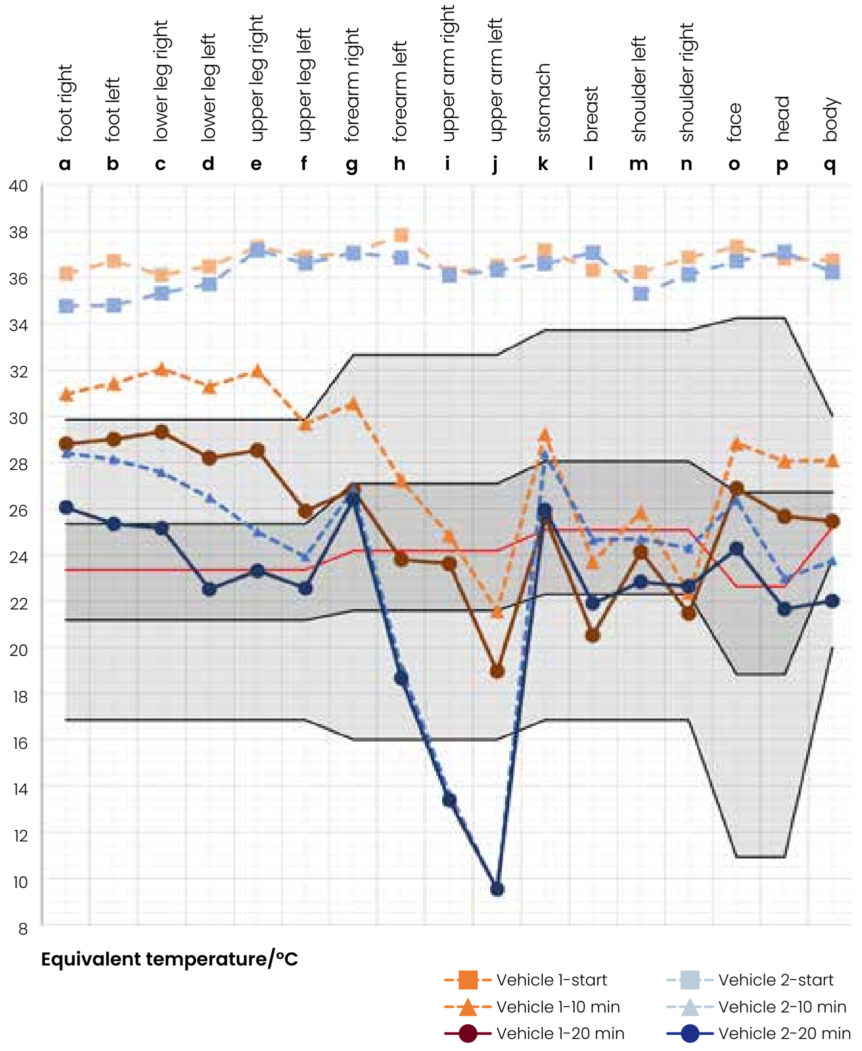
total output of over 500W were installed in the demonstrator vehicle. These are supplied with power directly via the 12V electrical system. The control unit developed by FEV makes it possible to divide the elements into sixteen different zones to determine the optimum calibration for thermal comfort.

Another measure is the use of an adjustable steering wheel heater. This is also operated via the 12V power supply and has a maximum output of 25W. The adjustability of the surface temperature allows development of a control strategy for improved efficiency.

### *Thermal measuring manikin for evaluating cabin measures*

The substantial number of cabin air conditioning measures have different effects on the occupants' perception of the thermal environment. It is no longer sufficient to simply measure the air temperature in the cabin. To conduct such complex objective assessments of thermal comfort in interior spaces, several types of measuring manikins exist on the market. However, some of the available manikins are not suitable for use in vehicle cabins, while the complexity of others drive costs which are prohibitive for this application. For this reason, FEV pursued the goal of designing and building a thermal manikin specially tailored for use in vehicle cabins.

To this end, it was essential to identify a method that enables an objective assessment of interior comfort. The local equivalent temperature, defined by DIN EN ISO 14505-2, was selected for this purpose from a large number of calculation models . This method summarizes the effect of convection and heat radiation on the human body in a theoretical equivalent temperature. To be able to measure the equivalent temperature, a manikin was equipped with a total of 25 measuring points for different body areas (Page 9, Figure 2). The 3D-printed housings of the individual modules each contain a sensor for determining the air temperature, thermal radiation, and air velocity. The design of the measuring points is also shown in Figure 2. In addition to the 25 locally distributed measuring points, the air humidity and $CO_2$ concentration in the cabin were determined centrally. A custom data acquisition system was developed by FEV to facilitate measurement of the above signals and storage to a computer.




**3**
Comparison of vehicle cool-down for two C-segment vehicles at an ambient temperature of 35 °C for different points in time.

The individual sensors can be calibrated, and the measured values evaluated, in software specially created for this purpose. The direct conversion of recorded values into the equivalent temperature allows an initial assessment of thermal comfort during the measurement. Automatic processing of the measurement data also allows the diagrams to be presented in a format consistent with the DIN EN ISO14505-2 standard to evaluate the equivalent temperature for various scenarios. As an example, Figure 3 shows an evaluation of two vehicles for the cooling of the interior at the start of the measurement, after 10 min, and after 20 min, with an ambient temperature of 35 °C.

These measurements already make it clear that differences in local comfort in the interior can be identified and analyzed. The comparison reveals, for example, that Vehicle 2 cools the area of the upper arms too much. This results in localized discomfort, which has a negative impact on the perception of overall thermal comfort. The results of the manikin were confirmed by subjective impressions of the project team and can be attributed to a local draft effect. This can be avoided by adapting the fan strategy or adjusting the air outlets. Overall, the manikin set up enables an objective evaluation of the interior air conditioning of modern battery electric vehicles.

### *Conclusion*

This article has highlighted some of FEV's activities to improve the development process for future cabin air conditioning concepts and their operating strategies. The article focuses on an internal research project in which a demonstrator vehicle was set up to investigate individual air conditioning enablers. Additionally, a manikin was presented that enables the objective evaluation of interior comfort by means of a local equivalent temperature. This will initially be used within the research project to evaluate the selected enablers in the demonstrator, with respect to their performance and energy efficiency. In a future iteration, operating strategies will also be developed that can be flexibly adapted to different air conditioning concepts. Predictive control approaches and data-driven methods will primarily be used for this purpose. In addition, it is planned to use the manikin to collect measurement data and set up a cabin air conditioning database.

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»The advent of level 3, 4, and 5 autonomous driving necessitates a comprehensive reassessment and redesign of the interior.«

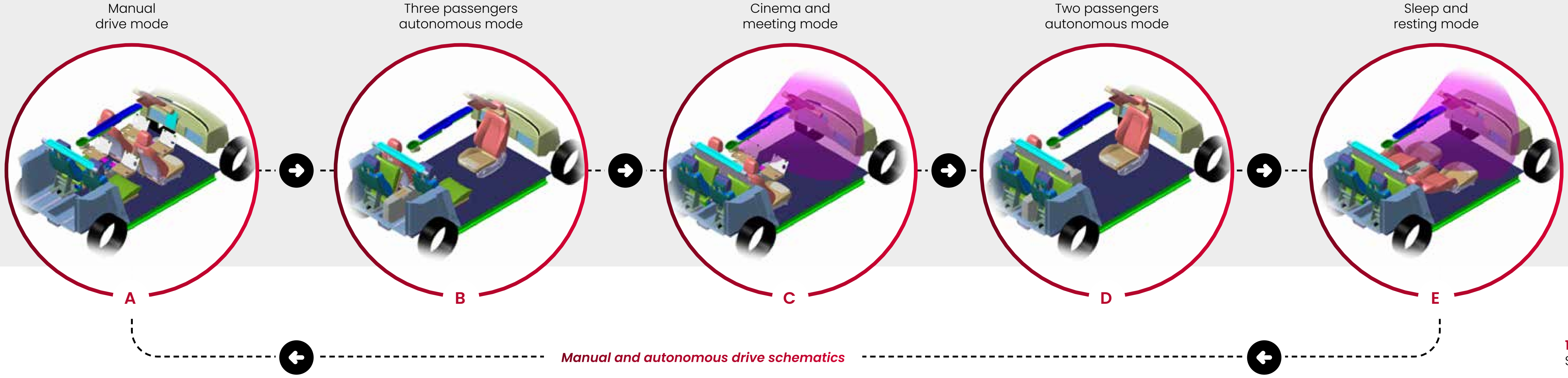
# #2 Future-proof ***interior solutions***

In the continually evolving automotive industry, the past decade has seen a rapid shift in paradigms towards electric and autonomous vehicles. This transition necessitates not only a change in the powertrain, but also a redesign of the vehicle interior in accordance with sustainability imperatives. To address these challenges, research is essential to develop a new vehicle design concept that seamlessly integrates autonomous driving features and aligns with the diverse expectations of the tech-savvy users. This article, the nexus of these factors is examined by investigating the relationship between automotive innovation and the evolving aspirations of the new generation of users.

The new generation of users are customers, who epitomize a technology-infused generation that is both influencing and being influenced by an ever-advancing digital environment. In contrast to their predecessors, contemporary vehicle interiors are designed primarily for level 1 and level 2 autonomous vehicle models. However, the advent of level 3, 4, and 5 autonomous driving necessitates a comprehensive reassessment and redesign of these interiors. By concentrating on the intricate design issues that will shape the vehicles of tomorrow, this article aims to investigate the intricate interplay between the preferences of users and the transformative demands posed by the transition towards higher levels of vehicle autonomy. Ultimately, based on the results of this analysis, a cost-effective solution for C-segment vehicle interiors has been provided.

In the following, the dynamic intersection of autonomous vehicle interiors and the different preferences of users is examined. The results are based on the extensive survey results presented in the article "Interior of the Future – Occupant Requirements during Automated Driving"*.

*Reference: Steffen Wilker, Tolga Pekruh, Rumeysa Akar, «Interior of the Future – Occupant Requirements during Automated Driving», ATZ worldwide, 2023.




1.
Seating modes.

## *Definition of occupant requirements*

In the quoted study, the package and design requirements of occupants were identified based on a survey of 7,510 people from 25 countries in 2022. The idea of safe and innovative solutions was examined, taking into account the concerns and fears expressed by the survey participants.

The resulting requirements were then translated into design inputs in accordance with specifications set by the Society of Automotive Engineers (SAE) regulatory guidelines. The process guarantees that the needs of passengers and the regulations that apply to them are fully integrated into the design framework.

## *Design study*

The study is designed for a Class C autonomous vehicle. It was designed in 2D and then in 3D, using CATIA V5 software, taking into account the following SAE Regulation rules. The dimensions in the design were determined according to the 95th percentile manikin. The book “H-Point: The Fundamentals of Car Design & Packaging” was used to determine the H-Point in vehicle packaging. The H-point defines the theoretical, relative position of an occupant's hips. Dimensions included in the regulation that are not included in this book were determined with reference to equivalent vehicles.

| SAE regulation parameters | I project | Sample car |
|---|---|---|
| **Width (mm)** | 1,811 | 1,799 |
| **Height (mm)** | 1,550 | 1,552 |
| **Wheelbase (mm)** | 2,750 | 2,765 |
| **Ground clearance (mm)** | 140.5 | 150 |

**Table**
Comparison of SAE regulation parameters:
I Project sample car

## *Steps of 2D design*

**a:** The two-dimensional design process commenced with the identification of the H-point. The dimensions of the vehicle wheelbase and height were taken as a point of reference from similar vehicles.

**b:** In order to establish the correct angle for positioning of the manikin’s foot, the foot plane angle was calculated in accordance with the methodology set forth in SAE J4004.

**c:** 95th percentile SAE manikin position was defined according to the reference angle values specified in standards and articles.

**d:** The point of contact between the manikin’s foot and the accelerator pedal of the vehicle was determined as AHP (Acceleration Heel Point) when the manikin was positioned.

**e:** The L6 value was calculated using the formula in SAE J4004. The H17 value was determined by using the benchmark vehicles in similar items to be within the SAE limit size range.

**f:** The eyellipse position was taken from SAE J941 formulas. Eye center point and eyellipse were determined from these formulas.

**g:** The rear passenger H-point was determined by reference to similar vehicles, taking into account ergonomic conditions. Foot clear-ance distance standard couple dimensions were preferred.

**h:** A calculation was made of how the pillars block the driver's field of vision.

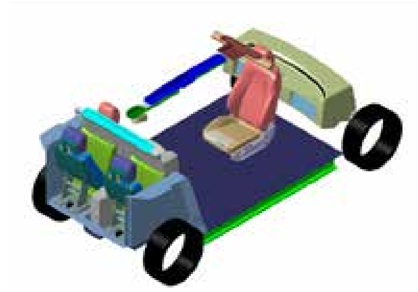
**i:** The hand reach envelope surface boundaries were calculated to determine the front console design and tablet computer location.

**j:** The head contour position was determined and the contour volume calculated.

## *Results*

In line with the results of the design study, customer expecta-tions, and regulations, 2D concepts were successfully converted into 3D models. Thanks to the designs, the volume efficiency of the vehicle was achieved and electrification possibilities were utilized more effectively. The main results of each design component are as follows:

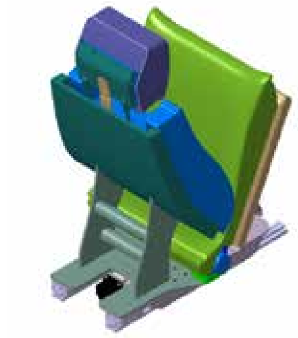
2.
Swivel functional front seats.



**Swivel functional front seats**

Based on the survey results, the movable and swiveling front seats were designed to enhance the social space for passengers. This allows passengers to eat, sleep, chat, watch videos, and organize meetings during the journey using various seating combinations.

3.
Foldable
rear seat.



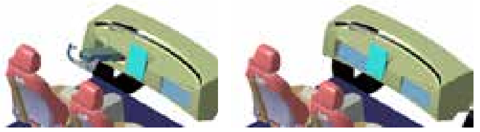
**Foldable electrically assisted rear seats**
The rear seating area is equipped with electric folding mechanisms, allowing the seats to be stowed within the vehicle's cargo compartment, providing space for movement of the front seats to the sleeping position. This efficient utilization of the vehicle's internal space allows two passengers to sleep or repose at the same time in autonomous driving conditions.

