Introduction

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Abstract For more than a century, our society has been dependent upon oil. Today, worldwide industry and government are forced to consider alternative and sustainable solutions for transportation. Vehicles, driven by alternative drivetrain offer an unique advantage concerning energy efficiency, emissions reduction and reduced petroleum use. Thus, they have become a research focus around the world. Electric driven vehicles are seen as one way of reducing oil use and GHG emissions but the challenges for their market introduction often focus on the performance and cost of batteries as well as the corresponding charging infrastructure. Other essential aspects are often not taken into account. Therefore, a special Task of the Implementing Agreement Hybrid and Electric Vehicles under the umbrella of the International Energy Agency (IEA)—Task 17—analyzed technology options for the optimization of electric and hybrid vehicle components and drivetrain configurations that will enhance vehicle energy efficiency performance. This chapter highlights the milestones in history of electrified vehicles and explains the objectives, as well as working methods of Task 17—"System Optimization and Vehicle Integration for Enhanced Overall Vehicle Performance".

1 The Need for Sustainable Mobility

Today, there are around 1 billion automobiles in use worldwide. This large number of vehicles has caused and continues to cause a series of major issues in our society, like GHG emissions; air pollution; oil depletion; energy security and population growth (see Fig. 1).

Regarding world population and urbanization there will be a strong shift towards urban population till the year 2050, as it can be seen from reports of the United Nations (UN) in Fig. 2.

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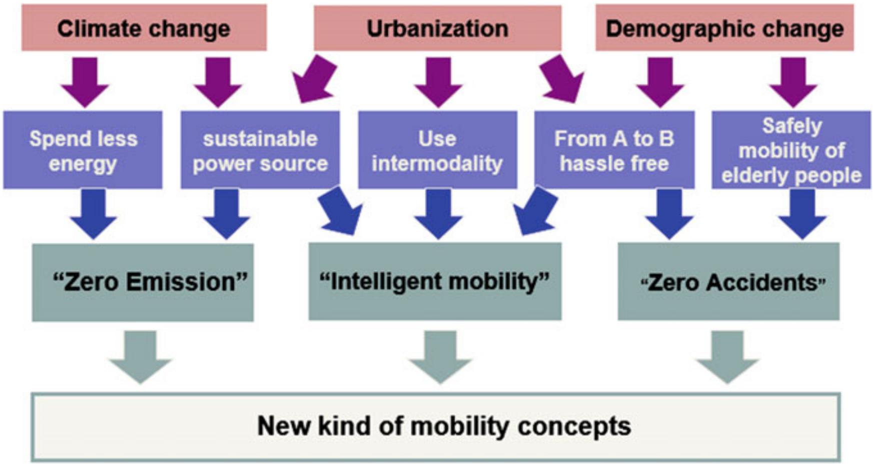

Fig. 1 Global megatrends strongly influence the future of mobility

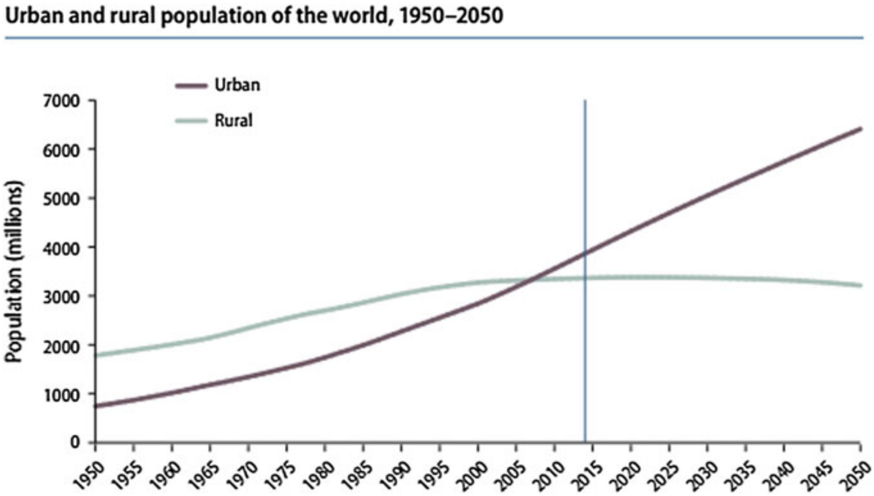

Fig. 2 Development of urban and rural population worldwide [1]

