HiPE

High Performance Power Electronics Integrations

First HiPE Newsletter November 2023

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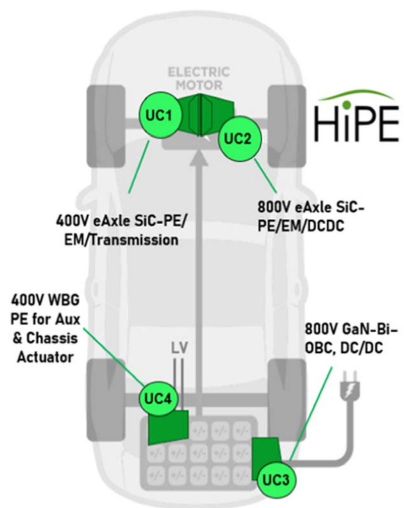


The **HiPE project** is part of the EU Call "HORIZON-CL5-2021-D5-01-02. Nextgen vehicles: Nextgen EV components: Integration of advanced power electronics and associated controls (**2ZERO**)". The **HiPE consortium** brings together **13 participants** from industrial and research backgrounds, covering the whole relevant value chain, to **develop a new family of highly energy-efficient, cost-effective, modular, compact and integrated wide bandgap (WBG) power electronics solutions** for the next generation of battery electric vehicles (BEVs), and to facilitate a significant market penetration of WBG in the automotive sector.

The project outputs will include:

- a scalable and modular family of WBG-based traction inverters with significantly improved specific cooling performance, suitable for 400V, 800V and 1200V applications, with power ratings from 50 to 250 kW, integrated into electric drives including the high-to-low voltage (HV/LV) DC/DC converters, thus enabling drastic size and weight reductions (**UC1, UC2**)
- a family of integrated WBG-based bidirectional on-board chargers (OBCs) and HV/LV DC/DC converters, with optimized innovative topologies, including use of GaN (**UC3**)
- integrated, fault-tolerant and cost-effective GaN-based power electronics for high-voltage ancillaries and chassis actuators (**UC4**)

The development of these outputs will imply significant research and innovation in terms of circuit topologies, electro-magnetic interference filters, integrated double-side pin-fin and immersion/impingement/two-phase cooling, stray inductance reduction, DC-link capacitors, materials, manufacturing techniques, as well as intelligent model-based and data-driven control, achieved through simulation and optimization methodologies. The result will be an unprecedented level of functional integration, e.g., the **HiPE** smart power electronics solutions will include intelligent and predictive controllers to optimize performance, innovative and computationally efficient data-driven approaches to monitor the state-of-health of the relevant hardware, as well as novel self-adaptive digital-twin-based methodologies to tailor the component- and vehicle-level algorithms to the specific condition of the hardware installed on each individual BEV, and actively improve reliability and availability of the electronic parts during field use.

The first year of the HiPE project has been completed and the project is well on track to reach its planned research and innovation goals. This newsletter provides highlights from the technical work completed by the different work packages as well as an overview of the project and an introduction of the involved project partners.

The HiPE Project at a glance

HiPE Vision

The development activities of HiPE will imply significant research and innovation in terms of circuit topologies, electro-magnetic interference filters, integrated double-side pin-fin and immersion/impingement/two-phase cooling, stray inductance reduction, DC-link capacitors, materials, manufacturing techniques, as well as intelligent model-based and data-driven control, achieved through simulation and optimisation methodologies.

HiPE Mission

The project mission will be an unprecedented level of functional integration, e.g., the HiPE smart power electronics solutions will include intelligent and predictive controllers to optimise performance, innovative and computationally efficient data-driven approaches to monitor the state-of-health of the relevant hardware, as well as novel self-adaptive digital-twin-based methodologies to tailor the component- and vehicle-level algorithms to the specific condition of the hardware installed on each individual BEV, and actively improve reliability and availability of the electronic parts during field use.

Ambition of HiPE

Integrated WBG-based electric drive

HiPE ambition is to research and develop the next generation of highly efficient and affordable integrated electric drives for BEVs resulting in electric drive power density values in electric drive power density in excess of 25 kW/L, specific power values in excess of 6 kW/kg, and >23% inverter cost reduction with respect to the current best-in-cost WBG-based inverters, meet and exceed the quantitative performance and cost indicators set by the US DRIVE and UK APC roadmaps.