4.
Tablet holder position of middle console.

**Movable functional middle console**
The center console was redesigned with two independent movement capabilities to allow use by front or rear passengers or to allow for reloca-tion to provide space for movement of the front seats into multiple seating or sleeping positions.

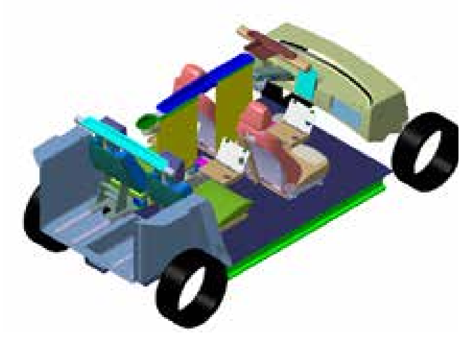
In addition to the traditional function as an armrest, there are also foldable tables for each seat. These have integrated cup holders as well as holders for 10-inch tablets. This means that individual entertainment media can be provided at each seat without integrating expensive monitors into the vehicle.

5.
Telescopic steering mode on/mode off



**Telescopic steering**
The steering mechanism, which employs a telescopic rail system, has been designed with autonomous driving in mind. This has resulted in the steering wheel being situated within the front console, which can be concealed with the aid of a hand. This allows for a more efficient utilisation of the vehicle's interior volume, thereby providing the necessary space for the front seats to rotate.

6.
Multi-purpose curtains separate personal areas.



**Multi-purpose curtain**
Various curtain systems have been integrated into the design. One in front of the windshield forms a projection surface for films, presentations or online meetings. The content is projected onto the sur-face via a projector in the rear. Two further curtains form a partition between the seats for individual free space in the vehicle. A fourth curtain serves as a cover for the rear seats stowed in the trunk.

## *Conclusion*

The concepts presented show possibilities for future flexible interior solutions in the C-segment, which can be designed to be affordable for the mass market. The customer's wishes for individual entertainment options and flexible seat configurations were reflected. All configurations can be adjusted depending on seat occupancy while driving, which is not possible in most concept carriers today, as many settings can only be made when stationary. With the integration of the concepts in the C-segment, the volume market is represented.

A conscious attempt was made to present the flexibility in a sedan/hatchback, as this represents the smallest installation space and therefore other vehicles such as SUVs or Vans can easily be adapted. The survey results from the mentioned study clearly show that classic sedan/hatchback vehicles will continue to dominate the European vehicle market in the future, however, adaptions allow for convenient transfer to other markets.

In the autonomous vehicle, the driver will increasingly become a passenger, who will have comparable demands to today's passengers. The increasing trend towards car sharing is taken into account in the concept vehicle as well, with partitions and the use of tablets rather than built-in monitors offering the capability to ensure privacy without the risk of damage to components or the need for occupants to readjust. For the car sharing operator, this also reduces the risk of damage and failure of multimedia components.

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# #3 Cost-efficient ***vehicle homologation***

Global regulations aiming to decrease greenhouse gas emissions, combined with geopolitical instability affecting oil prices, have caused electric vehicles sales to increase year-over-year.

In 2023, global PHEV and EV sales grew 13%, attributed mainly to growth in the Chinese domestic market where 33% of all new passenger cars sold were a PHEV or EV. Europe followed at 21% and the USA at just under 10%.

The momentum in European PHEV and EV sales slowed last year, due in large part to would-be buyers that are waiting on more affordable models to arrive. For this area in particular, Chinese brands have a significant advantage thanks to an abundance of low-cost labor and a more mature EV market. Yet another key advantage enjoyed by Chinese brands is the robust reserve of key minerals required for the production of batteries and electric motors.

This cost advantage, however, is now going to be significantly affected by European import tariffs. In addition, the US has almost become almost impenetrable for Chinese OEMs due to import tariffs applied years ago. Therefore, Chinese EV manufacturers must find ways to further reduce costs in order to convincingly penetrate the EU market and gain a foothold in the US.

Regardless of the country of origin, this article intends to highlight means to reduce the development costs often associated with meeting US and EU technical regulations.

### *Homologation*

To enter the EU or the USA, manufacturers are confronted with a myriad of regulations. In the EU, automotive-specific approval regulations are gathered in the EU Whole Vehicle Type Approval framework. It consists of more than 100 vehicle type approval regulations, comprising easily more than 1,000 technical and process requirements which are continuously being amended.

With almost 8% market share of BEV's in the EU in 2024, Chinese OEMs have proven to be successful in passing the complex and demanding landscape of EU regulations.

The challenge of successful homologation is to anticipate this complex, demanding and continuously changing landscape of regulations in a cost-efficient manner, by avoiding costly changes and achieving certification in the first iteration.

**Realization**

The first measure centers around interpretation of regulations. Designing hardware, software and E/E based on a conservative interpretation often results in over-engineering, and therefore, excessive costs. Cutting corners isn't an option for obvious reasons, and so the goal for any manufacturer is to achieve an ideal balance and hit the sweet spot. For the EU, this requires not only a deep understanding of the applicable regulations, but also a trust-based relationship with technical service, wherein interpretations can be discussed openly with appreciation for each party's respective positions. For the US, it requires a comprehensive understanding of the principles of self-certification and the corresponding legal obligations.

A second option of reducing costs related to meeting US and EU legal requirements is to combine the considerations for both markets into one project. Contending with the requirements separately will not only drive up development costs, but is almost certain to result in costly delays in product time-to-market. Avoiding this requires a thorough knowledge of the regulations, finding gaps and overlaps between them, and an ability to merge them into a singular requirements package.

Thanks to more than 45 years in automotive development projects with OEMs around the globe, FEV has a proven track record of doing just that. Leveraging a team of experienced homologation specialists who have reputable and trustworthy contacts within the regulatory space, the engineering service provider is an ideal partner for homologation-related development projects. Providing support from engineering all the way through successful homologation sets FEV apart from other service providers like DEKRA and TÜV, who in the EU are prohibited from participating in the development process with OEMs in order to avoid conflicts of interest during the certification phase. They are allowed to explain what regulations require, but not allowed to translate that into technical solutions.

1. FEV provides support with certification.

## *FEV's approach*

Integration of US and EU legal requirements into vehicle development processes, and doing so in a cost efficient and First Time Right manner (FTR), is achieved in four main steps:

**Requirements definition**
FEV maintains a database of all current and expected EU vehicle type approval regulations, as well as US FMVSS and CARB/EPA standards relevant to the EU and US market. Depending on the manufacturers SOP date, FEV selects all regulations which must be considered. A complicating factor is that often draft regulations (i.e., amendments to existing) will define the HW, E/E or SW design, because many regulations tend to change faster than the development cycle of a new vehicle. In any case, if both the EU and US markets are targeted in one project as previously recommended, FEV will merge the applicable standards into a singular requirements package.

The next critical step is a successful hand-over to, and understanding by, system engineers of these requirements. They must be SMART and understandable by engineers, often requiring legal language to be replaced by engineering language. This is yet another area where FEV's strong engineering background and regulatory fluency is an asset to customers.

To ensure traceability of requirements throughout the development process of a vehicle, FEV works with sophisticated Requirements Management (RM) software, but also has the experience and flexibility to work with other RM solutions used by various manufacturers.

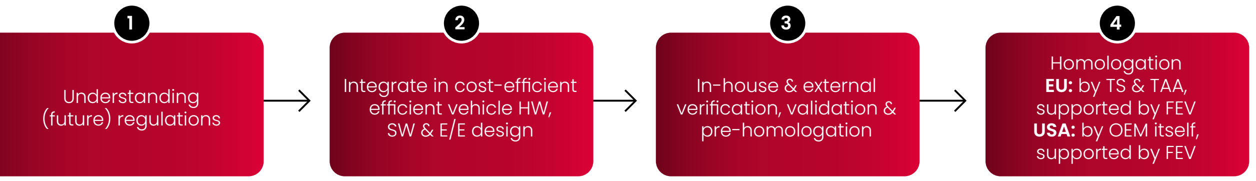
**HW, SW and E/E requirements & design**
Being an engineering company at its core, FEV can deliver turnkey design solutions for components, systems and whole vehicles. This engineering experience also allows the company to support system engineers within manufacturers, helping them to integrate legal requirements into their system-level requirements and system design in the most cost-effective and technically sound manners possible.

As mentioned above, an important step towards reducing costs is seeking an interpretation of the regulations which both satisfies the technical services and allows technical solutions which are preferable from a cost engineering perspective.

As soon as the customer has defined a concept (e.g., a mechanical, E/E, or functional design concept), FEV will approach technical services and strive for their acceptance of the concept, based on the interpretation of the regulations. This reduces the risks of unwanted design iterations and offers the potential to lower the cost of compliance significantly.

**Verification and validation**
Checking conformity of HW, SW and E/E design with the thousands of applicable requirements must be done in the early phases of product development and not at the end. This is essential to reduce risk of having to do costly redesigns.

The purpose of verification is to assess if a design satisfies all requirements that were defined for it. It often focuses on component and system level needs, whereas validation is meant to assess the functionality, performance, and properties of systems when integrated into the vehicle and exposed to real-world circumstances. Conformity of the vehicle and its systems to legislation is also a crucial part of validation. Only after successfully confirming conformity, can the actual homologation process begin.




**2.**
FEV reliably accompanies its customers throughout the complex homologation process.

FEV has years of experience in conducting testing which is designed to verify and validate HW, SW and E/E designs at a component, system and vehicle level. In close deliberation with the system engineers of its customers, FEV's experienced test engineers will create development validation plans which can be integrated with ALM and PLM tool suites of the customers to ensure full traceability of test results, linked to specific release versions of HW, SW and E/E.

Within the context of homologation, the result of this phase is a design which is confirmed to be compliant with all vehicle type approval requirements assigned to it. It reduces the unacceptable risk of failure during the official stage of the homologation process.

**Homologation (EU)/self certification (USA)**
The final step in the process of assuring conformity with technical regulations is the actual certification process.

In the EU, this is done by an accredited provider known as a Technical Service (TS), like TÜV, DEKRA or IDIADA, in cooperation with an EU Type Approval Authority (TAA) like KBA or RDW. In short, the TS witnesses homologation tests being executed at the manufacturers site or suitable external lab, writes an official test report, and then submits the report to the TAA. The TAA in turn issues the type approval. This needs to be done for every component and system subject to type approval regulations, as well as for the vehicle as a whole—known as the Whole Vehicle Type Approval.

FEV guides its customers through this administratively intense and time consuming process, leveraging years of experience its experts have in collaborating with Type Approval Authorities and technical services.

The process in the USA is very different. Manufacturers must certify themselves. There is no TS or TAA guiding the OEM through the process and checking if everything is done correctly. That is the sole responsibility of the OEM, and authorities expect the manufacturers to certify their products as compliant exercising reasonable care. In practice this means taking into account the latest standards and best practices available in the US and applying them throughout the development process. And in the end, validating the vehicle and its systems against these standards and documenting the evidence of conformity in a traceable manner.

FEV supports its customers in performing this self-certification. Moreover, FEV has the appropriate experience and deep knowledge of EU and US processes such that the minimum amount of testing and reporting efforts needs to be made in order to satisfy the authorities on both sides of the ocean.

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## *Conclusion*

Launching a vehicle on the EU and/or US market is challenging for various reasons, one being the regulatory hurdles that needs to be cleared in a cost-efficient manner. This requires a holistic approach where regulations for multiple regions are considered simultaneously and well-integrated into the HE, SW and E/E design, verification and validation processes.

FEV, with its engineering DNA, combined with a deep understanding of, and experience with, certification processes, is the ideal partner for foreign and domestic manufacturers to expand their foothold in the EU and US markets.

# #4
# Exceeding customer expectations – *FEV's global vehicle attribute development*

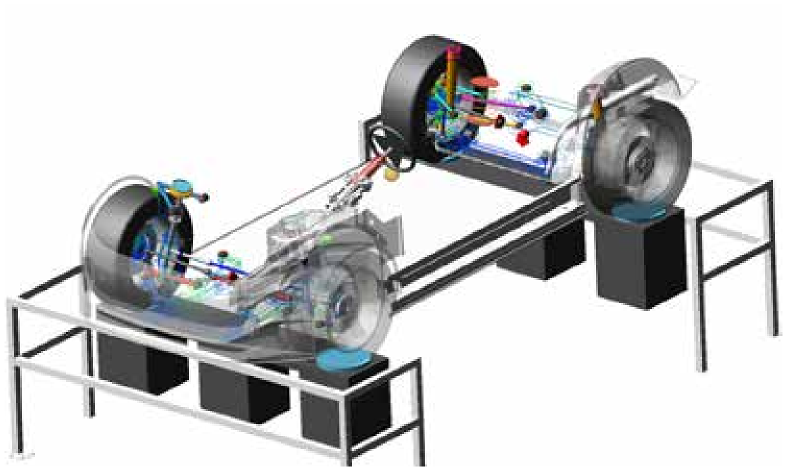
The development of vehicle attributes is critical for market success and customer acceptance. FEV offers comprehensive support to optimize the performance and efficiency of modern vehicles. This article will focus on driving dynamics, NVH, aerodynamics and thermal management; which alongside the powertrain, are particularly important in development.

Comprehensive expertise is indispensable, especially in global competition, with respect to specific requirements of core markets. FEV considers the climatic and regulatory conditions of various regions to increase vehicle range and driving comfort and thus ensures the competitiveness of its customers. The following article presents methods and procedures for selected key topics.

## *Vehicle dynamics*

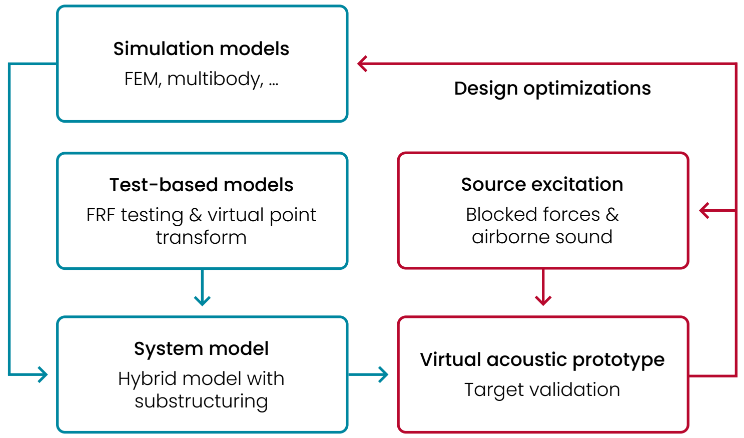
Vehicle dynamics is one of the key attributes that shape the DNA of a vehicle. Important core aspects are vehicle safety, driving pleasure, and driving comfort. It is important to find the right compromise to suit various vehicle types and their desired characteristics. Depending on the vehicle class, the brand DNA, and the positioning in the respective market, requirements are defined at vehicle level to ultimately create, for example, sporty driving behavior or a particularly comfortable driving experience. Many objective and subjective goals for driving dynamics are defined and pursued for this specific purpose.

