A3PS

Rethinking Propulsion.

Eco-Mobility 2030plus

Roadmap

October 2018

Eco-Mobility 2030[plus]

A3PS Technology Roadmap for the Successful Development and Introduction of Future Vehicles and Energy Carriers

Preface

As representative of the responsible Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT), I would like to take the opportunity to add some own thoughts to this roadmap.

The automotive industry – or more precisely – Austrian automotive supply industry represents a significant value for the Austrian gross national product. Austria exports higher values in automotive parts and components than it imports in new, complete vehicles. The automotive sector has the highest share of researchers – about 14%.

To secure Austria's competitiveness in this field and to support the successful market launch of innovative, advanced vehicle technologies, a closer collaboration between the automotive, energy supply industry and Austrian research institutions was initiated. Under the auspices of the Austrian Federal Ministry for Transport, Innovation and Technology, the A3PS was founded in 2006 as a partnership model to support an active technology policy of the ministry and to strengthen Austria's R&D activities in the field of the automotive supply industry.

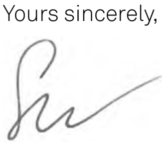
Since its foundation, A3PS has developed into a well-established organization, serving as a reliable intermediary between public and private interests and supports research and development for a clean, sustainable, affordable and safer mobility.

To reach a common understanding of key future developments of automotive technologies and to transform it in a long-term funding program with industry and research institutions is the key mission of A3PS. Many of the so realized projects developed in a major success story for our country.

Over the years, A3PS established a broad portfolio of services for its member institutions. One of these services is the "Roadmap Eco-Mobility 2030plus" which aims to represent Austria's well-founded expertise in the broad field of advanced vehicle technologies and energy carriers. It also provides a comprehensive perspective on future vehicle technology trends and required R&D activities.

I look forward to the continuation of this fruitful cooperation between BMVIT and the members of A3PS and I invite all interested Austrian, European and international institutions to join us on the way to a cleaner and more efficient mobility in the future.

Yours sincerely,



Ingolf Schädler

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A3PS – Austrian Association for Advanced Propulsion Systems

The goal of A3PS is to enforce R&D and innovation in the area of advanced propulsion systems and energy carriers as well as the storage for mobile applications. In order to introduce them onto the market successfully, A3PS utilizes the following objectives and tasks:

► **Cooperation**
Regularly joint activities to enable cooperation and common projects for member institutions

► **Networking**
Stimulating R&D cooperation in embedding the Austrian industry and research institutions into new national and international value chains in leading positions

► **Information**
Strengthening the competence of Austrian enterprises and research institutions by collecting, compiling and disseminating information on advanced propulsion systems and new energy carriers and informing the public about the potentials of advanced propulsion systems and energy carriers

► **Competence Presentation**
Presenting Austria's technology competence at national and international conferences and initiatives

► **Representation of Interests**
Supporting the representation of Austrian interests in international committees and initiatives of the EU and the IEA

► **Orientation**
Establishing a common view between industry, research institutions and technology policy by developing a common strategy, roadmaps and position papers for reinforcing technology development

► **Advisory function**
Providing fact-based consultancy and recommendations for policy makers to support the optimization of their policy instruments (funding programs, regulations, standards, public procurement, etc.) and informing the public of the opportunities and perspectives of these new technologies

Executive Summary

From A3PS members' point of view, besides individual customer needs, the main drivers for the development of future vehicle technologies will be environmental aspects (emissions and efficiency) as well as the future target of zero fatalities in road transport.

The clear specifications of environmental and energy policy for the drastic reduction of emissions of greenhouse gases and toxic substances as well as the increase of energy efficiency and the share of renewable energy sources will, in the coming decades, cause the development of a multitude of advanced propulsion technologies and fuels, which optimally correspond to the respective application purpose and vehicle class. In the interest of sustainability, this diversification of propulsion systems should also generate economic and social benefits in addition to the ecological ones. The A3PS members have summarized these power train technologies with the term "eco-mobility". Finding cost-effective methods for the production of small quantities through series production and intelligent industrialization is a fundamental requirement in order to make the forthcoming diversification also an economic success.

Suitable technologies range from advanced thermodynamic power train technologies including the use of renewable and CO_2 neutral fuels, to hybrid drives, to pure electric drives with batteries or fuel cells. Advanced thermodynamic as well as hybrid power trains which are both already available in the short term, will also maintain a significant share of the market in the medium and long-term. Besides the optimization of each single component, the integrated view of the overall vehicle plays a major role in the optimization of energy efficiency and emission behavior.

The internal combustion engine (ICE) may – for the first time – lose the position of being the dominant power unit for passenger cars in the period covered by the roadmap (2030). However, when high power is needed over a long time, i.e. in trucks or other heavy equipment, internal combustion engines cannot easily be replaced. There is still a lot of potential for further improvement for both diesel and gasoline engines. Even where zero emission requirements are concerned, there is a potential for ICE to comply. Due to the large number of vehicles on the market, advanced thermodynamic power trains can make a significant contribution to achieving greenhouse gas (GHG) and pollutants emission goals. The high research and development (R&D) demand for further optimization steps in internal combustion engines is of essential economic importance for Austria.

Electric power trains (including fuel cell power trains) are characterized by a very high "tank/battery"-to-wheel efficiency, the potential for zero local emissions, and a totally new driving experience. A special role in hybrid systems can be predicted for the PHEVs (Plug-In Hybrids), since they are privileged by legislation. Also, upcoming 48V systems may have a bright future, especially in passenger cars which are produced in high numbers under extraordinary price pressure. With the increasing electrification of the power train the transmission assumes greater importance than ever before. Full integration of all electric components into the transmission ("hybrid transmission") is a trend.

The very promising potentials of electric power trains are in contrast to a considerable need for R&D in order to ready these technologies for the market. For this purpose, the focus must especially be placed on the optimization of key components such as batteries or fuel cells and the reduction of expensive raw materials. Further challenges are the supply from renewable energy sources and the development of the required charging and hydrogen refueling infrastructure.

The market introduction of fuel cell vehicles by predominantly Asian OEMs started in selected regions in 2014. Activities, especially concerning infrastructure but also to assure reliability and lifetime of fuel cells, must now be further pursued and results must be transferred to the international markets. Through the early market launch, A3PS members expect even tougher international competition. Therefore, strong R&D efforts on fuel cell components as well as test and validation systems are required in order to strengthen Austria's position in this field.

Aside from advanced power train technologies, "Advanced Power Train Integration Technologies on Vehicle Level" such as energy harvesting, cabin heating and air conditioning systems, regenerative braking systems and control units (xCU) considerably influence the vehicle performance, fuel consumption, efficiency and environmental impact. Furthermore, advanced development tools & methodologies are required to reduce development time and cost while improving quality.

The majority of all accidents are caused by the human factor. Advanced active vehicle control systems have the potential to avoid those accidents and therefore to save human lives. Experts in automated driving around the globe expect a dramatic reduction of vehicle collisions, accidents and fatalities once these functionalities are deployed into most of the vehicles on road. The fact that worst case crashes will happen at a significantly lower velocity compared to today, will finally result in radical new vehicle concepts with less energy consumption and better driving performance.

By gradually taking over the driver's tasks, fully automated vehicles will be the logical extension of advanced vehicle control systems in the long term. The technology path for those systems leads from advanced vehicle control systems via connected vehicle technologies to fully automated driving. Required vehicle technologies lie in the field of extensive sensor technologies, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, electrically actuated and electronically controlled components (x by wire), positioning and mapping, as well as predictive operation and control strategies. These technologies, on the other hand, will result in increased demands on complex control architectures and data information management. In a last step, all motorized traffic participants need to be integrated into a common control concept in the long term, which will require increasing activities in the vehicle's field of full integration into infrastructure guidance systems.

An important opportunity for Austria will be the development of appropriate testing infrastructures for power trains, connectivity and vehicles. Two test regions (ALP.Lab and DigiTrans) have already been launched in Styria an Upper Austria. Last but not least, a major role for the successful implementation of automated driving vehicles will pose organizational and legal challenges (e.g. Vienna Agreement, which has meanwhile been altered for testing purposes) in order to clarify the responsibilities between the driver, vehicle and the infrastructure.

Transportation biofuels will continue to play a central role in the long term, due to their high energy density, the use of the existing refueling infrastructure for liquid and gaseous biofuels as well as their relative simple use in internal combustion engines, and due to the potentially significant reduction of greenhouse gas emissions. Priority will be given to heavy duty long-distance transport, where some battery electric busses and trucks might come to the market, but will remain a minority. R&D is required for technological optimization of biofuel production and the mutual adaptation of engine and biofuels. When it comes to environmental effects, taking a life cycle perspective is essential, considering not only greenhouse gas emissions, but also aspects such as land use, water use, food and feed production and biodiversity for cultivation in sensitive regions.

Renewable hydrogen has a unique position due to diverse generation paths and due to its storage capability as a chemical energy carrier, which is the main benefit compared to electric power. R&D is required for technological optimization of decentralized renewable hydrogen generation. Hydrogen for transport requires large-scale build-up of a new refueling infrastructure which is a great financial challenge for the energy supply industry.

Due to the diversity of power trains, energy supply chains and the related bandwidth of environmental effects, the potential future contribution of transportation systems to the improvement of sustainability (including economy, environment and society) must be evaluated on a scientific and robust basis. Life cycle thinking therefore needs to become an intrinsic perspective of OEMs and energy suppliers already during the research and development phase of eco-efficient and sustainable transport systems.

In order to successfully overcome the hurdles on the path to eco-mobility, this roadmap stresses the following requirements on technology policy:

- Technology-neutral legislation
- Results-oriented calls
- Long-term commitment of public support is required
- Funding along the entire innovation cycle
- Technology-neutral, results-oriented calls
- Support of cooperative interdisciplinary R&D projects
- Strengthened international cooperation in R&D
- Acceptance of partners from foreign countries into funded projects
- Improved review process with feedback after the completion of the project
- Subsidies for establishing companies and stimulation of venture capital

This roadmap offers an overview of the intended R&D activities and development focal points of Austria's industry and research in the coming years. Additionally, it has led to a valuable exchange of information between the experts of the A3PS members, organized in four workgroups (BEV, ICE, FC and Hydrogen, and Advanced Vehicle Technologies). Besides the development of a common view on the anticipated technological development paths, it also has enabled specific perspectives for future cooperation of the members in new R&D consortiums.

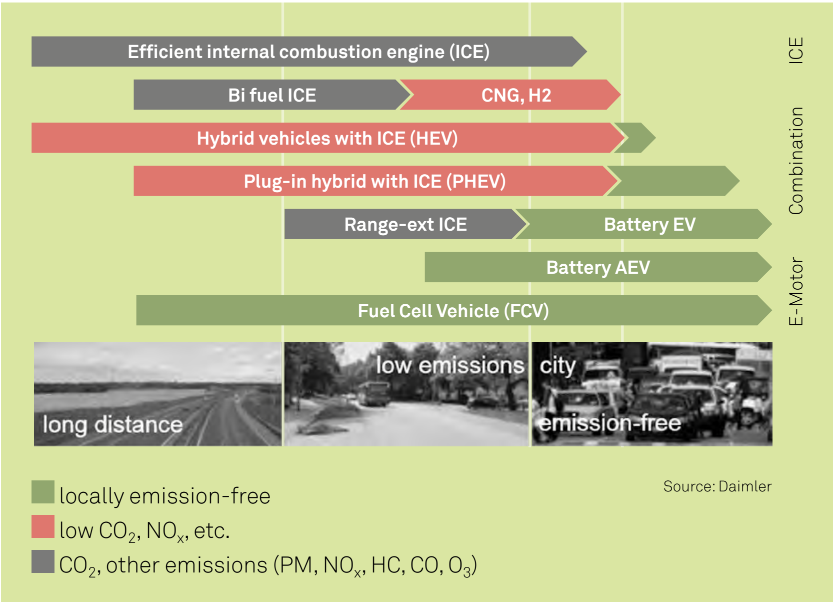
Introduction

Requirements on future vehicles will become more demanding than ever before. On the one hand they will need to comply with stringent future emission regulations (e.g. EU6c) under more challenging conditions (WLTP, RDE). On the other hand according to newest information it seems to be certain that the European legislature will head for CO_2 emission targets around 60 g/km in 2030, which definitely cannot be achieved with conventional technology. Additionally, social aspects which are difficult to predict such as changing consumer behavior or new mobility concepts must be taken into account. From the present A3PS members' point of view, future vehicles will be driven by aspects as summarized below:

- ► Environmental impact, mainly CO_2 emissions
- ► Efficiency
- ► Change from limited fossil fuels to renewable bio-fuels
- ► Raw materials availability shortage
- ► Active safety (zero fatality)

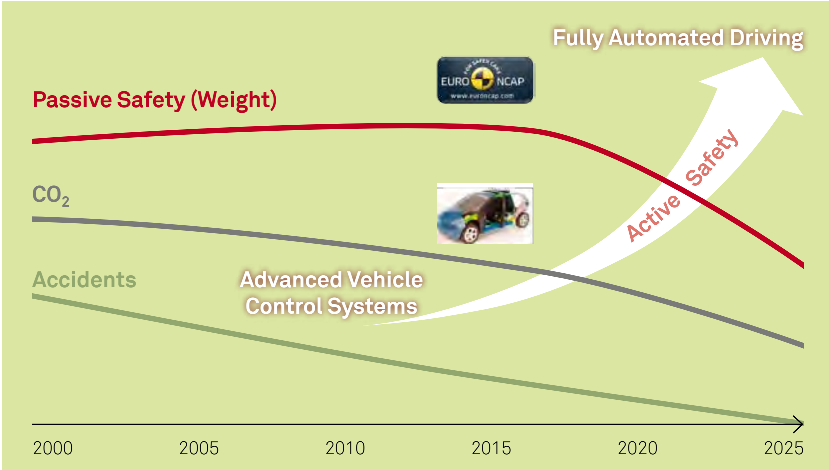
Those drivers, in the short and medium terms, will cause the development of a variety of alternative vehicle technologies and fuels, which optimally correspond to the respective application purpose and vehicle class as assumed in the figure below.

The A3PS members have summarized this variety of technologies with the term "eco-mobility".



Source: Daimler

Besides energy efficiency and emissions, zero fatality must be a goal. From today's perspective, this scenario can only be achieved by a combination of passive and active safety measures and advanced vehicle control systems. Finally it could lead towards fully automated driving. This approach, not only to minimize the consequences of accidents (passive safety) but also to avoid accidents at all, offers the opportunity to reduce the amount of materials and weight needed for passive safety measures. Therefore radical new lightweight vehicle concepts can be realized in the long term.



Source: A3PS

Less weight and improvement of safety through advanced vehicle control systems

In summary, in order to comply with future targets, eco-mobility vehicles will be characterized by:

- Less emissions
- Increased energy efficiency
- Nearly crash-free vehicle movement on roads/zero fatality
- New, radical changes of vehicle concept towards lightweight structure
- Comfort improvement
- More coordinated (synchronized) vehicle movement at optimal speeds
- Better utilization of existing infrastructure capacity on roads (as well as parking facilities)
- New concepts for cargo mobility and for mobility for individuals (car sharing, ride hailing etc.)

In addition to the benefits listed above, the diversification of power train technologies should also generate economic and social benefits. The Austrian automotive (supply) industry is an important sector of the national economy, as it counts 30,000 employees (with a market of over 13.8 bn. EUR) and 70,000 in the directly connected surrounding sectors (with a market of 21.5 bn. EUR). The export rate in the automotive sector is about 90% and, of all the industry sectors, the automotive sector has the highest share of researchers – about 14%.

Source: Fachverband der Fahrzeugindustrie Österreichs

Austria's industry and research institutions have a high level of competence in the field of advanced power train and vehicle technologies as well as energy carriers. In order to keep this strong position and increase added value, it is important to take advantage of the opportunities of these new technologies without delay. Therefore, a coordinated approach between industry, research institutions and technology policy as well as a common view is necessary. For the preparation of the roadmap, all A3PS members members (besides the four A3PS working groups) as well as interested parties in the various areas were included. Especially in the newly added field of advanced vehicle control systems, several companies were identified and invited to participate.

The aim of this roadmap is to point out promising technologies and measures in the following fields:

- Power train technologies
- Overall vehicle technologies (including advanced vehicle control strategies)
- Fuels
- Life cycle assessment

All technologies and measures mentioned in the following chapters are of high relevance to the Austrian industry and research institutions. Activities in these areas are currently ongoing or at least planned.

Text passages regarding commercial vehicles (including heavy duty, buses and off-road) and corresponding measures are marked with a truck icon.

All technologies and measures are evaluated regarding the following criteria:

- pollution (e.g. NOx, particulate matter) and noise reduction
- GHG (CO_2) emission & resources consumption
- Added value
- R&D demand for successful implementation on the market
- Safety [1]
- Security [1]

In each of the following chapters, the information is summarized in two types of tables.

In a first overview all technologies including their market maturities in terms of TRL [2] are shown.

The second type of table shows each technology in far more detail, including aims and research demand (specific measures). For each measure, the current TRL status is given in accordance with the list below. It is important to point out that even if a TRL of 9 is reached for a certain technology or component there is still R&D demand (e.g. for further downsizing, cost reduction, efficiency improvement, safety increase or lower resource consumption).

- **TRL 1** – Basic principles observed
- **TRL 2** – Technology concept formulated
- **TRL 3** – Experimental proof of concept
- **TRL 4** – Technology validated in lab
- **TRL 5** – Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
- **TRL 6** – Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
- **TRL 7** – System prototype demonstration in an operational environment
- **TRL 8** – System complete and qualified
- **TRL 9** – Actual system proven in an operational environment (competitive manufacturing in the case of key enabling technologies)

Source: Horizon 2020 - Work programme 2014-2015, Annex G: Technology readiness levels (TRL)

1 only for "Advanced Vehicle Control Systems"
2 TRL (Technology Readiness Levels); Source: Horizon 2020 - Work programme 2014-2015, Annex G: Technology Readiness Levels

Furthermore, the respective technologies are evaluated on the basis of benefits and the R&D demand as well as the type of (research) project required in order to bring the technologies onto the market.

The “Type of Project Required” in the following technology tables serves as important orientation in the development of new funding instruments. The projects mentioned are categorized according to the *community framework for state aid for research and development and innovation (2006/C 323/01):*

- **‘Fundamental Research’** means experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any direct practical application or use in view.
- **‘Industrial Research’** means the planned research or critical investigation aimed at the acquisition of new knowledge and skills for developing new products, processes or services or for bringing about a significant improvement in existing products, processes or services. It comprises the creation of components of complex systems, which is necessary for industrial research, notably for generic technology validation, to the exclusion of prototypes as covered by ‘Experimental Development’.
- **‘Experimental Development’** means the acquiring, combining, shaping and using of existing scientific, technological, business and other relevant knowledge and skills for the purpose of producing plans and arrangements or designs for new, altered or improved products, processes or services. These may also include, for example, other activities aimed at the conceptual definition, planning and documentation of new products, processes and services. The activities may comprise producing drafts, drawings, plans and other documentation, provided that they are not intended for commercial use.
- In addition, **‘Demo’** projects with the aim of demonstrating the day-to-day utility of advanced vehicle technologies and/or advanced energy carriers with national and international visibility.

Power Train Technologies

Advanced Thermodynamic Power Train Technologies

There is a global consensus that the internal combustion engine (ICE) will remain the dominant power unit in the period covered by the roadmap. Current spark (gasoline) and compression ignition (diesel) engines are already highly efficient compared to their theoretical potential. However, there is still a lot of potential for improvement. Fuel consumption can be further reduced by 20% or more with additional variability, mechatronic subsystems and the application of new materials for further friction reduction. **This means, a peak efficiency of 50% is a realistic long-term target for both the diesel as well as the gasoline ICE.**

Special attention needs to be paid to local emissions, since they are the root cause of all traffic restrictions in urban areas. The main focus needs to be on NO_x and particulate matter limits. Even where zero emission requirements are concerned, there is a potential for ICE to comply with these.

Aside from toxic emissions, the most stringent challenge is the European CO_2 legislation which demands 95g CO_2/km by mid of 2020. This target can hardly be achieved with conventional power train technologies. It is anticipated that measures like extreme downsizing and downspeeding are required for heavier vehicles to come closer to this target. When pursuing this path, efforts have to be strongly concentrated on supercharging of the engines to maintain acceptable driving performance.

Besides the optimization of each single component, it should be mentioned that the integrated view of the overall vehicle plays a major role in the optimization of energy efficiency and emission behavior.

The main development routes are:

- High variability (variable compression ratio, CNG and LNG operation)
- Alternative combustion systems
- Downsizing/downspeeding (high R&D demand for super charging in order to maintain drivability)
- Exhaust gas after treatment (focus on $DeNO_x$, PF)
- Structural optimization (new materials, advanced joining technologies, high-strength functional materials)
- Advancedhybrid systems (KERS, improved ultra-caps)
- ICE powertrain with eDriveline Systems (eTransfer Case, electrified axle drive front and rear)
- Minimization of friction losses (new materials and surface structures)
- Thermal management (reduction of heat losses, waste heat recovery)
- Transmission optimization (high reduction gears, friction alternative lubricants, clutch & actuators, axle drive incl. differential, hybrid materials, joinings, thermal management)
- Development tools and methodologies (simulation & control platform/development)

The high R&D demand for further optimization steps in internal combustion engines is the main business foundation of A3PS member organizations and is therefore of essential economic importance.

Advanced Gasoline Engines

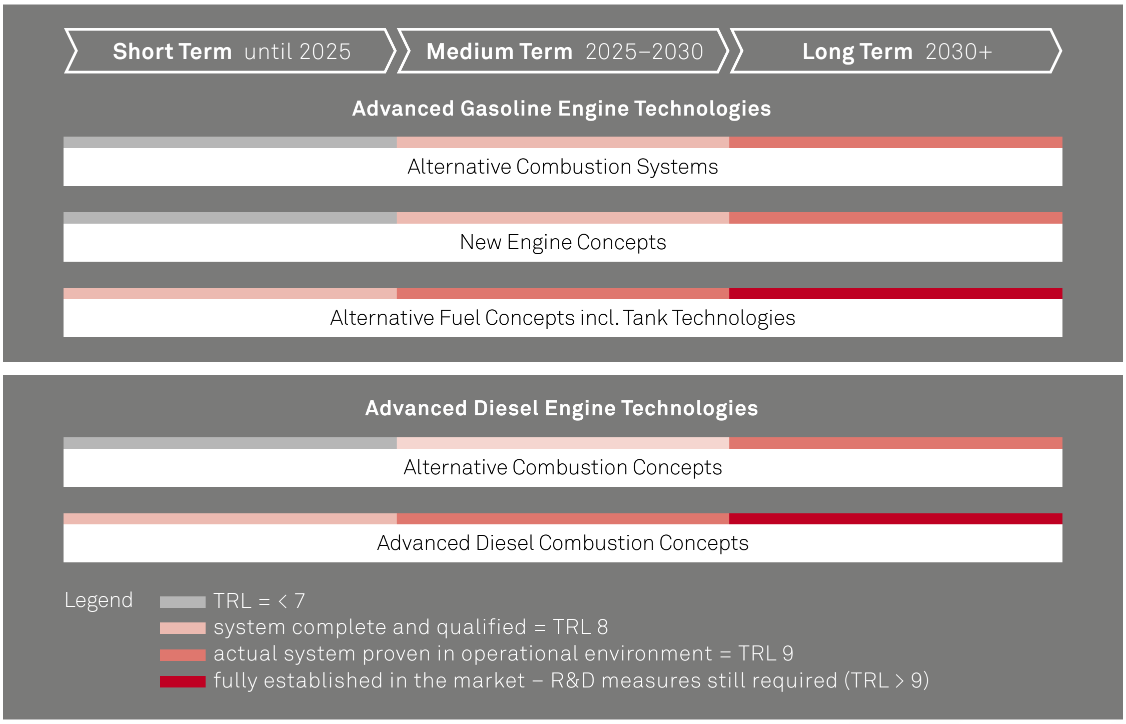
Further optimization of the gasoline engine is aimed at reducing fuel consumption while complying with emissions legislation (i.e. passenger cars EU6c in WLTP/RDE, two-wheeler EU4).

