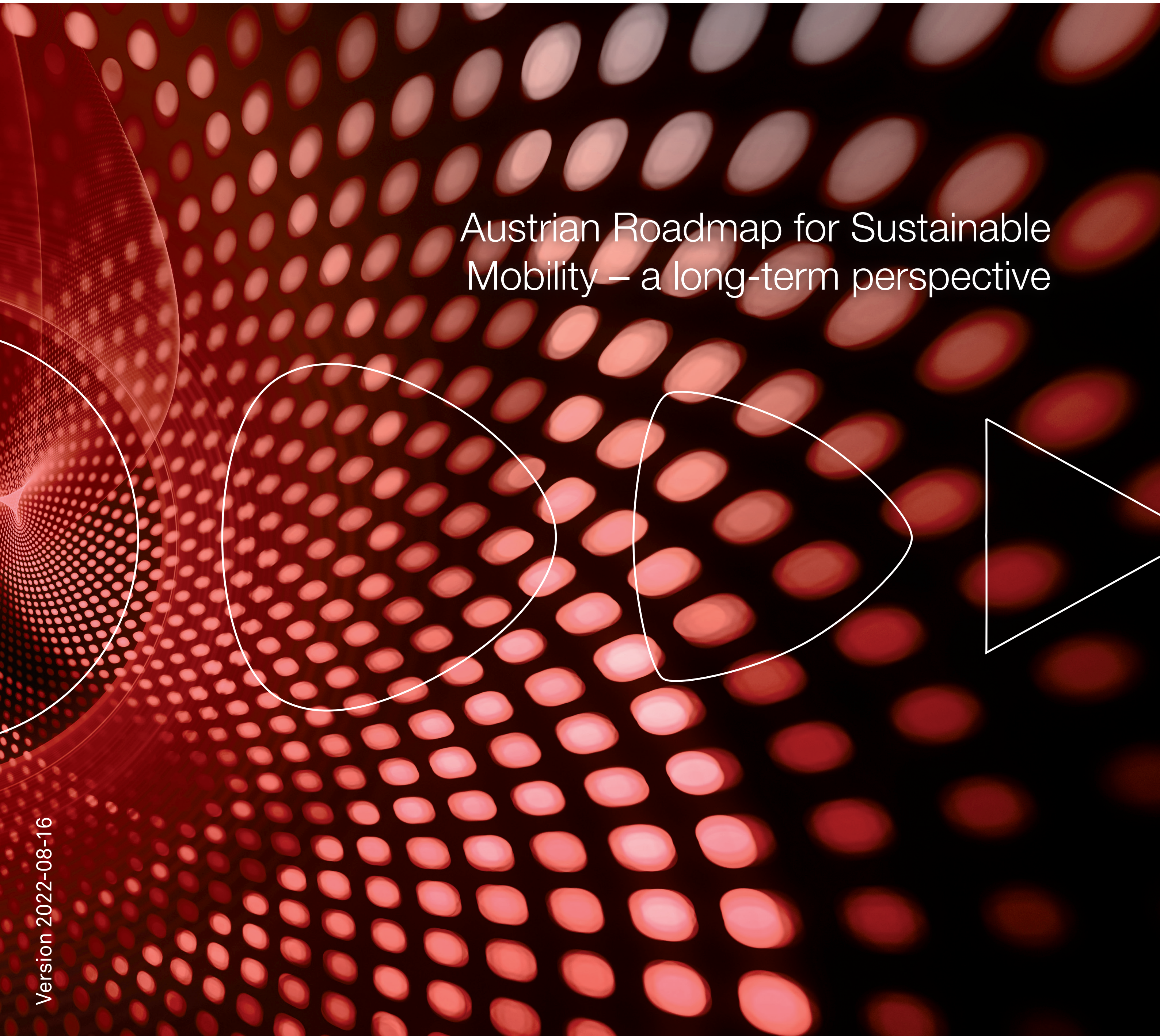
Austrian Association for Advanced Propulsion Systems

A3PS

Rethinking Propulsion.