Requirements for the chassis systems, such as suspension concepts and kinematics, are then derived from the previously defined vehicle dynamics objectives. In the early development phase, advanced simulation techniques are used to design the kinematics and compliance of the suspension. In this phase, component requirements such as spring, stabilizer or bushing stiffness are also defined. The virtual development process features the iteration of single parameters within multiple simulation loops, to finally ensure that all objectives from the concept development phase can be fulfilled.



1.
Vehicle on virtual K&C rig.

2.
Hybrid NVH simulation models using substructuring and blocked forces.




Once the base design has been completed, selected parameters such as the shock absorber characteristics are later refined by vehicle dynamics experts in road tests to create the desired driving experience. During road test refinement, modern systems such as electric steering assistance, steer-by-wire, brake-by-wire, and electric stability control are also calibrated so that the desired driving dynamics and vehicle safety targets are attained.

Ultimately, the goal is to tune all chassis systems in such a way that the desired driving dynamics are achieved. This is accomplished through a detailed and careful definition of requirements, a reliable virtual base calibration using a precise "digital twin" (Figure 1) and fine-tuning in road tests by experienced vehicle dynamics experts.

The vehicle dynamics requirements of different markets, such as Asia and Europe, differ due to customer expectations regarding driving comfort and driving experience, but also due to other boundary conditions, such as road layout, road surface, or legislation regarding speed restrictions and possible trailer operation. It is therefore highly recommended to define the market-specific requirements and, if necessary, to fine-tune them individually. Thanks to the company's expertise in global markets, FEV can define and implement the requirements of all major markets in a knowledgeable and efficient manner.

## *Noise Vibration Harshness (NVH)*

The absence of the familiar sounds of the combustion engine in modern electric vehicles (EV) means that noise sources that were once barely perceptible are now proving to be unpleasant for the occupants. The high demands of customers regarding the background noise in the interior of EV are therefore a challenge for the development of future vehicles. To address this, FEV has implemented new methods for NVH target cascading and concept development. The aim is to create the "Sound of Silence" that meets customer expectations and offers a high level of driving comfort. The brand-defining acoustic driving experience can then be added through active sound design (ASD).

Hybrid NVH simulations are an important tool for early design decisions. Challenges in early concept phases include complex noise transfer paths for which sufficiently accurate high-frequency simulation models are usually not yet available. FEV's hybrid approach, which combines simulation and test models, helps to overcome this. The process for these models is illustrated in Figure 2 and explained below.

In the case of NVH isolation design, for example, the complex transfer path from the attachment points of selected components on the car body to the driver's ear is determined by testing on a benchmark vehicle. Sub-structuring enables the virtual coupling of a simulation model for the isolation concept of the components with the benchmark vehicle.

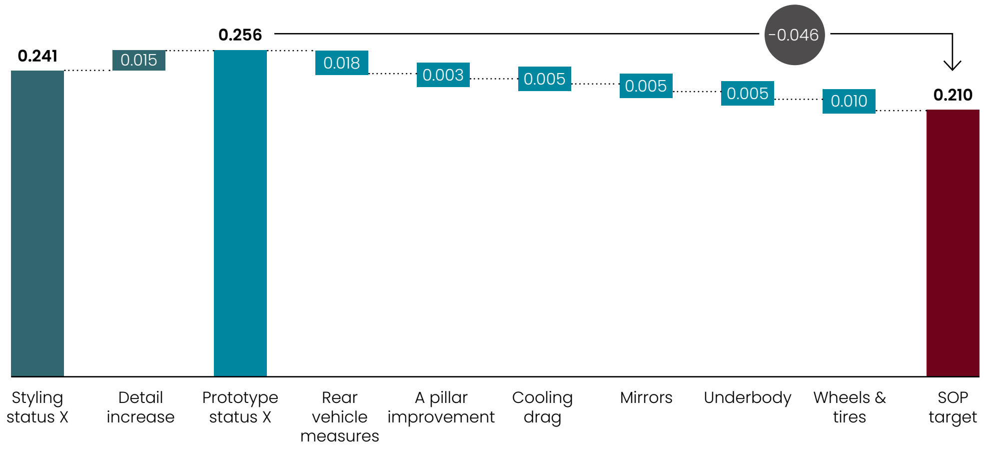
Another challenge is to obtain accurate excitation data from noise sources, as measurements are always influenced by the acoustic and structural dynamic properties of the test bench.

Component-based transfer path analysis (TPA) provides a methodology to predict the noise level with virtual vehicle models using so-called "blocked forces". The blocked forces reflect the correct excitation data that are independent of the component test bench. These forces can be transferred to virtual models to simulate the interior noise level. The resulting hybrid vehicle models enable the creation of virtual acoustic prototypes to predict the NVH behavior of different isolation concepts.

FEV combines the simulation methodology shown with strict target cascading in the NVH development process. Here, the overarching market and customer requirements are broken down to individual components to ensure that all objectives can be achieved. The simulation models are always adapted and expanded in line with the current state of development.

## *Aerodynamics*

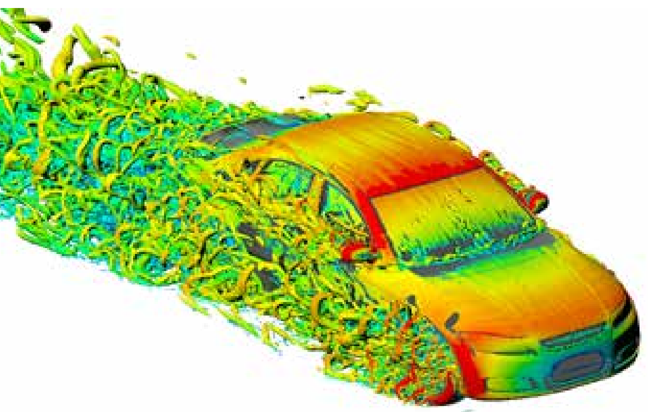
Aerodynamics is a key attribute for achieving vehicle energy requirements, such as the range of an EV or the efficiency of a long-haul heavy-duty truck. One major advantage of aerodynamics is the possibility to realize significant benefit by purely modifying the shape of various surfaces. This mostly goes without any adverse effects on cost or weight. Aerodynamics optimization is relevant throughout the entire vehicle development process, starting with styling phase and lasting throughout vehicle homologation. Being a vehicle-level attribute, the challenges of aerodynamics are very diverse. Measures must be integrated in alignment with potential conflicting requirements from various product stakeholders. Thus, the availability of outstanding development methods such as computational fluid dynamics (CFD) and wind tunnel testing are essential. In all these aspects, FEV has built up significant expertise, obtained through numerous development and research projects over the course of many years, making FEV an ideal partner for vehicle development.




**3.**
Aero walk - overview of individual measures to improve the aerodynamic properties of the vehicle.

The priorities of aerodynamics vary throughout the development process. In the early concept phase, its focus is on optimizing significant shape parameters of styling surfaces, for example the rear section of the vehicle. With increasing maturity and a higher level of detail, further areas are considered. These include, for example, the optimization of cooling drag on underbody and wheel areas. For the evaluation of measures, the focus is on CFD simulations, particularly in the early phase. These are later supplemented by wind tunnel testing on the clay model or prototype vehicle. The Aero-Walk provides a continuous overview for evaluating the measures (Figure 3).

FEV relies on a high proportion of CFD simulations for development and uses wind tunnels for detail optimization and validation only. This keeps prototype and wind tunnel related program costs to a minimum. To make this possible, constant improvement of CFD methods is a top priority. Various methodological approaches are available for evaluating aerodynamics, depending on the desired or necessary effort. This can be steady-state simulations for quick evaluation and comparison of measures or transient hybrid RANS/LES methods for adequate drag prediction and visualization of unsteady vortex structures, as shown in Figure 4. FEV is actively involved in various research projects in the dynamic environment of new CFD methods to constantly improve its predictive capabilities and methodologies.



**4.**
Isosurface of Q-Criterion = 10,000 $s^{-2}$ for DrivAer Notchback vehicle

## *Thermal management*

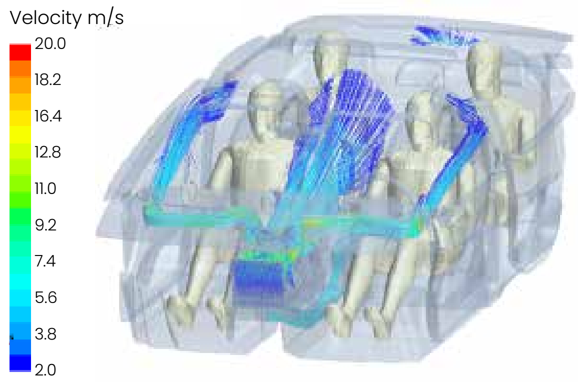
In the automotive industry, the efficiency and performance of thermal management systems play a decisive role in the market success of modern vehicles (see also Page 28). An optimally designed thermal management system not only helps to improve vehicle performance and reliability, but also to increase safety and comfort. Especially in regions with extreme climatic conditions, where both high temperatures in summer and severe cold in winter can prevail, reliable thermal management is essential.

In the Asian market, for example, climatic conditions are often characterized by high humidity and extreme temperatures. This requires special adaptations to the air conditioning and cooling systems to ensure optimum performance and comfort in the vehicle interior. FEV's advanced simulation techniques, such as the cabin airflow simulation shown in Figure 5, make it possible to precisely optimize the air distribution inside the vehicle.

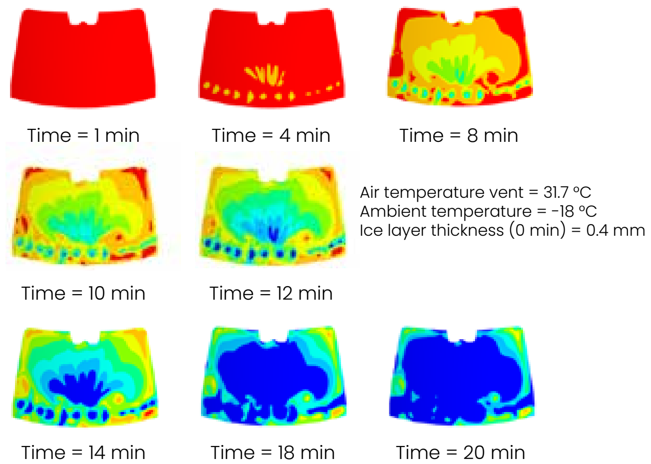
In European regions, requirements may have additional complexity as the focus is on comfort and safety competes with stricter requirements for energy-efficiency. Aerodynamic optimization and the integration of heat pumps to reduce energy consumption play a central role here. The simulation of a windshield de-icing system to fulfill homologation specifications shown in Figure 6 is an example of FEV's tailor-made solutions that can be adapted to comply with European norms and standards.

The continuous further development of thermal management technologies is being driven by the increasing electrification and digitalization of vehicles in all major regions. Future trends include the integration of intelligent systems that enable predictive control of temperature conditions and the use of materials with improved thermal conductivity properties. These developments will help to further improve the efficiency, safety, and environmental compatibility of vehicles and enable OEMs to meet the requirements of global markets.

Thermal management remains a key area of automotive development that contributes significantly to competitiveness. Through FEV's expertise and customized solutions, the specific requirements of virtually any market can be met.




**5.**
CFD simulation of the air flow through the passenger compartment.




**6.**
Simulation of windshield de-icing to check the objective of the homologation specifications.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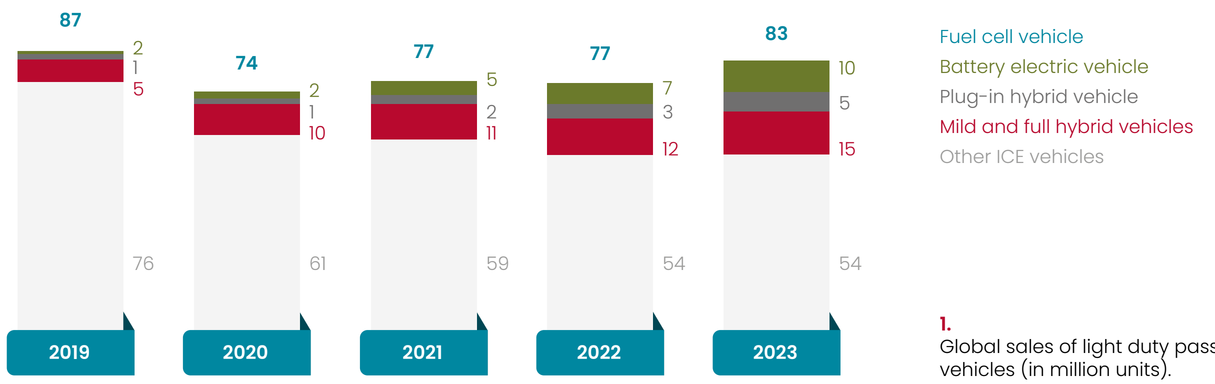
## *Conclusion*

FEV is a uniquely capable partner for the attribute development of vehicles, which is critical to achieving market success. FEV's many years of experience in the global markets (e.g., Europe, Asia, and the USA) and its expertise in methods development ensure that FEV can flexibly influence various development phases and thus contribute to the fulfillment of global program requirements.