While in 1800, around 3 % of the world's population has lived in urban areas, today nearly 54 % of the world's population is located in urban areas. By 2025, there will be 29 megacities and by 2050, over 70 % of the world population will live in big cities.

Therefore, efficient and zero-impact transportation will be one of the key challenges of our society. Major trends like connectivity, shared mobility, automated driving, light weight vehicles, digital experience and alternative

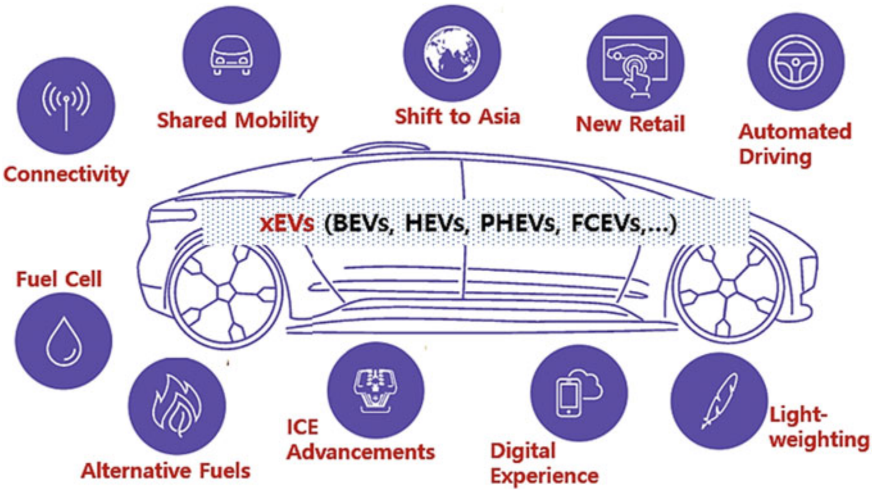

Fig. 3 Major trends will impact the future of the automobile

fuels will have a massive impact of the future of the automotive industry, as it is illustrated in Fig. 3.

> The automotive industry is dealing with two major trends:
>
> - *electrification of the drive train and*
> - *autonomous driving*

Worldwide industry and government are forced to consider alternative and sustainable solutions for transportation. Vehicles, driven by alternative drive train offer a unique advantage concerning energy efficiency, emissions reduction, reduced petroleum use and have thus become a research focus around the world. Therefore decarbonizing transport is providing to be one of the largest Research and Development (R&D) projects of the early 21st century. Low-carbon technologies are therefore rapidly advancing, including petrol and diesel hybrids, battery electric, and hydrogen fuel cell being developed by nearly every major manufacturer.

> *A battery electric vehicle (BEV) is an electrical vehicle (EV) that utilizes chemical energy stored in rechargeable battery packs. Electric vehicles use electric motors instead of, or in addition to, internal combustion engines (ICEs). Vehicles using both electric motors and ICEs are called hybrid vehicles (HEVs) and are usually not considered pure BEVs. Hybrid vehicles with batteries that can be charged and used without their ICE are called plug-in hybrid electric vehicles (PHEVs) and are pure BEVs while they are not burning fuel [2].*

1.1 Timeline—History of EVs

The idea of driving electrically is not brand-new. Who invented the very first EV is uncertain and several inventors have been given credit. In fact, the EV has been around for over 100 years, and it has an interesting history of development that continues to the present.

