European Innovation for Next Generation Electrified Vehicles and Components

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***Abstract*—Electrification of road transport is a key challenge to reach the emission targets while enabling efficient mobility for persons and goods. Even though solutions already exist on the market, e-mobility is still a niche market. Main challenges for large scale deployment include higher maturity with respect to performance (e.g., range), development efficiency (e.g., time-to-market), or production costs. Additionally, an important market transformation currently occurs with the co-development of automated driving functions, connectivity, mobility-as-a-service. In this context, the European Commission started different research programs in 2018 with a total volume of more than 50Mi€. Target of this paper is to present an overview of these programs and discuss how this portfolio will provide significant advances for e-mobility relying on European technologies.**

Keywords—e-mobility, seamless development, e-drive, HV battery, e-motor, energy management

I. INTRODUCTION

The automotive domain is currently facing two revolutions at a time: the shift towards electrification and towards autonomous driving. Both revolutions are tightly linked to societal challenges such as clean transportation [1][2], zero fatalities [3][4], mobility for an ageing population, as well as to customer needs towards more personalized mobility. Both revolutions are strongly supported or even enabled by ICT (information and communication technologies) and consequently result to a shift in the value creation as well as required skills in the automotive domain. New regulations and incentives for e-mobility are published to support this trend; parallel to this, new business models such as car sharing are emerging; connected car [5][6] is a further important driver in this context. Summarizing, the automotive market is currently being revolutionized and reorganized, electrification and autonomous driving supported by ICT playing a central role.

Parallel to that, there is a strong political commitment worldwide towards green mobility and reduction of pollutant emissions, caused by attempts to deal with the climate change and the air quality, especially in large urban areas. The expected results are addressing the urgency in tackling the issue of climate change through the reduction of the emissions at the source level. Powertrain electrification supports satisfying various environmental initiatives as well as ever so more stringent legislation. Simultaneously, the consumers expect performance improvements at no additional costs. Therefore, there is a need for the technology to mature to reduce the risk of potential failures and to significantly reduce the production costs. The maturity would also help secure a smooth transition from the user perspective, in terms of driving performance and cost. The concurrent customer demands (e.g. higher or at least comparable performance levels, drivability and comfort, improved safety and styling) must be met at acceptable costs (purchase costs as well as the operating costs despite the trend of rising fuel prices).

With falling prices and recent technological advances, the second generation of electric vehicles (EVs) that is now in production makes electromobility an affordable and viable option for more and more people. With the help of strong governmental support, it appears that electromobility is on the verge of major expansion in Europe and the rest of the world. To maintain this EV momentum, the latest edition of ERTRAC roadmap for electrification of road transport [7] defines four big initiatives outlining the R&D needs. The European projects VISION-xEV, XILforEV, ACHILES, EVC1000, FITGEN, SELFIE, SYS2WHEEL and CEVOLVER have been started in this context to tackle these challenges and provide solutions for the efficient development and validation of electrified vehicles, as well as for the development of innovative architectures, components and systems for next generation electrified vehicles. Main contribution of this paper is to introduce these initiatives and discuss their complementarities. The paper is organized as follow: In Section 2 and 3 the projects related to virtual product development and validation, and innovative architectures, components and systems, respectively, are presented. Section 4 discusses the complementarity of the portfolio, and finally Section 5 concludes this work.

II. INCREASING THE EFFICIENCY FOR DEVELOPMENT AND VALIDATION OF INNOVATIVE E-VEHICLES

A. VISION-xEV

In complex multi-domain products such as vehicles, the development of different components and sub-systems are done separately and then connecting them together does not lead to optimal result, since an additional overall development step is needed to harmonize the whole system. Additionally, due to the involvement of a high number of engineers in the development activities, issues related to communication and model/data exchange can hardly be avoided.