Austrian Roadmap for Sustainable Mobility – a long-term perspective



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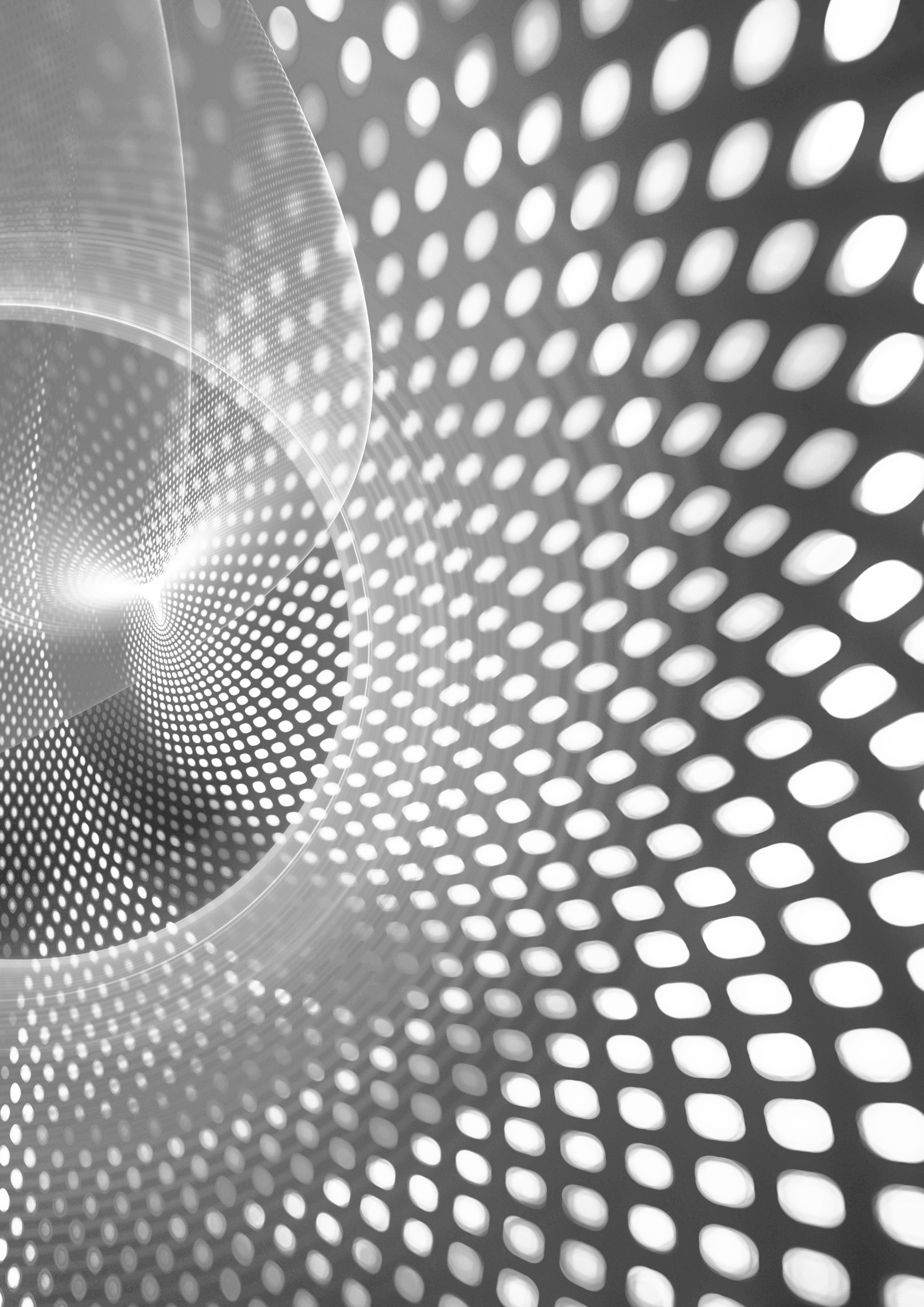
Austrian Roadmap for Sustainable Mobility – a long-term perspective

Version 2022



Preface


Photo by Luiza Puiu

June 2022 is marked by a remarkable decision by the European Parliament: its members decided to support an effective EU ban on the sale of new petrol and diesel cars from 2035. Also in June, the publication of the Austrian hydrogen strategy made clear that for the Austrian Economics and Climate Ministries climate neutral hydrogen should be used at maximum efficiency. For the transport sector, there is a clear emphasis on HDVs and busses. As Director General Innovation & Technology at the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) I am happy to add some introductory remarkts to this roadmap.

The 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 a high share of researchers – about 11,5 %.

To secure Austria's competitiveness in this field and to support the successful market launch of innovative, zero-emission, advanced vehicle technologies, a closer collaboration between the automotive, energy supply industry and Austrian research institutions was initiated. Under the auspices of BMVIT (now BMK), 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.

Currently, the EU is revising its climate, energy and transport-related legislation as part of the "Fit for 55" package. 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 its past projects developed into 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 "Austrian Roadmap for Sustainable Mobility", which aims to represent Austria's well-founded expertise in the broad field of advanced vehicle technologies and carbon neutral energy carriers. It also provides a comprehensive perspective of its members on future vehicle technology trends and required R&D activities.
I look forward to the continuation of this fruitful cooperation between BMK and A3PS and its members 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,

Henriette Spyra
Director General for Innovation Policy,
Austrian Federal Ministry for Transport, Innovation and Technology, Vienna

Introduction

The present **Austrian Roadmap for Sustainable Mobility** summarizes envisaged developments and trends, as well as priorities of the industrial and scientific A3PS members. It aims to provide an overview on the R&D challenges in the coming years and the necessary R&D activities to strengthen Austria as a business location. Mission and target of this Roadmap is to illustrate the state of the art of current research fields in road transport systems as well as showing the research demand – short-term, medium-term and long-term!

A3PS, founded in 2006 as initiative of BMK* discussed, phrased and prioritized with members from industry and research institutions, the contents of this roadmap in the last few months. This roadmap shows clearly arranged all advanced propulsion systems: battery electric powertrain technologies, fuel cell technologies and hybrid automotive powertrains with combustion engines, which convert renewable liquid or gaseous energy carriers. The whole life cycle assessment is essential to find the best solution for different mobility applications depending on available energy carriers. In the chapter "Advanced Powertrain Integration Technologies on Vehicle Level" the whole vehicle as well as ADAS (Advanced Driver Assistance System) is thought along if relevant to the powertrain (e.g. increase of efficiency), lightweight construction, etc.

*Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology https://www.bmk.gv.at/en.html

Circular economy must be considered in all technology sectors. This increases the research demand since beside of functional efficiency, safety, security, durability, etc., recyclability and second life must be considered. This is essential for the overall vehicle, components, batteries, bearing parts, etc.