In ***1898***, more than three decades before founding his namesake company, 22-year-old Ferdinand Porsche designed his first-ever automobile: an electric-powered car officially known as the Egger-Lohner EV. Porsche's prototype car boasted a low-friction drive train, due to the hub-mounted electric motors directly driving the wheels, as it can be seen in Fig. 4. In case of saving weight and creating room for a petrol engine, Porsche swapped the original 74-cell accumulator in his electro-mobile for a smaller battery with 44 cells. In the middle of the vehicle he installed two water-cooled 3.5 horsepower (hp) (2.6 kW) DeDion Bouton (a former car manufacturer from France) petrol engines—driving two generators to create electricity—each producing 2.5 hp (1.84 kW). Both engines operated independently, each delivering 20 A with a voltage of 90 V.

By the turn of the ***20th Century***, EVs were outselling gasoline cars. In major cities like New York or London, electric taxis had appeared. People liked them because they didn't smell, vibrate or make noise and they were easy to drive.

During the ***1920s*** the EV ceases to be a viable commercial product as a number of factors caused its downfall, like the desire for longer distance vehicles, their lack of horsepower, and the ready availability of gasoline.

With skipping some years of automotive history, we end up at World War II, where fuel shortages increased interest again in EVs, but those efforts were short-lived. It wasn't until the ***1970s*** that another shortage fueled interest in EVs.

In ***1977***, Volkswagen (VW) built a "City-Taxi" for an exhibition in the New Yorker Museum of Modern Art under the motto "The transport and environment-friendly vehicle for urban agglomerations and thus a considerable improvement in

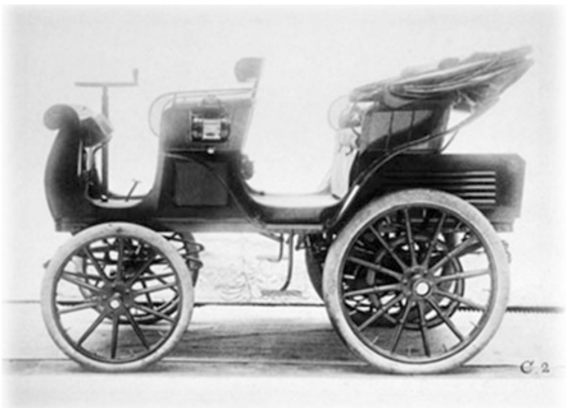

Fig. 4 Ferdinand Porsche's 1901 'Semper Vivus,' the world's first hybrid automobile [3]

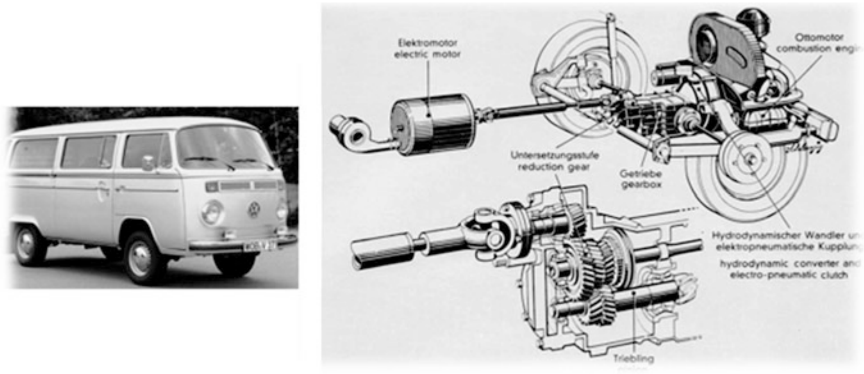

Fig. 5 VW Hybrid Bus T2, bus (*left*) and build-up (*right*) [4]

the quality of life in the city" (see Fig. 5). In this year already the still partly valid problem of today's EVs was formulated by a VW spokesman: *"Electric vehicles are independent of liquid and gaseous fuels—on the other hand, however, limited in payload and range." But also a possibly solution was considered: "With hybrid drive it is possible to compensate the range and power deficit of your e-mobile with a gasoline engine"*. [Source: unknown]