High-performance computing (HPC) capabilities are increasingly available today, they allow to efficiently perform complex computations as well as large series calculations covering thousands of parameter variations, and hence enable the efficient development and pre-optimization of physics-based virtual prototypes (digital twins) on both component and system level. Adopting detailed digital twins of components and sub-systems and integrating them into complex powertrain and vehicle models enables massive frontloading of development activities and hence can significantly reduce development time, cost and finally time to market. In this way, a huge percentage of traditional development efforts can be shifted from road, test rigs and laboratories to simulation and virtual testing.

VISION-xEV [8] investigates beyond the state-of-the-art component development and system integration modelling and simulation to maximize the use of digital product development and to reduce lab and road testing. The goal of VISION-xEV is to unveil and demonstrate a consistent modelling and simulation-based methodology for component development and system integration. VISION-xEV aims to enable virtual prototyping from component to sub-system to powertrain/vehicle level to support the efficient and effective development of future electrified/hybrid vehicles.

Fast reduced order physical-based models suitable for efficient application to the virtual integration of components and sub-systems represent the building blocks of the VISION-xEV simulation framework. Besides, strategies and methods for component and sub-system model parameterization based on simulation results of high-fidelity multidimensional simulations, as well as for their seamless validation based on physical data from experiments, are elaborated. The major elements of the VISION-xEV component development and system integration framework are innovative scalable simulation models of the relevant powertrain components and sub-systems as well as suitably extended and adapted coupling and co-simulation methods to enable seamless interaction of the individual virtual components and sub-systems regardless of the adopted modelling platforms, see Figure 1. The proposed approach is demonstrated in four relevant industrial use cases.

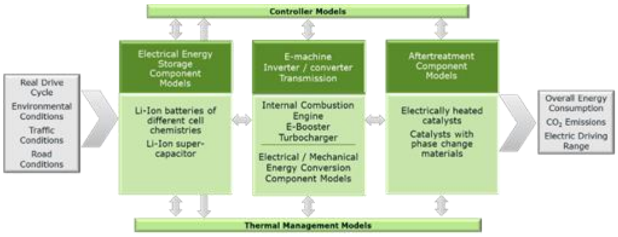

Figure 1: VISION-xEV component development and system integration

B. *XILforEV*

Overall development process of electric vehicles consists of many stages, elements and components, which are being characterized nowadays by unequal levels of technological maturity and by allocation to different physical domains. It leads at least to the following design challenges: (i) harmonization of actuation dynamics of EV powertrain and chassis; (ii) delivering required user acceptance of new EV functionalities; and (iii) addressing more complex requirements to the fault-tolerance and robustness. To address these problems, the XILforEV project [9] proposes a new approach aimed at developing a connected and shared X-in-the-loop (XIL) experimental environment uniting test platforms and setups from different physical domains and situated in different locations. The domains under discussion can cover (but are not limited to) hardware-in-the-loop test rigs, dynamometers, software simulators, driving simulators and other variants of experimental infrastructures. Real-time running of specific test scenarios simultaneously on (i) all connected platforms/devices with (ii) the same real-time models of objects and operating environments allows exploring interdependencies between various physical processes that can be hardly identified or even expected on the design development stage. In the long-term perspective, the plug-in concept of including various test platforms/devices and easy on-demand access to the test campaigns for developers, engineers and researchers will bring a vast impact to the EV design community through connecting experimental environments around the world.

The XILforEV project is based on previous studies of the participating institutions [10]. The key project elements are four use cases dedicated to the design of innovative solutions for brake blending, ride blending, integrated EV chassis control, and EV fail-safety [11]. For these use cases two distributed XIL architectures are being implemented, see Figure 2. For the distributed local case, test setups are distributed within one location using local communication. In another case, test setups are distributed between different geographical locations using Internet connection.

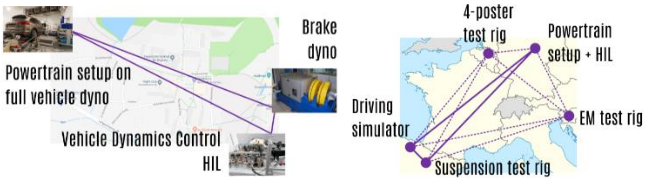

Figure 2: Distributed local (left) and distributed remote (right) XILforEV architecture.