Integrated bidirectional WBG-based OBC and HV/LV DC/DC converter

HiPE will create a knowledge base on the potential of: a) using Gallium Nitride (GaNs) for on board charger (OBC) applications, and comparisons with more conventional silicon-carbide (SiC-)based implementations; b) integrating the OBC and HV/LV DC/DC; and c) selecting the most appropriate bidirectional OBC topology, depending on the BEV requirements, to achieve high power ratings (e.g., 22 kW) with at least 98% efficiency and 5 kW/L power density.

Smart electric drives for chassis actuators and auxiliaries

HiPE will research a paradigm shift in the development of actuation systems for BEVs, by proposing 400V and 800V active electro-hydraulic suspension actuators, with smart GaN-based electric drives including predicting health management (PHM) and connectivity functionalities, as well as reduced number of solenoids, compensated by enhanced controllability of the hydraulic pump.

Advanced cooling and predictive thermal and energy management

HiPE aims to design direct cooling systems that can significantly increase heat transfer rates and cooling performance by integrating technologies not yet investigated for automotive PE components, i.e., jet impingement cooling, phase changing materials, immersion cooling, new pin-fin designs as well as heat-pipes, with implementation costs that are lower or at least the same as with current cooling technologies.

Predictive health management

HiPE aims at assuring the car user reaches its current destination and will be achieved by implementing compact versions of the digital twins directly into the real-time electronic systems. This new "mission guarantee" idea will boost customer satisfaction, as it offers not only a safe journey, but also promises no more breakdowns before the destination is reached.

HiPE Objectives

- **Objective 1 | Improve the efficiency of integrated WBG-based power electronics components and systems**
- **Objective 2 | Reduce the cost of power electronics components and systems**
- **Objective 3 | Reduce size and weight of power electronics and electric powertrains systems**
- **Objective 4 | Increase reliability and dependability through integrated design and intelligent control systems**
- **Objective 5 | Implement WBG-based power electronics meeting automotive quality levels systems**

HiPE Partners

The HiPE consortium consists of 13 partners from seven different European countries. The following Tables give an overview over who they are and what they contribute to HiPE.

Virtual Vehicle Research GmbH (ViF)

The company: ViF is a leading international R&D center in the automotive and rail industries. The center focuses on the advanced virtualisation of vehicle development. This linking of numerical simulations and hardware testing leads to a comprehensive hardware–software system design. The company was and is project coordinator of several national and European R&D projects (such as HiPE, HEIDI, greenSPEED, XL-Connect, SYS2WHEEL or EUREKA Test.EPS) and contributes its expertise not only as a coordinator but also as a project partner in various projects (such as HiPERFORM, HiEFFICIENT, SHOW or ADVICE).

Contribution to HiPE: ViF is the coordinator of the project and therefore responsible for the overall management and coordination of the HiPE project (including administrative tasks). On the technical side ViF leads the Thermal Management work package to design and select improved cooling solutions for the four HiPE Use Cases. Virtual Vehicle also supports other technical tasks with their knowledge and data.

AVL List GmbH (AVL)

The company: AVL is one of the world's leading mobility technology companies for development, simulation, and testing in the automotive industry, and in other sectors. Drawing on pioneering spirit, it provides concepts, solutions, and methodologies for a greener, safer, and better world of mobility. To achieve the vision of climate-neutral mobility, AVL drives innovative and affordable solutions for all applications—from traditional to hybrid to battery and fuel cell electric technologies. The company is also in the consortium of several national and international R&D projects such as FC-IMPACT, EUREKA Test.EPS, SHOW, ADVICE and HiPE.

Contribution to HiPE: AVL contributes to several tasks within HiPE. This includes component and system integration and calibration, including the development of simulation software as well as Thermal Management cooling design and integration for Use Case (UC) 2.

Ford Otomotiv Sanayi Anonim Sirketi (Ford Otosan or FO)

The company: Ford Otosan, being one of the top three exporting companies in Turkey since 2004, has achieved 12 consecutive years of automotive industry championship and is Turkiye goods product export champion for 8 years in a row. In 2022, export of vehicles and spare parts from Turkiye continued with 94 countries in 5 continents worth 6,2 billion USD. With 1688 R&D employees, Ford Otosan has the largest R&D organisation in the Turkish industry and is exporting engineering. It serves as the global engineering center for Ford's heavy commercial vehicles, related diesel engines, and engine systems, as well as the support center for Ford's light commercial vehicle design and engineering. FO was and is also engaged in different European R&D projects such as SYS2WHEEL, HiPERFORM, Power2Power, HiEFFICIENT and more.