# #5 *ICE to PHEV:* Navigating the transition

The shift from Internal Combustion Engine (ICE) vehicles to Plug-in Hybrid Electric Vehicles (PHEV) marks a pivotal transformation in the automotive industry. This change is driven by stringent emission regulations, technological advancements, and evolving consumer preferences. PHEV offer a balanced approach, combining the benefits of electric vehicles (EV) with the flexibility of conventional ICE vehicles, making them an ideal bridge towards a sustainable automotive future. With Hybrid-BEV, FEV had already presented a solution in this context, which is based on an EV platform with a battery capacity of 30-40 kWh and also has an ICE – in this case as a range extender (see Figure 4, page 31 and also SPECTRUM 74). As a result, it offers great cost-saving potential as well as weight and space advantages with a high range with minimal $CO_2$ emissions. In the meantime, PHEVs are dominated by range extender solutions (REEV) so that FEV has once again demonstrated its innovative strength with this development. This article will cover the market trends, engineering challenges, usability benefits, recycling considerations, manufacturing adaptations, and sales strategies involved in this transition.

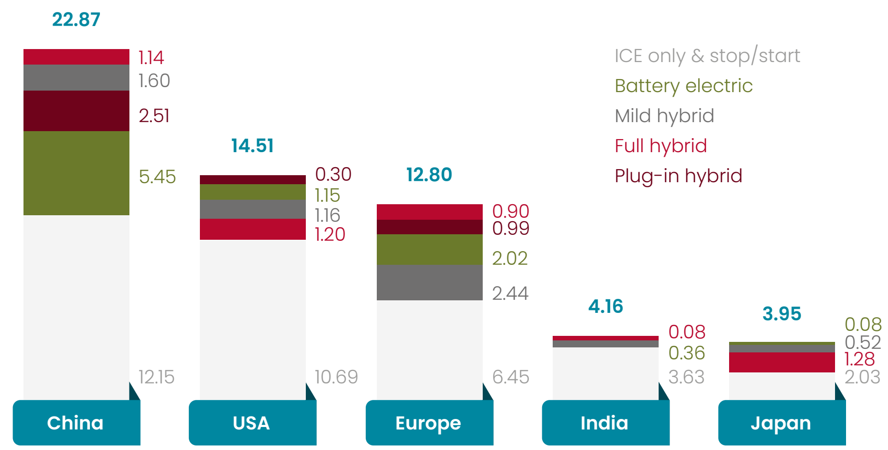


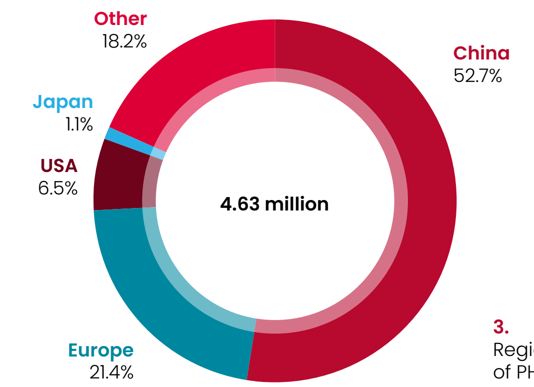

1.
Global sales of light duty passenger vehicles (in million units).

## *Market research*

The transition from ICE to PHEV is not merely a technological evolution but a market-driven transformation. It is evident from the sales data that the global PHEV market is experiencing significant growth. In 2023, nearly 15 million new electric cars were registered globally, marking a 44.5% increase compared to 2022. PHEV accounted for a substantial portion of these registrations, with the majority coming from China (52.7%), followed by Europe (21.4%), indicating a strong market shift towards hybrid solutions that combine the benefits of electric and conventional vehicles. Government policies, consumer incentives, and the increasing availability of charging infrastructure are key drivers behind these regional growth patterns.

2.
Region wise powertrain split sales in 2023 (in million units).




3.
Region wise sales of PHEV in 2023.

## *Engineering challenges in the transition from ICE to PHEV*

The shift from ICE to PHEV vehicles presents a set of unique engineering challenges. These challenges require a deep understanding of both traditional automotive technologies and modern electric powertrains.

**Powertrain integration**
One of the primary challenges in converting an ICE to a PHEV is the integration of two distinct power sources – the ICE and the electric motor. This dual-system architecture necessitates sophisticated powertrain control strategies to seamlessly switch between electric and combustion modes. Balancing these systems to optimize fuel efficiency, emissions reduction, and vehicle performance requires precise engineering and advanced control algorithms.

**Battery technology and packaging**
Like all electrified vehicles, the heart of any PHEV is its battery pack, which must be integrated into a vehicle originally designed for an ICE. This integration poses several challenges:

**I.** Space constraints: PHEV batteries are typically larger than those in traditional ICE vehicles, requiring careful consideration of vehicle packaging to maintain interior space and vehicle dynamics.

**II.** Thermal management: batteries generate significant heat, especially during charging and discharging cycles. Effective thermal management systems are crucial to ensure the longevity and safety of the battery pack. This involves integrating cooling systems that can handle the thermal load without compromising vehicle performance.

**III.** Weight distribution: adjustments in the vehicle's suspension and chassis design must be made to accommodate the added weight of the battery pack, altering the vehicle's weight distribution and impacting handling and stability.

**IV.** Passive safety and crash-proof HV cable routing: in addition to the core challenges, there is a critical focus on ensuring passive safety, especially in scenarios like side pole impacts. Designing a crash-proof HV cable routing system is essential to prevent potential hazards during collisions, ensuring the safety of the vehicle's occupants.

**Electrical architecture modifications**
Converting an ICE vehicle to a PHEV also requires significant modifications to the vehicle's electrical architecture. The electrical system must be upgraded to support the higher voltage and current demands of the electric motor and battery pack. This involves:

**I.** Wiring and connectors: high-voltage components necessitate the use of specialized wiring and connectors that can safely handle increased electrical loads.

**II.** Onboard charging system: integrating an onboard charger to enable plug-in functionality is another key challenge. This system must be designed to work seamlessly with the vehicle's existing electrical infrastructure while ensuring efficient energy transfer and safety.

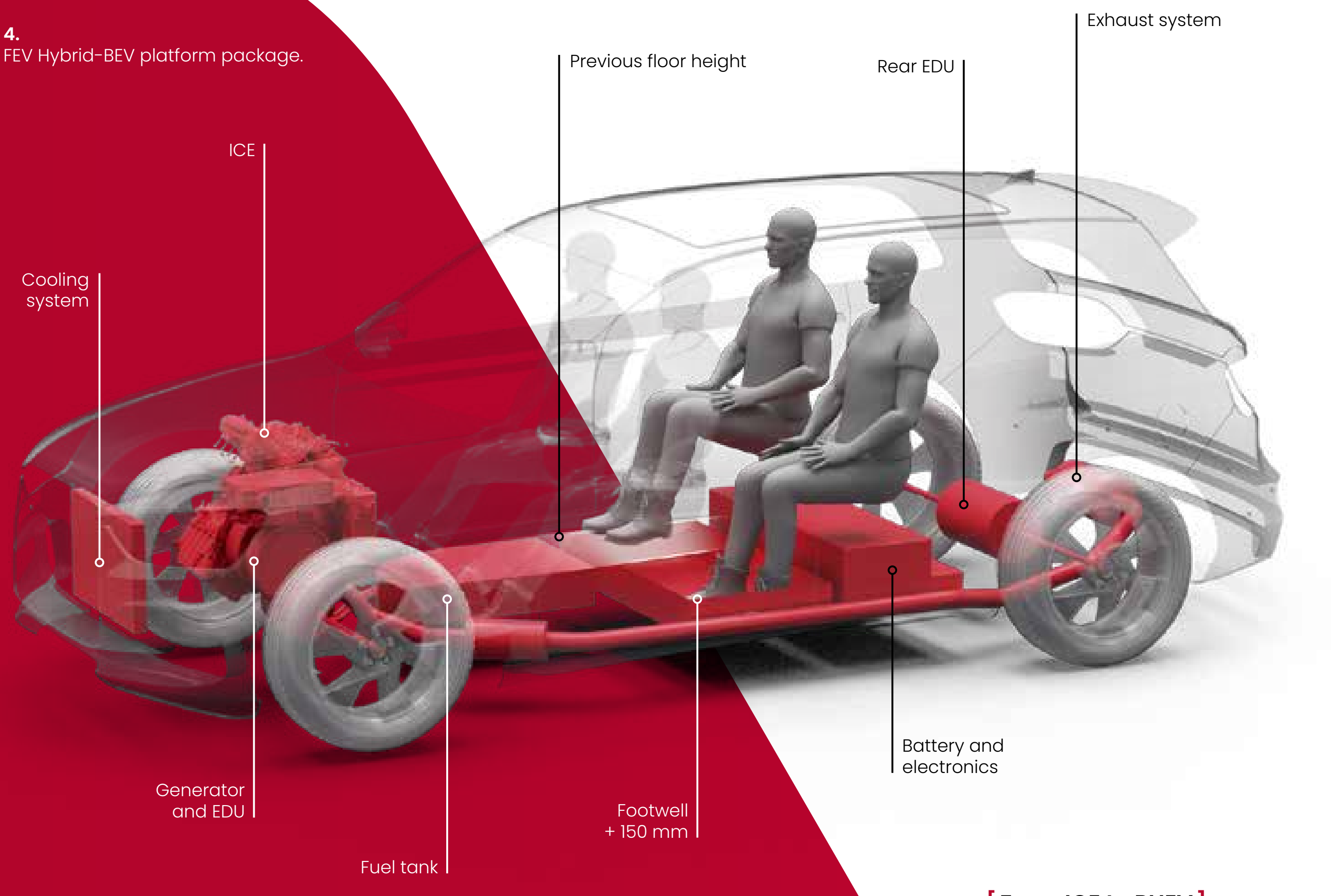
**III.** Control systems: the addition of an electric motor and battery pack requires the development of new control systems to manage energy flow, regenerative braking, and the interaction between the electric and combustion power sources.

**Vehicle dynamics and performance**
Maintaining the performance characteristics of the original ICE vehicle while incorporating electric power is a significant engineering task. The added weight of the battery pack, changes in weight distribution, and the need for seamless transitions between power sources all impact vehicle dynamics. Recalibration of suspension systems, brakes, and steering must be done to ensure that the PHEV delivers a driving experience comparable to its ICE counterpart.

**Emissions and regulatory compliance**
PHEV offer the potential for reduced emissions, but achieving these reductions involves several challenges:

**I.** Exhaust aftertreatment systems: the aftertreatment system must function efficiently even during intermittent engine operation, which occurs frequently in PHEV. Ensuring optimal performance during cold starts and electric-only driving periods requires advanced catalysts and particulate filters that are effective under variable operating conditions.

**4.**
FEV Hybrid-BEV platform package.



»PHEV offer a balanced approach, combining the benefits of EVs with the flexibility of conventional ICE vehicles, making them an ideal bridge towards a sustainable automotive future.«

**II.** Emission testing cycles: PHEV must comply with stringent emissions regulations across various testing cycles, such as WLTP and EPA protocols. These cycles may not fully reflect real-world usage, where drivers alternate between electric and combustion power. Effective calibration of hybrid control systems is crucial to minimize emissions in diverse driving scenarios.

**III.** Onboard Diagnostics (OBD) compliance: PHEV are required to have OBD systems that monitor and report the performance of emission control systems. These systems must be reliable and tamper-resistant to ensure ongoing compliance with emission standards.

**IV.** Global regulatory variations: PHEV must meet different emission standards in various regions, necessitating adaptable powertrain and aftertreatment technologies. This complexity requires manufacturers to develop flexible solutions to satisfy the specific regulatory demands of each market.

## *Usability*

PHEV offer several advantages over traditional ICE vehicles and even fully electric vehicles (EV):

**Extended range**
PHEV provide the flexibility of extended range through their gasoline engines, alleviating range anxiety associated with pure EV. This makes them particularly suitable for long-distance travel and for consumers who do not have consistent access to charging infrastructure. This dual power source ensures that drivers can rely on gasoline power when electric charging is not feasible, making PHEV versatile for varied driving conditions.

**Reduced emissions**
By enabling electric-only driving for short distances, PHEV significantly reduce overall emissions compared to ICE vehicles. This dual-mode capability means that drivers can minimize their environmental impact during daily commutes while still having the flexibility to travel longer distances when needed. The electric-only implications are especially beneficial in dense population centers.

**Versatility**
PHEV can be a suitable solution for regions with limited charging infrastructure, as they can rely on gasoline power when necessary. This versatility makes them a practical choice for consumers in rural or less-developed areas where charging stations are sparse. Their adaptability to different driving environments enhances their appeal to a broader range of consumers.

## *Recycling and end-of-life management*

The shift to PHEV also brings considerations for the end-of-life phase:

**1.** Battery recycling: effective recycling programs are essential to manage the disposal and recycling of used batteries. Advances in battery recycling technologies are making it possible to recover valuable materials such as lithium, cobalt, and nickel. These materials can be reused in the production of new batteries, reducing the need for virgin raw materials and minimizing the environmental impact associated with mining and refining these materials. Legislation in various countries is also pushing for more robust recycling frameworks to handle the increasing volume of used batteries.

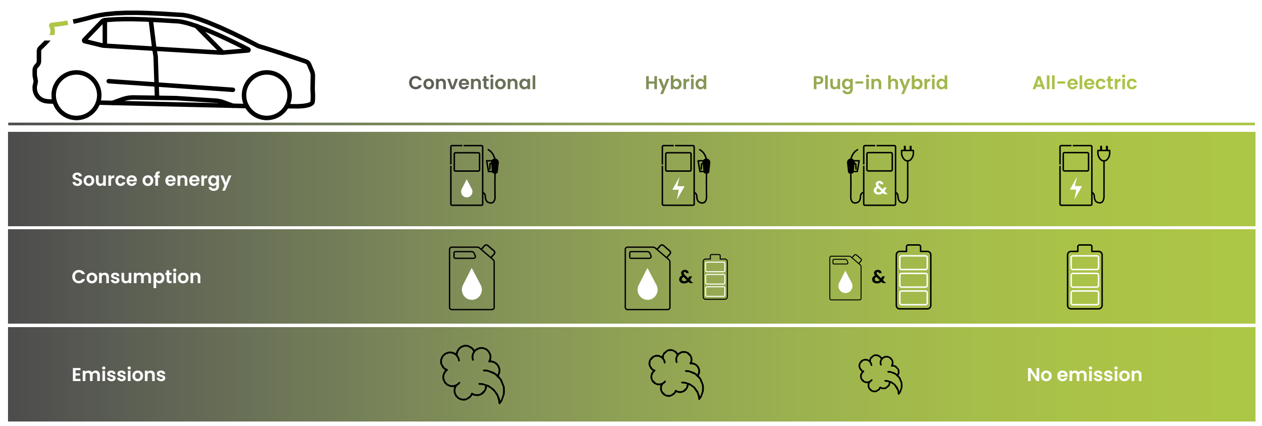
**2.** Component reuse: many components of PHEV, such as electric motors and power electronics, can be refurbished and reused, reducing waste and conserving resources. Establishing a circular economy approach in the automotive industry can further enhance overall sustainability efforts. Innovative refurbishment processes are being developed to extend the lifecycle of these components significantly.