III. INNOVATIVE ARCHITECTURES, COMPONENTS AND SYSTEMS FOR NEXT GENERATION E-VEHICLES

A. *ACHILES*

The main objectives are to reduce the EV total cost of ownership (TCO) by 10 % and to increase the driving range by at least 11 % with increased autonomy. In order to reach these objectives, an innovative E/E control system architecture is considered with enhanced parts and functionalities [12]. In particular, the project will integrate and further develop four innovative technological concepts (see Figure 3):

1. A new wheel concept design will be equipped with full by-wire braking, including a new friction brake concept and considering regenerative braking. The brake lifetime will be improved while lowering the emissions, with improved user comfort.
2. An innovative torque vectoring algorithm will significantly improve the vehicle dynamics and increase its efficiency.

3. An out of phase control will allow to intentionally operate the electric motor inefficiently to dissipate the excess of braking energy in case of fully charged batteries. This will decrease the complexity of the final powertrain by removing the brake resistor, and increase the efficiency of the global system.
4. A centralized computer platform will host the e-drive functionalities and reduce the number of Energy Control Units (ECUs) and networks while fulfilling the safety & security requirements. It will also support centralized domain controller required to implement high automation and autonomy concepts, a key requirement for smart mobility [13].

The technological concepts developed in ACHILES provide an innovative group of components and functionalities. The independent design methodology followed ensures that they will be replicable in other advanced EV architecture and complementary to the other cluster initiatives. Validation and real world tests will be conducted to validate the concepts and project objectives.

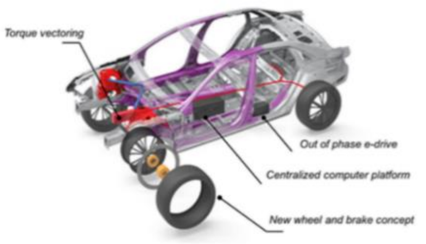

Figure 3: ACHILES project – Innovative technological concepts

B. *EVC1000*

Given the recent progress related to in-wheel motors technology, and the benefits of in-wheel architectures in terms of active safety, packaging and drivability, the EVC1000 project [14] (Electric vehicles components for 1000km daily trips) will focus on in-wheel drivetrain layouts, as well as a wheel-centric integrated propulsion system and EV manager, see Figure 4. More specifically, the consortium will develop:

1. New components for in-wheel powertrains: i) Efficient, scalable, reliable, low-cost and production-ready in-wheel motors suitable for a wide range of torque and power levels [15]; and ii) Compact centralised drive for in-wheel motor axles, based on Silicon Carbide technology, targeting superior levels of functional integration and failsafe operation – so called, eWD2. The designs consider electro-magnetic compatibility aspects, and include prognostics and health monitoring techniques of the electronic components.
2. New components for electrified chassis control with in-wheel motors: i) Brake-by-wire system, consisting of front electro-hydraulic brakes and rear electro-mechanical brakes for seamless brake blending, high regeneration capability and enhanced anti-lock braking system performance; and ii) Electro-magnetic and electro-pneumatic suspension actuators, targeting increased comfort and EV efficiency, e.g., through the optimal control of the ride height depending on the driving conditions.
3. Controllers for the novel EVC1000 components and new functionalities, exploiting the benefits of functional integration, vehicle connectivity and driving automation for advanced energy management, based on the results of previous projects and initiatives.