Contribution to HiPE: Ford Otosan is the Lead for Use Case 2 (800V WBG-Bi-OBC DC/DC) and is therefore responsible for the design, development and prototyping of UC2. Beside that the company defines design specifications for modular and brand-independent component and system simulation requirements as well as create (or support in creating) different simulation models and implement them accordingly. Ford Otosan also supports the creation of testing specification, the testing itself and other tasks in the different work packages.

Fraunhofer ENAS (FHG)

The company: FHG is a leading research and development center specialising in electronic nanosystems. ENAS focuses on cutting-edge technologies and innovations in the field of electronic nano systems, which encompass micro and nanoelectronics, microsystems technology, and smart systems integration. With a team of dedicated researchers and state-of-the-art facilities, FHG plays a pivotal role in advancing and optimising electronic components and systems for various applications. FHG also contributed to several European R&D projects: COMPAS, EVC100, HiPERFORM, Power2Power and HiEFFICIENT.

Contribution to HiPE: FHG is responsible for a reliability analysis and AI-based predictive Health Management (PHM) for Power Electrics (PE) compnents and systems and does other analysis. The company also characterises the critical materials for developing digital twins to the new inverters as well as creating compact versions of the digital twins.

Ideas & Motion SRL (I&M)

The company: I&M started operations in 2013. It originates from the intuition of a group of engineers who has succeeded in combining technical excellence and innovation with the development of worldwide successful automotive systems. I&M's main focus is technical excellence and innovation in the development of high-efficiency power inverters for the electric mobility sector, with very clear goals: research and development, innovation transfer into products and access to the best in class technologies. I&M was part of some European R&D projects: HiPERFORM, HiEFFICIENT, ADVICE, EVC1000 and more.

Contribution to HiPE: I&M exploits its experience in the development of traction inverters to design and prototype a GaN-based inverter for a full-electric active suspension system. The target power for this application is in the range of 1-2 kW operating at a DC voltage of 400 V.

Institute for Advanced Energy Systems & Transport Applications (IESTA)

The company: IESTA was founded in 2009 and is a combined industrial/academic research and consulting association for innovative mobility and energy systems. It offers state of the art methodologies for systematic creation of solutions and creates strategic partnerships between innovative Austrian and European enterprises, top listed research facilities and policy-makers in the area of research, technology development and innovation. IESTA was and is also part in several national and European R&D projects such as ADVICE, SYS2WHEEL, HiPE, EUREKA Test. EPS, SHOW, HADRIAN and so on.

Contribution to HiPE: IESTA is responsible for developing a HiPE-specific Cost Assessment Methodology and the accompanying calculation tool. This includes Total-cost-of-ownership (TCO), cost-benefit-analysis (CBA) as well as cost-effectiveness-analysis (CEA) calculations for the different HiPE Use Cases. The company is also responsible for all Dissemination, Communication & Exploitation related tasks.

Marelli Europe SPA (MAR)

The company: MAR is a leading global technology company in the automotive sector, specialising in the design and production of advanced automotive systems, components, and solutions. With a rich heritage of innovation and engineering excellence, Marelli is dedicated to driving the future of mobility with cutting-edge technology and a commitment to sustainability. The company was also part of the Autodrive project.

Contribution to HiPE: MAR exploits its experience by designing, developing, realising and integrating PE systems for UC1 and UC2 as well as providing the corresponding simulation models. Beside that it develops software, program protocol and firmware, is providing and integrating innovative and novel semiconductor cooling concepts and supports several other tasks within HiPE with their technical expertice.

Technical Univeristy of Ilmenau (TUIL)

The company: TUIL is a renowed institution dedicated to pursuit of excellence in engineering, science, and technology education and research. Established in 1894, the university has a rich history of providing high-quality education and fostering innovation. It offers a wide range of programs in fields such as engineering, natural sciences, computer science, economics, and media studies, catering to students from around the world. TUIL is involved in HiPE as well as other European projects such as HighScape and EM-Tech.

Contribution to HiPE: TUIL supports HiPE essentially with the experimental validation of the project results. In addition, TUIL provides an integration plan and test specifications and requirements, protocols for component and system interfaces, thermal data and solutions, as well as the development of basic control functions and an integrated controller.