Research and development for innovative and sustainable mobility has been playing an important role in Austria over the last decades. The publication "Fahrzeugtechnologien in und aus Österreich"[1] provides an overview of national and international funded propulsion technology projects.

This Roadmap illustrates the research demand – it doesn't provide a forecast which technology will prevail nor specific recommendations for politics. Instead, the roadmap presents the advantages and disadvantages of proposed solutions in a fact-based manner but does not make any evaluation. Technologies with application in the long-term future also require research.

Pandemic and war are forcing us to redefine mobility, but above all the energy transition and the absolutely necessary fulfilment of climate goals are driving the mobility transition towards climate-neutral mobility while maintaining social standards. In order to achieve the committed European and national climate goals and to cope with the complex challenges of the mobility system and the associated global economic system, the BMK supports the policy for research, technology and innovation (FTI) with a focus on mobility technological, social and organizational innovations and thus contributes to a sustainable transformation of the mobility sector. Innovation in and from Austria for a climate-neutral mobility system is condensed in the **R&I Mobility Strategy**[2]. Ways to achieve the goals of the Paris climate agreement are also shown in the "Mobilitätsmasterplan 2030"[3]. This roadmap shows contributions to the implementation of the strategies from BMK.

According to the goals of the European Commission, the A3PS expert groups encourage, that Austria supports a climate-neutral, sustainable, efficient and safe transport system by

1) **Technology-neutral support of mobility and powertrain innovations** in Austria, taking a holistic view of the value creation process, based on the **LCA** (Life Cycle Assessment) method ("from cradle to grave") in order to meet the 2030 targets and to enable mission 2050 targets in full.
2) **Establishment of a legal framework**, norms, standards and a strategy for R&D activities, the rapid implementation of R&D results and regular operation (road / off-road, rail, shipping, aviation).
3) **Fostering of core competences** in the field of mobility and powertrain innovations in Austria with a strong focus on value creation in Austria.

The EU is currently revising its climate, energy, and transport-related legislation as part of the so-called 'Fit for 55' package.[4] This is intended to adapt the applicable rules to the goals for 2030 and 2050. The package also includes several new initiatives and is expected to be negotiated until the end of 2022.

The **Austrian Roadmap for Sustainable Mobility** supports the orientation of national R&D activities and technology policy impulses, as a supplement to priorities that are set at European level.

As a "living document", the Austrian Roadmap for Sustainable Mobility is regularly checked for topicality and revised if necessary.

The Austrian Roadmap is focused on promising technologies and measures in the following fields:

- Powertrain technologies
- Overall vehicle technologies (enabling a CO_2 emission decrease, e.g. control strategies, ADAS, light weight design)

[1] https://mobilitaetderzukunft.at/resources/pdf/broschueren/Barrierearm_Fahrzeugtechnologien-in-und-aus-Oesterreich-20200622.pdf?m=1596021528&, retrieved 17 June 2022

[2] https://mobilitaetderzukunft.at/en/strategy/randi-mobility-strategy.php, retrieved 17 June 2022

[3] https://www.bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html, retrieved 17 June 2022

[4] https://www.consilium.europa.eu/de/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/, retrieved 17 June 2022

- Energy carriers & sustainable 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.

In every following chapter, the information is summarized in tables, which show each technology in detail, including aims and research demand (specific measures). For each measure, the current TRL* (TRL[2022]) 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, recyclability or lower resource consumption).

All technology innovations need to consider the 2030 Agenda with its 17 Sustainable Development Goals (SDGs). The 2030 Agenda is a global plan to promote sustainable peace and prosperity and protect our planet.[5]

The Austrian Roadmap is also available for download online at https://www.a3ps.at/a3ps-roadmaps

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)

Furthermore, the types of (research) projects are specified, which are required in order to bring the technologies onto the market.

The **"Type of Project Required"** in the technology tables provides 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):

[5] https://unric.org/de/17ziele/, retrieved 8 June 2022

'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 acquiring, combining, shaping and using of existing scientific, technological, business and other relevant knowledge and skills for the purpose of producing plans, arrangements or designs and conceptual definitions for new, altered or improved products, processes or services.

'Demonstration' means 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.

Circular Economy & Life Cycle Assessment

A circular economy is "a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible".[6] Circular economy aims to tackle global challenges like climate change, biodiversity loss, waste, and pollution by emphasizing the design-based implementation of the three base principles of the model. The three principles required for the transformation to a circular economy are: eliminating waste and pollution, circulating products and materials, and the regeneration of nature. Circular economy is defined in contradistinction to the traditional linear economy.[7]

Life Cycle Assessment (LCA) is the method to evaluate the environmental impacts (e.g. carbon footprint, material resource and energy consumption, water footprint, pollutant emissions, etc.) during the entire life cycle of a transport system. The life cycle phases

[6] https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits, retrieved 14 June 2022

[7] https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview, retrieved 14 June 2022

* TRL (Technology Readiness Levels); Source: Horizon 2020 - Work programme 2014-2015, Annex G: Technology Readiness Levels

include extraction and refining of (critical) raw materials, vehicle manufacturing, distribution, vehicle use, recycling and final disposal (from cradle to grave). It also includes the sourcing of the energy of the transport system. LCA differs from so-called Well-to-Wheel (WtW-) analysis that exclude vehicle manufacturing as well as end of life treatment. Life cycle assessment allows the comparison of different systems offering the same transportation service during the same time period.