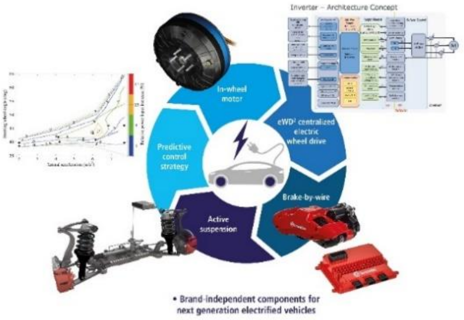

Figure 4: EVC1000 – Brand-independent components for next generation electrified vehicles

EVC1000 will assess the energy efficiency benefits of the new technologies compared to existing EVs. This will include demonstration of long distance daily trips of up to 1000 km across different Member States with no more than 90 minutes additional travel time due to charging, and without additional degradation of the components.

C. *FITGEN*

The H2020 project FITGEN (Functionally Integrated E-axle Ready for Mass Market Third Generation Electric Vehicles) aims at developing a functionally integrated e-axle ready for implementation in the third-generation electric vehicles (i.e. 2025 and beyond). The e-axle is made by of a 6-phase Buried-Permanent-Magnet Synchronous Machine (BPM-SM), driven by a SiC-inverter and coupled with a single speed transmission. It is complemented by a DC/DC-converter for high voltage operation of the motor in traction and for enabling fast charging of the battery (120 kW-peak) plus an integrated AC/DC on-board charger. Figure 5 reports a schematic of the architecture, with its different components and a simplified electrical scheme visible. The e-axle aims at achieving the following performances:

- 40 % increase of the power density of the BPM-SM compared to SotA 2018, i.e. 5.0 kW/kg with operation above 18,000 rpm and peak efficiency at 96.5%;
- 50 % increase of the power density of the SiC-inverter, 25 kW/l and peak efficiency at 99%;
- affordable and integrated fast charge capability (80 kW, average);
- production cost target at 2,000 €/unit (2030 market, cost of BPM-SM, power electronics and transmission);

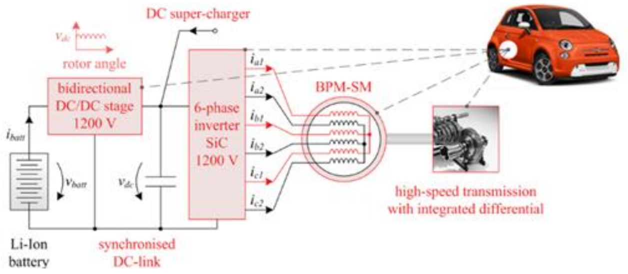

Figure 5: FITGEN e-axle overall architecture (reported graphics are indicative; the final implementation of the e-axle might change).

The e-axle is delivered at the end of the project at TRL 7 (i.e. system prototype demonstration in operational environment) in all its components and demonstrated on an electric vehicle platform designed for the European market (A-segment reference platform, i.e. FIAT 500 electric, as per Figure 5). In the project, three vehicle platforms are considered: (1) the A-segment BEV in 2WD configuration planned for its demonstration, (2) a small SUV in PHEV in 4WD configuration with the combustion engine on the front axle and the electric traction on the rear axle, and (3) a large SUV BEV in 4WD configuration with the electric traction on both front and rear axle. A set of speed profiles, including both homologation procedures (WLTP and US06) and real driving cycles (urban and mixed, both acquired in Torino, Italy), have been considered to size the e-axle against the reference platforms. Additionally, a highway driving condition at 110 km/h constant speed has been considered, with a target electric driving range above 700 km with one fully charged battery at the beginning plus three stops for fast charging in between. The preliminary e-axle architecture is built around a 20-to-22,000 rpm motor coupled with a 1:12.5 reduction ratio transmission, identifying the minimum required torque for the most demanding platform (i.e. large SUV) at 180 Nm and corner speed of 4,800 rpm (i.e. 90 kW motor).