Finally, in the ***1990s*** major auto manufacturers began to offer mainstream electric and hybrid options. In the late 1980s and 1990s, General Motors worked to put an EV on the market. Announced by Chairman Roger Smith in 1990 as the "Impact," the car that hit the streets in Arizona and California was called the EV1 (see Fig. 6). The EV1 was made available through limited lease-only agreements. By 2002, 1,117 EV1 s had been produced, though production had ended in 1999, when GM shut down the EV1 assembly line. The car's 3-phase AC induction electric motor produced 137 brake horsepower (102 kW) at 7000 RPM. The drag coefficient of 0.19 was the lowest of any production automobile in history, while typical production cars have drag coefficients in the 0.3 to 0.4 range. At 4,310 mm (169.7 inches (in)) in length, and 1,765 mm (69.5 in) in width, the EV1 was a subcompact car, with a 2-door coupé body style.

Fig. 6 General Motors—EV1—the first mainstream EV [5]

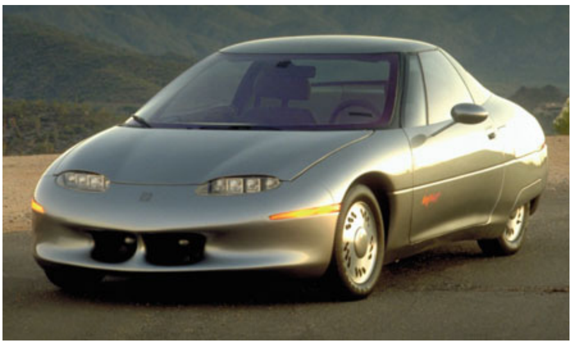

Fig. 7 Mitsubishi i MiEV [6]

Fig. 8 EVs of the 20th century; Tesla S (*left*) [7] and Renault Twizzy (*right*) [8]

In ***2011***, the Mitsubishi i MiEV was the first EV to sell more than 10,000 units. Only a few months later, the Nissan Leaf overtook the i MiEV as the best-selling all-EV ever (see Fig. 7).

The success of the Leaf ended up being the catalyst for other auto manufacturers to start producing their own EV models like the Ford Focus Electric, Smart electric drive, Volvo C30, Chevy Volt, Tesla Model S (see Fig. 8), Renault Twizzy Z.E., BMW ActiveE and several others.

Today there is a much more aggressive attempt to normalize the EV.

Right now, range; infrastructure and public awareness are the hurdles to overcome. Regardless of these challenges, lithium ion battery technology continues to improve, and it seems inevitable that the EV will continue to rise in popularity, as the sales of EV increase throughout the world.

Certainly, this section doesn't show all steps and events from the past, as it can be seen in the drawing [9] in Fig. 9. It just highlighted some of the most important ones to visualize, that the movement to EVs has been a slow process. It has always been dictated by consumer desires, price, and practicality.