The current and future design of individual mobility plays a major role in discussions about climate change. One aspect of this is the actual environmental balance of the different drive types over the entire life cycle of a vehicle. A possibility for a comprehensive comparison of vehicle drive types with regard to climate-relevant greenhouse gas emissions from production to operation to recycling is possible via an expert-tool for LCA developed by Joanneum Research, ÖAMTC, ADAC and FIA [8], which was published in 2019.

LCA of BEVs involves a large range of influencing factors, such as the electricity supply (incl. intermediate storage of fluctuating renewable electricity) for BEV operation, as well as energy supply for battery manufacturing (share of renewable energy sources), the cell chemistry and related extraction and refining of critical raw materials (e.g. Nickel, Cobalt, Lithium) as well as the production of materials for battery casing (e.g. Aluminium) and the electric motor (e.g. rare earth metals). End-of-life involves the topics "second use of batteries" (e.g. for stationary storage and/or reuse of battery cells) and related allocation of environmental impacts between first and second use, as well as recycling. Battery recycling is an important element to (partly) close "critical" material cycles, however challenges such as (global) used battery collection, diversity of cell chemistries and recycling process efficiencies remain to be solved.

LCA of FCEVs involves a range of influencing factors, such as hydrogen production (incl. use of the co-products oxygen and heat and the system integration, e.g. grid services) for FCEV operation, which can be supplied by various conversion processes and primary energy sources, the system energy efficiency of hydrogen production and use in the fuel cell, the manufacturing of the FCEV propulsion system and related extraction and refining of (critical) raw materials, and the lifetime of the fuel cell in the operation phase. End-of-life aspects include vehicle and fuel cell recycling as an important element to (partly) close (critical) material cycles. Additionally, the environmental effects of carbon fibers (CF) for H_2 tank systems, and the end of life of CF like reuse and recycling are essential to be analyzed in consistent LCA to develop a circular economy approach for CF use.

Key factor in LCA of hybrid vehicle architectures is the change in energy demand and efficiency during operation. While research focuses on increasing system efficiency, the impact of the additional weight of the specific components of hybrid vehicles on energy demand also depends on real world driving. LCA of drop-in biofuels and so-called e-fuels based on carbon capture and their utilization involves a wide range of supply chains of different types of biomasses, biomass conversion processes, renewable electricity, hydrogen production, CO_2 sources and separation technologies. LCA-results are therefore highly influenced by the CO_2 source, the degree of process integration and system efficiency, by the allocation of double used fossil CO_2 emissions between emitter and receiver and the long-term availability of fossil-based CO_2 sources.

[8] https://www.oeamtc.at/thema/autokauf/experten-tool-zeigt-erstmals-gesamtumweltbilanz-aller-pkw-antriebsarten-32522717, retrieved 8 June 2022

A3PS – Austrian Association for Advanced Propulsion Systems

A3PS is the **strategic platform** of the Austrian technology policy, industry and research institutions and stimulates the development of advanced propulsion systems and energy carriers – to build up common competence and to accelerate market launches.

A3PS addresses all **advanced powertrain technologies** contributing to the improvement of energy efficiency and to the avoidance of emissions and supporting the whole innovation cycle (research, development, deployment).

A3PS members congregate in **four thematic working groups**. These working groups elaborated positions, trends, R&D demands and demands concerning the essential legal framework for prospective technologies for this roadmap.

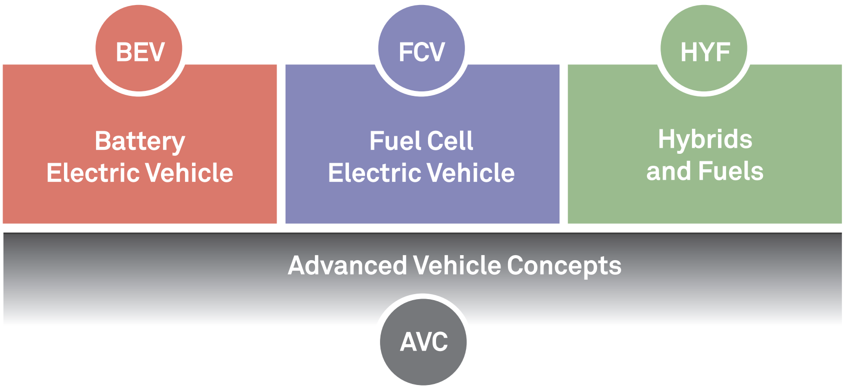


Figure 1: A3PS thematic working groups

BEV – Battery Electric Vehicle
Working group BEV focuses on strong scientific and informative public relations work about battery electric vehicles. The group analyses strengths and weaknesses of battery electric vehicles and points out research and development needs.

FCV – Fuel Cell Electric Vehicle
FCV working group's focus is on hydrogen fuel cell electric vehicles. Besides, the group also deals with hydrogen production, infrastructure and storage, since sustainable production, price and availability of hydrogen play a key role for the success of fuel cell vehicles.

HYF – Hybrids and Fuels
Working group HYF concentrates on the identification of needs for research on hybrid technology, CO_2 neutral energy carriers for vehicles as well as internal combustion engines, aiming at efficiency and climate neutrality. The strengths of Austrian institutions in this field are discussed and highlighted.

AVC – Advanced Vehicle Concepts
Working group AVC deals with advanced and future vehicle concepts comprising new lightweight materials, innovative production technologies & digitalization of processes and digitalization & automation of vehicles and infrastructure. The group links to the other three working groups and focuses on a system perspective and integration.