**3.** Sustainability programs: manufacturers are increasingly adopting sustainability programs that focus on the entire lifecycle of the vehicle, from production to disposal, to minimize environmental impact. These programs often include initiatives to reduce energy consumption, lower emissions during manufacturing, and implement eco-friendly materials and processes. Efforts include using recycled materials in new vehicle production and improving energy efficiency in manufacturing plants.

## *Manufacturing*

Transitioning from ICE to PHEV production poses several manufacturing challenges:

**1.** Flexible production lines: manufacturers need to adapt their production lines to accommodate the assembly of complex hybrid systems. This requires significant investments in new tooling and training for assembly line workers, ensuring that they are capable of handling the intricacies of hybrid powertrain assembly. Robotic automation and modular production techniques are increasingly being used to improve flexibility and efficiency.




**5.**
Comparison of different propulsion types.

**2.** Supply chain management: ensuring a steady supply of high-quality battery cells is critical. This involves developing partnerships with reliable battery manufacturers and investing in supply chain resilience to mitigate risks such as material shortages. Additionally, securing a diverse supplier base can help manufacturers avoid disruptions and maintain consistent production schedules. Collaborative approaches with suppliers are essential to manage these complex supply chains effectively.

**3.** Quality control: the integration of electric and combustion components necessitates stringent quality control measures to ensure the reliability and safety of the hybrid systems. Advanced testing facilities and protocols are essential to meet these standards, incorporating both automated and manual inspection processes to detect any potential defects. Continuous improvement methodologies, such as Six Sigma, are being applied throughout the industry to enhance quality assurance processes.

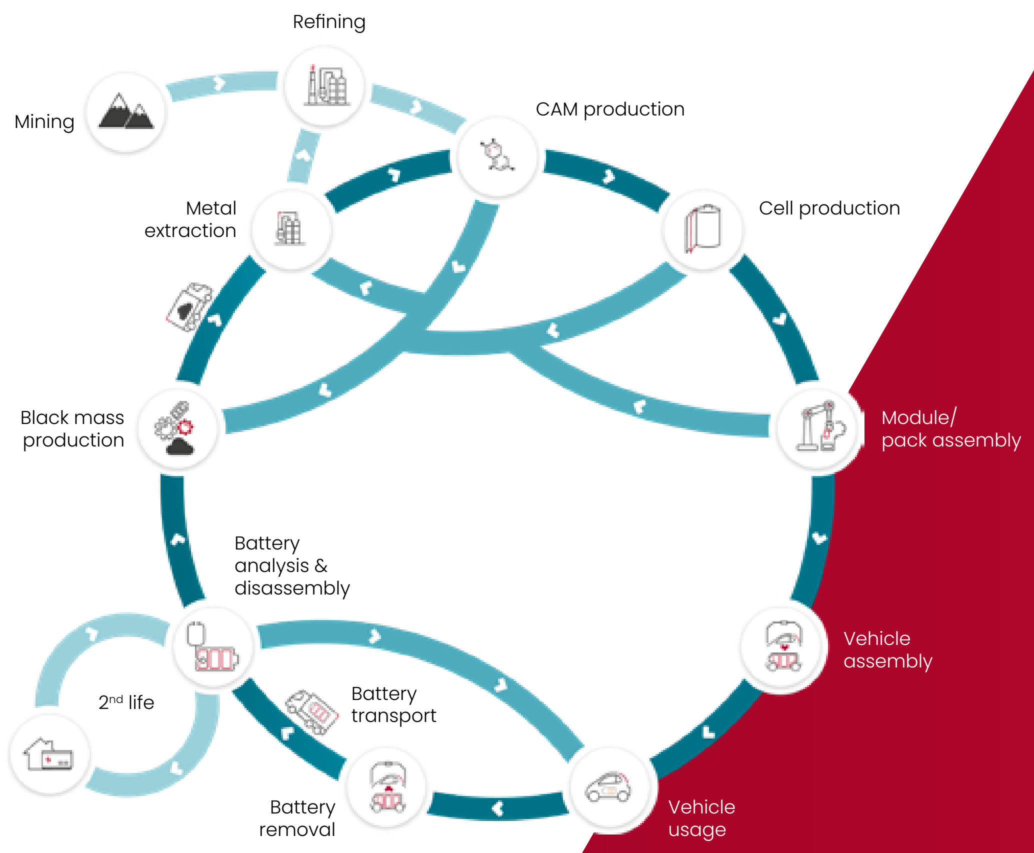
## *Sales and market penetration*

The success of PHEV in the market hinges on several factors:

**1.** Consumer awareness: educating consumers about the benefits of PHEV as a mature and reliable technology is crucial to their continued growth in the market. This includes highlighting their fuel efficiency, lower emissions, and the convenience of combining electric and gasoline power. Consumer awareness campaigns should leverage various media channels to reach a broad audience and emphasize the practical benefits of owning a PHEV. Interactive online tools and virtual reality experiences are also being used by manufacturers to educate potential buyers.

**2.** Incentives and policies: government incentives, such as tax rebates, subsidies, and exemptions from road taxes, play a significant role in driving PHEV adoption. Countries with strong incentive programs, such as China and certain European nations, have seen higher PHEV sales. These incentives lower the initial cost barrier for consumers, making PHEV more accessible and attractive. Policy frameworks are also evolving to support the installation of charging infrastructure and to promote research and development in the PHEV sector.

**3.** Dealership training: sales personnel need to be well-versed in the features and advantages of PHEV to effectively communicate these to potential buyers. This involves comprehensive training programs and support materials, ensuring that sales staff can address common concerns and provide detailed explanations on the operation and benefits of PHEV. Ongoing training and certification programs are crucial to keep dealership staff updated on the latest PHEV advancements and market trends.




**6.** Battery circular economy.

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## *Conclusion*

The transition from ICE to PHEV vehicles represents a significant step towards sustainable transportation, especially in countries with limited charging infrastructure and therefore small EV fleets. By leveraging advancements in technology, flexible manufacturing processes and comprehensive market strategies, the automotive industry can successfully navigate this shift. The projected growth of PHEVs underlines their crucial role in reducing overall vehicle emissions by 2035. Innovative concepts offer enormous benefits for manufacturers and consumers in terms of cost savings, comfort and long range while minimizing $CO_2$ emissions. This makes PHEVs an attractive option for consumers worldwide. These benefits ensure that PHEVs will continue to appeal to a wide range of potential buyers, from urban commuters to rural users. As the industry continues to improve and optimize said technologies, PHEVs will play a crucial role in the journey towards a greener and more sustainable future. In addition, there are serial hybrid configurations such as FEV's hybrid BEV.

# #6 Electrification ***off the highway***

The pressure to reduce $CO_2$ emissions is a primary driver for electrification in the mobility sector. In particular, within the off-highway vehicle segment, including construction and agricultural machinery, it is anticipated that $CO_2$ emission limits will be introduced by around 2030. However, several factors are already accelerating the transition to electromobility in these industries. Companies in the construction and agricultural sectors are increasingly setting ambitious goals to reduce their emissions. This trend is leading to a growing demand for low-emission and emission-free solutions for mobile machines in the off-highway sector.

## *Technology drivers and challenges in the off-highway segment*

The construction industry, in particular, is seeing a rising demand for emission-free construction sites. This trend is driving the development of battery-electric construction machinery. The prospect of $CO_2$ penalties and financial incentives for electric machines is worsening the total cost of ownership (TCO) for traditional fossil-fuel-powered machinery, promoting the shift to electric alternatives. Additionally, the transfer of technology from the more advanced passenger and commercial vehicle sectors is contributing to the availability and cost reduction of electric drive components.

»The demand for emission-free construction sites is growing, which is driving the development of battery-electric construction machinery.«

Despite these advancements, manufacturers of off-highway vehicles face several challenges. These are often used under extreme conditions and temperatures, posing unique challenges for electrification. Dust, dirt, strong shocks, heavy loads, and special requirements for controlled vehicle speeds place significant demands on the drivetrain components. These conditions necessitate careful selection and design of systems to ensure reliability and durability.

Another key consideration is the durability and serviceability of the systems. These machines must operate reliably under harsh conditions. Developing subsystems that meet these requirements is a complex task requiring innovative approaches. At the same time, the charging infrastructure for these vehicles is often underdeveloped, adding further challenges to electrification in the off-highway sector.

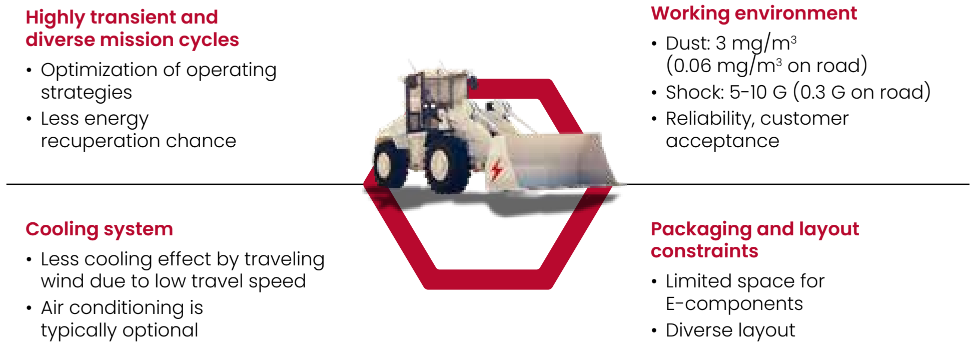
## Applications and advantages of electric drives

The diverse tasks that these machines must perform, along with comparatively low production volumes and long life cycles, further increase the development challenges. A strategy that considers these challenges is essential to ensure the long-term success of manufacturers. A successful strategy for an electrified vehicle starts with analyzing specific usage requirements.

Projects and concept studies carried out by FEV on electrified construction machinery show that the success of electrification activities relies on a combination of attractive use cases, short development times, improved usability, and reduced TCO. The establishment of electric machines in the manufacturers' portfolios and the value-added features of these products ensure acceptance and growing demand among end customers.

A notable case study involves FEV's successful development of a line of fully electric tractors. These vehicles, initially viewed with skepticism by customers, have proven themselves in operation, generating high market demand. Additionally, FEV has retrofitted excavators from conventional diesel engines to serial hybrid systems with downsized diesel engines. These hybrid solutions demonstrate the advantages of partially emission-free and silent operation in real-world scenarios without compromising performance requirements. At the same time, serial hybridization with a downsized diesel engine allows continued use of conventional fuel supplies at construction sites, enhancing flexibility.

Further applications, where fully electric drives have been implemented, offer significant potential for $CO_2$ reduction, lower operating costs, and benefit from the advantages of electric drive systems. These include reduced noise levels, improved machine control and performance, a higher degree of automation, and enhanced predictive maintenance capabilities.

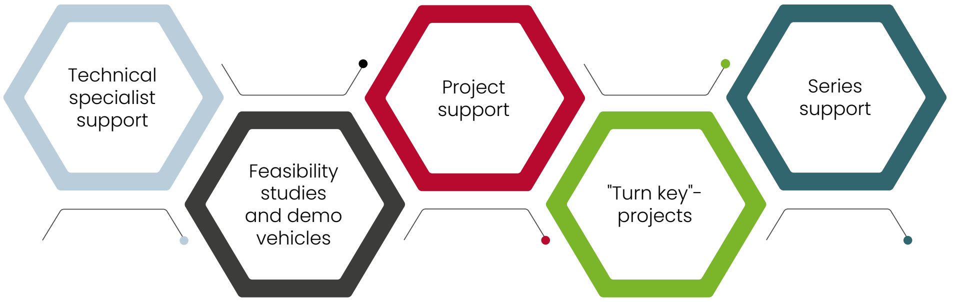



**1.**
Challenges in off-highway applications.

## Optimizing drive concepts

To choose the right drive concept and successfully transition from diesel to electric drives, the operational environment and usage strategy of the machines must be carefully considered. Conventional development approaches, which have proven effective for diesel-powered vehicles, are often less suitable for battery-electric vehicles. These processes are frequently not flexible enough to make the necessary compromises for cost-effective battery design. Furthermore, there are often preconceptions that limit the range of solutions for a competitive battery portfolio.

These preconceptions include the belief that a battery-electric vehicle must have the same characteristics as a diesel-powered model, or that only certain types of batteries are viable. A systematic approach that considers the interactions between the electric powertrain and vehicle architecture early in the development process is crucial to avoid costly adjustments later in the program.




**2.**
FEV is a strong partner in the development process.

FEV, as a full-service engineering provider, supports its clients in both the traditional construction of demonstrator vehicles in a conversion design, and the development of entirely new concepts for complete vehicles, from series development to Start of Production (SOP) and beyond. FEV's multidisciplinary approaches enable target-oriented compromises to be made while leveraging the latest technologies and supply chain advancements.

## Conclusion

In summary, market forces are already driving electrification forward. However, there are still numerous challenges that need to be overcome in order to achieve broad acceptance of battery-electric off-highway machines and fully integrate viable concepts into the manufacturers' product portfolios. Traditional development approaches often lead to expensive and highly customized solutions. Multidisciplinary approaches that consider all aspects of vehicle development are key to creating a competitive and profitable battery-electric vehicle portfolio. In this regard, FEV is a strong partner, actively shaping the future of off-highway electrification with deep expertise and innovative technologies.