D. SELFIE

SELFIE is an acronym for ‘Self sustained and smart battery thermal management solution for battery electric vehicles’ [16]. The core idea is to develop an innovative and novel thermal management solution for the battery pack on an EV when carrying out fast charging with rates up to 6C (using a 180 kW charger). By doing so, the charging time can be brought down to approximately ten minutes. The project main objectives (see Figure 6) are as follows:

- Development of new/advanced components for battery packs that enable a step change in thermal management, energy efficiency and cost.
- Design and optimization of battery thermal management system that enables a step change in battery thermal system efficiency and cost.
- Integration, assembly, manufacturing and bench testing of the developed battery thermal management system.
- Demonstration and validation of the battery thermal management system

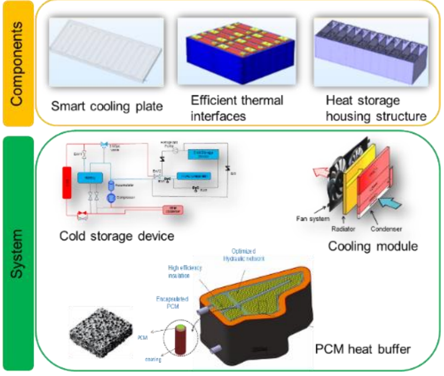

Figure 6: SELFIE – developments at component and system level

A bottom-up approach is taken within the project where first a suitable battery is chosen followed by a blueprint of the system architecture, individual component specification, individual component simulation, system level simulation, bench testing of the system and finally demonstration on the vehicle. This approach helps in identifying the technical capabilities of what the system as whole is able to achieve. The planned innovation lies in the adaptability of battery thermal management system to cater to the cooling needs of the battery pack under different charging conditions – normal and fast charging [17]. This means, the electric vehicle can be charged at any C rate whilst keeping the battery pack temperature in the sweet spot of 30 to 40°C, preventing degradation and the risk of thermal runaway. State of the art thermal management systems are cooled actively or passively [18]. In SELFIE, new concepts involving refrigerant and two phase cooling along with cold storage will be explored.

E. SYS2WHEEL

City logistic is one of the most polluting segments of the transport sector. Commercial vehicles substantially contribute to CO2 emissions, NOx emissions and particulate matter in large cities. Moreover, commercial vehicles also contribute to noise by generating a ~2 to 10 times higher noise levels than passenger cars. Additionally, operating patterns of the urban freight vehicles (e.g. short trips, high stopping frequency etc.), resulted in ~20% of energy consumption of overall road transport [19]. Due to the economy growth, urban freight transport is predicted to grow 39% in Europe by 2030 relative to 2006 [20] (in ton-kilometers). Consequently, policy makers set the goal of reaching CO2 free city logistics by 2030. These figures clearly demonstrate that city logistics faces severe challenges. Therefore, clean, efficient, high-capacity city logistic is indispensable for the competitiveness, economic growth and job preservation of the Europe. In this context, electric commercial vehicles have the potential to be a game-changer for the urban logistics since they can improve air quality, and reduce energy consumption, oil dependency, and noise in cities.

Figure 7: SYS2WHEEL in a nutshell

The ultimate goal of sys2WHEEL is to develop sustainable city logistics and improve mobility, accessibility, and quality of life of European citizens by taking a transdisciplinary approach. The project approach is depicted in Figure 7, the main project goals are

- Objective 1: SYS2WHEEL will reduce cost in mass production by at least 20% through components becoming obsolete and through reduction of wiring costs as time-sensitive networks will be applicable.
- Objective 2: The powertrain efficiency will be increased by improved e-motor windings, advanced rare-earth magnets, reduced powertrain rotating parts, reduced losses, advanced control and weight reduction. It will be demonstrated with a full size hardware and software implementation into two existing commercial demonstrator vehicles.

- Objective 3: Affordability and user-friendliness will be achieved by enhanced modularity and packaging. Automotive quality will be addressed by advanced fail-operational safety and ISO 26262 compliance, modular and scalable technologies and lowered total cost of ownership.