Gasoline engines operated with alternative fuels such as natural gas/biogas, H_2 gas blends and synthetic fuels (syn-fuels) can reduce CO_2 emissions significantly. In addition, biogas has the potential to be produced locally in Austria. With appropriate engine modification, adjustments to the engine management, the tank and the fuel system, engines can be operated by all aforementioned fuels and their blends in the so-called multi fuel operation. Multi fuel engines have the full potential to reduce pollutants and CO_2 emissions with relatively small additional R&D effort.

The use of biogas which is locally produced in Austria has an even higher potential to reduce CO_2 emissions by the theoretical "CO_2 closed loop". CNG storage systems have already been introduced onto the market, but still have potential for improvement in terms of weight and cost reduction.

For commercial vehicles, storage technologies for Liquefied Natural Gas (LNG) as well as technologies for methane conversion at low temperature levels play a major role.

Market Readiness of Advanced Thermodynamic Power Train Technologies



However, with an already advanced development level, further attempts face increased R&D costs. Austrian companies have built up considerable know-how with the technologies mentioned in the following table and cooperate with OEMs and domestic research institutions.

Advanced Diesel Engines

The main challenge of diesel engines is to comply with NO_x and particulate emission RDE-legislation. Therefore, further development in aftertreatment of exhaust gases is required. Especially selective catalytic reduction technology (SCR) and $DeNO_x$-storage catalyst technology need to be addressed.

In the engine system, optimizing gas exchange, EGR and the combustion processes can reduce exhaust emissions. Downsizing is effective not only for gasoline engines but also for diesel engines. Limits are set by increased NO_x emissions at higher downsizing rates. All technologies for further optimization of the diesel engine are characterized by relatively strong R&D efforts.

In the field of heavy duty vehicles and buses, optimized diesel engines and natural gas engines are considered relevant impellent technologies. The technologies presented in the table are allocated to these two categories.

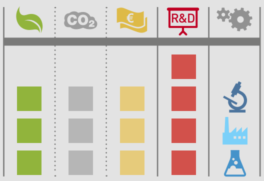
Meeting emission legislation is the main challenge of diesel engines also in commercial vehicles. Optimized combustion processes (also considering syn-fuels, DME, OME etc.) in combination with aftertreatment of exhaust gases aim to reduce fuel consumption and emissions. Emission targets are realized by very complex but also extremely effective systems for aftertreatment of exhaust gases such as improved SCR and advanced diesel particulate filter (DPF) technologies.

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Advanced Gasoline Engines

Alternative Combustion Systems

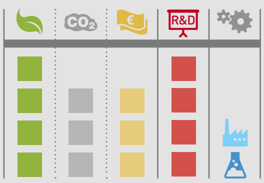
EU6 and RDE



- advanced control **TRL 2-7**
- exhaust gas aftertreatment (DeNO$_x$, PF) **TRL 5-9**
- charge exchange/EGR optimization **TRL 6-9**
- combustion technology for next generation advanced fuels **TRL 6-9**
- variable valve timing and compression - flexible cylinder charge **TRL 4-7**
- next generation of ignition systems **TRL 2-5**

New Engine Concepts

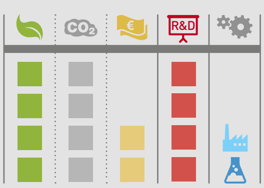
EU7-EUx and significant efficiency improvement (η >50%)



- high-pressure direct injection **TRL 3-6**
- multiple injection **TRL 5-7**
- range extender engines with limited operation ranges (incl. single point operation) **TRL 5-6**
- variable compression ratio **TRL 4-7**
- reduction of friction losses **TRL 4-9**
- reduction of heat losses, waste heat recovery **TRL 1-4**

Alternative Fuel Concepts incl. Tank Technologies

emission & WTW-Zero-CO_2 efficiency



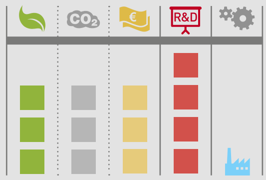
- increased/variable compression **TRL 3-9**
- on-board reforming **TRL 3-5**
- multi fuel ability **TRL 6-9**
- direct injection **TRL 5-7**
- material research **TRL 3-5**
- catalyst development **TRL 3-5**
- natural gas blends in ICE **TRL 5-7**
- advanced gas combustion systems **TRL 2-4**
- LNG-storage technologies (cost, lightweight constructions) **TRL 3-7**
- methane conversion at low temperature levels (exhaust gas aftertreatment) **TRL 7-8**

	Short Term until 2025	Medium Term 2025–2030	Long Term 2030+

Advanced Diesel Engines

Alternative Combustion Concepts

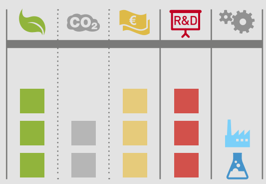
emissions (NO_x, particle)
efficiency (η >50%)



- variable compression TRL 2-4 (short term to long term)
- new engine designs (for advanced fuels and range extenders) TRL 1-3 (short term to long term)
- variable valve timing TRL 4-6 (medium term to long term)
- fully flexible injection systems TRL 2-7 (medium term to long term)

Advanced Diesel Combustion Concepts

EU6 and RDE
further fleet CO_2 reduction



- exhaust gas aftertreatment and EGR optimization ($DeNO_x$, DPF) TRL 5-9 (short term to medium term)
- advanced, model based control TRL 5-8 (short term to medium term)
- exhaust gas aftertreatment: SCR/sulphur compatible TRL 8 (truck; short term to medium term)
- exhaust gas aftertreatment: optimization of material and cost TRL 4-8 (truck; short term to long term)
- EUx with efficiency improvement TRL 5-7 (truck; short term to medium term)

Legend

Benefit

- pollution (e.g. NOx, particles) and noise reduction
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required

- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)

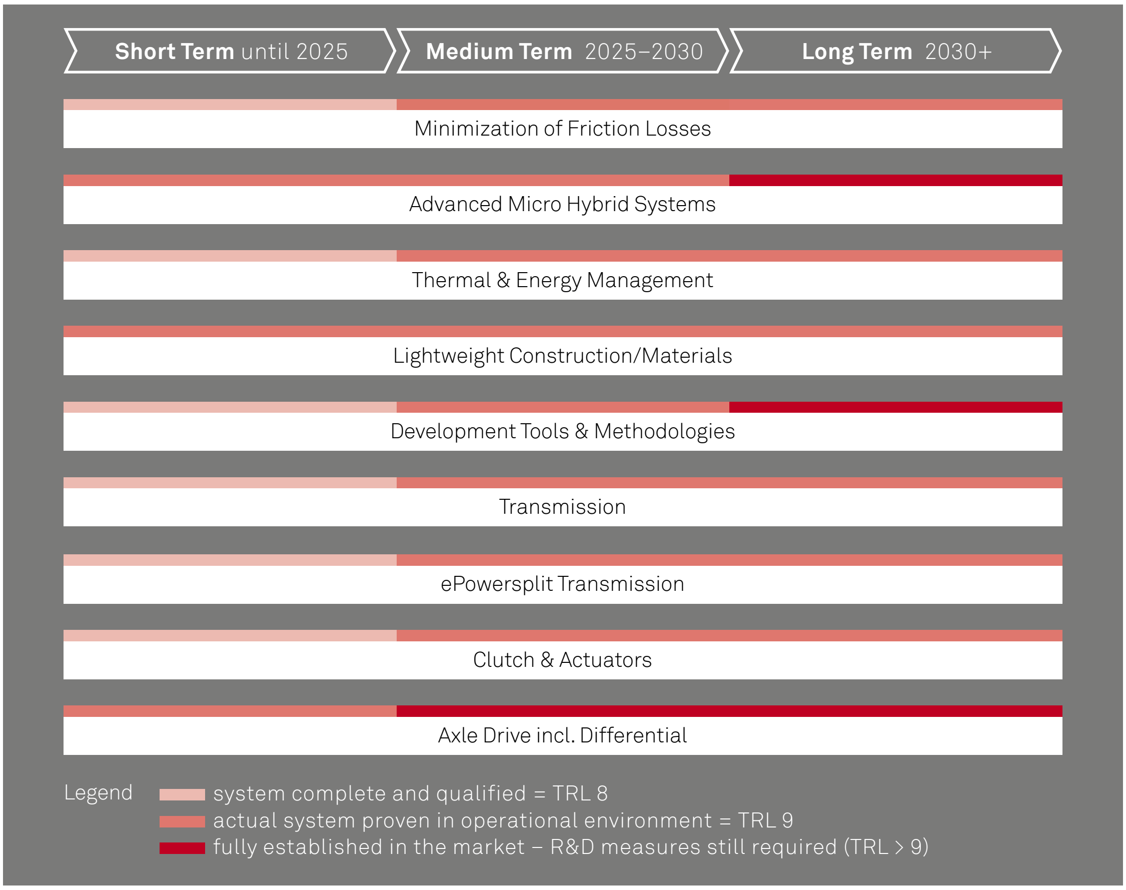
TRL 1: basic principles observed
TRL 2: technology concept formulated
TRL 3: experimental proof of concept
TRL 4: technology validated in lab
TRL 5: technology validated in relevant environment
TRL 6: technology demonstrated in relevant environment
TRL 7: system prototype demonstration in operational environment
TRL 8: system complete and qualified
TRL 9: actual system proven in operational environment

* potential to reduce CO_2 emission and to raise independency from fossil resources

Cross-Cutting Technologies

The following technologies are relevant for the optimization of both, gasoline and diesel engines as well as the overall advanced gasoline or diesel power trains.

Market Readiness of Considered Cross-Cutting Technologies



Minimizing friction has a high potential to reduce CO_2 and even pollutant emissions. Therefore, a strong effort in basic materials research is required. Waste Heat Recovery (including thermo-chemical approaches) uses the ICE's residual heat to reduce energy consumption significantly by converting heat losses into electric or chemical energy. Electrified, demand-driven auxiliary components can further improve efficiency and reduce CO_2 emissions. The first systems, such as pumps and compressors, have already been partially introduced to the market and further developments are being promoted. Still, a very high level of R&D effort is required.

Even for engine design, lightweight design and materials will play a major role. High-strength materials and in the long run, materials with special thermal properties (low thermal conductivity and capacity), will be introduced. For transmission and axle drives lightweight design and materials are covered mainly by functional integration.

New "breakthrough" materials will make it possible to develop new, highly efficient engines, for example, utilizing significant higher compression ratios. An important aspect of using new materials is the consideration of the entire product life cycle, including recycling. In order to gain an advantage in know-how, Austria must keep a close collaboration with industry and university research institutes in the field of basic material research. Optimized development tools and methodologies that allow a flexible deep dive in the level of detail during the development process are required in order to reduce development time and cost whilst improving quality.

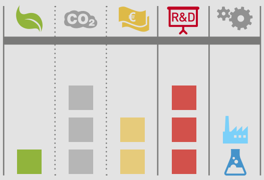
The transmission still has some noteworthy optimization potential, particularly in terms of, costs, highly integration (package), efficiency (friction reduction, splashing losses), actuation accuracy, smart control strategy, thermal management, high quality over lifetime, recycling and converter optimization (automatic transmission).

Short Term until 2025	**Medium Term** 2025–2030	**Long Term** 2030+

Transmission

Transmission

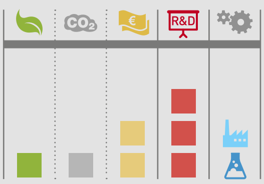
efficiency/weight reduction/ durability/advanced functionality/noise reduction



- control strategy including advanced model based control and functional safety **TRL 2-5**
- high reduction gears for electric drive trains (e.g. planetary gear) **TRL 5-7**
- optimization of friction/thermal management/converter optimization **TRL 6-8**
- high component and function integration for hybrid transmissions (incl. AMT) **TRL 4-6**
- lubricants and coolants for transmissions **TRL 5-7**
- costs and quality assurance concepts (e.g. new bearings) **TRL 5-7**

Clutch & Actuators

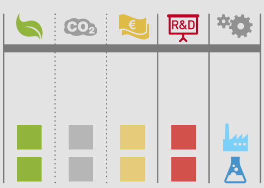
efficiency/durability/ heat resistance/ control strategy/safety



- friction material **TRL 4-5**
- fluids **TRL 4-6**
- electro-magnetic systems **TRL 2-5**
- alternative clutch types with higher efficiency and better durability **TRL 6-8**
- alternative plate materials and surface structure **TRL 6-8**
- alternative actuator systems (e.g. solenoid) **TRL 6-8**
- actuator with higher efficiency, durability and functional safety (cyber security) **TRL 6-8**
- functional software for higher positioning accuracy and predictive warranty **TRL 6-8**

Axle Drive incl. Differential

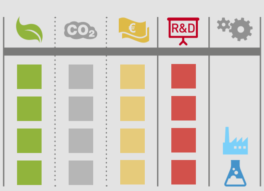
efficiency/weight/durability/ safety/noise reduction



- advanced pinion technologies (e.g. outside diameter reduction) **TRL 2-4**
- highly integrated differentials **TRL 3-5**
- multi purpose fluids **TRL 4-6**
- sealing/bearings **TRL 3-5**
- axle drive disconnect system (electro magnetic actuation) **TRL 4-6**

ICE powertrain with eDriveline Systems

efficiency/weight/durability/ safety/noise reduction



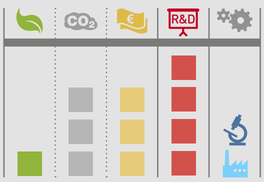
- new transfer case systems with added functionality (e.g. safety, driving performance) **TRL 2-4**
- new front and rear axle drive systems with added functionality (e.g. power split, efficiency and safety improvement) **TRL 3-5**
- functional software for driving strategy **TRL 4-6**
- new de-coupling systems for on-demand propulsion power management **TRL 3-5**
- improved E-motor and inverter technologies for 48 Volt with cost improvement, higher efficiency, integration and functional safety **TRL 5-7**
- Advanced transmission concepts (e.g. i2 CVT and power split transmission) **TRL 3-5**

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Cross-Cutting Technologies

Minimization of Friction Losses

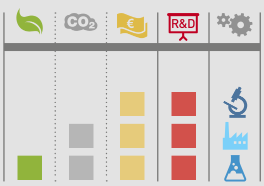
efficiency



- alternative lubricant **TRL 2-4** (short, medium and long term)
- material coating **TRL 3-5** (short, medium and long term)
- new materials (e.g. plastics) **TRL 1-3** (short, medium and long term)
- new bearings with new materials **TRL 3-7** (medium and long term)
- surfaces structuring (nano structures) **TRL 2-6** (medium and long term)
- splash/spin loss reduction **TRL 7-8** (short term)

Thermal & Energy Management

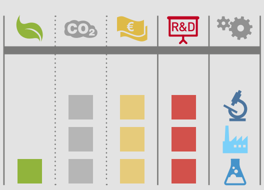
emissions/efficiency/safety, increased functionality



- waste heat recovery (e.g. ORC, thermo-chemical approaches, TEG) **TRL 3-6** (short, medium and long term)
- thermal and thermo-electrical systems **TRL 4-5** (short, medium and long term)
- reduction of heat losses and heat storage (incl. encapsulation) **TRL 2-5** (medium and long term)
- thermal-electric conversion **TRL 3-5** (short, medium and long term)
- advanced control strategies, self learning **TRL 4-6** (short and medium term)

Lightweight Construction/ Materials

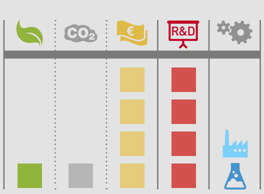
efficiency/mass reduction/ manufacturing/costs/recycling



- new advanced joining technologies **TRL 3-4** (short, medium and long term)
- LCA/recycling **TRL 6-7** (short, medium and long term)
- high strength functional materials for engines, transmissions and electrical components **TRL 2-5** (short, medium and long term)
- highly integrated components including thermal management **TRL 2-5** (medium and long term)

Development Tools & Methodologies

time to market/cost/safety/ security



- simulation & control platform/simulation & development **TRL 2-5** (short, medium and long term)
- testing systems and measurement technique/manufacturing, EoL testing **TRL 3-5** (short, medium and long term)
- e.g. simulation on molecular level for after treatment **TRL 2-3** (short and medium term)
- model based development tools (joint virtual & real world tools, digital twins) **TRL 3-7** (short and medium term)
- real time models for XiL-development **TRL 2-6** (medium and long term)
- in time fully connected design and manufacturing simulation process **TRL 2-3** (long term)

Legend

Benefit

- pollution (e.g. NOx, particles) and noise reduction
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required

- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)

- TRL 1: basic principles observed
- TRL 2: technology concept formulated
- TRL 3: experimental proof of concept
- TRL 4: technology validated in lab
- TRL 5: technology validated in relevant environment
- TRL 6: technology demonstrated in relevant environment
- TRL 7: system prototype demonstration in operational environment
- TRL 8: system complete and qualified
- TRL 9: actual system proven in operational environment

* potential to reduce CO_2 emission and to raise independency from fossil resources

Renewable Fuels for Internal Combustion Engines

The use of renewable fuels in internal combustion engines allows a significant reduction of GHG emissions (down to CO_2 neutral mobility) for the existing car fleet. Of all options to reduce GHG emissions from road transport, the use of renewable energy has the largest potential.

In the long term, even beyond 2050, optimized combustion engines will still be needed and applied in power trains for heavy passenger cars, hybrid utility vehicles (e.g. in heavy duty or long-distance road transportation), trains, ships and airplanes as well as in stationary applications. Therefore R&D must aim for increased efficiency and zero-impact emissions. Each improvement will directly contribute to short and medium term reductions of GHG and local pollutants emissions. Depending on the GHG emissions from the production pathway, renewable fuels can be more environmentally friendly than systems with all electric power trains, and additionally offer the advantage to be used in the existing infrastructure.

There is a range of renewable fuels that can contribute to decarbonizing the transport sector. The considered fuels are either based on biomass only or combine hydrogen from renewable electricity with a carbon source through a PtX technology. Focus of this chapter is on renewable fuels that can directly replace fossil fuels in road transport (and thus can be used by common internal combustion engines and existing infrastructure with little to no adjustments). These fuels are classified based on whether they can be used in spark ignition engines only, compression ignition engines only, or in both engine types (see Table Fuel Categories). They can either be used as a substitute or as a blending component. The use of hydrogen is not considered in this chapter.

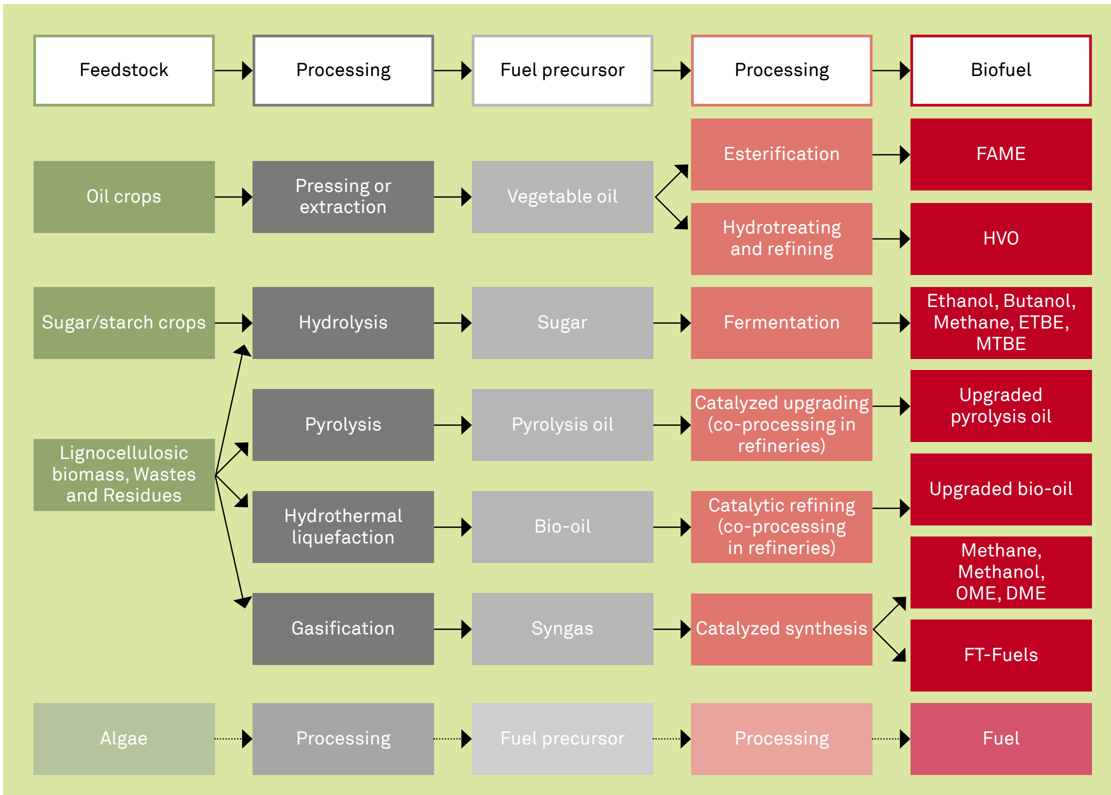
Fuel Categories (full substitute or blend)

Spark Ignition Engines	Compression Ignition Engines	Spark or Compression Ignition Engines
■ Alcohols (Methanol, Ethanol, …)	■ FAME	■ Fischer-Tropsch-Fuels from biomass [1]
■ ETBE, MTBE	■ HVO	■ Methane [2]
		■ OME, DME [3]
		■ Algae-based fuels [1]
		■ Co-processed fuels [1]
		■ E-Fuels (PtL, PtG) [1]

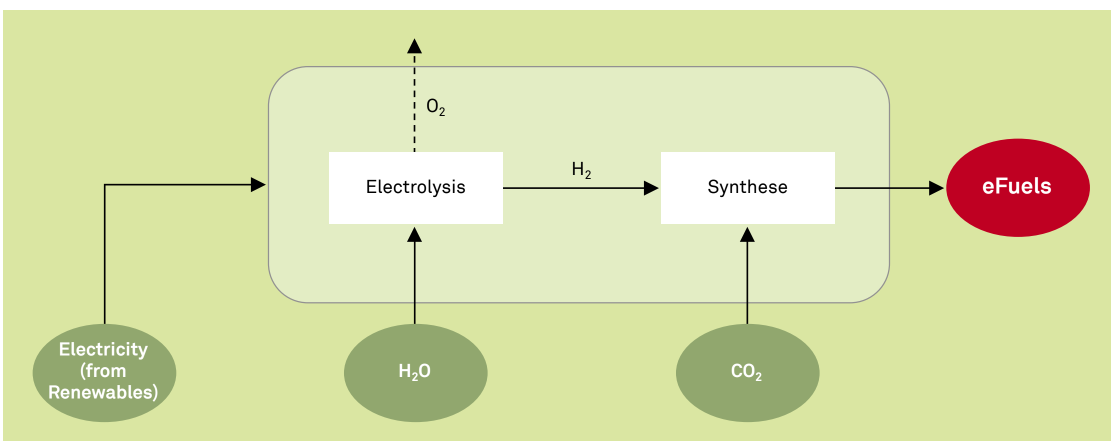
1 Various fuel products (diesel, gasoline, kerosene)
2 Note: dual-fuel operation in compression ignition engines
3 Although OME and DME are usually applied in compression ignition engines, they can also serve as additives in spark ignition engines.