Tenneco Automotive Europe (TEN)

The company: TEN is a market leader in conventional and advanced suspension products by delivering 90 million shock absorbers and suspension products to its customers. The global research and development center for ride performance is located in Sint-Truiden Belgium with expertise in the fields of advanced suspensions, control systems, core engineering, simulation and advanced manufacturing.

Contribution to HiPE: TEN develops chassis actuators, low-level controllers and provides the demonstrator vehicle for UC4. Said demonstrator vehicle will be tested on Proving Grounds in Belgium under supervision of TEN. The company supports as well other tasks within the project.

Ustav Teorie Informance a Automatizace AV CR (UTIA)

The company: The Institute of Information Theory and Automation (UTIA) is a public non-university research institution which administratively falls under the Czech Academy of Sciences. UTIA conducts fundamental and applied research in computer science, signal and image processing, pattern recognition, system science, and control theory.

Contribution to HiPE: UTIA performs simulation and evaluation at system level, power cycle tests and failure analyses and contributes to virtual DoE studies and compact digital twins schemes with focus on wire bond and die bond degradation and supports other tasks.

ŠKODA AUTO a.s. (SKO)

The company: Škoda Auto as part of the Volkswagen Group, is a Czech automobile manufacturer with a rich history dating back to its foundation in 1895. Škoda Auto also independently manufactures and develops components such as MEB battery systems, engines and transmissions as part of the Volkswagen Group; these components are also used in vehicles of other Group brands. The company operates at three sites in the Czech Republic; has additional production capacity in China, Slovakia and India primarily through Group partnerships, as well as in Ukraine with a local partner. The company employs over 40,000 people globally and is active in around 100 markets.

Contribution to HiPE: Škoda Auto is responsible for UC1 and provides the corresponding demonstrator vehicle and its components. It also leads the development of the automotive requrements and specifications, component interfaces protocols and functionalities as well as the integration of components. The company also involes in other activities such as simulation modeling, testing and the cost assessment.

Nexperia Germany GmbH (NEX)

The company: NEX is an integrated device manufacturer IDM in the design, manufacturing, and distribution of discrete, logic, and MOSFET semiconductor components for various applications in the electronics industry. Nexperia Germany operates from Hamburg Lokstedt with the following vertically integrated functions: R&D, semiconductor manufacturing, operations, quality, marketing, finance, HR, and more. Together with the mother organization Nexperia B.V., headquartered in the Netherlands, Nexperia is a global semiconductor firm with over 15,000 employees across Europe, Asia, and the United States. with a focus on providing advanced solutions for a wide range of markets, including automotive, industrial, & consumer-electronics.

Contribution to HiPE: NEX is committed to advancing innovation and research in the field of power semiconductors based on GaN & SiC. NEX provides novel PE devices (especially the SiC and GaN semiconductors and MOSFETs) and packaging solutions and it defines concepts for integrated GaN PE for chassis actuators. Beside that it supports several other tasks within HiPE.

University of Surrey (UoS)

The company: The University of Surrey, located in Guildford, Surrey, United Kingdom, is a distinguished institution known for its dedication to academic excellence, innovative research, and a commitment to preparing students for success in a rapidly changing world. Surrey's commitment to research and innovation is evident in its state-of-the-art facilities and its contributions to groundbreaking research in areas such as technology, health, and sustainability. The university actively collaborates with industry partners, fostering connections that benefit both students and the global community. UoS was and is also part of several European R&D projects such as ADVICE, SYS2WHEEL and EVC100.

Contribution to HiPE: UoS is responsible for generating vehicle simulation models and controllers as well as simulation-based optimisations, and evaluation of HiPE architecture and helps with other tasks related to simulation models. Beside that UoS supervises as well the vehicle tests on Proving Grounds in Belgium in cooperation with TEN.

Achievements from the First Year of HiPE Project

The first year of the HiPE project has been completed and the project is well on track to reach its planned research and innovation goals. This newsletter provides highlights from the technical work completed in the first 12 months of the project.