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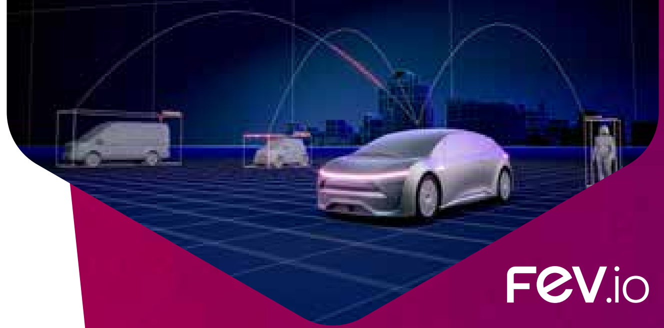
# feel evolution



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The importance of rail transportation is growing significantly worldwide, as a solution for local and mid-distance carrying of goods and people. The main reasons are:

- Energy efficiency (reduction of $CO_2$ emissions)
- Cost reduction
- Higher capacity (amount of people/ goods per cubic meter).

Both for urban (subways) and rural travel (up to 800 kilometers) rail transportation can significantly reduce pollution and traffic, while increasing safety.

High-speed solutions further leveraged as passenger applications, make them time-convenient and efficient alternative for middle distances, and therefore an attractive alternative to both passenger cars and airplanes. To exploit the best potential, on the three items above, it is necessary to apply a holistic approach, to involve high-level experts with specific knowledge in the field, and to be able to support OEMs in different locations over the world. With more than 30 years experience and global presence in the rail industry, FEV is playing a key role in this field.

**Three main enablers:**

- Development and validation of the complete train: from initial requirements to concept design and detailed CAD/CAE development of different sub-systems, up to the specific tools for final assembly.
- Ability to use the specific tools and procedures typical in the rail industry.
- Competence to support innovation, with a comprehensive approach while leveraging solutions, technologies and methods from other sectors.

## *Sustainability and innovation: hydrogen*

Trains can be easily powered by electricity and therefore can be seen as "green" by definition. Nevertheless, a significant number of worldwide applications are still powered by diesel engines due to delayed returns on investments, as specified in the study UNIFE2020 (Figure 1, Page 40). For those applications, the possibility to replace diesel with hydrogen powertrains is key to make them ecologically acceptable. FEV has supported these types of innovation projects ($H_2$ powered trains) in Italy and Germany.

Together with the technical challenges on the train itself (e.g., $H_2$ storage and piping), there are further needs for development in the infrastructure with respect to filling stations, repair and train storage. The framework of European regulations to define the related technical specifications and use cases is of equal importance. Referring to the $H_2$-train itself, there is an intermediate "power car", where most of the innovations are located. The electric power is produced directly by the fuel-cell, that transforms $H_2$ (supplied from the tank) and $O_2$ (from the environment), with water as the only emission. High performance lithium batteries act as a buffer, to support the fuel-cell in peak power demand and to recuperate the braking energy.

## *Weight and cost reduction*

Lightweighting of trains is key for energy savings, which must always be pursued with a clear focus on cost optimization.

FEV has developed extensive experience in the use of modern technologies, e. g., extrusion, welding, thermoforming and bonding and materials like aluminum, glass/carbon fiber reinforced plastics and recycled/recyclable polymers. Due to the limited production volumes, typical of rail industry, manufacturing/assembly technologies should come with low investment. In addition, environmental protection requires the use of recyclable and/or low impact materials.

## *Development and manufacturing*

Having completed an extensive range of product and tool development activities, FEV is continuously supporting the improvement of efficiency, capacity, and comfort of trains. The use of modern and innovative methods and tools, in conjunction with proximity to its customers, allows FEV to fulfill the challenging needs of rail OEMs. Depending on the specific project targets, the company can easily involve its related competence centers distributed worldwide and network of external partners to satisfy its customers' needs.

The use of modern CAD/CAE and PLM tools, as well as new methodologies such as systems (SE) engineering and Model Based Systems Engineering (MBSE) enables flexible set-up of the working teams, for time/cost optimization.

## *Support in all project phases*

FEV supports the development and engineering of urban, rural, and high-speed applications, working on the different project phases, which are the initial train configuration and lay-out, feasibility and concept evaluations, detailed development, manufacturing set-up and tools and subsystems. These are, for example, the front-end, body, upper/under-body fittings, interior/exterior trims, lighting, upper/lower shields, wiring harness and piping.

Furthermore, FEV can define the styling surfaces as the input/starting point for the engineering activity. This is followed by further phases of part split, layout definition and concept design, to name a few.

Going more in detail to the development of interior trims, the styling surfaces are split in main engineering parts, with initial definition of connecting solutions to the car body. The layout of inner subsystems with related wire/pipe connections and routing, initially drafted for space-allocation, is then combined with initial 3D models coming from suppliers, in accordance with the end-customer requests, regulation requirements, and carry-over constraints. This gradual definition and detailing of engineering solutions goes through a defined number of loops, within the concurrent engineering environment of the OEM and in tight interaction with main suppliers.

Specific expertise is also required for a proper definition of multilayer floors, that have to fulfill several additional functions over the base layer, such as noise insulation, thermal management and ease of cleaning Another important activity is related to integration, on the car roof, of heavy sub-systems such as electric power converters, batteries, HVAC systems, and other lighter components such as fire-fighting devices and antennas. Each one of those subsystems are then structurally connected to the body and electrically, pneumatically, or hydraulically connected with appropriate wiring/piping solutions, in close cooperation with the dedicated OEM's engineering departments.

Another important aspect, particularly for electrified power trains, is the "harness team", taking care of all the electric connections (high, medium, low voltage) in terms of 3D routing and detailed design, according to the related schematics. Final outputs of the subsequent loops from this activity are the 2D drawings for suppliers selected for the manufacturing and the instructions for the various steps of the assembly process, such as 3D annotated models.

As mentioned before, the detailed design of different areas of each car of the train is done through concurrent engineering activities, with each specialized team going through a pre-defined number of loops. Each of these projects leads to the realization of a series of details that are checked at the start of each project's gate. The use of modern CAD/CAE tools, for definition and verification of technical solutions, and a customized PLM system, to organize the assembly trees and part numbers/revisions, is key for efficient fulfillment of the challenging targets of each project. Every activity done by each member of the working team is coordinated to comply with specific OEM procedures, as appropriate.

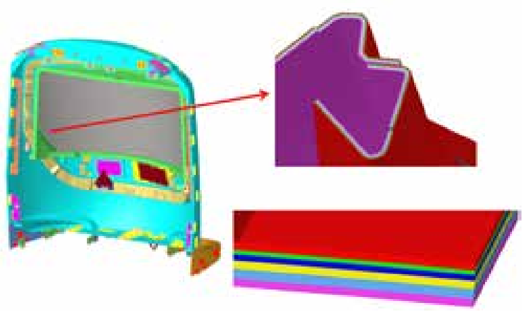
With its extensive experience and many successful projects in the rail industry, its global presence, and its wide set of expertise in both innovative powertrains and vehicles, FEV is a strong partner of rail OEMs and suppliers.

## *Technology transfer*

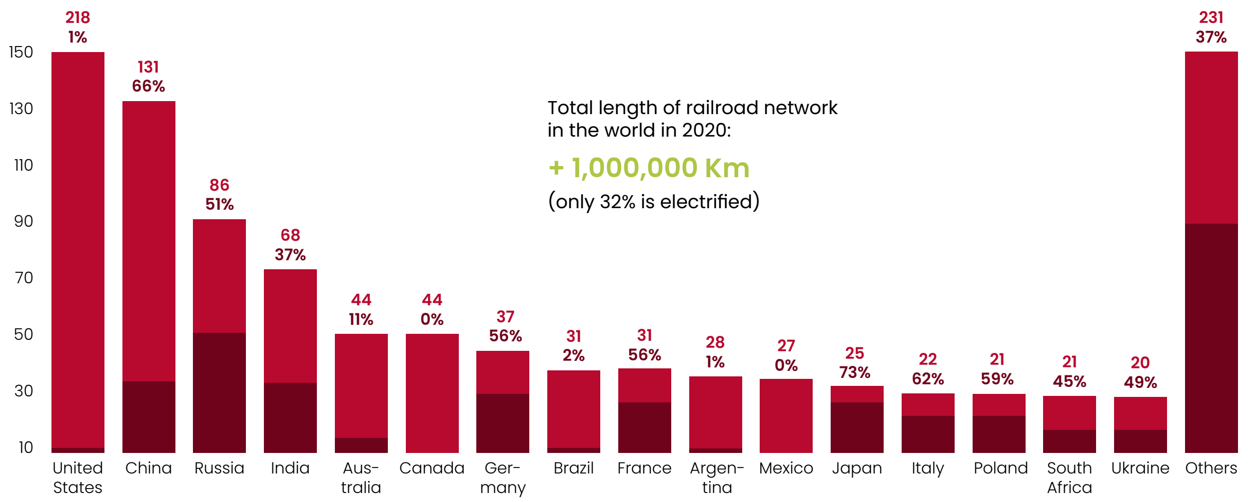
Innovative methods, tools, and design solutions that are introduced in an industry, often can benefit other industries.

Thanks to its extensive range of activities on powertrains and vehicles, in different business fields, FEV can provide added value to its rail customers in terms of innovation (tools, methods, design, simulation, testing, and manufacturing solutions).

FEV is the right engineering and innovation partner for railroad development, from small to large projects, providing a proper combination of skills distributed throughout the globe, along with suitable tools and professional commitment to fully satisfying the customer needs.



2
FEV 3D CAD data studies.




1
Electrification percentage of global railroad networks.
*Source: UNIFE 2020 data, including High Speed. Mainline, freight routers (Urban railway excludes).*

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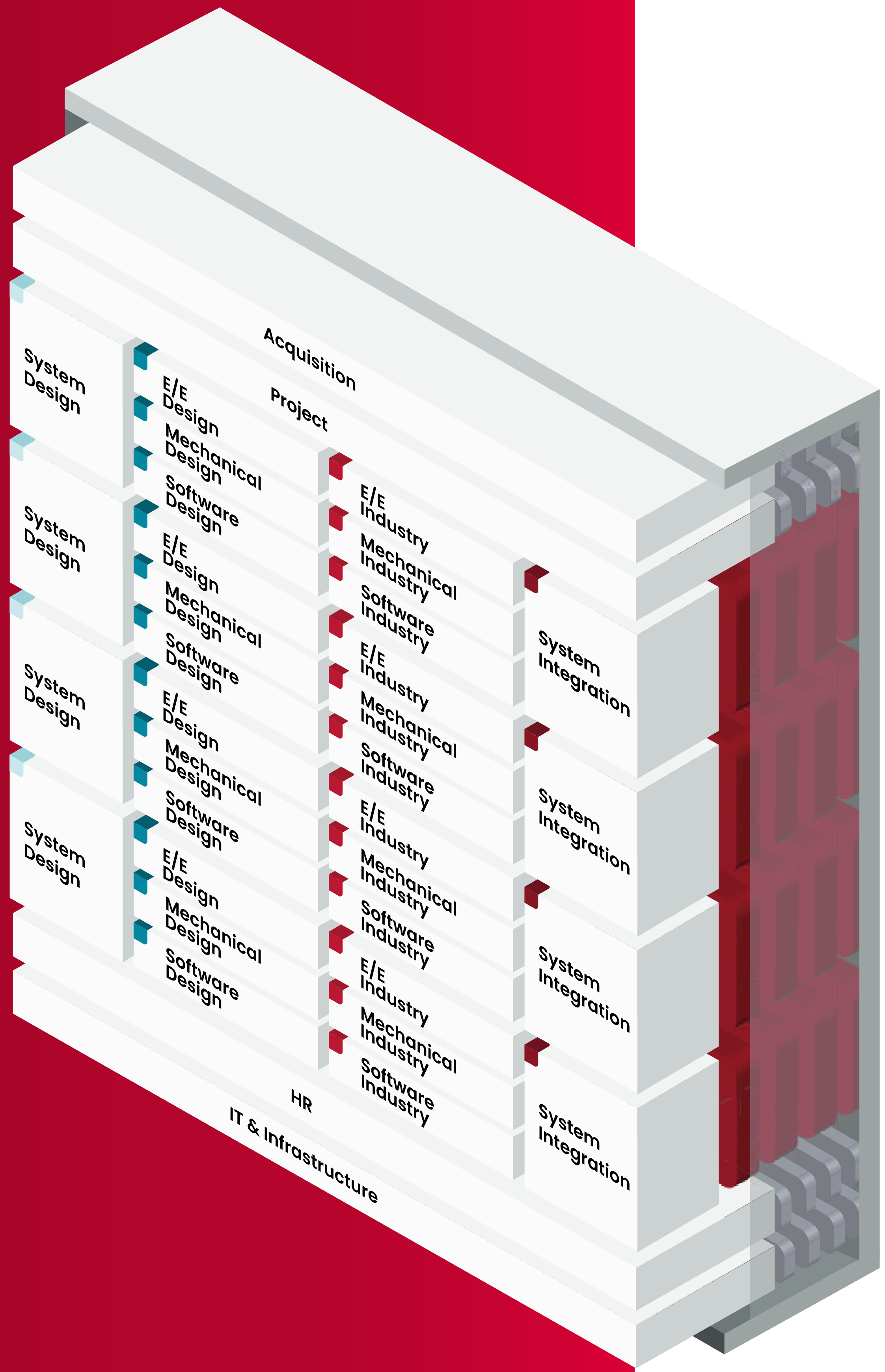



1.
FEV Engineering Process Framework.

This article addresses the core challenges of complexity, organization and a multitude of details in modern engineering by proposing a unified "engineering backbone" and an engineering process framework (EPF) to accelerate development; exemplified by the FEV Vehicle Development Process (VDP) integrated at product and domain levels, and further enhanced by incorporating Artificial Intelligence (AI) for increased speed and efficiency.

In the rapidly evolving landscape of modern engineering, the mobility industry is facing increasingly complex challenges. Today's engineering projects are about creating software-defined cyber-physical systems that fulfill elevated customer needs, comply with stringent regulations, and support ambitious business goals. These systems rely heavily on the interplay between hardware and software components. The integration of these, however, introduces a set of barriers that must be addressed to achieve success.

# #8
# Smarten up vehicle development – ***systems engineering*** by FEV

**Complexity barrier**
At its core lies the complex interdependency among components to create the desired emerging system behavior. In software-driven development, this interdependency is magnified, making it challenging to oversee all connections and leading to a heightened risk of integration errors. But ensuring all components to interact correctly to achieve the desired functionality and to prevent malfunctions is far from trivial.