A large number of production pathways exist for biofuels and for e-fuels. Figure 1 provides an overview of the production pathways for biofuels considered in this chapter, and Figure 2 provides a schematic representation of the production of e-fuels.

Production Pathways of Biofuels considered



Schematic of the Production of E-Fuels



The main driver for the implementation of renewable fuels is the European Renewable Energy Directive 2009/28/EC which prescribes that 10% of all fuels used in each member state in the transport sector shall be based on renewable energy sources by 2020. As mentioned above, internal combustion engines will remain the dominant power unit at least in the period covered by this roadmap and further on as part of various types of hybrid power trains. However, increasingly stringent requirements for GHG and local pollutant emissions will apply to these engines. Furthermore, the requirements for fuels are changing due to the consequent and continually ongoing optimization of the ICE (in particular the optimization of the combustion process).

The following table shows the market readiness of the considered renewable fuels according to the technology readiness level (TRL) of their production process and their application in ICEs.

Market Readiness the considered Renewable Fuels

Alcohols can be used as blending components in gasoline. Ethanol is the most widely used alcohol. Methanol and butanol are other options, but less common. Ethanol is mainly produced from sugar or starch crops as 1st generation; conversion technologies to produce ethanol from lignocellulosic biomass or other wastes and residues (2nd generation) are under development. Ethanol is currently distributed as blend with fossil fuel at 5% to 10% volume. For higher blends (E85), vehicle modifications are required. Even low blends of 10% to 20% reduce PM and CO_2 exhaust emissions significantly. Ethanol can be further processed into ETBE and then blended with fossil fuel. Methanol also has a potential to reduce exhaust emissions, but its toxicity may lead to application challenges.

FAME, a renewable diesel fuel is currently distributed as blend with fossil fuel to around 7%. FAME can be produced from vegetable oil or used cooking oil and animal fat as raw materials. The use of used cooking oil offers particularly high GHG emission reductions because of the use of waste materials. FAME blends have only little effect on exhaust emissions.

HVO is a renewable diesel fuel from hydrogenated vegetable oil. HVO can be mixed with fossil fuel and is free of sulfur and aromatics. Furthermore, the use of HVO significantly reduces PM, CO and HC compared to fossil fuel. HVO improves the NO_x-PM trade-off in engine applications.

The so-called Fischer-Tropsch process enables the production of synthetic fuels and is characterized by three main steps: gasification of carbon containing material in order to produce a raw gas, gas treatment to produce synthesis gas, and catalytic synthesis to produce synthetic fuels. Currently the process is mainly designed to obtain diesel fuel although also gasoline and jet fuel (kerosene) can be produced. Fischer-Tropsch-Fuels are free of sulfur and aromatics and significantly reduce the local pollutant emissions PM, CO and HC and improve the NO_x-PM trade-off compared to fossil fuel. Fischer-Tropsch-Fuels are of high quality and can be applied as full substitute or as blending component.

Fischer-Tropsch-Fuels from biomass use biomass as carbon containing material and have the potential to be fully CO_2 neutral.

Methane (natural gas or bio methane) can be used in modified combustion engines in mono-fuel (methane only) or dual-/bi-fuel (methane and/or gasoline/diesel) operation. Currently, bi-fuel engines are the most common ones, because of the bi-fuel possibility (flexibility) to drive with gasoline too. Gas engines have a high CO_2 reduction potential even with fossil methane, because of the lower C/H ratio compared to liquid fuels which reduces the exhaust emission significantly (approx. 25%). In addition methane has a high knocking resistance (ROZ) which allows higher compression ratios in spark ignition engines and therefore a significant efficiency increase. All natural gas engines deliver lowest PM emissions and lower CO and HC emissions as well. In addition many of the other unregulated emissions have been reported to be lower for natural gas vehicles than for gasoline or diesel vehicles.

Bio-Methane can be produced from various sources of biomass via two different pathways (fermentation or gasification). In any case, after upgrading, the resulting product is methane of a quality similar to that of natural gas. Bio-Methane can be blended at any ratio with or fully substitute natural gas.

DME (Dimethylether) and OME (Oxymethylenether) are synthetic fuels. A synthesis gas, which is produced from a carbon containing material, is processed to produce methanol. A byproduct of this process is DME. Methanol can directly be used as fuel or further processed to DME or OME in additional processing steps. DME can be used as substitute in dedicated vehicles, OME can also be used as blends. Similar to e-Fuels and Fischer-Tropsch-Fuels from biomass, DME and OME can be seen as close to CO_2 neutral. In addition, the PM exhaust emissions are almost zero and the NO_x exhaust emissions can be significantly reduced. On the other hand, the volumetric energy content of OME is significantly lower than that of fossil fuel.

Algae-based biofuels comprise a wide range of fuels which can be produced through a variety of conversion technologies. Currently the energy demand for microalgae cultivation and harvesting of the algal biomass is close to or even exceeds the amount of energy in the final product. Current research activities therefore focuses on higher value products.

In contrast to the state of the art blending of biofuels into the finished refinery product, co-processing technologies already implement the biomass feedstock (e.g. pyrolysis oil or bio-oil from hydrothermal liquefaction) in the fuel production process in the refinery. The resulting fuels are of the same quality as conventional refinery fuels and can be used as blends or full substitutes.

E-Fuels (PtL, PtG) are synthetic fuels which combine CO_2 as carbon source with hydrogen from renewable electricity. CO_2 can be sourced from exhaust gases of industrial processes (integrated energy), from biomass installations, or directly from air. E-Fuels can be used as an excellent surplus electricity (from variable renewable sources such as wind and solar) storage, and have the potential to be fully CO_2 neutral. PtL is mostly produced via the Fischer-Tropsch process and can be used as full substitute or blend. PtG (methane) can be produced via various processes including biogas fermentation and biomass gasification, can be stored in the existing natural gas grid, and can be used for industrial applications or in gas engine vehicles. The deployment of e-fuels will largely depend on the availability of renewable electricity.

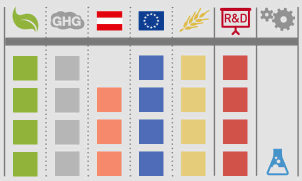
Renewable fuels have great potential to reduce GHG emissions and local pollutant emissions in the existing vehicle fleet. Even with increasing electrification of the mobility sector, renewable fuels will remain important for sectors, such as heavy duty trucking, aviation and shipping that are hard to decarbonize by other means. Production technologies utilizing oil crops or sugar and starch crops (1st generation or conventional biofuels) are already commercialized, while those based on lignocellulosic biomass, wastes and residues (2nd generation or advanced biofuels), algal biomass (3rd generation), or on CO_2 and hydrogen (e-Fuels) still require further research and development. Technology readiness levels and open research questions are indicated in the following figure.

Renewable Fuels for Spark or Compression Ignition Engines

	Short Term until 2025	Medium Term 2025–2030	Long Term 2030+

Fischer-Tropsch fuels from biomass

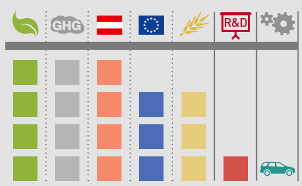
Target: commercial facilities (demo plant available)/replacement of diesel/premium fuel



- Short Term: Utilization of waste materials as feedstock **TRL 6**
- Short Term: Combination of gasification and FT synthesis **TRL 7**
- Short Term: Demonstration of gasification and FT synthesis at large scale **TRL 7**
- Medium Term: First commercial-scale gasification and FT synthesis facility **TRL 7**

Methane via anaerobic digestion

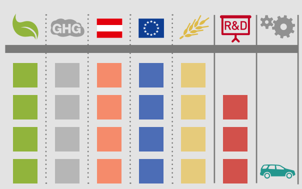
Target: commercial decentralized systems (pilot plant available)



- Short Term: cryogenic upgrading unit connecting several AD plants in remote areas **TRL 4-6**
- Medium Term: Integration of PtG units in decentralized AD plants **TRL 3-6**

Methane via gasification

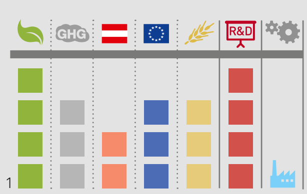
Target: commercial decentralized systems (demo plant available)



- Short Term: First commercial-scale gasification and methanation facility **TRL 8**

Algae-based fuels

Target: bring down the cultivation, harvesting and processing costs



- Short Term: Enhanced productivity of known algae species **TRL 6**
- Short to Medium Term: Enhanced stability of algae cultures **TRL 6**
- Medium Term: Cultivation of algae species with higher fatty acid content **TRL 6**
- Medium Term: Cultivation of mixed species cultures for higher stability and productivity **TRL 6**
- Medium Term: Reduction of production costs **TRL 6**
- Short Term: Target algal biomass as product to stimulate mass production **TRL 6**
- Medium to Long Term: Integration of algae biomass production with downstream processes **TRL 6**
- Medium to Long Term: Zero waste production/biorefinery concept **TRL 6**
- Short to Medium Term: Adaptation of regulations, guidelines and standards to the cultivation, processing and utilization of microalgae **TRL 6**

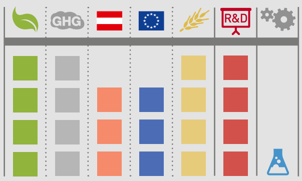
1 The impact depends on the actual fuel produced and thus cannot be specified in general.

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Renewable Fuels for Spark or Compression Ignition Engines

Co-processed fuels

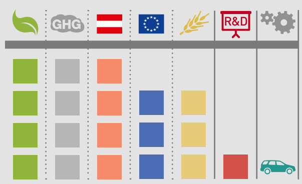
commercial facilities/ addition to refinery (demo plant available)/biogenic content in fossil fuels



- Medium Term: Hydrotreating & upgrading of FT-waxes, pyrolysis oil, or other biocrudes (products from HTL or APR) **TRL 3-6**

E-Fuels (PtL, PtG)

Pilot plants or demonstration units



- Short Term: Demonstration of small to medium scale PtL/PtG gas units, integration in AD plants, or other CO_2-sources **TRL 4-6**
- Short Term: Development of units or processes with higher efficiency for PtX, like low temperature rWGS reactor **TRL 4-6**
- Medium to Long Term: Technologies to separate CO_2 from the atmosphere **TRL3**
- Short to Medium Term: First Commercial E-Fuels Facility **TRL3**

Legend

Benefit

- pollution (e.g. NOx, particles) and noise reduction
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required

- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)

TRL 1: basic principles observed
TRL 2: technology concept formulated
TRL 3: experimental proof of concept
TRL 4: technology validated in lab
TRL 5: technology validated in relevant environment
TRL 6: technology demonstrated in relevant environment
TRL 7: system prototype demonstration in operational environment
TRL 8: system complete and qualified
TRL 9: actual system proven in operational environment

* potential to reduce CO_2 emission and to raise independency from fossil resources

Electric Power Train Technologies

Compared to thermodynamic power train technologies, electric power train technologies are characterized by a very high "tank/battery"-to-wheel efficiency and the potential for zero local emissions. Additionally, hybrid and pure electric power train technologies enable a totally new driving experience regarding driving behaviour and performance. These advantages justify high R&D effort. Although the basic technologies are developed and already available on the market, great efforts are needed to make these technologies affordable. This means high investments in optimization steps, especially in new development methodology, production technologies, modular design systems and application of less expensive materials. Only if these vehicles can be offered at reasonable prices, larger quantities can be sold, thus leading to a considerable environmental impact.

In this chapter, new technologies for hybrid and battery electric vehicles are considered. Due to the fact that industry and research institutions treat fuel cell power trains differently than those on hybrid and electric vehicle technologies, fuel cell technologies are dealt with in the following chapter – though fuel cell vehicles are, technically speaking, hybrid electric power trains. Plug-in hybrid electric vehicle (PHEV) have a high potential regarding CO_2 and emission reduction, higher than hybrid electric vehicles due to the larger battery capacity. Battery electric vehicles (BEV), however, are the best solution with respect to the local emissions [1].

In order to realize the full potential of PHEV and BEV, a sufficient charging infrastructure must be available and the use of renewable electricity is assumed, both of which require a highly committed technology policy. Furthermore, due to high power demand, PHEV and BEV need high voltage levels of up to 1000 V for peak performance.

In the field of heavy commercial vehicles and buses, the relevant power train concepts are depot-bonded battery electric and hybrid vehicles. Depot-bonded vehicles legitimate the pure battery-electric operation in the heavy-duty and bus sectors because the distances covered are calculable in both course and length. Depot-bonded vehicles in urban use with intensive stop and go traffic have advantages in pollutants and emissions due to the potentially higher braking energy recovery. The use of battery electric heavy vehicles has already been started, all electric battery powered trucks and buses for distances up to 800 km will be available by 2020.

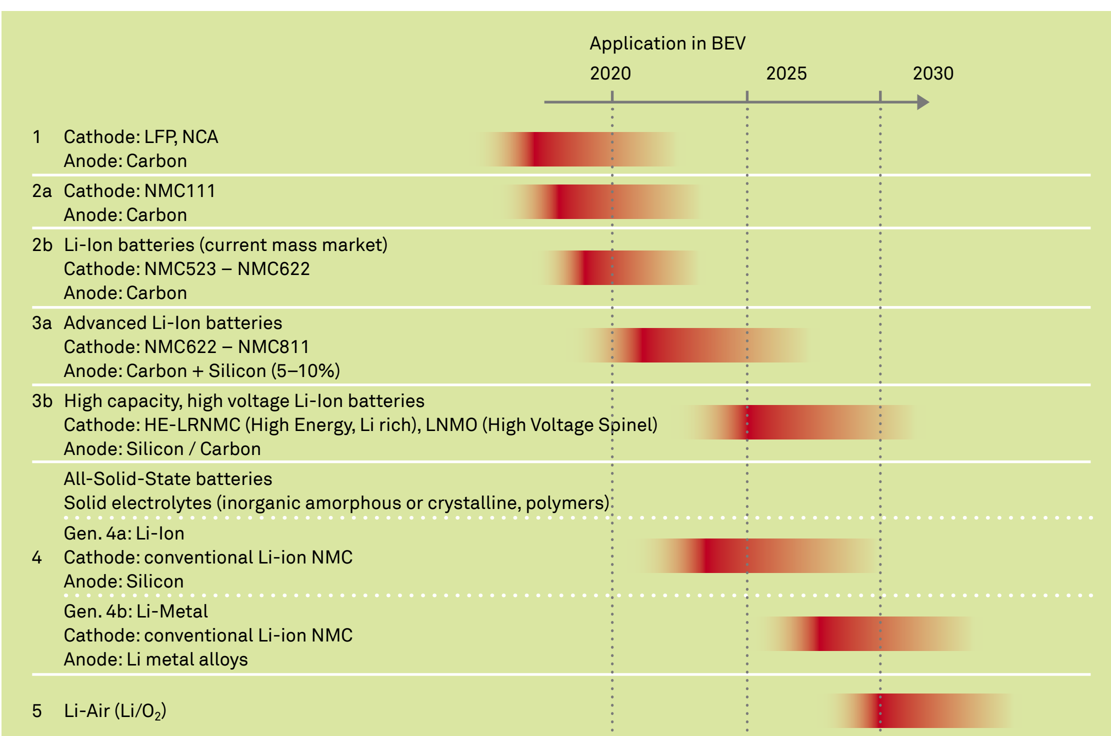
Energy Storages

The table below shows the main energy storage technologies for electric power trains. Regarding energy density and cost, battery technologies are the key drivers for the success of hybrid and pure electric vehicles. Experts predict that energy density will double and costs will fall to about 100 EUR/kWh on battery module level by 2020[2]. Positive environmental effects of battery electric vehicles are even bigger than with hybrid electric vehicles. Lithium-ion (Li-ion) battery technologies have permeated the market but they will be replaced by advanced Li-ion batteries (3rd generation) and solid state batteries (4th generation) in the long-term. R&D effort is therefore required continuously.

New battery technologies such as metal-oxygen batteries (Sulfur-, Na-, Mg-, Li-Oxygen) with higher energy (and possibly power densities) as well as highly modular integrated batteries will not penetrate the market before 2030. [2] Systems using pure oxygen will hit the market before those using air (which have to meet more challenging requirements due to varying air quality).

1 JRC Technical Report (2014). JEC Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context

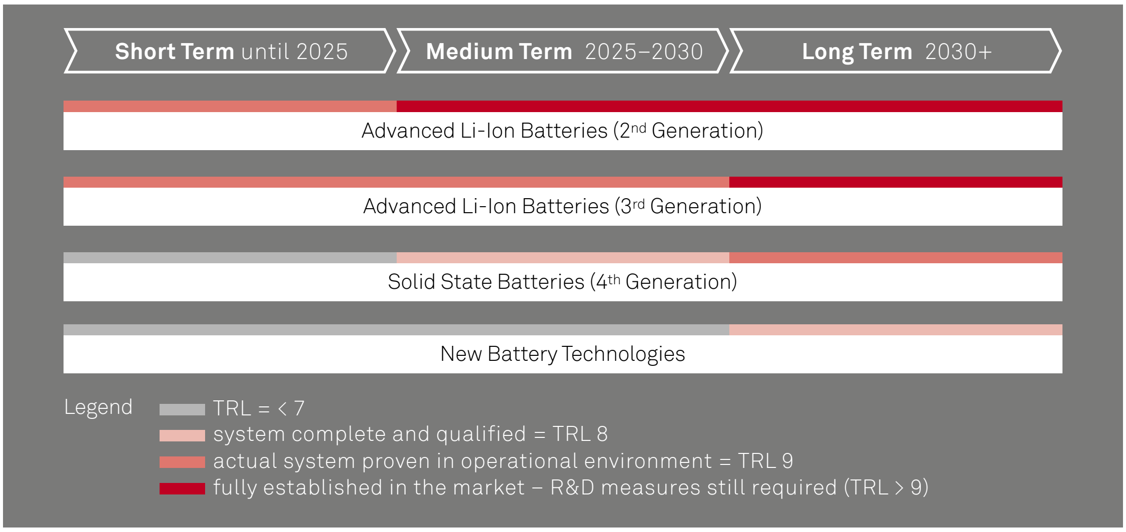
2 EBA (2018). European Battery Cell R&I Workshop 11–12 Jan 2018, Final Report



Timeline for different battery technology generations: market entry and application in BEV [3]

3 Sources: NPE (2016). Roadmap Batteriezellfertigung in D | EBA (2018). European Battery Cell R&I Workshop 11–12 Jan 2018, Final Report/expert interviews

Market Readiness of Energy Storage Technologies



In the past years, batteries for automotive applications have been improved tremendously, however further improvement is still necessary. The aim for all battery technologies is improving the energy content at a higher voltage level, power-to-energy-ratio and integration, reducing costs whilst increasing efficiency, durability (cycle stability) and safety.

Additionally, since (traction) batteries in automotive applications are quite new, there are several approaches to achieve the same objective. For example, established car manufacturers have the ambitious demand to fulfil automotive safety requirements not only on a system level but also on a cell level. On the other hand, recently established battery electric vehicle manufacturers have developed methods to obtain the same level of safety only on a systems level, using consumer electronics battery cells (with lower safety requirements).

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In addition to the measures shown in Table above, key activities in R&D for all battery technologies are concentrated in the areas of:

- Modelling and simulation
- New statistical methods
- Material research
- Cycle stability
- Recycling
- Process Equipment Development

Advanced mechanical and chemical modelling methods and simulation tools allow conclusions from battery cell level to systems levels and therefore save time considerably during the development process. The main difficulty lies in the proof of scalability for chemical simulation methods. As parameter variation results in complex and time-consuming tests, new statistical testing methods are required in order to reduce the effort for battery testing. Additionally, expert knowledge is rare in this field: rising it could be a great opportunity for Austrian industry and R&D institutions. Experts predict a high potential for material research including interplay of different materials to improve basic characteristics of future batteries.

Solid state batteries and new battery technologies require disproportionately high R&D efforts in order to achieve the large benefits possible. Great progress has been achieved in recent years, however, further research is essential – regarding improved chemical stability for sufficiently high cycling stability (e.g. for ceramic electrolytes), lower charge transfer resistance across electrode-electrolyte interfaces and dense ceramics (necessary to avoid Li dendrite formation). Another R&D topic is the replacement of Li by Na with higher (electro-) chemical stability.

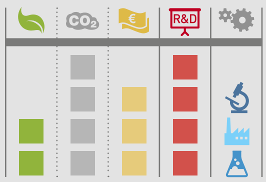
Very high R&D effort is expected on battery cell level, especially for the replacement of scarce resources like rare earth elements (e.g. Cobalt). Therefore, the focus is on new electrode materials and solid state technologies using materials with high availability (e.g. iron phosphates or organic electrode materials).