Executive Summary

All worldwide regulations are strongly committed to reducing pollutant emissions and global warming effects due to greenhouse gases.

The European Green Deal recently announced that in order to to protect Europe's citizens and ecosystems it is necessary to move towards a zero-pollution ambition, and better prevent and remedy pollution from air, water, soil, and consumer products. This transition is strongly relying on electrification and the public opinion to carry it, as it will substantially differ from fossil-sourced transportation structures in terms of costs, usage characteristics and environmental effects.

Our road transport system is rapidly transforming in response to climate change and resulting demand for a high sustainability over the full value chain and considering the full life cycle. Advanced propulsion systems are having steadily increasing market shares, connected and automated vehicles as well as the vision of smart and climate neutral cities demand for new infrastructures and mobility concepts. In order to define realistic sustainability goals – for all stakeholders in the mobility sector – and to select the most sustainable solution, the environmental impact of technologies and mobility concepts must be assessed and continuously monitored in a holistic way[*] (well-to-wheel or extended via a Life Cycle Assessment Analysis (LCA).

*[27] B. Brandstaetter, M. Mametti, A. Danninger, M. Noest et.al. "Life Cycle Assessment for the determination of the environmental impacts of road vehicle transport system including air pollution and climate change", EARPA Position paper May 2022, Brussels

All advanced powertrain technologies discussed in this Austrian Roadmap are characterized by a very high "tank/battery"-to-wheel efficiency and through a very high potential for zero local emissions.

Battery Electric Powertrain Technologies

Electrified powertrain technologies enable an incredible performance regarding drivability and - in combination with Advanced Driver Assistance Systems (ADAS) – personal safety and substantially support the defossilisation efforts to reach the climate targets. These advantages justify and request high R&D effort. Although the basic technical principles are developed and an increasing number of systems already industrialized on the market, great efforts are needed to make these systems more affordable, efficient, durable, and safe by developing new generations for components and systems for the use in electrified powertrains. Only if these vehicles can be offered at reasonable prices, larger quantities can be sold, thus leading to the necessary environmental impact for a 2050 net fossil carbon free society. Thereby it must be considered, that the indispensable precondition for positive environmental effects of battery electric vehicles is the availability of almost 100 % renewable electric energy.

In the chapter **Battery Electric Powertrain Technologies**, new technologies for next generations of Battery Electric Vehicles (BEV) are mainly considered.

It is a fact that industry and research institutions treat fuel cell powertrains differently than those on BEV technologies, though Fuel Cell Electric Vehicles (FCEV) are, technically speaking, hybrid electric powertrains. In this roadmap Hybrid Electric Vehicles (HEV) and Plug-in Hybrid Electric Vehicles (PHEV) are considered in the chapter **Hybrid Automotive Powertrains** and Fuel Cell Electric Vehicles (FCEV) in the chapter **Fuel Cell Technologies**. PHEVs offer a high potential regarding local CO_2 emission reduction, higher than HEVs due to the larger battery capacity. However, electric components discussed in the chapter **Battery Electric Powertrain Technologies** are also relevant for hybrid electric vehicles.

Fuel Cell Technologies

Austrian companies, research institutions and universities are engaged in the field of fuel cell technologies and their respective test and validation systems since decades. Due to the beginning ramp up phase of fuel cell and hydrogen technologies, A3PS members expect even tougher international competition in research and industry and therefore more instruments to strengthen the Austrian community are needed. The strategy for the development of the transport fuel cell system components will continue to pursue three overarching goals: cost reduction, increased performance (also efficiency) and lifetime.

Advancements in this domain will be beneficial to all transport applications regardless of their current state of the art. Sustainability, recycling and eco-design are also important principles that will play a role in the development of these components.

Hybrid Automotive Powertrains

Hybrid powertrains allow the combination of the advantages of pure electric propulsion, e.g. highly efficient torque generation with E-motors as well as recuperation and storage of break energy, with that of ICE driven vehicles, e.g. conversion of the chemical energy of a liquid energy carrier into mechanical energy in a robust device of highest power density insensitive against fuel impurities.

Obviously, such energy converters have to fulfill all – also future – emission standards and are, thus, fully environmentally compatible. Such powertrain systems can be used throughout the entire transition phase from fossil dominated to purely sustainably generated energy carriers.

The European grid is currently supplied only 60 % from low CO_2 sources and 40 % fossil, with a coal share of about 45 %. In any case, the grid expansion with green power plants must be carried out faster than the increase in grid consumers, otherwise every new consumer will have to be supplied by fossil fuel power plants and will cause additional significant CO_2

emissions. As a result, the most important goal of the energy transition – to run the European grid entirely on renewable energy – is moving further and further away. This fact can be counteracted by transport, which will be dominantly powered by Internal Combustion Engines (ICE) until well beyond 2030 (and beyond 2035 for non-car applications e.g.: Heavy Duty and Off Road Vehicles, etc.), by obtaining significant fuel consumption and fossil CO_2 reduction without disadvantages for the users via two approaches: fuel consumption reduction by (i) optimizing lCE's with or without an electric powertrain (hybrid vehicles), and (ii) green gaseous and liquid fuels.

Renewable Energy Carriers

Besides of propulsion technologies, renewable energy carriers play a significant role for sustainable mobility since battery electric vehicles as well as hybrids with ICE and fuel cell electric vehicles need energy carriers, which up today dominantly originate from a fossil feedstock. On the way to a sustainable mobility these energy carriers need to become defossilized. In this roadmap the term "defossilization" is preferred over the more common term "decarbonization" since synthetic gaseous or liquid fuels except of hydrogen (H_2) and ammonia (NH_3) include at least one carbon atom. This carbon is completely climate neutral as long as it is obtained from biomass or other sources where the carbon is kept in a dosed cycle (e.g., CO_2 capturing out of the air).