**Organizational barrier**
The organizational barrier is one of the most daunting challenges. Coordinating hundreds, if not thousands, of engineers spread across the globe is an enormous task. Effective collaboration is crucial to ensure that all team members are aligned and working towards a common objective. This requires robust management strategies and tools that facilitate communication, task allocation, and progress tracking. Without these, the risk of misalignment and project delays increases significantly.

»FEV's Engineering Process Framework enables a more practical application of systems engineering, bridging the gap between theoretical frameworks and real-world implementation.«

**Content barrier**

Lastly, the content barrier pertains to the overwhelming multitude of standards, legislations, and regulations that govern engineering projects. Compliance is non-negotiable, yet must be achieved without compromising user-friendliness, adaptability, and comprehensibility. Engineers must create and document work products that meet these stringent requirements, adding another layer of complexity to the process.

## *One common "engineering backbone" as foundation for acceleration*

In response to these challenges, FEV introduces a structure to overcome these barriers by implementing one "engineering backbone". Based on FEV CUBE (Compositional Unified System-Based Engineering), it is envisioned to align all engineering activities within the organization and provide a unified structure for tackling complex projects. Its core mission is to unite all disciplines to realize safe and secure engineering for software-driven systems, to create a comprehensive perspective on products to be engineered and foster effective collaboration.

**Breaking down complexity**

To effectively manage the complexity of advanced engineering projects, the first step is to break products down into manageable segments. By dividing the product into its surrounding ecosystem, the product itself (e.g., vehicle, plane), its domains, sub-domains, and finally its components, it is ensured that each part of the product is thoroughly understood and addressed. This hierarchical decomposition allows engineers to tackle smaller, more manageable challenges, which collectively contribute to the success of the entire project.

**Supporting engineering decisions**

The second essential step is to focus on making decisions at the right development stages. By organizing the engineering process into distinct engineering views, such as feature-driven system design, discipline-specific (software-, electrical- and mechanical-) design, discipline-specific industrialization and system integration, it is ensured that critical decisions are made at the most appropriate times. This approach minimizes the risk of overlooking important details and helps to maintain the project's momentum.

**Organizing concrete processes**

Combining these two elements, FEV's "engineering backbone" provides a framework for all process sets along all decomposition levels and engineering views. This systematic approach is vital for managing processes efficiently, ensuring that all team members are aware of their roles and responsibilities within the respective framework. By providing a clear structure for collaboration, engineers are enabled to work together effectively, leveraging each other's strengths to achieve common goals.

This structure lays a foundation to accelerate the development processes. To make it applicable FEV developed a framework to convert theory into practice. It is called Engineering Process Framework (EPF).

## *Converting theory into practice – the engineering process framework*

Building upon the foundation of the "engineering backbone", FEV introduces the Engineering Process Framework (EPF). It enables a more practical application of systems engineering, bridging the gap between theoretical frameworks and real-world implementation.

Figure 1 (Page 46) visualizes the basic principle of EPF, which can be likened to a "pharmacy cabinet". The two dimensions in the front, decomposition and engineering view, form the drawers of this cabinet. The drawers are organized by setting boxes called process areas. These boxes are filled with artifacts, required by standards such as A-SPICE, ISO26262, Cyber Security or SOTIF, according to the related decomposition and engineering view (scope of work).

Therefore, the figure shows, using the example of system design at product (vehicle)-level, what it looks like, if one is pulling a drawer. It can be seen that the drawer is organized according to the standard processes relevant to this combination of decomposition and engineering view. EPF serves as a tool to enhance the efficiency and effectiveness of engineering projects, from initial planning through its conclusion. Configuration of the EPF at project planning phase serves to ensure that the project meets the required standards and specific needs of the industry.

The matrix shape allows, for example, the ordering SW and E/E development at levels higher than component level, helping to address and organize the overarching domain system, software and E/E architectures and implementations, and to treat system requirements at the right level. Importantly, it also allows for a traditional component-oriented V-model shape, if desired. Further advantages are the easy mapping to the FEV project portfolio and mapping to different organizational structures. Once established, the framework also serves to store and structure artifacts of ongoing and new projects, as well as aid as a library for re-use of knowledge.

In this examination it becomes evident that the strength of this framework lies in its ability to adapt and apply to various specific processes within the engineering lifecycle.

## Acceleration with the FEV VDP

Based on an understanding of systems engineering and its engineering process framework, FEV has developed the FEV Vehicle Development Process (VDP). The VDP forms a framework for complete vehicle development projects, as well as partial scopes of work. With the help of a clear focus on systems and a high degree of virtual validation, FEV has succeeded in significantly shortening development times without compromising on quality.

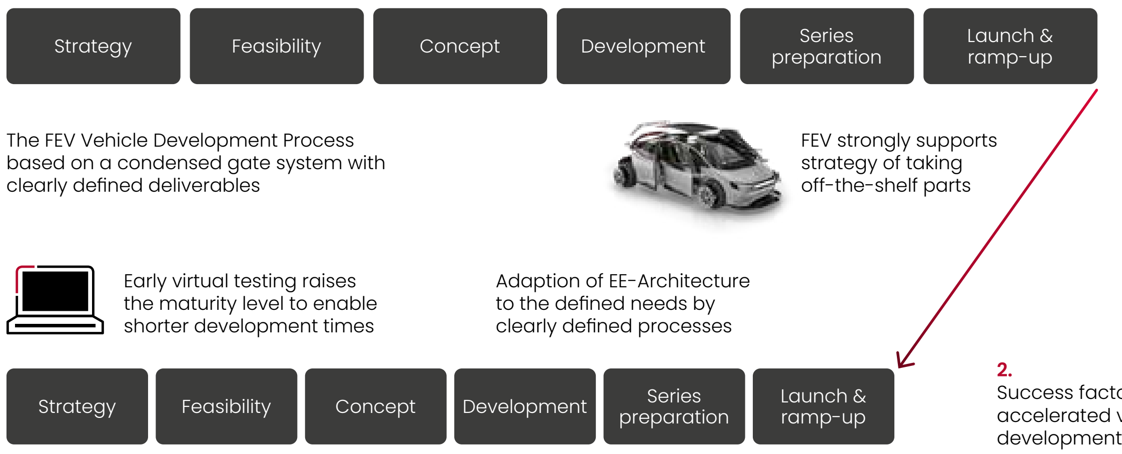
Like in standard vehicle development processes, the FEV VDP has a clear phase structure with overarching gates. These gates are clearly defined by the deliverables of the system-based development structures by FEV.

The success factors for an accelerated vehicle development process reside in the early cross-domain communication and clear commitment to aligned requirements embodied in FEV's "engineering backbone". This enables the integration of off-the-shelf (OTS) solutions, as well as an early alignment with manufacturing engineering. With this foundation, consistent virtualization of development processes further accelerates the VDP for reduced time to market. Integration of the FEV VDP in the EPF is crucial, since it allows gates to pass with the required quality within a given time.

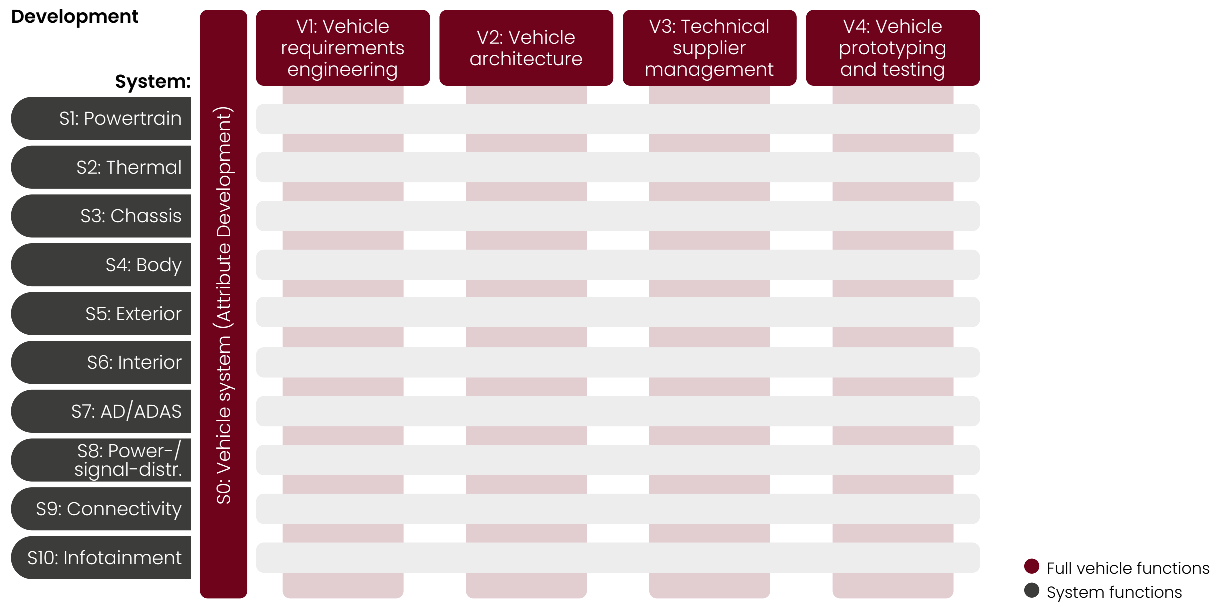
## FEV VDP fully integrated in EPF environment

One important success factor, consequential to complete vehicle development, is a clear structure for the project organization. In this context, the FEV VDP uses the structures and processes of the EPF and combines them into a whole for a vehicle development project. Therefore, the VDP provides a clear guideline on how to structure such a development project. A key element is the development area, that itself works like a matrix organization, featuring vehicle systems on one axis, and an overlaid complete vehicle structure facilitating interaction to the other axis; along with all necessary coordination activities between the systems (Figure 3).

The development area corresponds to the technical drawers of the EPF at vehicle and domain levels and can therefore make use of the underlying EPF processes to develop the technical content. The coordination to ensure clear breakdown of requirements, alignment of vehicle architecture, common technical supplier management, and coordinated vehicle prototyping and testing is realized through dedicated responsibilities across the systems.




**2.**
Success factors for an accelerated vehicle development process.

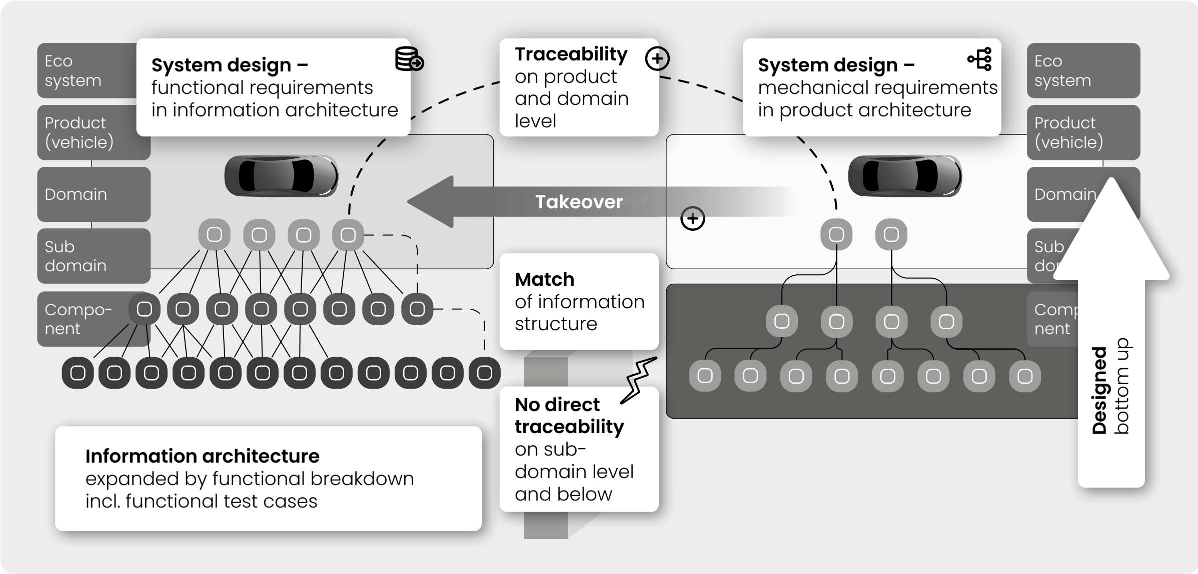



**3.**
Systems engineering base development core in the FEV VDP organization model.

## Real world application of the vehicle development process

In a recent customer project, FEV was requested by a globally leading automotive company to manage the development of a fully connected autonomous battery electric vehicle platform. One of the major project constraints was the date for start of production (SOP), which at the latest was 48 months after the project start. To achieve the scheduled milestones, the project called for use of OTS components and architectures. Engineering realizations including software, E/E, and mechanics were partially re-used by a mix of new and existing suppliers, which helped to ensure adherence to quality requirements and budget constraints.

The VDP enables the reuse of an already industrialized customer product, by updating both the product- and domain-level product architecture, as well as the information architecture in parallel. By assigning all existing, changed, and new functional requirements to the information architecture, it incorporates all desired new features. Unlike traditional top-down systems engineering approaches, FEV's method utilizes a bottom-up strategy, linking the legacy product structure to the updated information architecture. This approach allows to identify existing product architecture elements that can fulfill new feature requirements or pinpoint gaps that require iterative changes. The added value lies in the simultaneous creation and alignment of necessary interfaces between the information and product architectures. (Figure 4, Page 82).




4.
Linkage of information and product architecture.

The resulting information architecture serves as a foundational tool for future innovation. Test cases and requirements can be repurposed for future projects and derivatives. This approach is particularly beneficial for projects with a high number of product variants, such as heavy-duty vehicle development; providing an efficient path to evaluate the feasibility of reusing existing solutions in new variants.

In daily work, these benefits increase the efficiency and effectiveness of engineering and reduce costs. Along with useful frameworks to overcome the barriers of today's engineering challenges, FEV seeks out additional tools to be used for further streamlining of its engineering processes.