F. CEVOLVER

CEVOLVER is a research and innovation project to develop battery-electric vehicle that are usable for comfortable long day trips with an affordable battery [21]. The project takes a user-centric approach for optimising the development and operation of electric vehicles. The project exploits the opportunities of novel connected functions in combination with right-sized components, see Figure 8. The main objectives of CEVOLVER are

- Ensure a leap forward in user's confidence, functionalities and energy efficiency of future EVs by realising novel connected functionalities as reliable range prediction, Eco-routing and Eco-driving integrated together with Assured & Fast Charging, by achieving significant energy savings and enable long(er) distance trips with minimal additional travel time due to charging, and by leveraging user convenience and user's confidence and largely increase the trust in future EVs.
- Ensure the affordability of future electric vehicles by a user centric development approach by considering actual vehicle usage patterns to verify the design specification of the components, refining or deriving methodologies for supporting electric vehicle(subsystem) simulation models, and by providing innovative solutions to increase sales volumes and to open up further cost reductions in mass production.
- Validation of advanced components and systems, novel connected control strategies and functionalities by implementing/integrating selected components and systems, the connected control strategies and functionalities into an early-assessment prototyping vehicle & demonstrators.
- Assessment of the impact of the technical advancements of CEVOLVER and their applicability in different EV types and vehicle classes regarding the impact of the innovations in terms of energy saving potential, user experience and market potential (incl. cost reduction in mass production).

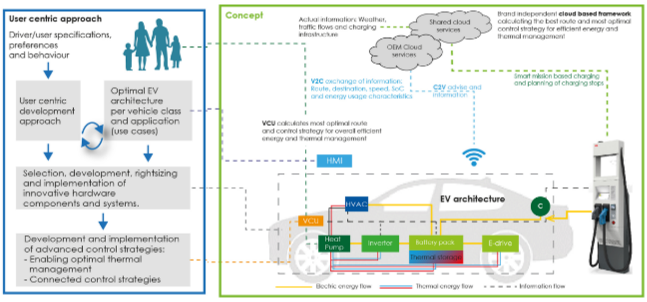

Figure 8: CEVLVER concept

IV. A COMPLEMENTARY PORTFOLIO OF R&D INITIATIVES

Figure 9 provides an overview of the European projects presented in this paper. The VISION-xEV and XILforEV (both granted in the GV-02-2018 call) focus on methods for virtual product development and production. VISION-xEV focuses on the design activities by providing seamless and integrated environments to homogeneously describe and analyse multiple aspects of the component and/or system (e.g., behavioral, thermal) and the resulting interactions. XILforEV focuses on V&V activities, by providing solutions to virtually assemble and test real components at different geographical locations. It is evident that both projects are complementary in terms of development phase, and are providing important methodology bricks to efficiently develop and validate the components and systems designed in the other projects.

The remaining projects have been granted in the GV-01-2018 calls, with the target to develop innovative, integrated, brand-independent architectures, components and systems for the next generation of EVs optimized with regard to the infrastructure. Note that further projects have been granted during the GV-01-2018 call and will be included in a future version of the paper. The ACHILES and SELFIE projects have a strong focus on component level. ACHILES targets the improvement of the E/E control system architecture with enhanced braking strategy and motion control dynamics. SELFIE aims at enabling fast charging with innovative components and thermal management approaches. FITGEN, EVC1000 and CEVOLVER focus on innovative components and their smart cooperation. FITGEN targets the overall design, prototyping, testing and vehicle integration of a brand-independent e-axle, combining e-motor, power-electronics and high-speed transmission with an innovative electric architecture. This design is capable of enhancing the usability and performance of the e-axle, unlocking affordable super-fast charging capability of the high voltage battery. In EVC1000, a corner concept is introduced with tight coordination between electrified powertrain and chassis. This targets a more comprehensive management of energy efficiency and vehicle dynamics (incl. comfort) aspects. CEVOLVER aims at increasing user acceptance of BEV with an affordably sized battery that can occasionally be used for long-distance trips. Last but not least, the SYS2WHEEL project provides a full-vehicle approach while focusing on freight transport. An important aspect is to integrate the application specificities early during vehicle design.