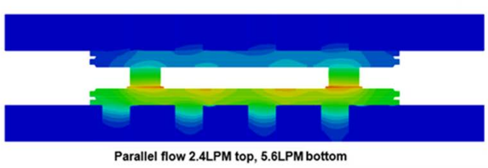
Computational fluid dynamics simulations (CFD) to improve cooling solutions

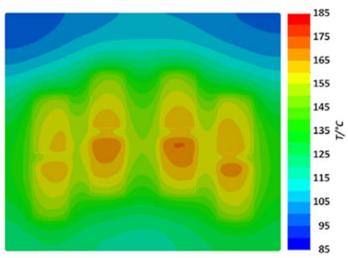
This task is part of WP6 and the primary target within this work package is to select and design the significantly improved cooling solutions for all four HiPE Use Cases.

To archieve this CFD simulations were carried out for different cooling methods to assess their impact on inverter thermal performance. The simulations were done in OpenFOAM with the main focus on optimizing the cooling channels at the top and bottom of the power module stack as well as the pin-fins in the cooling channels for better heat transfer and to maximize the cooling peformance. Simulations were split into ones single power module level to derive configurations and pin fin form factor and into one on inverter level (three Power Modules (PMs)) to to check validity of the cooler design derived from the single PM simulations for the inverter package. Three cooling concepts were tried as explained in the following:

Indirect Liquid cooling

Indirect liquid cooling has been proved to be the effective cooling method according to the literature. In our case, the cooling channel with pin-fins was designed on a single module level. The baseline design of the cooling channel and pin-fin was done considering the reasonable literature data just to observe the cooling performance for our case of heat flux input of the selected power module.

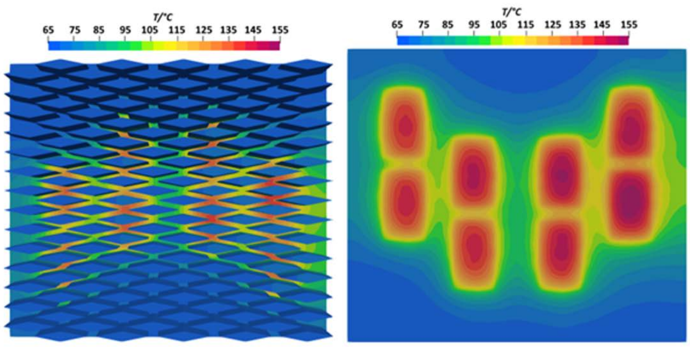


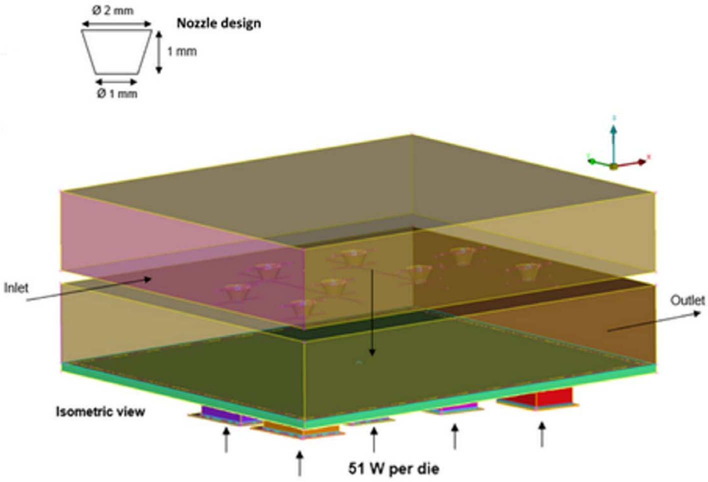


The figure on the left shows the temperature contour for the cooling channel of the cooling channel and its baseplate. It can be clearly seen that the coolant takes away the heat effectively keeping the temperature of the power module well within the limits.

Direct Cooling with pin-fin optimization

The next attempt to improve the cooling performance was just to increase the height of the channel and pin-fins which would in turn increase the heat transfer surface area. The attempt proved to be better where we could see the temperature of the chips were much less compared to the baseline simulations.

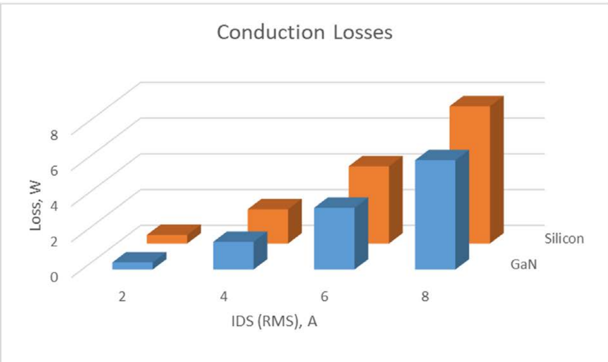




Impingement cooling

Impingement cooling is relatively new cooling concept and works well if the heat source is comparatively low. The cooling channel was design with two cooling passages connected by nozzles so that the coolant is impinged directly onto the baseplate with high velocity. Enabling the coolant to impinge directly above the heat source facilitates the cooling. Increasing the amount of coolant impinging the baseplate increases the heat transfer coefficient on the surface of the baseplate.