## *Further enhancing systems engineering with artificial intelligence (AI)*

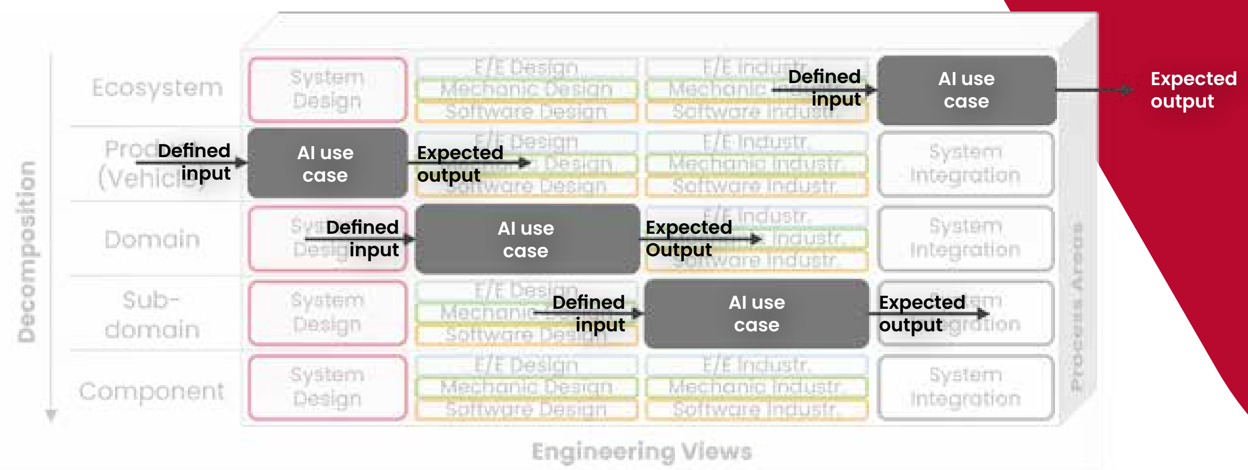
When looking to the future today, the integration of Artificial Intelligence (AI) within the engineering process framework offers exciting opportunities to further enhance the process efficiency and quality of results. The structure defined by EPF provides a robust framework with clear inputs and expected outputs at each stage of the engineering lifecycle.

This structured approach is ideally suited for the application of intelligent tools such as Generative AI (GenAI). It can be employed to optimize and automate various aspects of the process to streamline tasks, reduce errors, enhance decision-making, and thus increase the quality of the product. Several use cases illustrate how AI can be effectively integrated:

**1. Automated requirements generation and validation**
The recent development achievements in the field of GenAI and large-scale language models allow for multi-faceted assistance in systems engineering tasks throughout the entire development process. Starting from auto-generating specifications from project-specific sources, they can be employed in reviewing requirements for testability, independence, consistency or syntax, to generating software documentation and test cases. By configurating large language models individually and providing the right context, generative AI significantly reduces development time while further increasing the quality of work products.

**2. Enhanced design and simulation**
AI can support the development process by integrating multi-physics simulations based on Physics-Informed Neural Networks (PINN), leading to efficient and accurate models that account for complex interactions between various physical phenomena. As an example, FEV is developing this approach to enable rapid design iterations in the field of fuel cell stack development.

**3. Enhance effectiveness with copilot**
GenAI enhances software programming by automating code generation, which reduces manual coding efforts and accelerates development timelines. It also improves code quality by identifying and correcting errors, optimizing performance, and ensuring adherence to best practices through intelligent code review systems. FEV is currently assessing different solutions to ensure compliance and provide further data protection safeguards.




5.
Synergy of AI use cases within FEV's Engineering Process Framework.

**4. Documentation and compliance**
Generative AI can streamline documentation by automating the creation and maintenance of comprehensive and consistent wording, thereby reducing the manual effort required from engineers. It can enhance the quality by ensuring accuracy and compliance with standards such as A-SPICE, ISO26262, and CySec, through intelligent validation and error-checking capabilities. FEV is also currently working on a new solution in the field of OBD documentation.

## *Conclusion*

The combination of EPF and AI represents a powerful synergy that promises to revolutionize engineering practices at FEV. By leveraging AI within this framework, it can achieve unprecedented levels of efficiency, accuracy, and innovation. The journey of integrating AI within the EPF has just begun, and the potential benefits are vast.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# #9
# FEV expands ***benchmarking-offering***

BENCHMARKING

FEV has started operations of its new Benchmark Center (BMC) in Aachen (Germany). Thus, the globally leading development service provider in the fields of mobility, software and energy is continuously expanding its many years of experience in benchmarking. FEV offers its customers an extended range of services at the BMC, ranging from comprehensive analyses of entire vehicles to targeted support at component or technology level.

The demand for benchmarking analyses has been growing, not just since the increasing proportion of new battery-electric models and corresponding manufacturers worldwide. With the latest extensions, FEV responds to this situation and provides its customers with a decisive development advantage through its analysis results.

In Aachen, the new Benchmark Center (BMC) with an extended range of services is located on an area of 1,250 m² at the company headquarters, in the immediate vicinity of the FEV engineering department. The physical proximity now allows to put together interdisciplinary teams of experts flexibly in terms of time and subject matter, for example for holding workshops. This enables the company to draw on over 45 years of engineering experience for its customers in the automotive sector alone and to tailor this experience optimally to customer projects.

In addition to valuable expertise, the BMC utilizes the latest technology. For example, modern material analysis and X-ray equipment as well as 3D scanners are used for documentation and analysis.

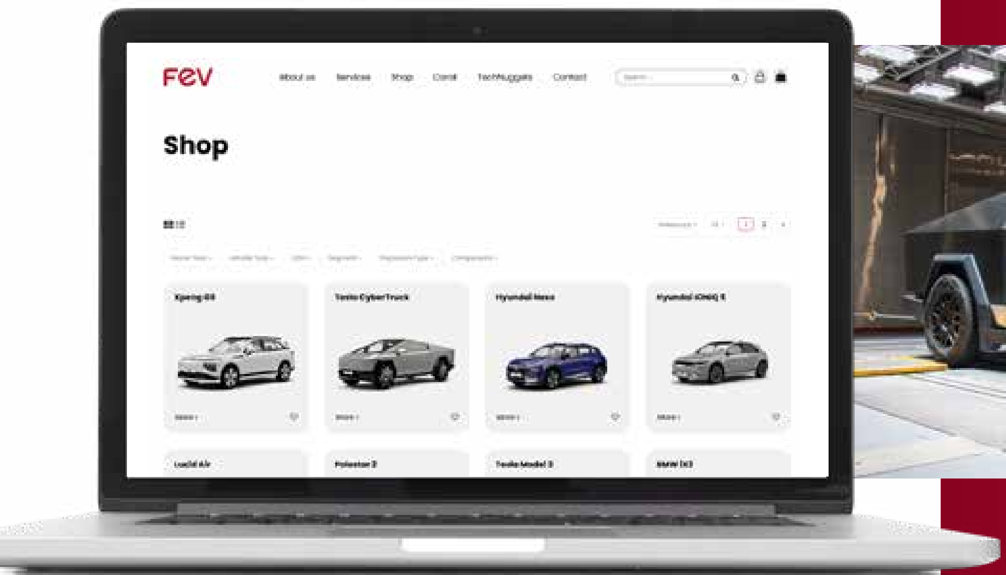
The new Benchmark Center features an exhibition area of 400 m², where visitors can experience vehicles and their hardware live and directly discover the differences and advantages of individual components or systems. A further space of 650 m² are used for documentation and workshop rooms, a photo studio as well as offices and meeting rooms. Workshops and ideation projects are realized on 200 m² in the Innovation Lab. Right next to the benchmarking hardware, spaces have been created that are designed for creativity and maximum output of the working teams in a pleasant atmosphere.

All data collected during the analyses to date and in the future will be integrated into the new cloud-based FEV benchmarking database "carat". This will make it even easier for FEV's customers to use the results optimally for their individual purposes by allowing them to analyze and compare data at all levels of the vehicle via the customizable database.

Beside the new BMC in Aachen, the global Benchmarking team has access to a global network at further three locations in North America, India and China. At the recently expanded Vehicle Development Center (VDC) in Detroit, FEV currently carries out controlled tests at vehicle and system level 2 to analyze for example energy consumption, control strategy, drivetrain efficiency and heat management.

FEV's benchmark experts are currently analyzing Tesla's Cybertruck and the Audi SQ6 e-tron.

**Further information on the benchmarking offer**




# Signature Solutions #10

**SPECTRUM regularly presents a selection of these unique solutions from FEV.**

## *FEV.io revolutionizes the in-vehicle user experience with infotainment solution driven by generative AI*

FEV.io, the software brand of FEV, lately presented an intelligent voice assistant that enables a completely new kind of user experience inside the vehicle. The solution uses generative AI to understand the needs of drivers and passengers and provide optimal solutions in real time.

The holistic development approach by FEV.io is based on an innovative AI framework. The generative AI, which is integrated into the core of the voice assistant, accesses data from a personal, secure cloud profile of the driver and uses live vehicle data as well as environmental parameters to search for the best possible support for the user in real time.

In today's digital and connected world, a new kind of user experience in the vehicle is increasingly expected. This is why the international team of FEV.io analyzes various everyday situations, outlines possible challenges and develops tailor-made, holistic solutions that guarantee the best possible user experience for the driver. The software specialist accompanies the development process from the initial idea to the finalized and tested solution ready for series production, whereby data security and privacy are naturally guaranteed at all times.

**Seamless and intuitive user experience**

The times when specific keywords had to be memorized to operate voice assistants are now a matter of the past. The FEV.io approach offers independent solutions for everyday questions. The following example illustrates the complexity of supposedly simple everyday situations in which the new FEV voice assistant can provide added value:

From the initial questions "When do I have my next appointment? What do I need to prepare for it?", further questions such as "Will I get there on time given the current traffic situation? Is my battery charge or fuel level sufficient for this route?"

The assistance system automatically considers these subsequent steps and offers appropriate solutions.

The system can also control other vehicle functions like the air conditioning or the infotainment system. From the simple expression "I´m tired", the generative AI derives measures such as playing stimulating music or lowering the temperature in the interior. The system also determines the next parking area as a navigation destination and encourages the driver to take a break there. In this way, AI can even increase the safety of the driver and other road users.

FEV combines its expertise in software development with many years of experience in vehicle development. The team draws on a global network of specialists providing customized solutions.

## *FEV's hydrogen storage control unit*

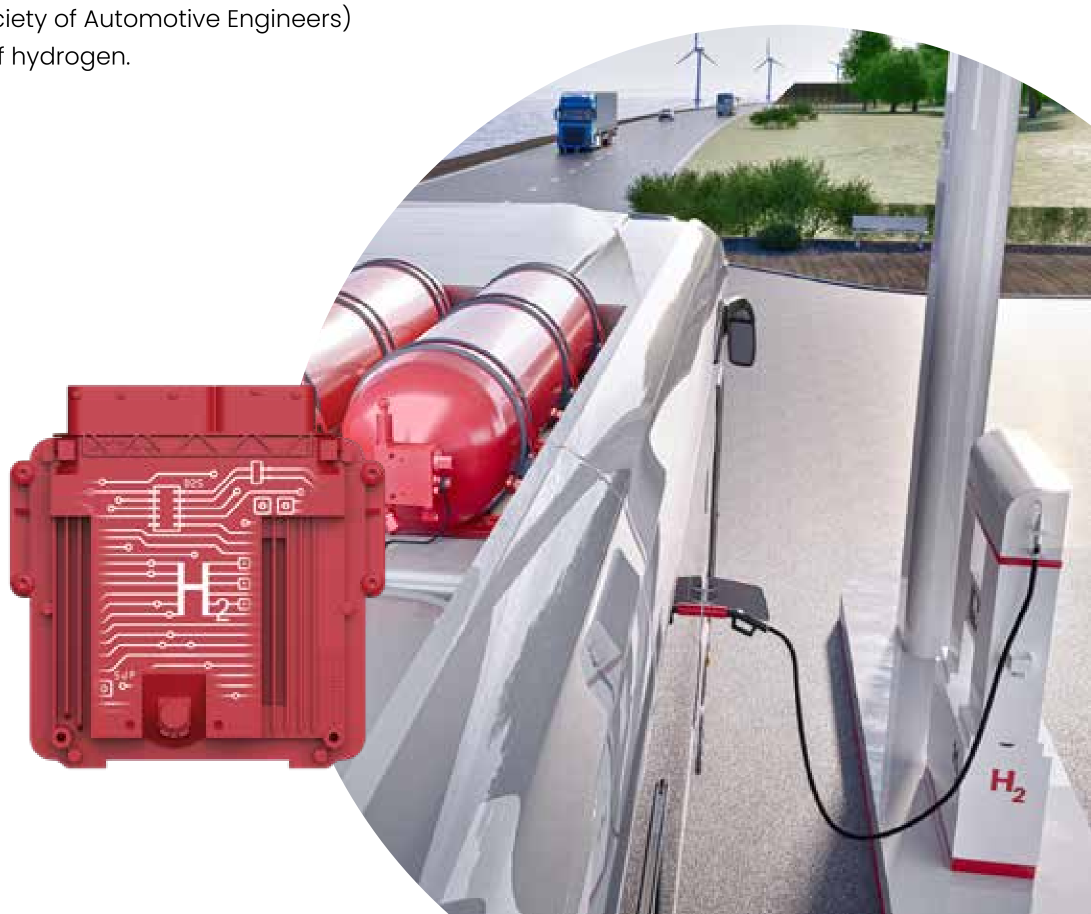
Hydrogen has a key role to play in the sustainable mobility and energy supply of tomorrow. Whether in fuel cells or in direct combustion, hydrogen enables a carbon-neutral power generation and is also an excellent way of storing energy. At the same time, safe and reliable storage is a particular technical challenge due to its physical and chemical properties. Besides suitable hardware such as leak-proof and rugged tank vessels, safe handling and dependable safety measures are essential.

FEV has developed a sophisticated software that enables the control and monitoring of hydrogen tank systems. The software can be used wherever gaseous hydrogen has to be stored for use in mobile applications, whether in cars, trucks or even trains. It also does not matter at which pressure level (350 bar or 700 bar) the system operates. The modular structure allows a unique adaptation to dedicated customer requirements and excellent system scalability. This shortens development times and saves costs.

During development, FEV's engineers strictly adhered to the standards of the SAE (the Society of Automotive Engineers) with respect to the storage of hydrogen.

Thanks to its unique and patent-pending diagnosis concept, the software is capable of seamlessly monitoring hydrogen tank systems and detecting even small leaks.

FEV offers the software as a black box for integrating into the customer's system or as a white box with sub-licensing by the supplier or OEM. In the latter variant, the customer can further develop the software according to its own requirements and adapt it to changing parameters.



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