This Roadmap will not go into detail about renewable electricity production and storage. This topic is covered in other publications[*]. The focus in this roadmap is on liquid and gaseous fuels based on biogenous feedstock and/or renewable electricity.

The use of renewable fuels (including renewable hydrogen) in internal combustion engines allows a significant reduction of GHG emissions (down to CO_2 neutral mobility, or even negative emissions in case of carbon capture and storage) for the existing vehicle fleet. Of all options to reduce GHG emissions from road transport, the use of renewable energy has the largest potential. The respective mobility applications and importance of hydrogen for reaching the climate target is also covered in the recently published hydrogen strategy "Wasserstoffstrategie für Österreich"[**].

Advanced Vehicle Concepts on Vehicle Level

Aside from advanced powertrain technologies treated in the previous chapters, this chapter focuses on technologies on vehicle Level, which considerably influence the vehicle performance, fuel consumption, efficiency and environmental impact. The optimized integration of advanded propulsion systems into the vehicle is a key to sucess.

Beside electrification, digitalization rises as a new challenge. Digitalization and digital twinning are the key to enable predictive control and bringing components and systems close to their limits, without having to consider production tolerance-based safety margins. Special emphasis will be put on these aspects in this updated version of the roadmap. On the other hand, some topics – although considered as relevant for automotive research – have been excluded from this roadmap in order to maintin the focus on propulsion systems.

These omitted topics are:

- Advanced human machine interfaces
- Traffic flow optimization: relevant for energy efficiency and pollutant minimization
- Comfort related topics (except thermal comfort, which impacts on energy efficiency): noise, haptic comfort etc. are relevant in automotive industry but are not considered in this roadmap
- Vehicle automation and autonomy: extremely relevant in general with high need of funded research, but not considered in this roadmap since the weight is more on the safety aspect than on the efficiency aspect

Advanced Driver Assistance Systems (ADAS) is thought along in this roadmap when directly relevant to the powertrain and to its efficiency. The whole field of ADAS would break the mould of this roadmap since we shouldn't consider only the vehicle level but also the infrastructure.

The chapter Advanced Vehicle Concepts, which is discussing topics on vehicle level, is structured as follows:

- Methodology, development tools and measurement
- Advanced auxiliaries, components and systems enabling energy savings
- Advanced vehicle control systems
- Lightweight design and materials

Challenges and R&D Requirements

Besides technology-related challenges in the core areas powertrain and vehicle technology, which are discussed in the respective chapters of this roadmap, other challenges have been identified, that require actions in other disciplines such as politics and regulations. These challenges with their corresponding actions are summarized in the closing chapter "Challenges" of this roadmap.

In order to intensify long-term research and development in all areas addressed within this roadmap, companies and R&D institutions require long-term and stable framework conditions and sufficient time for their activities.

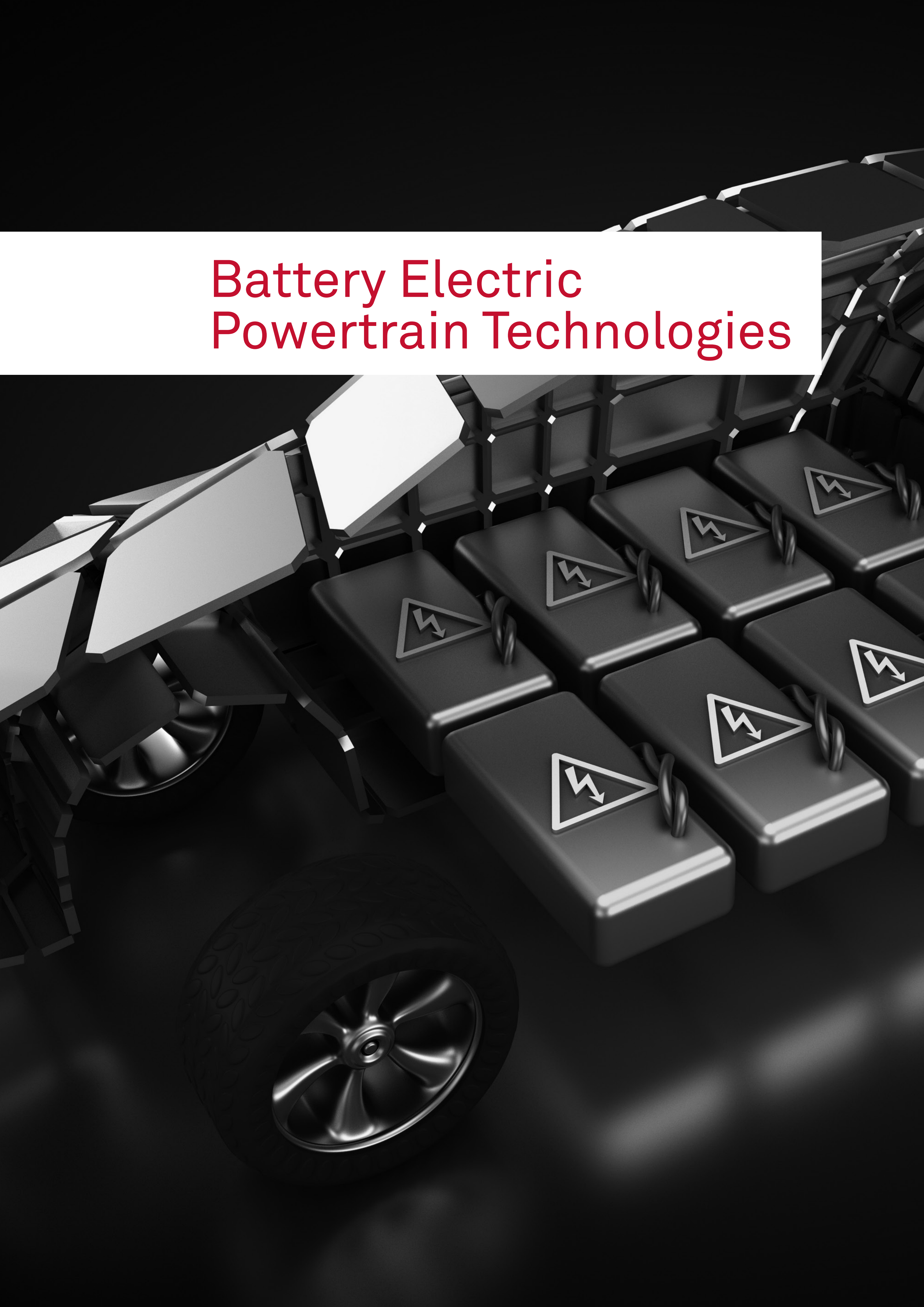
Politics should therefore focus on a long-term strategy for funding instruments. To implement sustainable energy and road transport systems, an integrated approach across the disciplines is necessary.