Overall, a set of complementary projects has been launched, with a focus on the democratization of e-mobility. All the projects are highly committed to their own challenging targets. Beside this, all the projects recognize the interest in clustering. The following advantages are foreseen:

- Access to a broader expert community to disseminate project results, thus increasing visibility for the project outcomes
- Availability of complementary expertise to efficiently address more comprehensive challenges, possibly out of the project range at project start
- Capability to coordinate specific actions of common interests at cluster level to lever on community level

As of today, the E-VOLVE cluster and the ECA2030 community have been identified as relevant framework. Beside common dissemination and technical synchronization (such as this paper), further content of cooperation is currently being designed.

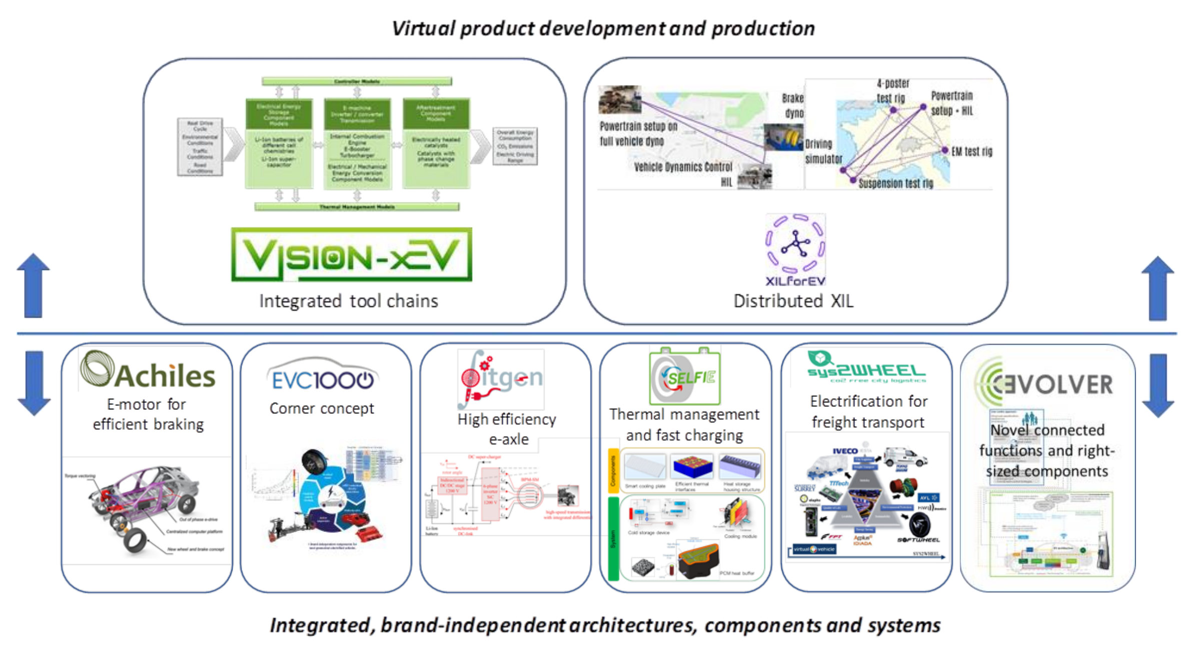

Figure 9: European innovation for next generation electrified vehicles and components (project granted in 2018)

V. CONCLUSION

Electrification of road transport is a key challenge to balance efficient mobility of persons and goods while reducing the impact on the environment. Nevertheless, strong incentives (e.g., regulations, fundings) are necessary to support this technology transition and enable electrified vehicles to achieve a similar maturity in terms of performances, reliability and costs as for the traditional vehicles. The portfolio of European projects granted in the Green Vehicle 2018 call shall significantly support this take-off – both from the perspective of each single topics addressed by the projects, and by their complementarity and thus their ability to address large missions. It is evident: sustainable transportation and e-mobility need joined forces!

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