First power loss and junction temperature simulations of GaN-based inverters



This task is part of WP3 and the main target within this work package is to implement simulation models for the development and optimization of HiPE PE architecture, to evaluate the scalability and modularity of said architecture, to implement innovative an predictive health management solutions and to assess the benefits fo the HiPE architecture.

To achieve precise estimations of power losses and junction temperature for the GaN transistors to be used, these components have been described within I&M's Simulator for Power Losses Evaluation (SimPLE) environment. SimPLE is represents the culmination of years of experience in device modelling, simulation, and usage at I&M. This modeling environment was developed for the accurate assessment of power loss estimation and design space exploration. It boasts an exceptional degree of modularity and flexability: it is possible to describe any power device virtually in a simple way, basing complex simulations on data that can derive either from the device's datasheet or from real-world measurements.

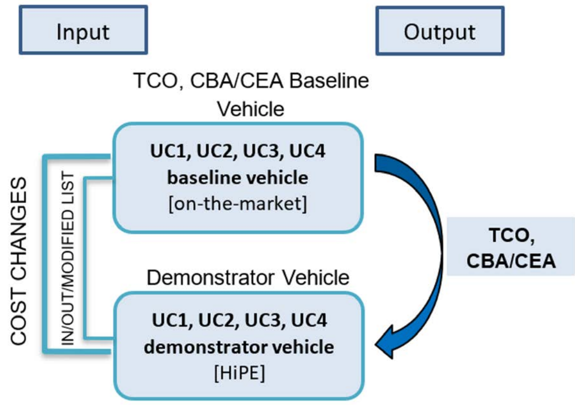
Thanks to the GaN SPICE models and the datasheets provided by Nexperia it was possible to implement a simplified transistor model in SimPLE and to compare this device against a silicon-based MOSFET with similar performance. From this analysis, it is possible to forecast a reduction of 20% in conduction losses and between 50% and 80% for the switching losses, with a consequent relaxation of thermal constraints.

The time required for a system level simulation is in the order of a few seconds, hence exploring different design configurations to find the best one for a given Use Case is simple and helps the designer during the investigation phase.

Development of the Cost Assessment Methodology

This task is part of WP5 and the primarily target of this work package is the testing, evaluation and demonstration as well as value analysis and cost assessment of the HiPE technologies.

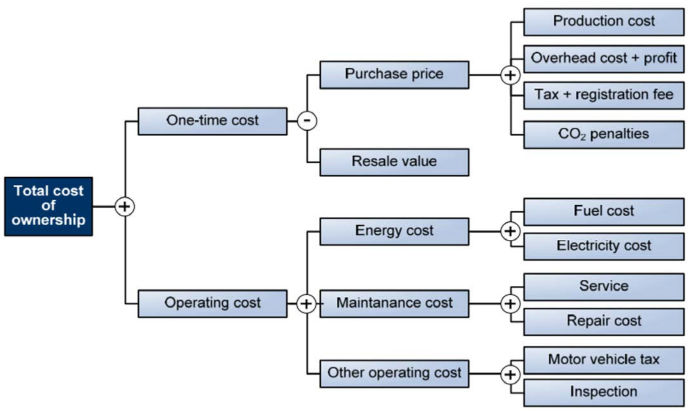
The Cost Assessment of HiPE consists of a total-cost-of-ownership (TCO), a cost-benefit-analysis (CBA) and cost-effectivness-analysis (CEA). Goal is to see at the end of the project, if the different HiPE cost targets could be achieved or not by comparing selected baseline vehicles (vehicles on the market **without** HiPE innovations) with the developed demonstrator vehicles (same vehicles as the baseline vehicles but **with** HiPE Innovations) for each Use Case.