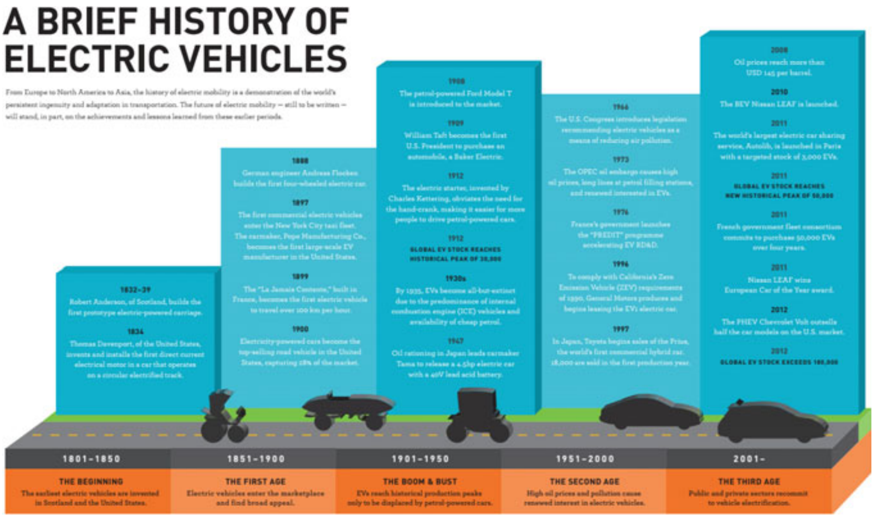

Fig. 9 Development of EVs from 1801−2001+ —(image courtesy of IEA)

There are predictions that the EV market will reach 8 % of total car sales by 2020. Studies conducted by the IEA pointed out, that there are approximately 700,000 BEVs and PHEVs on the streets (as per May 1st 2015). It's expected to reach the 1 million (Mio.) mark till the end of 2015.

According to the "European Roadmap Electrification of Road Transport" of the European Union, a mass production of dedicated BEVs and PHEVs is feasible by 2020 if fundamental progress is made in six technology fields:

- **energy storage systems,**
- **drive train technologies,**
- **vehicle integration,**
- **safety,**
- **road integration and**
- **grid integration**.

Mass deployment of the technology will however require significant increases of energy efficiency and reductions of cost which may be provided as of 2025 by a fully revised EV concept. Figure 10 shows the Milestones of the Roadmap mentioned above. The lower black curve symbolizes the evolutionary development of accumulated number of EV/PHEV. The upper black curve shows the expected development under assumption of reaching the major technological breakthroughs.

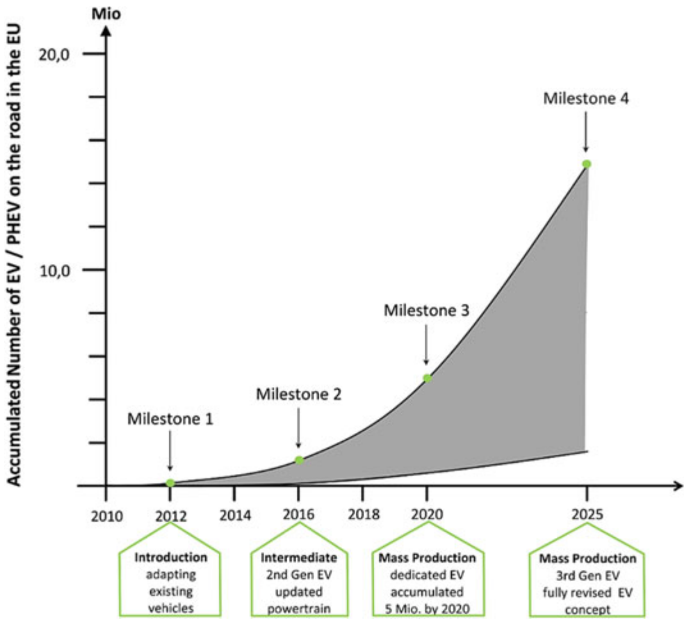

Fig. 10 Milestones of the European Roadmap Electrification of Road Transport [10]

The future of EVs, relies on how good the car batteries can become: how much power they can hold, and for how long.

1.2 Task 17—System Optimization and Vehicle Integration

Electric driven vehicles (BEVs, HEVs, PHEVs, FCEV, …)—further referred as xEVs in this report—are seen as one way of reducing oil use and GHG emissions and to improve local air quality. In recent years, sales of those vehicles have risen steadily but sales figures are far behind the expectations of car manufacturers.

The discussion of the difficulties facing electro-mobility (e-mobility) is often focused on battery performance, charging aspects like missing infrastructure and time and costs. Other aspects like the integration and optimized configuration of components including the optimization of the interfaces e.g. system management and monitoring should also be brought to the discussion since they could provide a significant contribution to the feasibility of this transport alternative.