	Short Term until 2025	**Medium Term** 2025–2030	**Long Term** 2030+

Energy Storages

Advanced Li-Ion Batteries (3rd Generation)

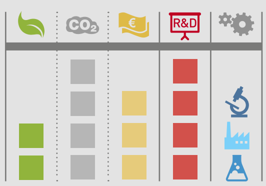
higher energy content/ power2energy ratio/ efficiency/durability/safety/ cost/integration



- high voltage on pack level with Li-Ion (NMC, LTO, LFP) **TRL 8-9** (short to medium term)
- avoiding toxic materials and scarce resources (e.g. Co) **TRL 8-9** (short to long term)
- highly integrated battery **TRL 5-9** (short to medium term)
- thermal management (reduced temperature sensitivity) **TRL 4-8** (short to long term)
- battery management system and battery diagnostics **TRL 8-9** (short term)
- Battery design, processes & strategies for recycling and 2nd life **TRL 5-7** (short to long term)
- advanced processing technologies, production pilot lines **TRL 4-7** (short to medium term)

Solid State Batteries

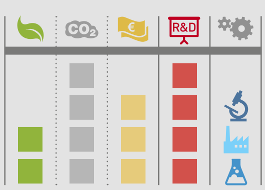
high energy content/ power density/efficiency/ durability/safety/cost/ integration



- cell design (material optimization, producibility, low carbon footprint ...) **TRL 2-3** (short to long term)
- multiscale modelling (material, cell & system level, processing ...) **TRL 2** (short to long term)
- battery system design (thermal management, BMS, safety) **TRL 3** (short to long term)
- manufacturing processes, research and production pilot lines **TRL 2-4** (short to long term)
- Battery design, processes & strategies for recycling and 2nd life **TRL 2-4** (short to long term)
- Material research (conductivity, electro-chemical stability, usable at temperatures up to and above 100°C, sulphide solid state electrolytes, lower toxicity, ...) **TRL 2** (short to long term)

New Battery Technologies

higher energy content/ power2energy ratio/efficiency/ durability/safety/cost/ integration/resource availability



- metal-oxygen (metal-air) batteries, Mg-Ion batteries etc. (high energy applications-range) **TRL 1-3** (short to long term)
- redox flow **TRL 1-3** (short to long term)
- highly integrated battery **TRL 1-3** (short to long term)
- thermal management **TRL 1-3** (medium to long term)
- battery management system **TRL 1-3** (long term)
- battery diagnostics **TRL 1-3** (long term)
- Battery design, processes & strategies for recycling and 2nd life **TRL 1-3** (medium to long term)

Legend

Benefit

- pollution (e.g. NOx, particles) and noise reduction
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required

- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)

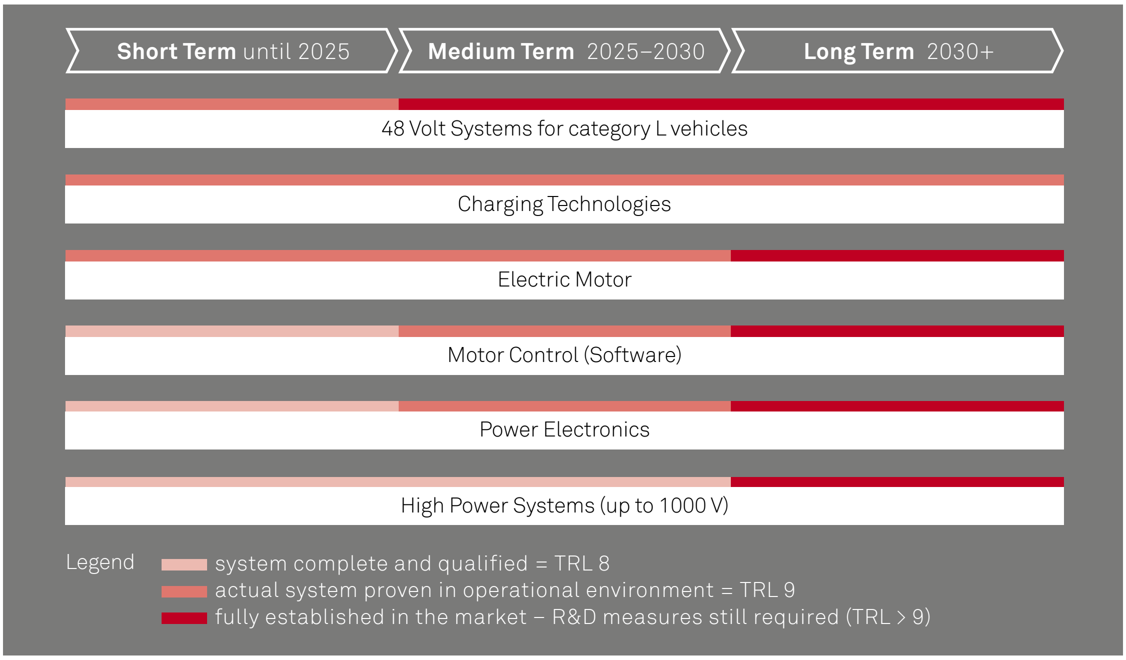
TRL 1: basic principles observed
TRL 2: technology concept formulated
TRL 3: experimental proof of concept
TRL 4: technology validated in lab
TRL 5: technology validated in relevant environment
TRL 6: technology demonstrated in relevant environment
TRL 7: system prototype demonstration in operational environment
TRL 8: system complete and qualified
TRL 9: actual system proven in operational environment

* potential to reduce CO_2 emission and to raise independency from fossil resources

Electric Components

Technologies for the electric components of electric power trains are listed in the table below.

Market Readiness of Electric Component Technologies



48V systems are of special interest in small electric vehicles of vehicle category L. In these vehicles with comparably low mass and power 48V systems will be applied for the power train as well as for auxiliary systems (brakes, steering, AC system etc.). An important aspect of 48V systems is that they do not require touch protection measures which are prescribed by law for systems over 60V. As a consequence, special training and safety equipment for high voltage handling in garages will not be needed in the short term.

48V systems will also play an important role in hybrid cars as part of the power trains (which is dealt with in the next chapter).

The introduction of 48V systems requires extensive research in the development of 48V components such as electric motors and inverters based on different technologies compared to the high voltage systems used in "big" hybrids. Especially the fusing and switching technology of the high currents is a big challenge.

The development of efficient charging technologies is critical to the success of battery electric vehicles. Conductive charging systems (with plugs) are available and have already been partially introduced to the market. Inductive charging is seen as a medium to long-term charging technology. Since the efficiency of such systems is still too low and the effects of magnetic fields on the human body and the environment is still unknown, further investigation and R&D effort is needed. Battery swapping systems require a high level of standardization, which affects OEMs in their freedom of design. Besides, they require a high number of additional batteries to guarantee the constant availability of charged batteries. This is seen as a financial and logistical challenge. Cost and image are serious hurdles as long as warranty jurisdiction is

4 Vehicle category L: vehicles with two or three wheels; vehicles with four wheels with mass lower than 550 kg (excluding battery mass) and power up to 15 kW. E.g. powered cycles, two- and three-wheel mopeds, two- and three-wheel motorcycles, motorcycles with side-cars, light and heavy on-road quads and light and heavy quadri-mobiles for passengers and goods transport. (source: Regulation (EU) No 168/2013 of the European Parliament and of the Council)

not legally clarified in the EU. Consequently, for A3PS members, battery swapping systems are not worthwhile for common use. The production of battery and charging systems has a high potential to create added value in Austria.

Fast charging (charging with high current) is another technology to shorten the charging time. However, fast charging requires sophisticated thermal management of the battery in order to prevent a reduction of the battery's durability and a loss of efficiency of the charging process itself. Besides, it presents major challenges to satisfy the high power demand and the stability of the grid. One approach to overcome grid restraints is to use buffering batteries in the charging stations – first solutions are already available at the market. However, fast charging technologies help to meet users' range anxiety, even though field tests show that users rely only to a rather small extent on fast charging because they tend to charge their vehicles at home or work.

Large effects in terms of mitigation of pollutants and GHG emissions and generation of added value can be achieved by further developments of the electric motor. Advanced electric motor structures like new winding types, motor materials or motor topologies as well as the motor-inverter-integration offer high potentials. Highly integrated electric motors with high revolution speeds provide the required performance with lower weight and less space needed.

In addition, key areas of motor development are scalability, low or non-magnetic concepts, cooling concepts and thermal stability, special transmission solutions coupling electric motor and ICE and functional safety of all components. Advanced motor control improves efficiency, peak power density and peak power performance and torque accuracy (driving performance).

Regarding "Motor Control and Diagnostic Software" the aims are fast parameterization, enhanced modularization and increased safety features. Therefore, significant R&D effort is necessary for advanced, model-based modelling such as easy self-learning, and adaptive and flexible algorithms.

Of high importance is the development of highly integrated gear boxes (reduction gear) for electric power trains, which have to achieve low internal losses, optimised dynamic behaviour and optimised NVH behaviour (noise, vibration, harshness) necessary to cope with the high revolution speeds of electric motors. The R&D effort is high, as all mechanical components for automotive use (bearing, seal, magnet fastening, etc.) are at an early stage of development.

The term "Power Electronics" summarizes the converter, DC-DC converter and on-board charging unit. Short-term activities primarily relate to increased efficiency, miniaturization and new cooling concepts with special emphasis on "high temperature" cooling. New materials, "self-learning" inverters and high volume production (e.g. GaN and SiC for fast low-loss switching inverters) will minimize costs in the medium and long term and create added value. Safety circuit, minimized parasitic loss topologies and passive power electronics components (fuses, resistors, capacitors, inductors) which can cope with the high energy density and automotive safety and cost requirements are missing today and need to be developed. High R&D efforts in manufacturing processes are necessary to tap the full added value potential in Austria.

High Power Systems with up to 1,000V voltage level offer the advantage of lower electric currents necessary to achieve the required electric power throughput. Hence, the benefits are thinner cables, smaller and more efficient electric motors, lower heat generation (in current-conducting cables). These benefits will be of high importance for fast charging systems. Passive power electronics components (fuses, resistors, capacitors, inductors) which can cope with the high energy density and automotive safety requirements are missing today and need to be developed. In the short to medium term high power systems will be made available in the segment of luxury class vehicles, first applications will hit the market around 2020.

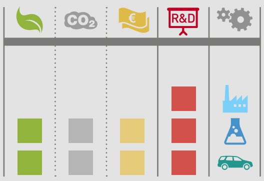
Further, cost reductions are necessary in the production of all electric power train components, allowing for a high number of end users to be able to afford and utilize the benefits of these technologies, and thereby to magnify the positive environmental impacts. Therefore, applied research and development – especially in the field of production technologies – continue to be required (even on technologies with TRL 9 or higher).

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Electric Components

48 Volt Systems for category L vehicles

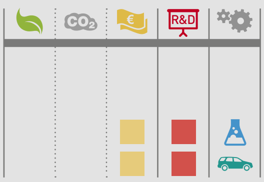
cost/efficiency/functionality



- electric motors **TRL 7-9**
- inverters **TRL 7-8**
- fuse and switching technology **TRL 7-8**
- actuators and electric valves (e.g. for ICE), auxiliary drives (e.g. for AC systems) **TRL 7-8**
- DC-DC converter **TRL 6-9**
- control and diagnostics **TRL 6-9**

Charging Technologies

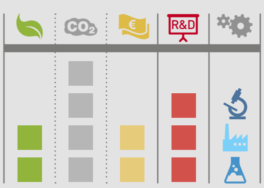
efficiency/user friendly/safety



- conductive charging **TRL 7-8**
- inductive charging **TRL 5**
- Fast charging @ high voltage (< 1000 V) **TRL 8-9**

Electric Motor

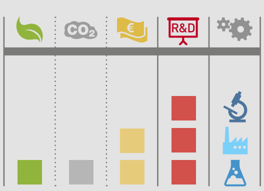
efficiency/cost/safety/reliability/high volume production/thermal stability



- advanced materials **TRL 5**
- manufacturing processes (e.g. joinings, winding technologies) production process for automotive **TRL 4-6**
- speeds > 20.000 rpm (bearing, seal, magnet fastening) **TRL 3-5**
- low-count or non-permanent-magnet concepts **TRL 4**
- lightweight wheel hub motors **TRL 4**
- transmission (reduction gear) (NVH, efficiency …) **TRL 6-9**
- Cooling Concepts **TRL 4-9**
- testing and validation **TRL 4-6**

Motor Control (Software)

fast parameterization/modularization/safety



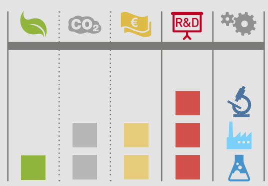
- advanced modeling (algorithms, simulation – easy self learning, adaptive, flexible) **TRL 3**
- data analysis/state monitoring **TRL 3**
- model based control and diagnostics **TRL 2-4**
- testing and validation (SiL) **TRL 4-6**

Short Term until 2025	**Medium Term** 2025–2030	**Long Term** 2030+

Electric Components

Power Electronics

efficiency/cost/safety/reliability



- integration in motor or battery **TRL 7**
- new power semiconductor (cost efficient, high temperature operation, life time on semiconductor level) **TRL 3**
- capacitors (high temperature capacity, space requirements) **TRL 6-9**
- assembling and joining technologies **TRL 6**
- functional integration (active HV-discharge, high speed safety) **TRL 6**
- self-learning converter/new materials **TRL 4**
- Cooling concepts **TRL 7-9**
- Safety circuit and passive power electronic components **TRL 5-9**
- New materials (printed circuit boards, housings, capacitors etc.) **TRL 4-6**

Legend

Benefit

pollution (e.g. NOx, particles) and noise reduction

CO_2 emission & resources consumption*

added value

R&D demand

Type of project required

(material) fundamental research

industrial research

experimental development

demonstration

Technology readiness levels (TRL)

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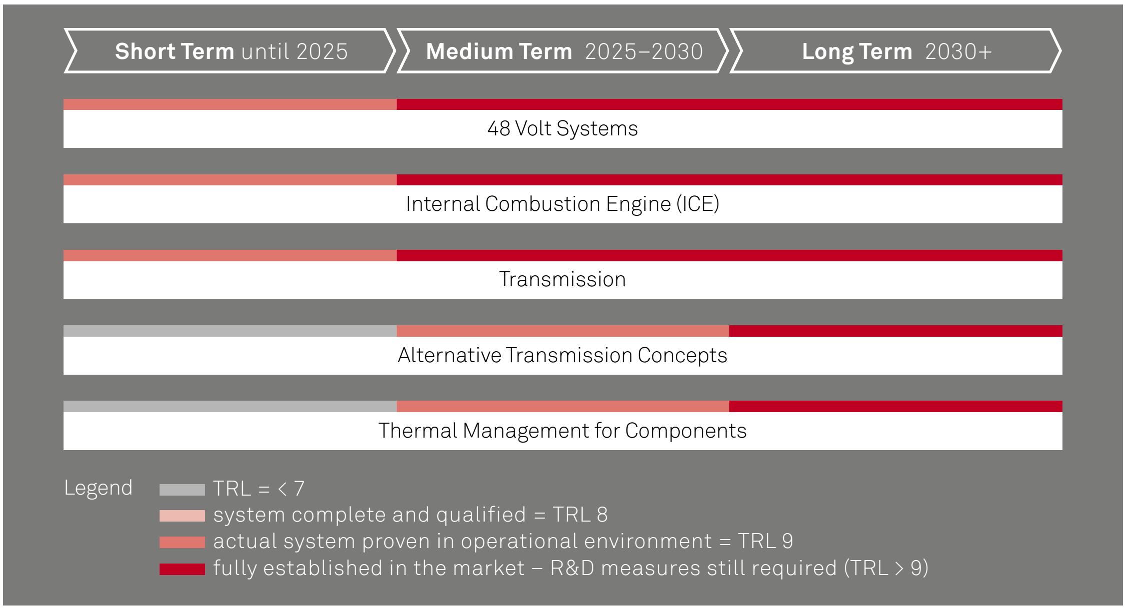
* potential to reduce CO_2 emission and to raise independency from fossil resources

Subsystems for Hybrid Electric Vehicles (Internal Combustion Engine, Transmission and Thermal Management)

The table below summarizes main technologies required in hybrid electric vehicles (HEV): ICE, transmission concepts, 48 Volt Systems and thermal management.

Market Readiness of ICE, Transmission and Thermal Management Technologies



A special role in HEV can be predicted for 48V systems, especially in passenger cars which are produced in high numbers under extraordinary price pressure. Cost efficient hybrid systems based on 48V will be an attractive solution in this segment. 48V systems will be applied as part of the power train as well as for auxiliary systems (brakes, steering, AC system etc.). It is anticipated that, in the near future, luxury cars will use a 48V board net voltage since auxiliary comfort systems are reaching their limits with 12V systems.

Micro hybrid systems using 12V systems cannot provide sufficiently effective environmental benefits, as the achieved power levels up to 3-4 kW are not sufficient for electrical cruising or regenerative braking. So 48V systems which provide power levels up to 8 to 10 kW – recently reported up to 30 kW, thus already reaching the mildly hybrid area – promise to provide remarkable fuel consumption or CO_2 reductions in functions such as regenerative braking, ICE assist via electric supercharge technologies or even the so-called “sailing” which becomes possible at these power levels.

A cost-effective solution is to implement a Belt-Starter-Generator (BSG). A further benefit can be created by “phlegmatizing” the ICE dynamics, the so-called “peak shaving”.

An important aspect of 48V systems is that they do not require touch protection measures which are prescribed by law for systems over 60V. As a consequence, special training and safety equipment for high voltage handling in garages will not be needed in the short term.

The introduction of 48V systems requires extensive research in the development of 48V components such as electric motors and inverters. Especially the fusing and switching technology of high currents is a big challenge. The development of 48V system components as bridge technology for large electric vehicles offers a good business opportunity for the Austrian industry.

Since the ICE is operated in a substantially different way (peak shaving, load point shifting, start/stop ...) in a hybrid compared to a pure thermodynamic power train, the special adaptation of existing combustion engines or the use of alternative combustion engines allows for a further reduction of emissions and fuel consumption. Conventional gasoline or diesel engines are only the short-term choice. Alternative approaches (modified combustion processes such as Miller/Atkinson) or even alternative engine concepts with small displacement for use in range extender applications, are promising options. (Corresponding research topics are included in chapter “Advanced Thermodynamic Power Train Technologies”.)

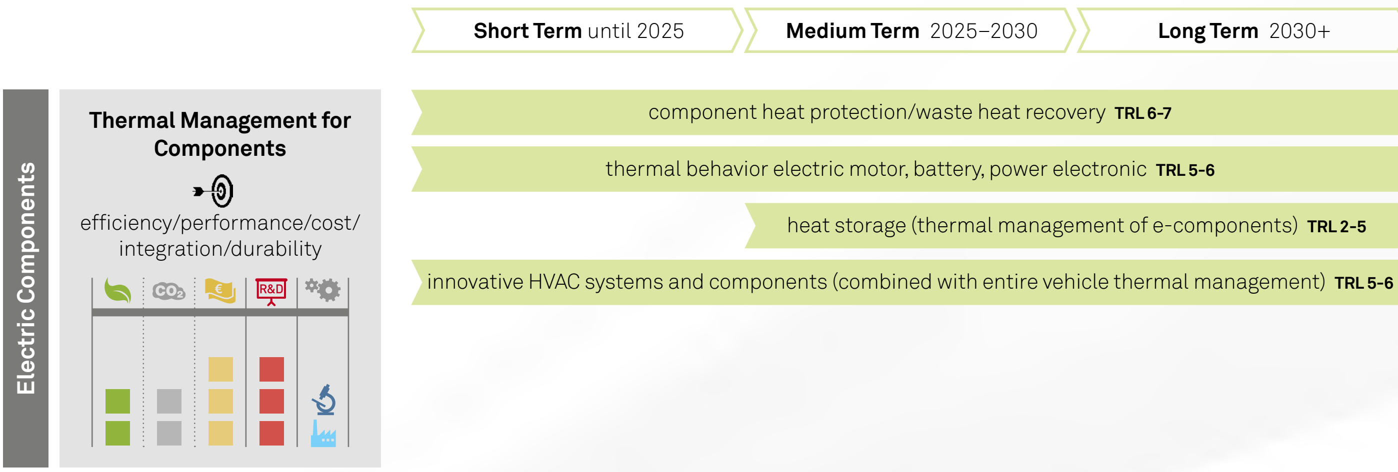
In the field of commercial vehicles, the R&D focus is on diesel and natural gas engine concepts, some of which have already been launched and will permeate the market in the medium term.

The transmission is becoming more important with the increasing electrification of the power train than ever before. Full integration of all electric components into the transmission (hybrid transmission) is a trend. Since the electric motor must be operated at high speeds (= high power density), new efficient and silent reduction gearing to the axle is required. A so-called hybrid transmission fulfils the function of an actuator to operate the ICE and electric motor in parallel and/or serially. The R&D effort and the added value in mass production are high. Fuel consumption can be reduced by up to 15% by optimizing the interaction between transmission and the overall power train. (Corresponding research topics are included in chapter "Advanced Thermodynamic Power Train Technologies".)

To reduce noise emissions from the ICE (in hybrid electric vehicles) and transmission, acoustics R&D continues to play an important role.

Due to their heavy weight, truck transmissions need to deal with much higher torques in both directions at higher numbers of transmission steps compared with passenger cars, making the integration of an electric motor more difficult. The R&D effort is particularly high, since durability and reliability expectations require more extensive testing than in passenger car applications. Austria's added value in this area mainly lies in the development of complete transmission systems (transmission, electric motor, inverter, clutch) with associated actuators and operating strategy.

Thermal management affects both the operating conditions for individual components and the comfort in the cabin. Cabin heating and cooling under extreme environmental temperatures can significantly reduce a (electric) vehicle's range. In some cases, for example in city traffic, the energy demand for heating can exceed the demand required for propulsion. New solutions for heat storage systems are of particular interest. Unused heat can be stored and effectively used at a later time (e.g. waste heat of power train components for interior heating the next day). Chemical heat storage systems (with no insulation requirements and indefinite storage duration) offer high potential for this purpose. Such storage systems are available at a basic level, but a lot of R&D effort is still required. The behaviour of the electric components such as batteries, inverters and electric motors are of special interest with regard to the vehicle components.



Research topics regarding ICE, transmissions and alternative transmission concepts are specified in chapter "Advanced Thermodynamic Power Train Technologies"

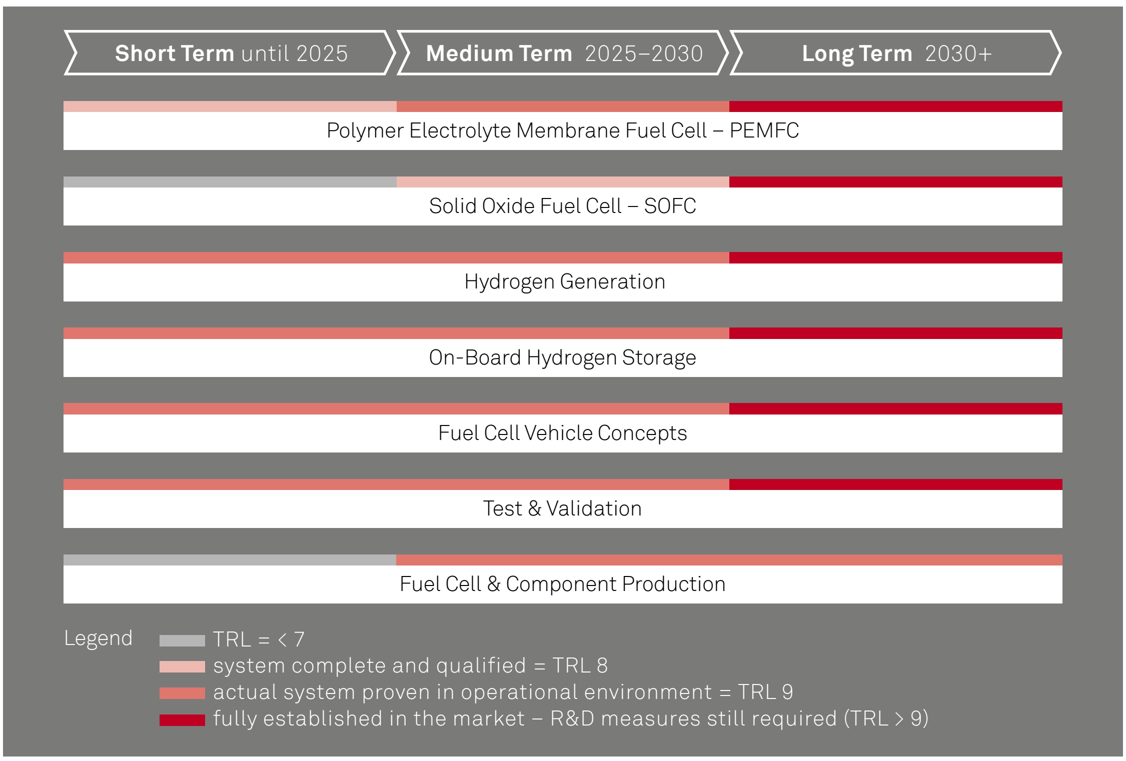
Fuel Cell System Technologies

Fuel cells (FC) have great savings potential for pollutant and CO_2 emissions – provided that hydrogen from renewable sources is used. In addition, local hydrogen production (without importing energy) is possible. A big chance for the introduction of fuel cell vehicles are synergies between the production of fuel cell vehicles and hybrid electric vehicles.

There are two main technologies of fuel cells for automotive applications. On the one hand the Polymer Electrolyte Membrane fuel cell (PEMFC) and on the other hand the Solid Oxide Fuel Cell (SOFC). PEMFCs distinguishing features include lower temperature/pressure ranges (e.g. 50°C to 100°C) and a special polymer electrolyte membrane. The SOFC has a solid oxide or ceramic electrolyte and operates at high temperature levels between 500°C and 1000°C. Both technologies, PEMFC and SOFC offer a great synergy potential with their respective electrolysis technologies, the polymer electrolyte membrane electrolysis and the solid oxide electrolysis cell (SOEC). Therefore, these technologies are also discussed in this roadmap.