Total-cost-of-Ownership (TCO)

A vehicle's **total-cost-of-ownership (TCO)** includes specific non-recurring/one-time costs (such as initial purchase price vs. resale value) as well as recurring/operating etc. costs (e.g., energy expenses, maintenance, insurances). All these cost categories vary depending on the length of ownership, mileage and technical specifications of the vehicle.

The **cost categories** used in the TCO are the following:
• Retail price
• Fixed costs (e.g. insurances)
• Workshop costs (e.g. vehicle inspections)
• Operating costs (e.g. fuel)
• Depreciation costs



The **basic procedure** to determine the TCO of the Baseline vehicles (BLVs) as well as Demonstrator vehicles (DVs) is as follows:
Step 1: The TCO of the BLVs is collected from a verified reference database. If TCO data is not available in the database, OEM cost engineering will deliver data from calculations and simulations.
Step 2: Subsequently, specific relative cost differences between the Demonstrator vehicles (BLVs) and the Baseline vehicles are determined.
Step 3: From this, the TCO of all Demonstrator vehicles can be calculated.

Cost-benefit-analysis/Cost-effectiveness-analysis (CBA/CEA)

The **CBA/CEA** defines cost-relevant metrics and targets for the components, subsystem and systems developed in HiPE and included in the technological portfolio introduced in the DV and provides tangible conclusions on the most beneficial/advantageous portfolio of components.
The CBA/CEA will focus on specific measures and innovations, components and subsystems of the vehicle. Corresponding relative changes between the BLVs and the DVs are assessed using a practicable approach.

The **basic procedure** for determining the benefit-cost ratios for the DVs is as follows:
Step 1: CBA/CEA of the BLV is investigated by the OEM concerned.
Step 2: The overall target categories (cost and the benefit categories e.g., efficiency, size&weight, etc.) are weighted relatively to each other, particularly reflecting the importance for the customer.
Step 3: The relative changes in costs and benefits for specific items (measures & innovations, components, subsystems) in the DV to those in the corresponding BLV are assessed.
Step 4: Finally, a benefit-cost ratio is calculated for the corresponding specific item in the DV in relation to the BLV.

Outlook for Year 2

This section gives a brief outlook on what is planned in the next project period.

Computational fluid dynamics simulations (CFD) to improve cooling solutions

From the already finished activities in WP6 **reduced order models of the CFD models** will be derived in the next steps focusing on SiC inverter cooling. The models will **provide insights into thermal specifics** i.e. mean temperatures of the most vulnerable elements inside the power electronics, based on operating and ambient conditions while significantly reducing computational time. Thus implementation in Digital Twins is feasible, which may greatly improve component reliability.

Also, as an outlook **fast computing thermal models for UC1 and UC2 vehicle cooling circuits** will be derived, which then will be combined with the 3d ROM. Cooling circuit simulations provide the relevant ambient conditions for considered components, hence important boundary conditions for driving cycle assessments.

First power loss and junction temperature simulations of GaN-based inverters

This activity will proceed with two validation steps. The **first step** will involve the use of computational fluid dynamics models to ensure that the expected thermal behavior has been accurately described within the simulation environment. The **second step** will serve to finalize this validation by comparing the simulation results with measurements taken from real samples developed throughout the project.

Through the development and the validation of this digital twin the **best architecture will be identified for the inverter**, expediting the design of real samples to be used on the test bench for testing the conceptual idea of a full-electric levelling system.

Development of the Cost Assessment Methodology

The next steps in this activity will be to **develop the calculation tool** for the Cost Assessment. With this tool it will be possible to calculate the TCO and CBA/CEA on a highly detailed level, even considering country specific taxes, incentives and e.g. energy prices (which would have e.g. an impact on the operating costs of Battery Electric Vehicles).

After that the **data collection** for the Demonstrator vehicles will start by asking the OEMs and other project partners for vehicle specific data, relevant for the Cost Assessment. Generic data such as Taxes, Subsidies, Energy Prices, Fuel Prices will be derived from literature or other sources available to the public.

General Project Information

More information on HiPE is available on our website: hipeproject.eu

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Project Partners

Coordinated by

Partners

Project Facts

Project Coordinator: Bernhard Brandstätter
Institution: Virtual Vehicle Research GmbH
Website: www.hipeproject.eu
Duration: 36 months

Project Start: 1st November 2022
Consortium: 13 partners
Project Budget: 5,481,274 Euro
Project Funding: 5,481,274 Euro

Acknowledgement

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