Therefore Task 17 within the Implementing Agreement (IA) "Hybrid and Electric Vehicles" (HEV) of the International Energy Agency (IEA) was started in 2010.

Member Countries contributing to Task 17 were Austria, Germany, Switzerland, and the United States. Assignment of this Task was to analyze technology options for the optimization of EVs, PHEVs and HEVs as well as components and drive train configurations that will enhance vehicle energy efficiency and performance.

Electronic systems, used to operate and monitor all types of vehicle have benefited from substantial improvements during the past few years. Additionally these systems have also improved the prospects for xEVs. Improved power electronics have resulted in new opportunities to control and steer the increasingly complex-component configurations. In addition, new integration options for components have undergone rapid improvements during the past few years. Further optimization of these components is necessary—like new concepts for integrating them in the overall system and tuning them—to meet the specific requirements of different vehicle applications.

These developments and the opportunities they provide have been analyzed in Task 17.

1.2.1 Scope of Task 17

The **scope** of this Task was the monitoring and analysis of progress in design and configuration as well as trends and strategies for vehicles with high degree of electrification.

Thus, Task 17 was focusing on:

- overview and analysis of **present vehicle components** on the market available and further analysis of their development potential,
- overview and comparison of **selected current configurations of components** in vehicles on the market in terms of an advanced vehicle performance assessment,
- analysis of existing **component technologies** and their development potential,
- **Original Equipment Manufacturer** (OEM)s-review of different strategies and technologies for EVs and follow-up of new prototypes,
- analysis of theoretical **possible operation and configuration concepts** and assessment of their advantages and disadvantages,
- **workshops** with Task members and additional external experts' from industry and research institutions,
- overview and analysis of different **simulation tools** and
- considerations of design depending on different applications for EVs.

1.2.2 Impacts of Task 17

The following **impacts** on the following aspects of system performance have been analyzed:

- **integration and control of software solutions** (by software architecture strategies for real-time minimization of losses),
- **improvements in energy efficiency** (by optimizing thermal and electric energy management), operational safety and durability through better monitoring of component operation,
- **reductions in the cost of components** (through increased efficiency in operation and production, alternative materials, etc.),
- **reductions in weight/volume** through the optimized assembly of the drive train,
- **Range Extender modules** (internal combustion engine, fuel cell), electronic control concepts for Range Extenders,
- **configurations for energy storage systems** and/or Range Extenders and
- **drive train configurations** (fixed and variable gearing, single and multiple motor drive, in-wheel drive).

1.2.3 Working Methods of Task 17

Task activities predominantly consisted of preparing this technology assessment report on trends and providing opportunities for member countries to exchange information. The scope of work has focused on the participant's capabilities and fields of expertise and basically covered the monitoring and analysis of component development and vehicle architecture relative to trends and strategies for EVs progress. Thus, working methods included:

- **questionnaires, personal interviews and several workshops** with industry (in- and outside automotive companies, academia, user organizations, technology and innovation policy experts),
- **foresight analyses** of future options and opportunities,
- **simulation** of different component configurations,
- **International networking** using momentum and achievements of external partners (EU-FP7, FCH-JU, ERTRAC, etc.),
- **information exchange** and close coordination with other running Tasks of the Implementing Agreement using their results for vehicle integration investigations,
- **cooperation with other Agreements** like the Implementing Agreement for Advanced Motor Fuels or Advanced Fuel Cells and
- **dissemination of results** of participating countries in giving support to their policy and industrial decision makers and leading R&D representatives in their responsibility for setting of research priorities.

Fig. 11 Impressions from Task 17 workshops

The most common method of work was represented by workshops (see Fig. 11), which enabled the dissemination of information about relevant activities within an international context.

Since 2010, nine workshops took place, including experts from industry as well as R&D and policy makers.