The interlinking and exchange of information between the BMK, representing Austria in several platforms, and the A3PS members, is very important and is considered necessary to continue to be as successful as in the past.

*[23] https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf, retrieved 8 June 2022 https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0576.pdf, retrieved 8 June 2022 https://www.klimafonds.gv.at/wp-content/uploads/sites/16/Technologieroadmap_Energiespeichersysteme2018.pdf, retrieved 8 June 2022

**[24] https://www.bmk.gv.at/themen/energie/energieversorgung/wasserstoff/strategie.html, retrieved 8 June 2022

Battery Electric Powertrain Technologies



Battery Electric Powertrain Technologies

Compared to thermodynamic powertrain technologies, electric powertrain technologies are characterized by a very high “tank/battery”-to-wheel efficiency and the potential for zero local emissions. Electric powertrain technologies enable an incredible performance regarding drivability and - in combination with Advanced Driver Assistance Systems (ADAS) - personal safety and substantially support the defossilization efforts to reach the climate targets. These advantages justify and request high R&D effort. Although the basic technical principles are developed and an increasing number of systems already industrialized are on the market, great efforts are needed to make these systems more affordable, efficient, durable, and safe by developing new component- and system-generations for the use in electric powertrain. This means high investments in optimization steps as well as disruptive research, especially in new technologies (software, hardware), development methodology (simulation), production technologies, modular and scalable designs for electric powertrain systems as well as application of less expensive and more reliable materials, which do not disturb the supply chain. Only if these vehicles can be offered at reasonable prices, larger quantities can be sold, thus leading to the necessary environmental impact for a 2050 net fossil carbon free society. Thereby it must be considered, that the indispensable precondition for positive environmental effects of battery electric vehicles is the availability of almost 100 % renewable electric energy.

In this chapter, new technologies for next generations of battery electric vehicles are considered. It is a fact that industry and research institutions treat fuel cell powertrains differently than battery electric vehicle technologies, though fuel cell vehicles are, technically speaking, hybrid electric powertrains. In this roadmap hybrid electric vehicles are considered in the Chapter Hybrid Automotive Powertrains and fuel cell electric vehicles in the Chapter Fuel Cell Technologies. Plug-in Hybrid Electric Vehicles (PHEV) offer a high potential regarding local CO_2 emission reduction, higher than hybrid electric vehicles due to the larger battery capacity. However, electric components discussed in this chapter are also relevant for hybrid electric vehicles. BEV and FCEV, however, are the best solution with respect to the local emissions[9,10].

Currently, Europe‘s electricity is 60 % green and 40 % fossil. As Europe has the world‘s largest meshed electricity grid, this means that a similar **consumer electricity mix** is available for every consumer in Europe, regardless of the country. As the available green electric power will be used in the grid first, this leads to the situation that additional consumers like an e-car recharged from the grid gets the power from fossil power generation (Displacement Mix, see [11]), unless the charging is done by e.g. non grid connected private PV generation. Only until the European grid is virtually 100 % CO_2 neutral and the regulating power plants for stabilizing the European grid release significantly less than e.g. 660 g CO_2 eq /kWh* fossil CO_2 emissions, the switch from fossil fuel vehicles to BEVs will significantly reduce CO_2 emissions from transport. The goal of a entirely green power grid can only be achieved if electricity demand grows at a slower rate than the increase in the electric energy generation of low CO_2 power plants. This means that saving electricity and not increasing the grid load must be the first priority. A well-balanced mixture of hybrid and full electric vehicles is needed to minimize the well-to-wheel CO_2 emissions from transport in the meantime. Research and development in the short-, mid- and long-term is key to achieve these minimum emissions in the particular powertrain types presented in the overall roadmap and to be prepared for a long-term fossil free transport system.