The market introduction of fuel cell vehicles by OEMs started in selected regions in 2014. Austrian companies, research institutions and universities are engaged in the fields of technologies summarized in the table below. The table shows that the activities must now be further pursued and results must be transferred to the international markets. Through the early market launch, A3PS members expect even tougher international competition.

Market readiness of advanced thermodynamic power train technologies



Therefore, great R&D efforts on fuel cell components and test and validation systems are required in order to strengthen Austria's position in this field. Current R&D activities on fuel cell components are focused on efficiency, endurance, lifetime and cost.

The large investments in high volume production required to lower the costs of fuel cell systems and therefore the price of the vehicles are the biggest obstacle for the introduction of fuel cell systems.

For the application in passenger vehicles, the focus is currently on the PEM Fuel Cell. Depending on the power train design, fuel cells operate at power levels from 15 to 30 kW for range extender vehicles, APU applications and Combined Heat and Power (CHP) applications up to 100 kW and more power for "pure" fuel cell vehicles. Fuel Cell range extender vehicles are battery electric vehicles with fuel cells for maintaining charge or as a fall-back solution in case of a discharged battery. In "pure" fuel cell vehicles, the fuel cell provides the total amount of electrical drive energy. A small battery or super capacitors are required to buffer highly dynamic load changes and peak performances.

Very strong R&D effort is required especially for the development of new low-cost materials with high durability under high dynamic loads for the fuel cell. With regard to the second generation of fuel cell vehicles, the focus is put on the replacement of noble metal catalysts in the fuel cell.

In order to reduce the use of the EU-defined "critical raw materials", more R&D is required in the field of lightweight powder-metallurgical manufactured SOFC stack components, qualified catalysts and high temperature electrolysis (SOEC) – for instance via low or platinum-free resources, and through recycling, reducing or avoiding the use of rare earth elements. This is of special importance, since electrolysis is the only way to produce green hydrogen.

As for hydrogen storage, in the first generation of fuel cell vehicles, tanks with a pressure level of up to 700 bar are used. A very strong R&D effort is required for the development of hydrogen storage systems that reach high storage densities at lower levels of pressure while costs are reduced.

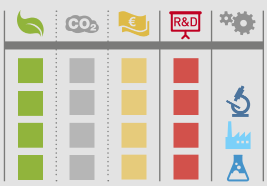
In the heavy-duty sector, the use of PEM fuel cells in city buses is considered an early commercial market. In the field of heavy-duty vehicles and buses, the SOFC will be ready for the market in the short term, used as an auxiliary power unit and as a range extender. In addition, hydrogen storage and refueling will follow the new standard with a pressure level of 700 bar in the short term.

Short Term until 2025	Medium Term 2025–2030	Long Term 2030+

Fuel Cell System Technologies

PEM Fuel Cells
(for REX-FCV and "pure" FCV/synergies with PEM-electrolysis)

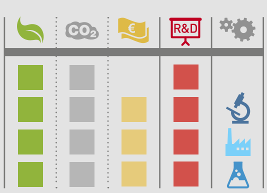
efficiency
endurance
lifetime
cost reduction



- reduction of noble metal catalysts **TRL 7**
- replacement of noble metal catalysts **TRL 3**
- innovative/cost reduced electrolytes and membranes **TRL 4**
- cold start behavior **TRL 8-9**
- media conditioning (e.g. charging, humidifying) **TRL 5-7**
- medium temperature fuel cells (>80°C) **TRL 5-7**
- control, diagnostics (e.g. in-situ analysis of degradation, calibration, optimization) **TRL 4-6**
- dynamic behavior (control, sensors, calibration, optimization) **TRL 7**
- specific thermal management **TRL 7-8**
- root cause analysis (e.g. degradation & failure detection/model based prediction) **TRL 2-6**
- cost engineering (production technologies, novel materials, simplification ...) **TRL 2-6**
- hydrogen gas quality (impact on degradation ...) **TRL 4**
- production technologies and recycling **TRL 4-6**

SOFC
(synergies with CHP and SOEC)

efficiency
endurance
lifetime
cost reduction



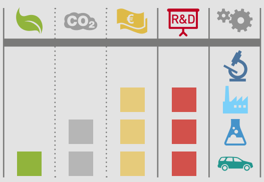
- internal hydrocarbon reforming (catalysts) **TRL 2-3**
- reduction of operating temperature of fuel processing and electrochemical conversion **TRL 1-3**
- increased syngas and methane acceptance **TRL 7**
- increased mass and charge transport (increased specific power) **TRL 2-4**
- new electrolytes and electrodes **TRL 2-4**
- specific gas and thermal management **TRL 4-5**
- root cause analysis, failure/degradation and diagnosis **TRL 2-6**
- metal supported cell (MSC) for APU and REX **TRL 5-7**
- MSC stack technology for APU and REX **TRL 5-6**
- powder-metallurgical manufactured SOFC stack components **TRL 6-8**
- SOFC as APU **TRL 7**

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Fuel Cell System Technologies

Hydrogen Generation

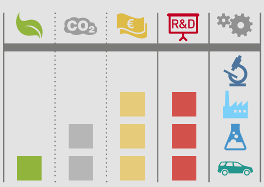
cost/lifetime/safety/ optimization of production process/weight reduction/ packaging



- low temperature electrolysis (PEMEC) **TRL 5-7**
- high temperature electrolysis (SOEC) **TRL 3-4**
- central and de-centralized hydrogen production concepts **TRL 4-6**
- refueling stations (reliability, costs, official verification …) **TRL 4-6**
- optimization of energy supply – linkage of electricity and gas grid **TRL 3-5**
- compliance of hydrogen quality **TRL 2-4**
- high pressure electrolysis **TRL 3-4**
- improved distribution (trailer, pipeline …) **TRL 3-4**
- LH_2 **TRL 4-6**

On-Board Hydrogen Storage

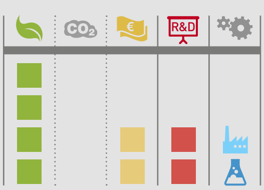
cost/lifetime/safety/ optimization of production process/weight reduction/ packaging



- ionic liquids **TRL 2-3**
- new sensor technologies for production and lifetime monitoring for components **TRL 2-4**
- new sensor technologies for lifetime monitoring for components and systems (synergies with production/model based prediction) **TRL 2-4**
- joining technology (tubes, fittings) **TRL 6-7**
- break through H_2 storage materials and concepts **TRL 1-3**
- solid state storages **TRL 3**
- fiber technology (impregnation …) **TRL 3**
- freeform hydrogen tank **TRL 2**
- liner production **TRL 4-6**

Fuel Cell Vehicle Concepts

NVH optimization/ increase customer acceptance



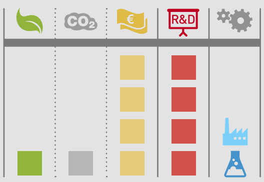
- demonstration activities of vehicles and infrastructure (public transport, fleet applications …) **TRL 5**
- passenger cars **TRL 6-8**
- heavy duty applications (trucks) **TRL 4-6**
- fuel cell dominant concepts **TRL 6-8**
- fuel cell range extender concepts (SOFC, PEM) **TRL 4-6**
- public awareness **TRL 4**
- life cycle analysis of vehicle concepts **TRL 4-6**
- special vehicles (tractor, industrial trucks, sport vehicles) **TRL 4-6**
- functional safety **TRL 6-8**

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Fuel Cell System Technologies

Test & Validation

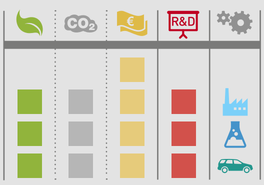
technical, ecological and economic analysis of fuel cell and hydrogen storage systems (components, systems and vehicles)



- HiL and on board real world analysis **TRL 4-7**
- long term tests under real conditions and accelerated stress tests (AST) **TRL 4-5**
- automated measurement and test environment for components and systems **TRL 5-7**
- high pressure test bed incl. refueling infrastructure **TRL 8**
- model based development incl. real xiL testing **TRL 2-5**
- gas analytic (e.g. N_2/H_2 in anode/anode loop, CO/CO_2 at stack cathode outlet) **TRL 6**
- end of line test systems (fuel cell, tank, valves ...) **TRL 3-6**
- virtual validation **TRL 2-4**
- mechanical stress tests **TRL 5-6**
- analysis methods for hydrogen gas quality **TRL 5-6**

Fuel Cell & Component Production

cost reduction/high volume production technlogies



- OBD storage sensors **TRL 1-2**
- valves, sensors, pumps, blowers, thermal management components **TRL 2-8**
- low cost cell and stack components **TRL 2-5**
- Controller units **TRL 3-8**
- Creation of Austrian technology and supplier network **TRL 3-8**
- Production and recycling of fuel cells **TRL 4-6**

Legend

Benefit

pollution (e.g. NOx, particles) and noise reduction

CO_2 emission & resources consumption*

added value

R&D demand

Type of project required

(material) fundamental research

industrial research

experimental development

demonstration

Technology readiness levels (TRL)

TRL 1: basic principles observed
TRL 2: technology concept formulated
TRL 3: experimental proof of concept
TRL 4: technology validated in lab
TRL 5: technology validated in relevant environment
TRL 6: technology demonstrated in relevant environment
TRL 7: system prototype demonstration in operational environment
TRL 8: system complete and qualified
TRL 9: actual system proven in operational environment

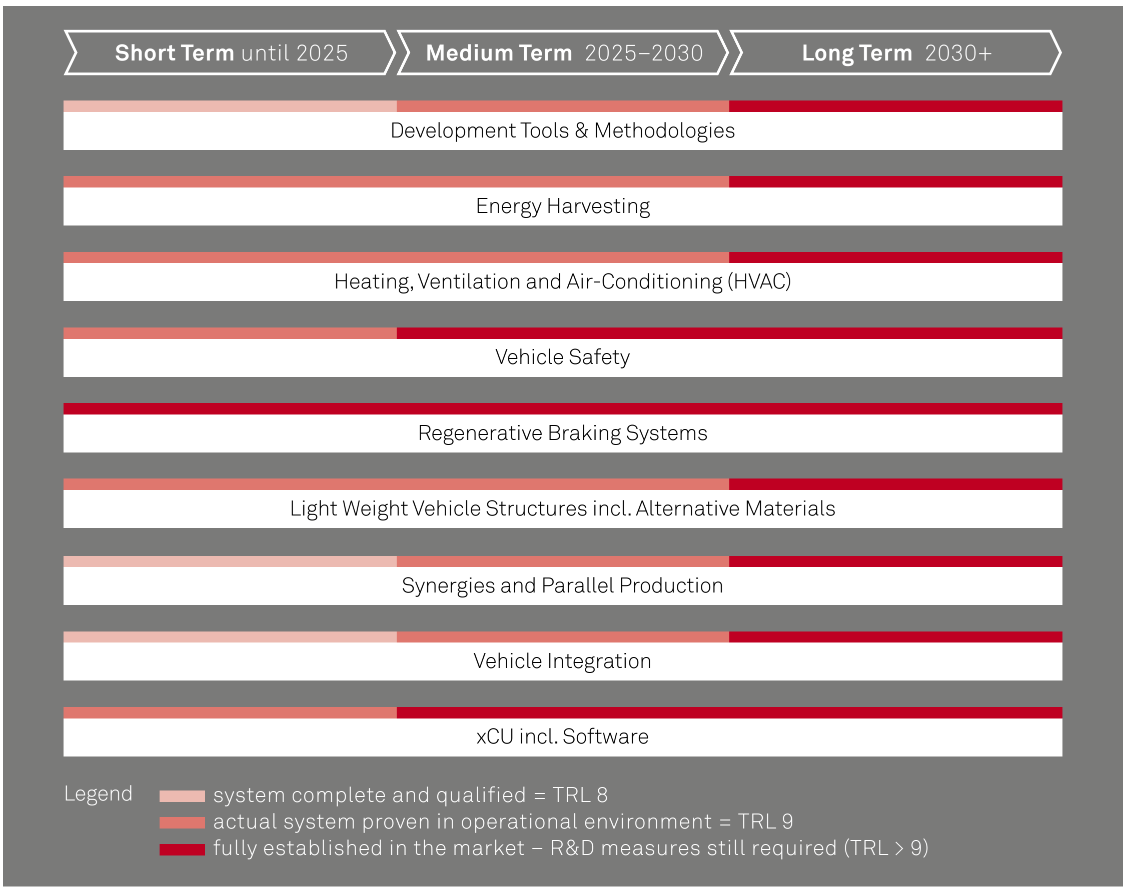
* potential to reduce CO_2 emission and to raise independency from fossil resources

Advanced Power Train Integration Technologies on Vehicle Level

Aside from advanced power train technologies mentioned in the previous chapters, this chapter summarizes technologies which considerably influence the vehicle performance, fuel consumption, efficiency and environmental impact. Enabling technologies for development and vehicle integration of advanced power train technologies are included. Beside electrification "digitalization" rises up as new challenge. The latter major trend will lead to new driver assistance systems, partially and fully automated vehicles and connected mobility systems bringing unprecedented comfort and safety to the users of vehicles. New technologies extend classical automotive engineering with new sensors, information and software technologies.

Starting with "Development Tools & Methodologies", the table below summarizes power train integration technologies in order to optimize energy efficiency and emission behaviour, overall cost, as well as the overall vehicle safety.

Market Readiness of Advanced Power Train Integration Technologies



Advanced "Development Tools & Methodologies", i.e. special simulation tools that allow a flexible deep dive into the level of detail during the development process are required to reduce development time and cost while improving quality. Local Austrian suppliers can increase their added value.

In the field of "Energy Harvesting", the aim is mainly to increase energy efficiency by optimizing the use of available waste energy. Therefore, measures like vehicle integration, Organic Rankine Cycle (ORC), chemical WHR or thermoelectric generators are promising options that require a strong R&D effort.

Conventional cabin heating and air conditioning systems use the waste heat from the combustion engine for heating and belt-driven air conditioning compressors for cooling. Since highly efficient power trains (whether advanced thermodynamic or pure electric) produce less waste heat, heating the cabin requires new innovative and efficient solutions. Therefore, heating and cooling must be treated in an overall context, including infrastructure. Pre-heating and pre-cooling of the cabin at the charging station without affecting the range or use of adiabatic cooling systems and navigation-aided early shutdowns must be considered. Additionally, hybrid or pure electric power trains require demand-driven air conditioning compressors as the combustion engine is not operated permanently. Furthermore, due to the relatively low capacity of the present battery technologies, heating, ventilation and air conditioning (HVAC) reduces the total range of the vehicle tremendously. New technologies for efficient HVAC are latent heat storages, new materials such as zeolite, active thermal materials and heat pump systems.

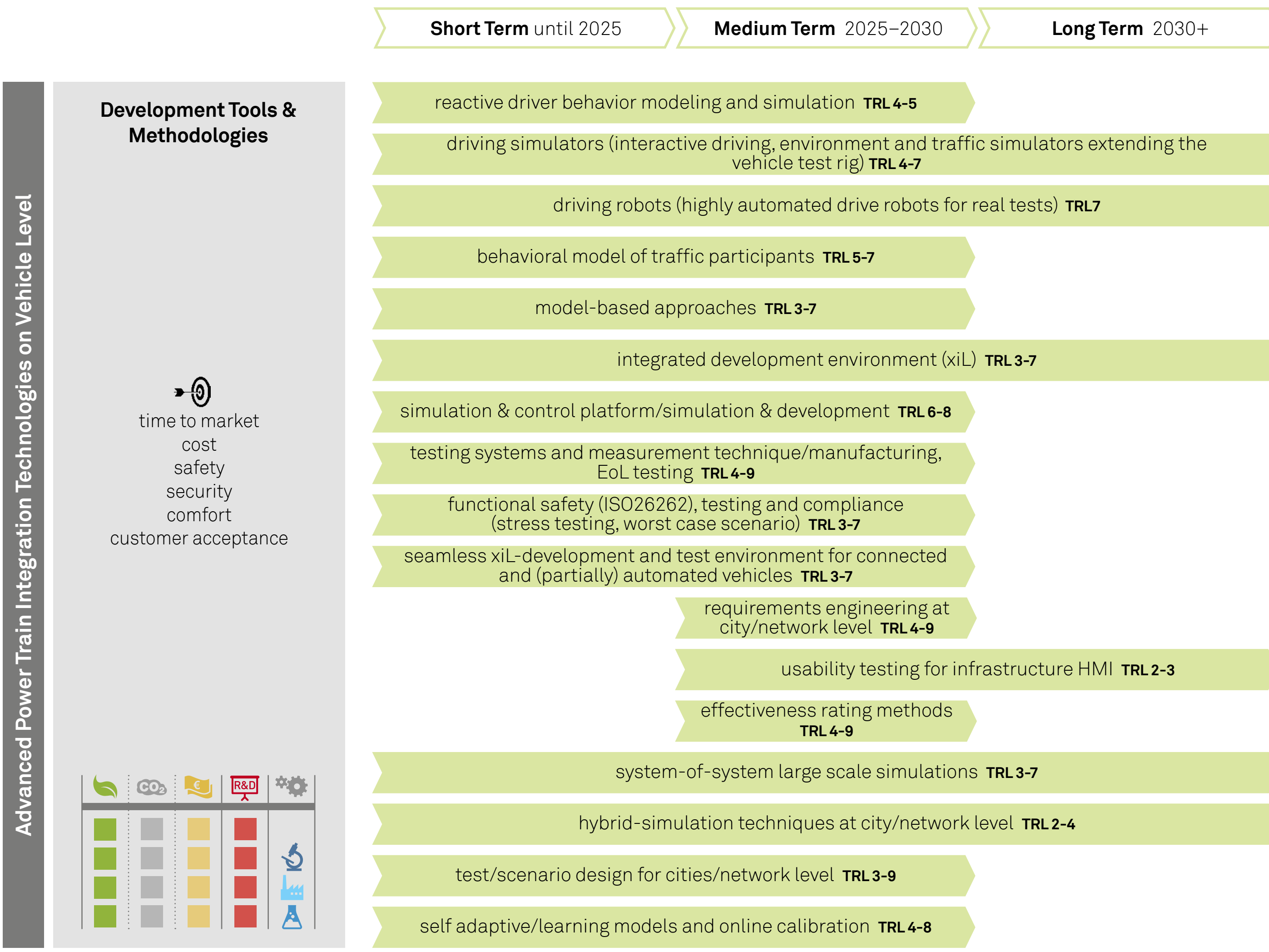
Innovative "Regenerative Braking Systems" help to enhance efficiency and braking comfort whilst reducing particles if compared with conventional disk braking systems. R&D effort is required in the field of high performance 4-wheel regenerative braking systems for optimal energy recuperation as well as in the field of mechanical energy storage devices.

Significant efforts will be necessary to ensure "Vehicle Safety", which increases with the complexity of the power train. The "Synergies and Parallel Production" of thermodynamic, hybrid and FC power trains are promising options to lower production costs.

Huge R&D efforts have to be put into vehicle integration. For new power train technologies, experts estimate that the function on the component level is only responsible for about 10% of the overall effort whilst vehicle integration causes about 90%. Further development in geometrical and functional "Vehicle Integration" as well as in new modular vehicle concepts (e.g. simulation) is required.

Great R&D efforts are being made in the field of control units (xCU). The term "xCU" encompasses all control units that are relevant for advanced power trains, including the operating strategy. Optimized operation strategies can increase efficiency and reduce pollutant emissions. Predictive operating strategies play an important role, as well as the consideration of a combined controller, for both passenger cars and commercial vehicles.

For future control strategies and systems AI technologies need to be considered and developed towards the particular demands of vehicle and vehicle powertrains.



Legend

Benefit

- pollution (e.g. NOx, particles) and noise reduction
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required

- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)

- TRL 1: basic principles observed
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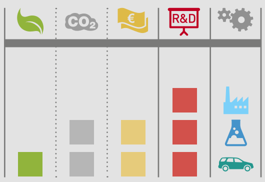
* potential to reduce CO_2 emission and to raise independency from fossil resources

Advanced Power Train Integration Technologies on Vehicle Level

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Energy Harvesting

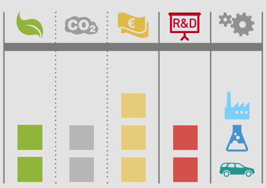
efficiency
optimum use of available energy
remote energy supply



- optimized integration of energy harvesting technology into overall vehicle energy system **TRL 3-6**
- ORC (organic Rankine cycle) implemented in car for waste heat recovery **TRL 5-8**
- thermoelectric generators **TRL 3-5**
- optimization of bottoming cycles, fluids and machineries/auxiliaries **TRL 3-5**
- optimization of thermoelectric materials and devices **TRL 3-5**

Heating, Ventilation and Air-Conditioning (HVAC)

efficiency (range) vs. comfort
integration



- latent heat storage **TRL 5-7**
- new materials (zeolite) **TRL 4-7**
- active thermal materials **TRL 3-5**
- heat pump system for HVAC **TRL 5-7**
- HVAC acoustics **TRL 3-5**

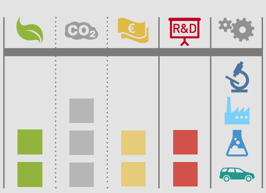
Vehicle Safety

increased safety for all traffic participants

- vulnerable road users (pedestrians, cyclists, …) **TRL 4-8**
- crash safety (battery, flywheel, hydrogen storage), occupant safety (a traffic mix of AD and non-AD vehicles has to be considered; new seating positions, new interiors) **TRL 3-9**
- functional safety ISO 26262 **TRL 7-9**
- vehicle qualification for road safety (new approaches due to CAVs) **TRL 5-7**
- new test procedures (AD has to be considered) **TRL 3-6**
- effectiveness rating instead of fixed test ratings **TRL 4-5**

Regenerative Braking Systems

efficiency/reducing particles/
braking comfort



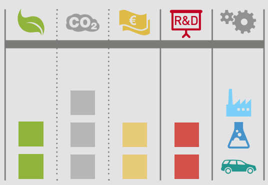
- high performance 4-wheel regenerative braking system for optimal energy recuperation **TRL 5-7**
- reducing particles/braking comfort **TRL 5-6**
- energy recuperation/actuators **TRL 7-9**
- mechanical energy storage devices **TRL 6-7**

Advanced Power Train Integration Technologies on Vehicle Level

	Short Term until 2025	**Medium Term** 2025–2030	**Long Term** 2030+

Lightweight Vehicle Structures incl. Alternative Materials

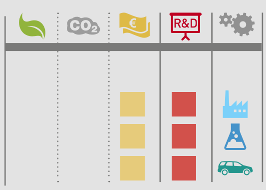
efficiency
mass reduction
manufacturing
costs
recycling



- lightweight acoustics **TRL 4-7** (short to medium term)
- wheel hub motors **TRL 7-8** (medium term)
- red. number of components/ new materials **TRL 6-7** (medium term)
- highly integrated battery **TRL 6-7** (short to medium term)
- electric motor & components **TRL 7-9** (short term)
- new simulation methods for failure prediction **TRL 3-7** (short to medium term)
- new joining techniques **TRL 3-7** (short to medium term)
- crash simulation **TRL 4-7** (short to medium term)
- multimaterial chassis design **TRL 3-8** (short to medium term)
- non destructive testing methods **TRL 3-8** (short term)
- new lightweight alloy development (Al-, Mg-based) **TRL 4-7** (short term)