In numbers:

- **nine workshops** took place on **seven locations** (worldwide):
- 2010: Vienna (Austria)—“***Kick Off Meeting*** *and* ***First Steps*** *for System Optimization and Vehicle Integration of EVs*”

- 2011: Geneva (Switzerland)—"***Current Status of R&D for EV Components - Focus on Energy Efficiency Improvements***"
- 2011: Chicago (United States)—"***Battery Management Systems***"
- 2012: Santa Monica (United States)—"***E/E-Architecture and Evaluation of Electric Vehicle Performance***"
- 2012: Vienna (Austria)—"***System Integration and Mass Impact***"
- 2013: Chicago (United States)—"***Innovative Thermal Management for Hybrid and Electric Vehicles***"
- 2013: Vienna (Austria)— "***Thermal Management Concepts for Hybrid and Electric Vehicles***"
- 2014: Schaffhausen (Switzerland)— "***Functional and Innovative Lightweight Structures and Materials in xEVs***"
- 2015: Berlin (Germany)—"***Power Electronics and Drive Train Technologies for future xEVs***",
- in total, **84 speakers** from 42 companies, institutes and policy makers participated in these workshops (compare Table 1), additionally about **131 participants** from **eight countries** have been participated in these **workshops** and on several **technical visits**, e.g. Vienna Climatic Wind Tunnel, Iron Library, Lightweight Center of Georg Fischer, etc.
- the **Operating Agent** was represented through the **Austrian Association for Advanced Propulsion Systems** (A3PS)—a strategic public private partnership which was initiated by the Austrian Federal Ministry for Transport, Innovation and Technology (bmvit) in order to support the development and market introduction of alternative propulsion systems and their energy carriers. This association enables a close cooperation between its stakeholders, the ministry as well as R&D and industry and **three Operating Agents** (Ms. Gabriela Telias (2010−2012), Mr. Mark-Michael Weltzl (2012−2013) and Mr. Michael Nikowitz (2013−2015) and one Vice-Operating Agent (Mr. Andreas Dorda (2010−2015) have been involved.

The desired output of Task 17 is this task report on its activities in order to give an up-to-date, neutral and comprehensive overview on current trends in xEVs worldwide.

Therefore the final report was split in the following subtopics:

- OEM and Industry—Review
- International Deployment
- Advanced Vehicle Performance Assessment—Testing
- System Optimization and Vehicle Integration:
    - E-Motors
    - Battery Management
    - Thermal Management

Table 1 List of workshop-participants (2010–2015)

3A Composites	4a manufacturing GmbH	Austrian Association for Advanced Propulsion Systems	Austrian Institute of Technology
Argonne National Laboratory	Alfred Wegener Institute	AVL List GmbH	Bern University of Applied Sciences
Bitter GmbH	Federal Ministry for Transport, Innovation and Technology	Robert Bosch GmbH	Federal Ministry of Education and Research
French Alternative Energies and Atomic Energy Commission	Connova AG	Delphi Thermal Systems	DLR - German Aerospace Center
Technical University of Denmark	eNOVA	Swiss Federal Institute of Technology in Zurich	European Commission
Fraunhofer Institute	Georg Fischer AG	Groschopp AG	Hella KGaA Hueck & Co.
Idaho National Laboratory	Inspire AG	Magna Steyr Fahrzeugtechnik AG & Co KG	University of Leoben
University of Applied Sciences and Arts Northwestern Switzerland	Porsche AG	Punch Powertrain	Qpunkt GmbH
Quadrant Plastic Composites	Rail Tec Arsenal	Rhine-Westphalia Institute of Technology Aachen	Siemens
Swiss Federal Office of Energy SFOE	Technical University of Vienna	U.S. Department of Energy	Valeo Climate Control
Virtual Vehicle	VDI/VDE-IT		

  - Simulation Tools
  - Lightweight
  - Power Electronic and Drive Train Technologies for future xEVs
- Summary

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