Synergies and Parallel Production

cost reduction/high volume production technologies/industry 4.0

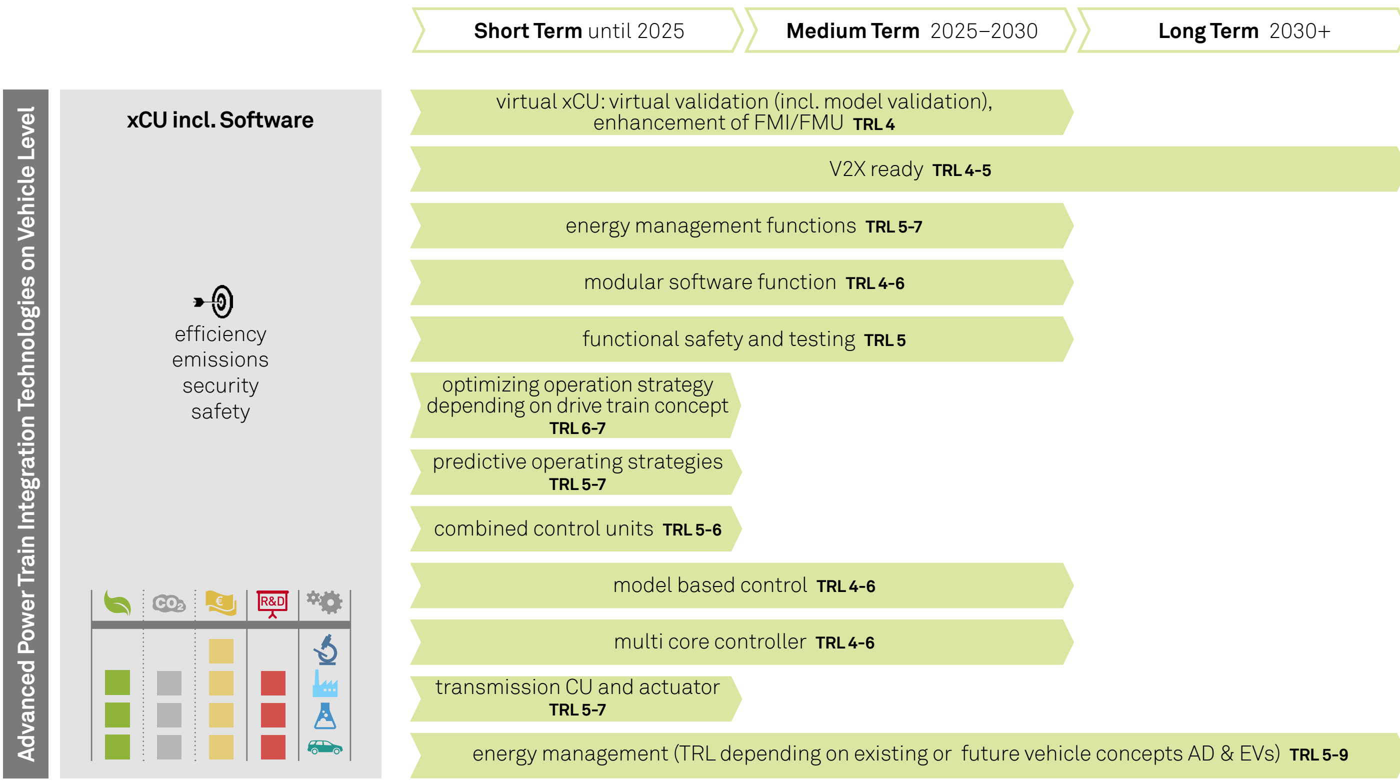


- "re-use of IT technologies" for automotive **TRL 4-8** (short to medium term)

Vehicle Integration

cost/packaging/
reducing number of parts/
safety/modularization

- objective assessment of automated vehicle functions **TRL 4-8** (short to long term)
- functional hardware integration **TRL 5-7** (short to medium term)
- standardized interfaces **TRL 5-7** (short to long term)
- assembly/service concepts **TRL 2-4** (short term)
- vehicle integration of drivetrain technologies **TRL 8** (short term)


Short Term until 2025
Medium Term 2025–2030
Long Term 2030+
Advanced Power Train Integration Technologies on Vehicle Level
xCU incl. Software
efficiency
emissions
security
safety
R&D
virtual xCU: virtual validation (incl. model validation), enhancement of FMI/FMU TRL 4
V2X ready TRL 4-5
energy management functions TRL 5-7
modular software function TRL 4-6
functional safety and testing TRL 5
optimizing operation strategy depending on drive train concept TRL 6-7
predictive operating strategies TRL 5-7
combined control units TRL 5-6
model based control TRL 4-6
multi core controller TRL 4-6
transmission CU and actuator TRL 5-7
energy management (TRL depending on existing or future vehicle concepts AD & EVs) TRL 5-9

Advanced Vehicle Control Systems

In line with the general trend in the automotive industry and the high level of activities of A3PS members, aspects in the field of advanced vehicle control systems must be taken into account in this roadmap. The technology path for those systems leads from Advanced Driver Assistant Systems (ADAS) via Connected Vehicle Technologies to fully automated driving. On a higher level, those technologies together with lightweight vehicle structures and materials are interlinked through the topic of vehicle safety. All of those technologies affect the vehicle safety and have impact on vehicle concepts and the power train.

The A3PS members keep track by monitoring the development in the field of advanced vehicle control systems. This is in order to justify innovation in overall vehicle technologies and to increase the chances for the Austrian industry. This also applies to many companies and institutions in the area of vehicle electronics and software.

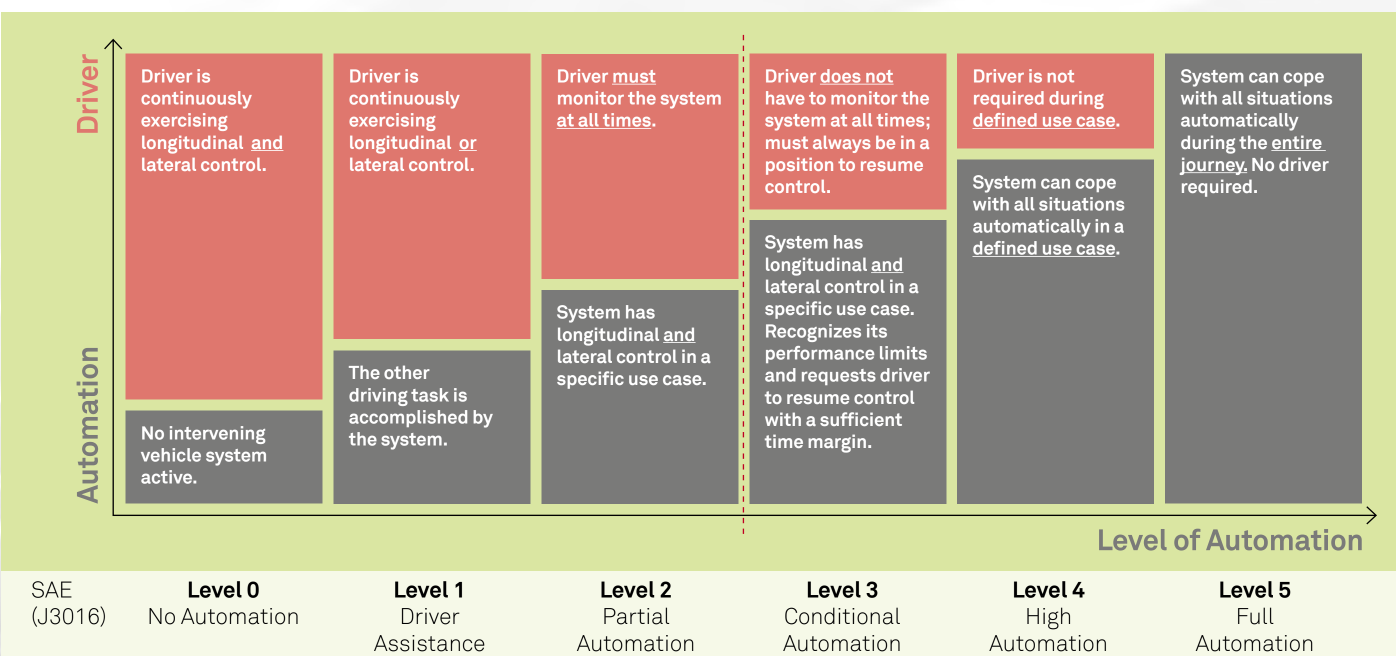
The technology progress for all kinds of road vehicles in the past decades has significantly improved safety, energy efficiency and emissions as well as the comfort of today's vehicles. But still, the number of fatalities and injured persons in road traffic is much too high and therefore extended effort is needed to bring these figures down.

R&D effort in the last 20 years around the globe results in advanced vehicle control technologies becoming mature for implementation in the traffic environment and can be seen as breakthrough for a future traffic with 'zero' fatalities whilst maximally utilizing the available infrastructure capacity. Once "zero" fatalities, injuries and accidents in the road transport system have been achieved, an era of totally new vehicle concepts will be possible with radical weight reduction, thus reducing energy consumption as well as significantly reducing road space requirements by those vehicles.

Still, the demand for road vehicles is growing on a global scale, whereas road infrastructure capacity can neither balance this demand today nor will it be extended in line with the number of vehicles. Therefore, automated vehicles are a key element for an efficient future road transport system.

This chapter drafts the path for the radical change from conventional vehicle concepts (SAE level 0) to fully automated driving vehicles (SAE level 5) in the long term. Actually, the huge effort being expended by academic and industrial R&D on numerous research projects, prototype development and systems reliability will lead to an "electronic revolution" inside the vehicle. The stepwise implementation of advanced vehicle control systems on the path to automated driving enabled by sophisticated electronic systems is drafted by SAE, as shown in the following figure.

Automation levels, oriented closely to the definition of BASt project group "Legal consequences of an increase in vehicle automation"

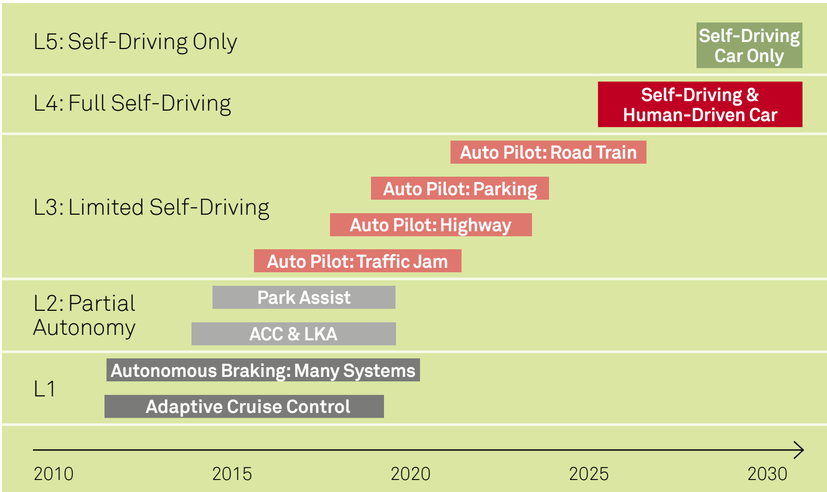


Source: VDA Position "Automated Driving"; 21.01.2014

The number of electronic components and sensors in road vehicles has increased tremendously within the last 10 years and will grow furthermore to thousands of components in the future. Thus, systems starting with ABS, electronic stability program (ESP), advanced driver assistance systems (ADAS), drive by wire components and software for highly automated driving and finally will result in vehicles which can be fully automatically operated in all conditions.

By taking over the driver's tasks gradually, fully automated vehicles will be the logical extension of advanced vehicle control systems in the long term. Therefore, the functionality, including all the safety aspects, still needs significant R&D effort to enable fully automated vehicles to be viable in the real transport environment.

Self-driving car evolution

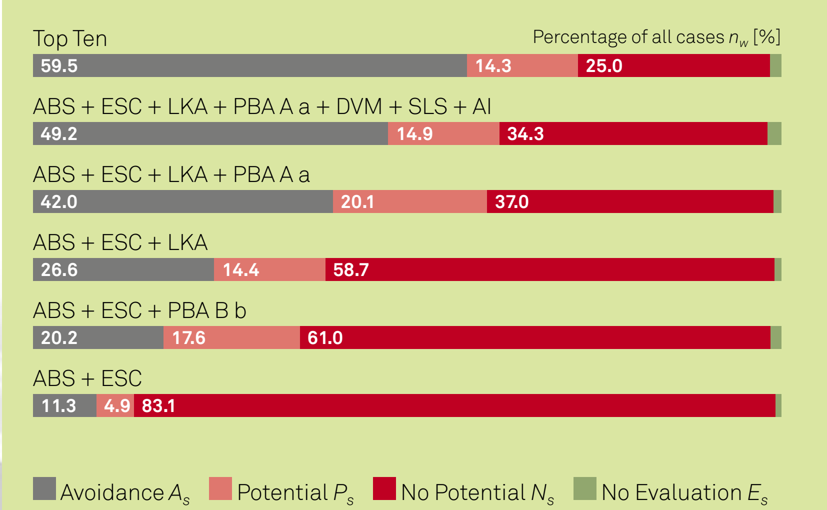


Source: IHS

The expected impact of these applications is to achieve zero fatalities globally and utilize available infrastructure capacity to a maximum, as it is expected that the number of vehicles will continue to increase in the next 20 years.

Advanced vehicle control systems mainly aim to increase energy efficiency and safety as well as to improve comfort and enable the communication between vehicle and infrastructure. Since the majority of all accidents is caused by the human element factor, advanced vehicle control systems have the potential to avoid those accidents and therefore, save human life. The chart below shows that an accident avoidance of over 50% is possible for a combination of ABS, ESC, lane keeping assist (LKA), predictive brake assist (PBA), automated emergency braking (AEB), driver vigilance monitoring (DVM), speed limiting systems (SLS) and alcohol interlock (AI).

Potential effectiveness of combined systems



Source: Eichberger et al, ATZ 2011

Experts in automated driving around the globe expect a dramatic reduction of vehicle collisions, accidents and fatalities in the range of minus 90% once these functionalities are deployed into e.g. 90% of the vehicles on the road. Assuming that a worst case crash happens at a max. speed of 10 km/h (around 3 m/sec) compared to today's regulation of Euro NCAP5 [equal to 50 km/h (15 m/sec)] the safety concept of all vehicles will have to be redrafted, enabling the application of lightweight structures, reducing the crash buffer, and finally resulting in less energy consumption and better propulsion performance. On the other hand, the classical testing with fixed test cases like Euro NCAP does not cover all the complexities of the systems for automated driving and may induce biases in the wrong direction.

Organizational and legal challenges will play a major role in the successful implementation of automated driving vehicles. In order to clarify the delineation of responsibilities between the driver, the vehicle and the infrastructure, a bundle of scenarios needs to be examined. One important issue is a missing legal framework that allows the testing of advanced driver assistance/vehicle control systems on existing road infrastructures in particular for higher SAE automation levels (3–5). Once the legal framework is set up, testing in dedicated public road sections will be possible.

Particular testing areas are in their build-up phase in Austria (e.g. ALP.Lab for automated cars, DigiTrans for automated freight transport and special issue vehicles), where especially bad road and weather conditions in a complicated mixed traffic environment can be tested in detail. Such testing areas shall include rural roads, city areas, high-speed areas as well as multilane roads where both vehicle and infrastructure technologies can be tested in a mixed vehicle environment. These traffic environments also include automated vehicles, non-automated vehicles, trucks, bicycles, dummy pedestrians, dummy animals, construction and artificial obstacles.

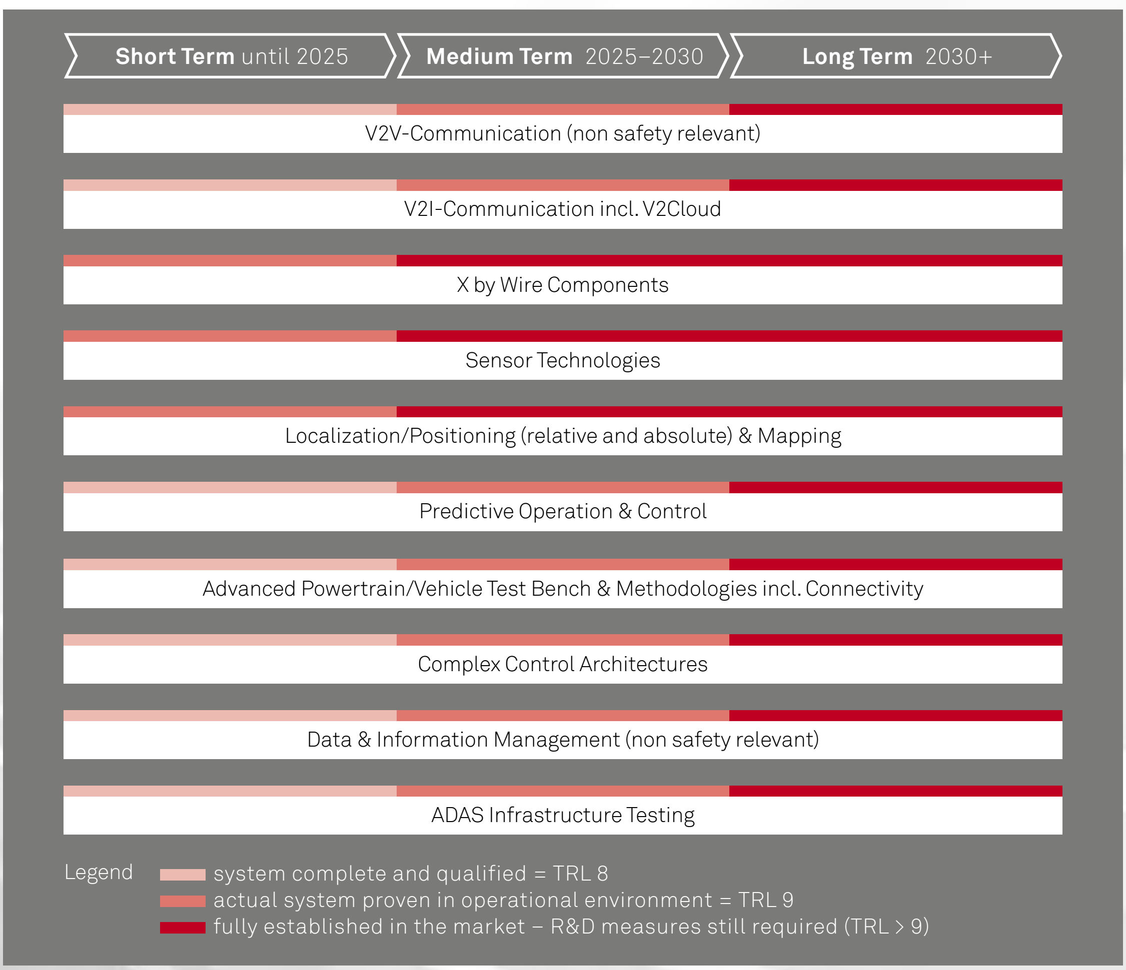
Demonstration of dependability, i.e. safety, security, integrity, availability, reliability and maintainability of automated driving vehicles will be of great importance.

In addition, standardization will be essential to provide clarity on the one hand (e.g. communication protocol and frequency) but on the other hand will offer a free scope for creativity (e.g. open standards).

Partial Automated Vehicles (up to SAE Level 2)

Technologies necessary to implement **vehicles up to SAE level 2** are summarized in the table below. Moreover, these technologies provide an important basis to enable technologies for vehicles of the higher SAE levels 3 to 5. Both the complex area of automated driving and the unclear legal situation require components that consider new use cases already in the design of components.

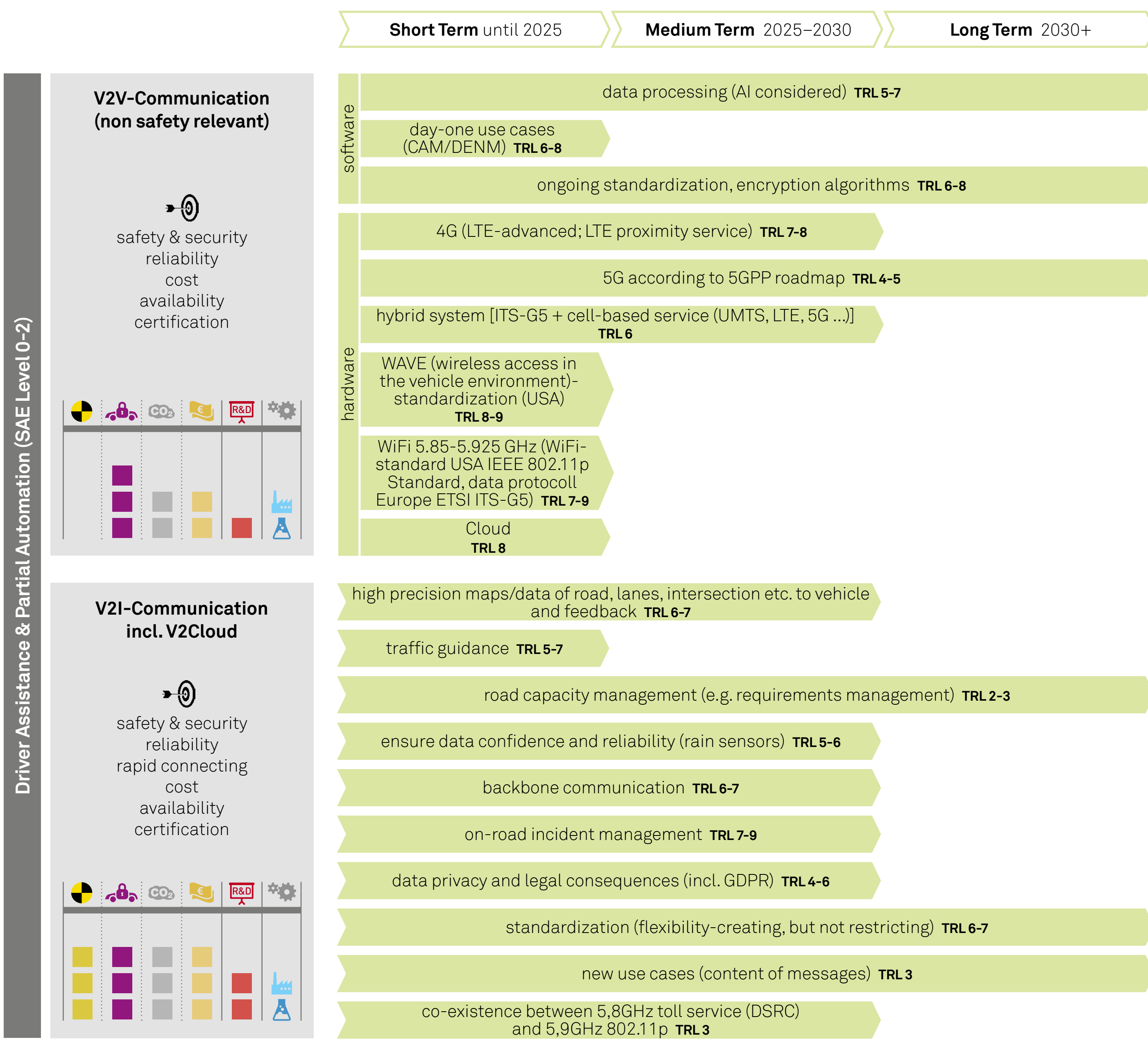
Market Readiness of Technologies for SAE Level 0-2



The key areas for the successful implementation of vehicles with partial automation (SAE level 2) are:

- Communication between vehicles and between vehicles and infrastructure (V2V, V2I)
- Electrically actuated and electronically (or optically) controlled components (x by wire)
- Positioning and mapping (high resolution maps, real time updating, indoor positioning)
- Predictive operation and control strategies (eco routing, reliable routing information)
- Testing infrastructure (for power train, connectivity, vehicle and infrastructure)

In addition, the priorities listed above result in increased demands on complex control architectures and data information management.

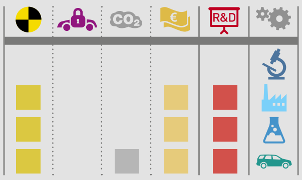


Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Driver Assistance & Partial Automation (SAE Level 0-2)

X by Wire Components

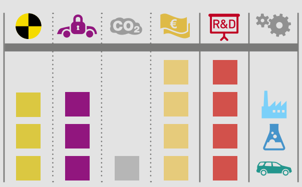
cost/efficiency/reliability/precision/certification



- functional safety ISO 26262 **TRL 8-9**
- steering **TRL 9**
- braking **TRL 8**
- power train control in automated environment (different levels) (engine, transmission, auxiliaries) **TRL 8**

Sensor Technologies

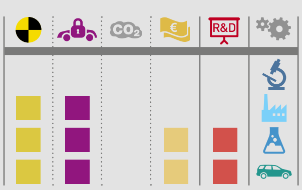
safety
reliability
precision
cost
reduction of amount of sensors



- virtual sensors/model-based measurement **TRL 3-5**
- structural health monitoring **TRL 5-7**
- sensor models and modeling techniques (in future more complex models comprising AI approaches) **TRL 5-8**
- test environment for sensors and actuators **TRL 4-6**
- stereo video camera (daylight and night vision) **TRL 8**
- 1-dimension LIDAR **TRL 8**
- 3D LIDAR **TRL 7**
- intelligent RADAR sensor technology **TRL 9**
- ultrasonic sensors **TRL 8**
- laser scanner **TRL 8**
- Time Of Flight (TOF)-cameras (PMD) **TRL 6**
- intelligent sensor fusion to create sufficient model of surrounding environment **TRL 6-8**
- the vehicle as precise traffic sensor **TRL 2-5**

Localization/Positioning (relative and absolute) & Mapping

safety/increase precision/reliability/cost reduction



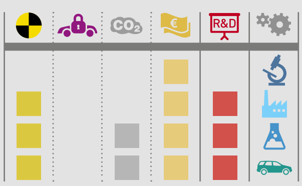
- cost-efficient competitive positioning solutions **TRL 6-8**
- completeness of external sources (e.g. high-resolution maps, real time updating of additional contents) **TRL 7-8**
- high precision GPS position of ego vehicle and other traffic (vehicles, bicycles, pedestrians, ...) **TRL 8**
- indoor positioning **TRL 7-8**
- GPS, GALILEO, GLONASS **TRL 9**
- Beidou (China) – currently local, but planned to become global **TRL 8**

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Driver Assistance & Partial Automation (SAE Level 0-2)

Predictive Operation & Control

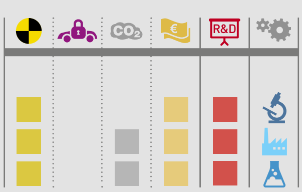
right-sizing components
vehicle efficiency
vehicle safety
reduce emissions
extended lifetime



- reliable mandatory routing information **TRL 8**
- maneuver based/scenario simulation **TRL 6**
- predictive transmission control **TRL 9**
- eco routing **TRL 9**
- hybrid predictive energy management **TRL 8-9**
- coasting assistant **TRL 9**
- e-horizon **TRL 9**
- HMI (e.g. gesture control) **TRL 7-9**
- predictive regenerative 4-wheel braking **TRL 7-8**
- predictive traffic control **TRL 4-5**: node/intersection/line control **TRL 5**, net control **TRL 4**
- traffic performance quantification under various regimes incl. safety and robustness metrics (beyond level of service, etc.) **TRL 4-5**
- cooperative traffic control strategies (e.g. platooning, etc.) **TRL 6-7**
- behavioral models for drivers and all kind of traffic participants (in particular VRU) **TRL4**

Advanced Test Benches, Environments & Methodologies (Powertrain, Vehicle, Sensors & Actuators) incl. Connectivity

reduction of real-world field testing
manage increased complexity
secure communication between vehicles
short time to market
secure and energy efficient development



- methodologies for distributed virtual and physical powertrain test rigs **TRL 6-8**
- GPS stimulation **TRL 7-8**
- video stimuli & simulation & testing **TRL 8**
- RADAR, LIDAR, ultrasonic stimuli & simulation & testing **TRL 7**
- C2C & C2I simulation **TRL 2-4**
- test environment for sensors and actuators **TRL 4-8**
- safety and security in one and the same system – related test modes, methods & equipment **TRL 2-4**
- Real World Test Beds (Regions) for Automated Vehicles (combined with RDE) **TRL 6-8**

Legend

Benefit
- safety
- security
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required
- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)
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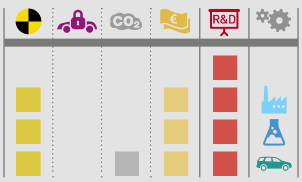
* potential to reduce CO_2 emission and to raise independency from fossil resources

Short Term until 2025 | **Medium Term** 2025–2030 | **Long Term** 2030+

Driver Assistance & Partial Automation (SAE Level 0-2)

Complex Control Architectures

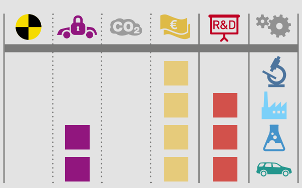
reducing number of components
increase efficiency
flexibility in function development



- reconfigurable systems for fail-operational applications (synergies with air and rail control) **TRL 5-6**
- functional safety (ISO26262) **TRL 7-8**
- reliable processing of cognitive data **TRL 7-8**
- dependable power computing **TRL 6**
- extended processor performance **TRL 6**
- sensor platforms **TRL 6**
- sensor fusion (camera & LIDAR; camera & RADAR; stereo camera, XFCD & stationary traffic sensors) **TRL 4-9**
- open-source software platform for automated driving **TRL 6-8**
- interfaces and message content (standardized message content) **TRL 6-8**
- hierarchy of controls and software modules (master/slave) **TRL 5-6**
- objective assessment of automated vehicle functions **TRL 7**
- overall, common control architecture for cooperative driving/ smart city **TRL 5-6**

Data & Information Management (non safety relevant)

data from three sources
(vehicle sensors, I2V, cloud2V)
and processing



- receive & feedback data algorithms (I2C,C2I, C2C) **TRL 4-8**
- algorithm design **TRL 4-8**
- information presentation (HMI) **TRL 3-6**
- sensor fusion data management **TRL 7-9**
- architecture logical/functional (incl. redundant algorithm) **TRL 3-8**
- on-board information model for vehicle and infrastructure **TRL 7**
- on-board information aggregation **TRL 7**
- after sales operational data optimization (e.g. software updates) **TRL 7**
- data synchronization between car and infrastructure **TRL 3**
- paying functions ("car as driving credit card") **TRL 7-9**

Conditional, High and Full Automation Vehicles (SAE Levels 3-5)

SAE levels 3-5 vehicles require increasing activities in the field of sensors and actuators, integration (components into vehicle as well as vehicle into infrastructure), safety-relevant communication as well as advanced technologies for positioning and vehicle surrounding detection. If they should cooperate, all traffic participants will need to be integrated into a common control concept in the long term.

Market Readiness of Technologies for SAE Level 3

Market Readiness of Technologies for SAE Level 4

Market Readiness of Technologies for SAE Level 5

Conditional Automation Vehicles (SAE Level 3)

SAE level 3 vehicles are able to drive automatically in specific use cases without manual intervention by the driver (e.g. driving on highways, lane keeping, passing roundabouts, etc.). Still there are many traffic situations where the driver has to take over full control of the vehicle. Therefore, strong R&D efforts are necessary in the field of "Complete Vehicle Surrounding Detection" and the integration of the vehicle into infrastructure. Additionally "Automation Enabling New Vehicle Concepts" can be initiated by measures such as novel safety and extreme lightweight concepts as well as demand-oriented vehicles. Radical new vehicle concepts will also have a lasting impact on the business models of car manufacturers. Due to the fact that the system is not able to drive automatically under all circumstances, the driver must stay in a position to resume control as requested in the Convention on Road Traffic of 1968 by UNECE ("Vienna Convention").

High Automation Vehicles (SAE Level 4)

Vehicles equipped with level 4 functionality cope with all traffic situations on public roads without manual intervention. As it is expected that international legal regulation defined by UN-ECE (so-called "Vienna Convention") will not be redrawn by the respective administrative nation bodies soon, it is still mandatory for a driver to sit behind the steering wheel. Safety-relevant V2V-communication and even more accurate positioning and mapping are mandatory.

Full Automation Vehicles (SAE Level 5)

As soon as the aforementioned "Vienna Agreement" has been suspended by national regulatory bodies, vehicles equipped with the complete set of automated functions will not need a driver behind the steering wheel. There won't even be a steering wheel in those vehicles at all.

Additionally, automated vehicles will support policy to comply with targets regarding energy efficiency, emissions, access to individual mobility and equality.

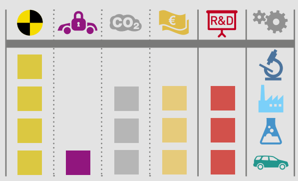
Note: For a long time, there will be a 'mixed environment' in road traffic, where unequipped vehicles, partly equipped vehicles and fully automated vehicles will operate or be operated on roads at the same time. This may cause a great deal of dangerous situations and place a heavy burden on system developers and vehicle manufacturers to cope with even more complex situations in the real, on-road traffic environment.

	Short Term until 2025	Medium Term 2025–2030	Long Term 2030+

Conditional Automation (SAE Level 3)

V2V-Communication Safety Relevant

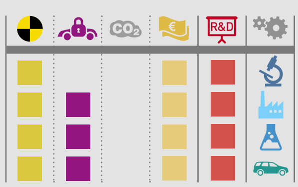
safety & security/reliability/ rapid connecting/cost/ availability/certification/ new use cases/ policy: reserve 5,9 GHz band only for automotive applications



- channel congestion control/ mitigation algorithms **TRL 8** (short term)
- extended safety message types (e.g. extended CAM) **TRL 3-5** (short to medium term)
- self-organizing "swarm intelligence" **TRL 2-4** (short to long term)
- standardization **TRL 6** (short to medium term)
- adaptive function design (e.g. for new use cases) **TRL 4-5** (short to medium term)
- security measures integrated in design **TRL 2-4** (short to medium term)

Complete Vehicle Surrounding Detection

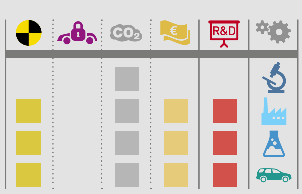
safety & security
level of integration
improving precision
improving reliability
reducing cost



- 3-dimensional LIDAR (improving precision and reliability) **TRL 7** (short term)
- improved ultrasonic sensors **TRL 7** (short term)
- integrated radar sensors **TRL 7** (short term)
- integrated video sensors **TRL 7** (short term)
- data harvesting and interpretation (application in worst case conditions, traffic signs, obstacles, humans/animals, ...) **TRL 6-7** (short to medium term)
- C2x-based surrounding detection **TRL 4-6** (short to medium term)
- advanced selective driver warnings/support systems (advanced HMI) **TRL 7-8** (short term)
- properties of objects beyond geometrically sensed (e.g. mass, stiffness, age/type of person, situation context, intended behavior...) **TRL 3-5** (short to medium term)
- friction coefficient of the road **TRL 6-8** (short term)
- intelligent sensor data fusion to create sufficient model of surrounding environment **TRL 6** (short to medium term)
- comparison of surrounding environment to maps (incl. correction feedback to keep maps up to date) **TRL 6-7** (short to medium term)
- advanced data processing methodologies **TRL 5-8** (short to medium term)
- advanced overall vehicle status model (MBSE) **TRL 8** (short term)
- novel sensor technologies **TRL 1-3** (medium to long term)

Automation Enabling New Vehicle Concepts

safety/comfort/energy efficiency /reducing space requirements



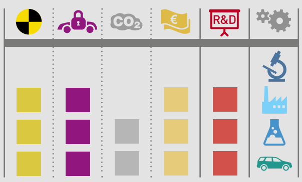
- novel safety concepts (incl. new seating positions, novel interiors, L-class vehicles) **TRL 4-8** (short to long term)
- extreme lightweight concepts (innovative materials, construction) **TRL 4-7** (short to medium term)
- new NCAP definitions **TRL 6-7** (short to medium term)
- demand oriented/customized vehicle concepts for different user groups (individual versus shared vehicles (e.g. robo taxi)) **TRL 4-6** (short to long term)

Short Term until 2025	**Medium Term** 2025–2030	**Long Term** 2030+

Conditional Automation (SAE Level 3)

Vehicle Integration into Infrastructure (VII)

transition from reactive to predictive and interactive traffic management (safety/traffic flow/energy efficiency/capacity utilization)/regulative measures for mandatory data delivered by car

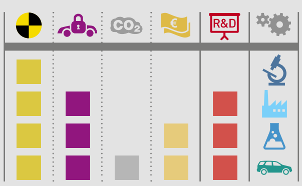


- individualized predictive traveler services **TRL 2-5**
- real time and predictive map information **TRL 6-8**
- predictive, automated and capacity oriented routing (infrastructure capacity management) **TRL 7-9**
- co-operative traffic management (e.g. traffic measures for major incidents) **TRL 3-8**

High Automation (SAE Level 4)

V2V-Communication Safety Relevant, Mandatory

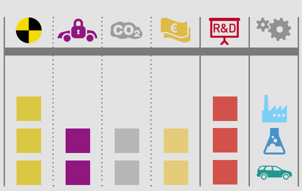
safety & security/reliability/rapid connecting/cost/availability/certification



- redundant systems for safety reasons **TRL 2-4**

Transport System Level Integration (Step 1)

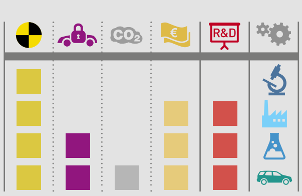
increased level of interaction between vehicle and infrastructure/optimized utilization of infrastructure capacity



- interfaces to other transport modes **TRL 4**
- improve level of prediction in all aspects of route transport **TRL 4-7**
- platooning (TRL depending on AD SAE level) **TRL 6-8**
- cooperative ACC **TRL 3-4**
- fleet management **TRL 6-8**
- overall control architecture **TRL 5-7**
- necessary content of information exchange **TRL 4-6**

Advanced Localization/Positioning (relative and absolute) & Mapping

safety & security/increase precision/reliability



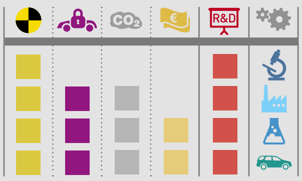
- indoor positioning for parking systems **TRL 7-8**
- increasing the position accuracy to approximately +/− 3 cm **TRL 5-6**
- data fusion for high precise positioning (dead reckoning, GNSS) **TRL 6-7**
- high precision GPS position of ego vehicle and other vehicles **TRL 6-8**
- fine localization under various conditions with/without/malfunction satellite navigation **TRL 3-4**

	Short Term until 2025	Medium Term 2025–2030	Long Term 2030+

Full Automation (SAE Level 5)

Full Transport System Level Integration

safety & security/full level of interaction between vehicle and infrastructure/upmost utilization of infrastructure capacity



- interfaces to other transport modes **TRL 4**
- improve level of prediction in all respects of route transport **TRL 2-4**
- enable better efficiency in road traffic e.g. automatic platooning, automatic usage of full road width, etc. **TRL 5-6**
- overall control architecture **TRL 2-4**

Legend

Benefit

- safety
- security
- CO_2 emission & resources consumption*
- added value

R&D demand

Type of project required

- (material) fundamental research
- industrial research
- experimental development
- demonstration

Technology readiness levels (TRL)

TRL 1: basic principles observed
TRL 2: technology concept formulated
TRL 3: experimental proof of concept
TRL 4: technology validated in lab
TRL 5: technology validated in relevant environment
TRL 6: technology demonstrated in relevant environment
TRL 7: system prototype demonstration in operational environment
TRL 8: system complete and qualified
TRL 9: actual system proven in operational environment

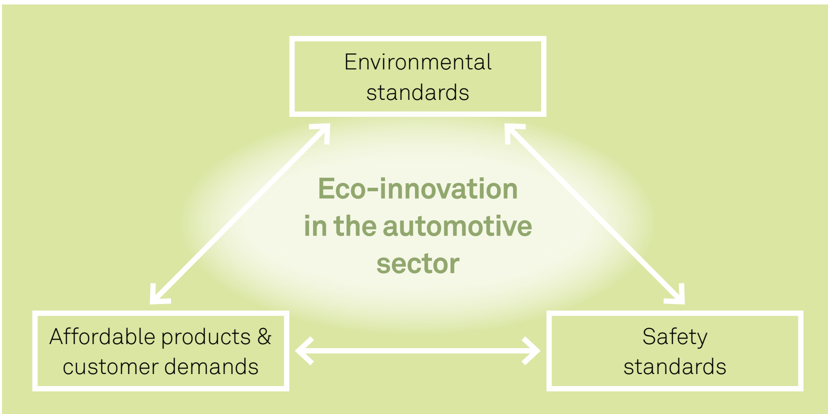
* potential to reduce CO_2 emission and to raise independency from fossil resources

Life Cycle Assessment (LCA) for Transport Systems

The life cycle perspective as an intrinsic part of eco-innovation in the automotive sector

The automotive sector with associated up and downstream industries and services is regarded as one of the major "engines" of the European economy. Its global competitiveness is, however, challenged by increasing pressures (see Figure below): environmental and safety standards, performance and price demands from both consumers and European regulations – e.g. Framework Directive 2007/46/EC for the approval of motor vehicles, Directive 2009/1/EC with regard to the reusability, recyclability and recoverability of motor vehicles, the "End of Life" Directive 2000/53/EC or the Renewable Energy Directive 2009/28/EC. The response to these challenges are the development of sustainable technologies and eco-innovation in the automotive sector, as described in this roadmap.

The pressures driving eco-innovation in the automotive sector (Rademaekers 2011)

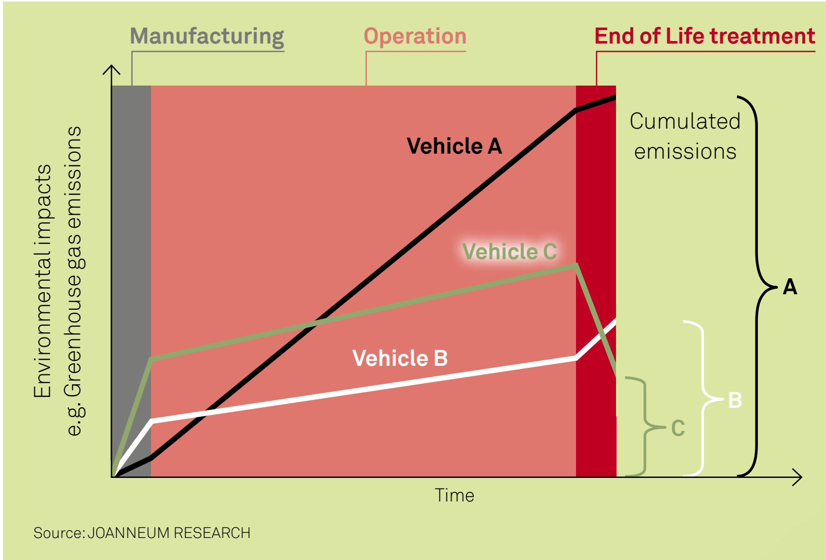


The key objective of eco-innovation is the efficient use of resources, including both energy and material resources. The efficient use of energy by advanced thermodynamic, hybrid and electric power trains as well as the use of renewable energy carriers all contribute to the sustainable development of the transportation sector. By substituting conventional vehicles and fossil-based fuels, environmental impacts as e.g. greenhouse gas (GHG) or particulate emissions are reduced. The efficient use of light and innovative materials such as carbon fibers, high-strength steel or aluminium also has the potential to meet environmental, safety and price demands. Material use efficiency needs to focus on both using the right materials by reducing the reliance on dwindling primary natural resources and looking for alternative materials, as well as using the materials right by maximizing the (re-) use of the materials available (Rademaekers 2011).

Eco-innovation in the automotive sector includes technologies in all stages of a vehicle's life cycle from material production, vehicle manufacturing and its use, to the end of life treatment. Life cycle thinking has therefore become an intrinsic perspective of OEMs already during the research and development phase of eco-efficient and sustainable transport systems. Due to the diversity of power trains, energy supply chains and related bandwidth of environmental effects, the potential future contribution of transportation systems to the improvement of sustainability must be evaluated on a scientific and robust basis.

The method of Life Cycle Assessment

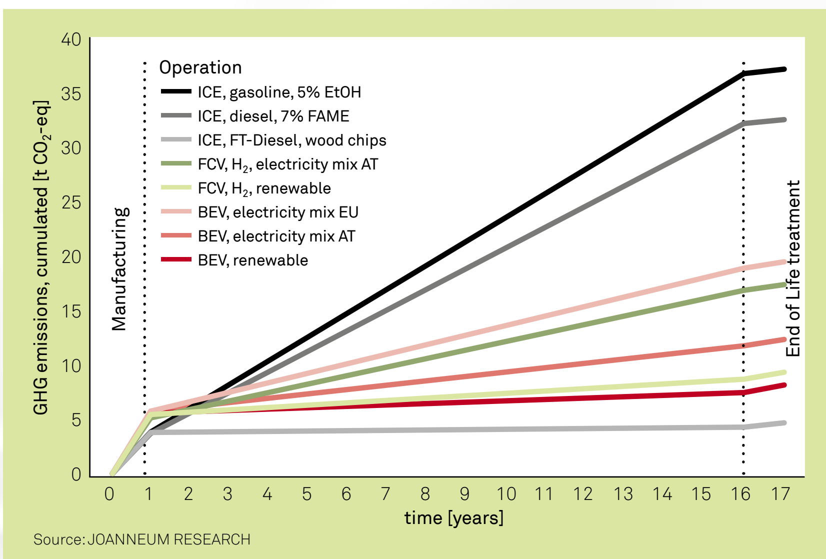
There is an international consensus that the environmental impacts of transportation systems can only be analyzed by the method of Life Cycle Assessment (LCA) including the production, operation (incl. fuel supply and vehicle operation) and the End of Life (EoL) treatment of its elements (see figure below). The International Standard ISO 14040/14044 defines life cycle assessment as follows: Life Cycle Assessment is a method to estimate the potential environmental impacts of a company, product, or service. The environmental impacts of the various stages in the life cycle are investigated. The stages include extraction of raw materials, manufacturing, distribution, product use, recycling and final disposal (from cradle to grave). Life cycle assessment allows the comparison of different systems offering the same transportation service during the same time period and identifies those life cycle phases having the highest environmental impacts (see following Figure).



Life cycle assessment of the three phases in the life cycle of a vehicle – production, operation (including fuel supply) and end of life treatment for hypothetical vehicle types

There are three different hypothetical vehicle cases shown (A, B and C). Compared to vehicle B, vehicle A has lower environmental effects in the production phase, but higher environmental effects in the operation phase. However, the cumulative environmental effects of vehicle B are lower, as the higher initial effects of the production phase are compensated for by the lower effects in the operating and End of Life phase. Vehicle C has the highest environmental effects in the production phase, but as most of the components are recycled into secondary materials, a substitution credit is given for the avoided primary material production.

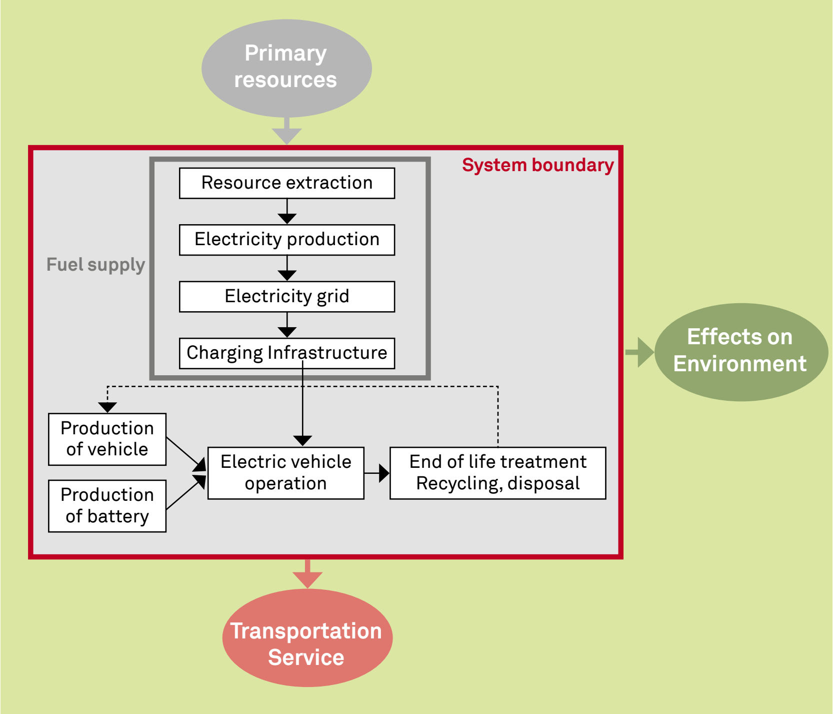
The resulting cumulated GHG emissions calculated for different combinations of power trains and fuels (energy carriers) of vehicles in 2030 are shown in the following Figure.



GHG emissions of different power trains and energy carriers or fuels of vehicles in 2030

The following Figure illustrates the elements and system boundaries of an electric vehicle's LCA. The system boundaries include all technical systems using and converting primary energy and material resources and resulting in a transportation service and having effects on the environment.

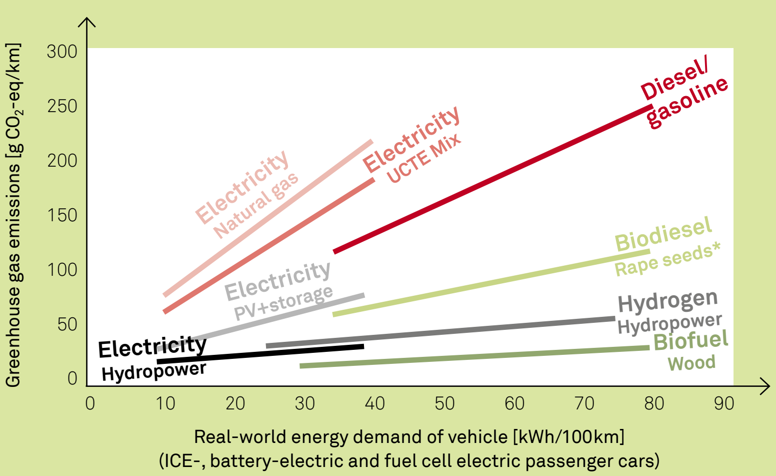
Example of a life cycle analysis (LCA) of an electric vehicle covering its whole value chain



Source: JOANNEUM RESEARCH

Many transportation system LCA today focus on the most relevant environmental impacts which are GHG emissions and primary energy demand. The following figure presents the range of results for GHG emissions of selected transportation systems, depending on the specific GHG emissions factors of selected primary and secondary energy carriers [g CO_2-eq/kWh] and the range of real world energy demand of ICE, battery electric and fuel cell electric passenger cars, reflecting the different efficiencies of the power trains.

Range of results of GHG emissions for selected transportation systems

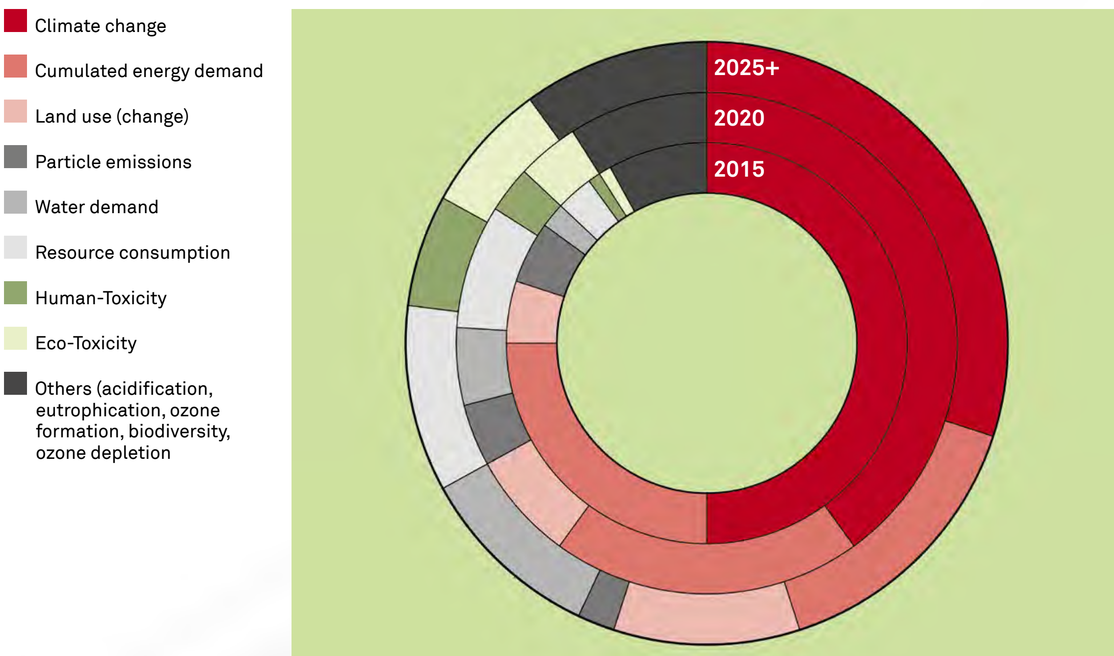


Source: LCA of passenger cars, JOANNEUM RESEARCH, *) without land use change

Besides GHG emissions and cumulated energy demand, which are the main goal of many LCA today, transportation systems have many other environmental effects in the total life cycle. The most relevant environmental effects are:

- Climate change/greenhouse gas emissions
- Fossil & renewable energy depletion
- Land use (change)
- Mineral and renewable resources depletion
- Water resource depletion
- Biodiversity
- Ozone depletion
- Human toxicity: cancer and non-cancer effects
- Acidification
- Particulate matter
- Freshwater eco-toxicity
- Ionizing radiations
- Photochemical ozone formation
- Terrestrial, freshwater and marine eutrophication

In Figure 6, the expected development of the relevance of the various environmental impacts of transportation systems is shown, starting from 2015 to 2020 to the perspective of the roadmap of 2025+. GHG emissions and cumulated energy demand will generally remain in the foreground. The increasing relevance of additional impact categories may be mainly driven by the increasing scarcity and economic value of resources for vehicle manufacturing (impact category: resource consumption), new resource exploration areas and methods (impact categories: land use change, water demand, toxicity) and the production of biofuels (impact categories: land use change, water demand, toxicity).



Source: JOANNEUM RESEARCH and Eco World Styria

Expected development of the relevance of the various environmental effects of transportation systems

LCA versus Well-to-Wheel and the Need for Harmonized and Sound Practice of LCA

The EC has started to integrate the life cycle approach in the automotive sector in the Renewable Energy Directive 2009/28/EC concerning the calculation of GHG emissions and energy use of vehicles. The EC has also published via its Joint Research Centre (JRC) the evaluation report "Well-to-Wheels analysis of future automotive fuels and power trains in the European context" (200 with latest update 2014) as a reference for all European stakeholders. Both Directive and JRC evaluation refer to the so-called "Well-to-Wheel" (WTW) analysis.

WTW analysis, however does not provide the complete picture, since it includes the production of a fuel and its use in a vehicle, but, does not include the vehicle manufacturing and end of life treatment as does a LCA. The justification for excluding the vehicle stems from the understanding that associated environmental effects (GHG emissions and fossil energy use) are an order of magnitude less than fuel related environmental effects of gasoline ICE vehicles. For advanced vehicle technologies that utilize renewable energy carriers, fuel related environmental effects decrease while those from vehicle production might instead increase. To give an example, a gasoline ICE vehicle emitting 150g CO_2-eq/km in LCA has about 20g CO_2-eq/km coming from production and end of life of the vehicle. A battery electric vehicle using renewable electricity from hydropower has about 35g CO_2-eq/km of which about 30g CO_2-eq/km are derived from the production and end of life of the battery electric vehicle. Hence, both the vehicle and energy supply must be considered in a LCA. A LCA in contrast to WTW-analysis therefore involves both additional material and energy conversion processes as well as environmental effects other than GHG emissions and fossil energy use (see figure above) – in particular local/regional environmental effects on ecosystems. This involves wider data sets and data calculations which require sound and harmonized handling if LCA shall provide transparent and comparable results for decision support. In the light of current discussions about lacking transparency concerning the environmental performance of conventional vehicles, LCA is a valuable tool to support the environmental credibility of eco-innovation.

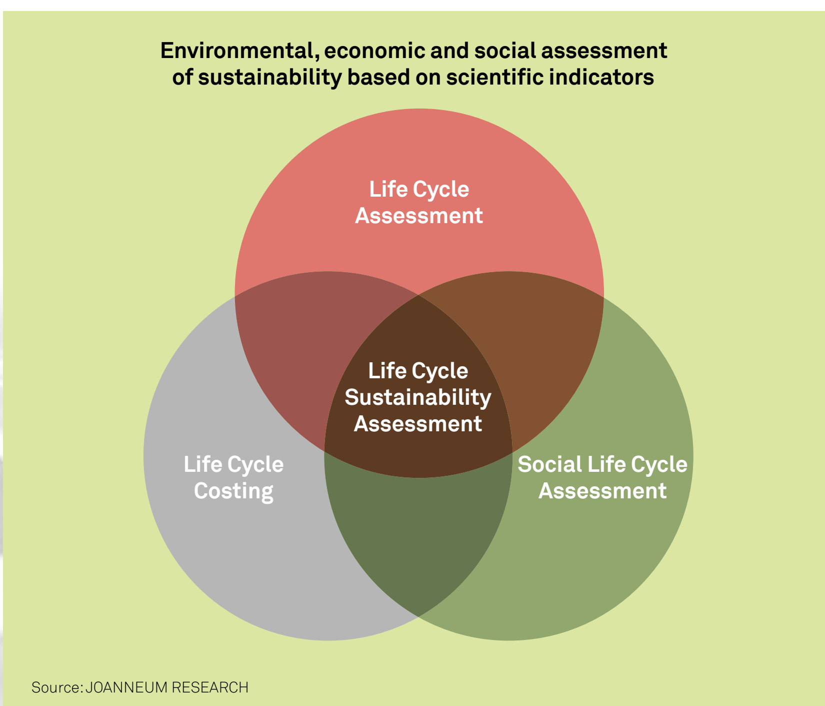
Austrian stakeholders in the automotive sector as front-runners in the development and manufacturing of eco-innovative technologies for vehicles and of renewable energy carriers can also become front-runners in providing transparent, comparable and – most importantly – fact-based metrics on the environmental performance of their products, based on LCA. Developing harmonized and sound Austrian LCA practice guidelines, tailored to the automotive sector, could also give an impulse to European-wide and international LCA method development and its practical application.

LCA as Part of the Life Cycle Sustainability Assessment

The environmental impact assessment using LCA is only one part of an overall sustainability assessment, which also includes economic and social aspects. It is generally agreed and accepted that a sustainability assessment of future transportation systems in comparison to existing conventional transportation systems must be based on a life cycle perspective, covering the entire value chains. The methodology used is the "Life Cycle Sustainability Assessment (LCSA)" as a combination of the three single methods (see Figure below):

- Life Cycle Assessment (LCA) for the environment
- Life Cycle Costing (LCC) for the economy and
- Social Life Cycle Assessment (sLCA) for the society

The Methods of Sustainability Assessment



Life Cycle Sustainability Assessment (LCSA):

- **Environment:** LCA – Life Cycle Assessment
- **Economy:** LCC – Life Cycle Costing
- **Society:** sLCA – Social Life Cycle Assessment/SIA-Social Impact Assessment

In summary, the main messages in relation to LCA of transportation systems are:

- Environmental impacts include more than vehicle exhaust pipe emissions.
- There is international agreement that environmental impact assessment must include the entire life cycle from cradle to grave covering vehicle production, fuel supply, vehicle operation and end of life treatment. LCA includes more than WTW.
- LCA results in improved understanding of complex value chains and in fact-based knowledge for the development of new transportation systems that maximize environmental benefits.
- Today it seems that GHG emissions and cumulated energy demand are the most relevant impact categories in LCA of transportation systems. Other impact categories such as land use change, water demand or toxicity will become more relevant in LCA, due to the increasing scarcity and economic value of resources for future vehicles and alternative propulsion systems, new resource exploration areas and methods and due to the production of an increasing share of renewable fuels.
- The development of harmonized and sound Austrian LCA practice guidelines tailored to the automotive sector could ensure transparent, comparable and – most importantly – fact-based metrics based on a complete LCA. This could help to secure the position of the Austrian automotive industry also as front-running stakeholders proving that eco-innovation keeps its promises.

References: Rademaekers K., Asaad S., Berg J. 2011. Study on the Competitiveness of the European Companies and Resource Efficiency. Final report by Ecorys, Rotterdam.

Challenges

Technology-related challenges in the core areas power train, vehicle technology as well as fuel development were discussed in the previous chapters. Besides that, challenges that require actions in other disciplines such as politics and regulations were identified. These challenges with their corresponding actions are summarized in the following table:

Challenges	Actions
Cost of Technology For a successful market introduction of advanced power train systems cost of key technologies like electrical storage, fuel cell and electrical components must be significantly reduced.	**Highly integrated propulsion system** Cost reduction through integration of mechanical assemblies and electrical components as well as scalability of power train systems considering the production/industrialization. **Minimize use of expensive materials** e.g. reduction of platinum in PEM fuel cells, rare earth magnets etc.
Series production and intelligent industrialization Alternative power train concepts require innovative, intelligent production methods in order to produce efficiently and in a cost-covering way, especially for smaller quantities.	**Development of innovative production processes** Development of production facilities for electric power trains to establish a value chain in Austria. New mechanical equipment to economically produce innovative products.
Independence of material shortages Electric power train and storage technologies require the increased use of special materials like rare earths, nickel, lithium, copper, platinum.	**Use of new materials** e.g. alternative magnet materials in the electrical machine, reduction of platinum in PEM fuel cells **Recycling of valuable materials** **New technologies** e.g. reluctance machine, separately excited machines
New Suppliers Due to the trend towards electrification of the power train, it is necessary to introduce companies mainly from the electronics sector to the automotive industry.	**Qualification process** To meet the high demands in the automobile industry, an appropriate qualification process must be established.
Ensure product quality and market-led product cycles New power train systems must meet all criteria such as functional safety, high product quality and efficiency. At the same time, sufficient short development times are required already at the first launch.	**Development of new simulation tools and measurement techniques** For new power train systems integrated tool chains need to be developed from simulation to series testing.
Control and regulation technology Future power train systems will be very much involved in their environment and infrastructure in order to maximize transport efficiency. This requires new control and regulation technology.	**Flexible on-board control software and standardized interfaces to the infrastructure** Development of modular and flexible control systems that can respond on environmental and infrastructure impacts via standardized interfaces.
Ensuring minimal use of energy and raw materials throughout the product life cycle Achieve maximum efficiency in terms of demand for raw materials and energy consumption during production, use and disposal.	**Providing unified measured values and evaluation tools** Definition of measured values for energy and resource efficiency as well as for the overall energy consumption (LCA, cradle to grave, WtW). Development of standardized evaluation methods and tools.
Reduce development time	**Simulation and Software** Software tools are needed to support technical potentials.
Harmonization	**International Approach** To avoid locally utilized isolated solutions, standards must be discussed in international committees. To represent Austria's interests and positions, participation in international committees is very important.

Requirements on Funding Instruments

To intensify long term research and development in all areas addressed within this roadmap, companies and R&D organisations require long-term and stable framework conditions and sufficient time for their activities. Politics should therefore focus on a long-term strategy for funding instruments. In order to implement sustainable energy and road transport systems, an integrated approach across the disciplines is necessary.

The development of advanced propulsion systems and energy carriers needs a sufficient number of highly qualified personnel. Therefore, education for future automotive and energy engineers should include additional expertise in the fields of electrical/electronic engineering, electrochemistry, simulation, process and production engineering as well as material science. Educational programs shall therefore be included in the funding instruments.

Investments in production capacities, that even exceed the R&D costs, should also be funded, helping the foundation of start-ups and the expanding of existing enterprises.

In order to optimize funding instruments and their corresponding processes, the following general framework from the A3PS members' point of view was identified:

- Funding along the entire innovation cycle (including testing infrastructure, cost reduction and new production technologies)
- Technology-neutral, results-oriented calls
- Short and simplified evaluation processes
- Cooperative and interdisciplinary R&D projects
- Strengthened international cooperation in R&D
- Acceptance of partners from foreign countries into funded projects
- Differentiated funding rates from research to demonstration projects
- Performance-based, sufficient project periods
- Improved review process with feedback after the completion of the project
- Subsidies for establishing companies and stimulation of venture capital

Especially for Austria's supply industry, the international interlinking and exchange is of great importance. Furthermore, it is important to be involved in the different European and international strategy processes. Relevant for A3PS members are, among others:

- ERTRAC (European Road Transport Research Advisory Council)
- FCH-JU (Fuel Cells and Hydrogen Joint Undertaking)
- IEA (International Energy Agency)
- IPHE (International Partnership for Hydrogen and Fuel Cells in the Economy)

The interlinking and exchange of information between the BMVIT, representing Austria in several platforms, and the A3PS members is very important and considered necessary to take place at regular time intervals.

List of Acronyms

3G, 4G, 5G	Mobile network generations
5G PPP	5G Public-Private Partnership
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
AD	Autonomous Driving
ADAS	Advanced Driver Assistance Systems
AEB	Automated Emergency Braking
AI	Artificial Intelligence/Alcohol Interlock
Al	Aluminium
AMT	Automated Manual Transmissions
APU	Auxiliary Power Unit
AST	Accelerated Stress Tests
AT	Automatic Transmission
Beidou	Chinese satellite navigation system
BEV	Battery Electric Vehicle
BSG	Belt-Starter-Generator
BtL	Biomass-to-Liquid
C2C	Car-to-Car
C2I	Car-to-Infrastructure
C2x	Communication from car to x (e.g. car, infrastructure)
CAM	Cooperative Awareness Message
CAV	Connected and Automated Vehicles
CFRP	Carbon Fiber-Reinforced Polymer
CHP	Combined Heat and Power
Cloud2V	Cloud-to-Vehicle
CNG	Compressed Natural Gas
CO	Carbon monoxide
CU	Control Unit
CVT	Continuously Variable Transmission
DC	Direct Current
DCT	Dual-Clutch Transmission
DENM	Decentralized Environmental Notification Message
DME	Dimethyl Ether
DPF	Diesel Particulate Filter
DSRC	Dedicated Short-Range Communications
DVM	Driver Vigilance Monitoring
EC	European Commission
EGR	Exhaust Gas Recirculation
EoL	End-of-Line/End-of-Life
ERTRAC	European Road Transport Research Advisory Council
ESC	Electronic Stability Control
ESP	Electronic Stability Program
ETSI	European Telecommunications Standards Institute
EU4, EU6, EU6c etc.	European Emission Regulations
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
FCC	Fluid Catalytic Cracking
FCH-JU	Fuel Cells and Hydrogen Joint Undertaking
FCV	Fuel Cell Vehicle
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Unit
FT	Fischer-Tropsch
GALILEO	GNSS currently being created by the European Union (EU) and Space Agency (ESA)
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GLONASS	Global Navigation Satellite System, operated by the Russian Aerospace Defence Forces
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
H_2	Hydrogen
HC	Hydrocarbon

HCCI	Homogeneous Charge Compression Ignition
HDO	Hydrodeoxygenation
HEV	Hybrid Electric Vehicle
HiL	Hardware in the Loop
HMI	Human Machine Interfaces
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
HVO	Hydrogenated oder Hydrotreated Vegetable Oils
I2C	Infrastructure-to-Car
ICE	Internal Combustion Engine
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IHS	Information Handling Services
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IR	Infrared
ISO	International Organization for Standardization
IT	Information Technology
ITS-G5	Commonly used term for IEEE 802.11p standard
JRC	Joint Research Centre
KERS	Kinetic Energy Recovery System
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
LFP	Lithium Ferrophosphate
Li	Lithium
LIDAR	Light Detection And Ranging
LKA	Lane Keeping Assist
LNG	Liquefied Natural Gas
LTE	Long-Term-Evolution
LTO	Lithium Titanate Oxide
MBSE	Model-Based Systems Engineering
Mg	Magnesium
MSC	Metal Supported Cell
MT	Manual Transmission
MW	Megawatt
N_2	Nitrogen
NCAP	European New Car Assessment Programme
NEDC	New European Driving Cycle
NMC	Nickel Manganese Cobalt
NOx	Mono-nitrogen oxides (NO and NO_2)
NVH	Noise, Vibration and Harshness
O_3	Ozone
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
OME	Oxymethylene Ether
ORC	Organic Rankine Cycle
PBA	Predictive Brake Assist
PEM	Polymer Electrolyte Membrane
PF	Particulate Filter
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
PMD	Photonic Mixing Device
PN	Particle Number
PPP	Public–Private Partnership
R&D	Research and Development
RADAR	Radio Detection And Ranging
RCS	Regulations, Codes and Standards
RDE	Real Driving Emissions
RED	Renewable Energy Directive
REX	Range Extender
SAE	Society of Automotive Engineers
SCR	Selective Catalytic Reduction
SIA	Social Impact Assessment
sLCA	Social Life Cycle Assessment
SLS	Speed Limiting Systems

SOEC	Solid Oxide Electrolyser Cell
SOFC	Solid Oxid Fuel Cell
TC	Torque Converter
TOF	Time Of Flight
TRL	Technology Readiness Level
TtW	Tank-to-Wheel
UMTS	Universal Mobile Telecommunications System
UNECE	United Nations Economic Commission for Europe
V2Cloud	Vehicle-to-Cloud
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDA	*Verband der Automobilindustrie*
ViI	Vehicle integration into Infrastructure
VRU	Vulnerable Road Users
WAVE	Wireless Access in Vehicular Environments
WHR	Waste Heat Recovery
WiFi	WLAN product based on IEEE 802.11 standards
WLAN	Wireless Local Area Network
WLTP	Worldwide harmonized Light vehicles Test Procedures
WtW	Well-to-Wheel
x by wire	Electrically actuated and electronically controlled components
xCU	Any Control Unit
XFCD	Extended Floating Car Data
xiL	Model, software or hardware in the Loop

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