However, necessary measures for renewable electricity are not part of this technology roadmap. The transition towards 100 % renewable electricity in Austria is part of the “Erneuerbaren-Ausbau-Gesetz”[12] of the ministry for climate action, environment, energy, mobility, innovation and technology. This law covers the feed-in of **electricity generation** from Austria into the European grid and requires Austria to use only green power plants for electricity generation by 2030.

To realize the full potential of 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, PHEVs and BEVs require high voltages in the range of 1000 V both for power and especially for adequate charging time.

* BEV with 20 kWh/100 km => 13,25 kg CO_2 eq and i.c.e. with 5,0 l Diesel/100 km => 13,25 kg CO_2 eq but without considering the additional CO_2 footprint for the battery production.

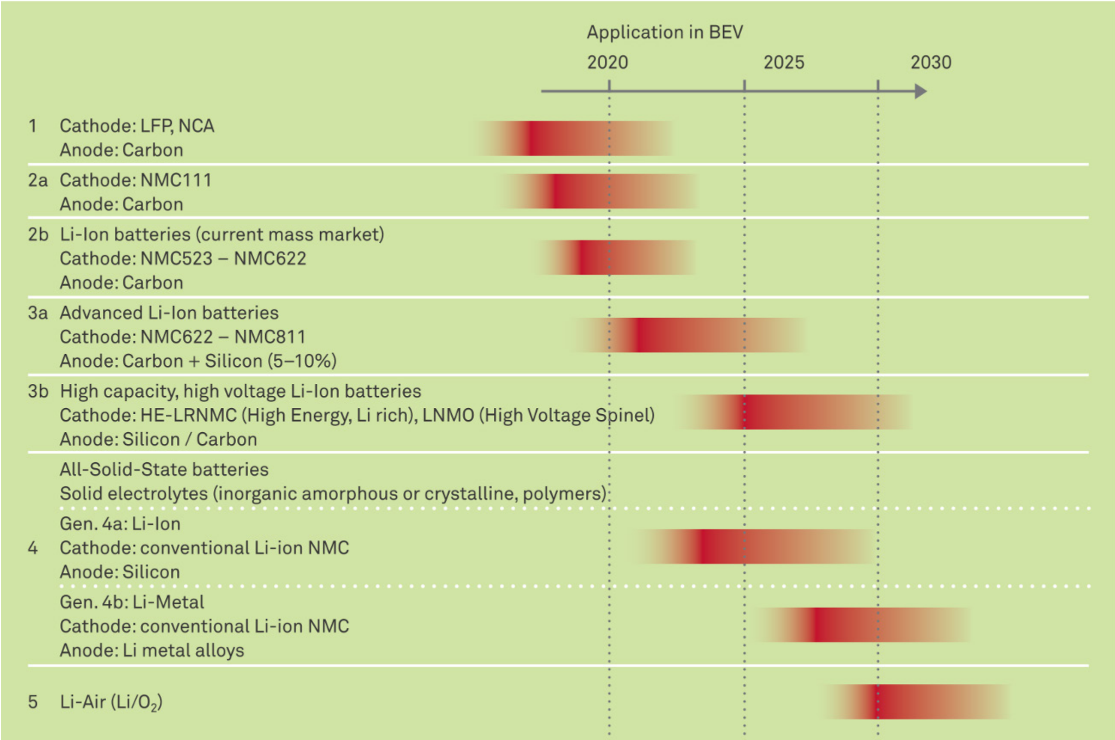
[9] ICCT (2021). White Paper: -A Global Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars; https://theicct.org/publication/a-global-comparison-of-the-life-cycle-greenhouse-gas-emissions-of-combustion-engine-and-electric-passenger-cars/, retrieved 8 June 2022

[10] JRC Technical Report (2014). JRC Well-to-Wheels Analysis of Future Automotive Fuels and Powertraains in the European Context, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC85327/ttw_report_v4a_online.pdf, retrieved 8 June 2022

[11] https://www.a3ps.at/downloads/appendix-roadmap2022; FfE The Research Center for Energy Economics, FfE e.V., EU Displacemen-Mix, https://www.ffe.de/wp-content/uploads/2020/04/EU-Displacement-Mix.pdf, retrieved 3 May 2022.

[12] https://www.bmk.gv.at/service/presse/gewessler/20210317_eag.html, retrieved 8 June 2022

Figure 2: Timeline for different battery technology generations: market entry and application in BEV[16]



In the field of heavy commercial vehicles and buses, the relevant powertrain concepts are depot-bonded battery electric 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 lowering pollutants and emissions due to the potentially higher braking energy recovery. The use of battery electric heavy-duty vehicles has already been started, full electric battery powered trucks and buses for distances over 400 km are already available in a first generation. High voltage is mandatory in order to achieve the expected performance levels in charging behaviour and least possible battery energies per vehicle. The focus will be on voltage levels in the range of 1000 V to 1250 V [13], in the long-term the voltage levels in this field of application might go up to even 1500 V [14]. The availability of semiconductors and power modules, which can cope with these high voltages and the dynamic loads in driving vehicles are indispensable for this technology and could be developed based on today's industrial applications.

Energy Storages

Figure 2 shows the main energy storage technologies for electric powertrains. Regarding energy density and cost, battery technologies are the key drivers for the success of electric vehicles. Experts predict that energy density will double for the present Lithium-ion (Li-ion) battery technology, and costs will fall to about 70 EUR/kWh on battery module level by 2030[15]. Li-ion battery technologies have permeated the market and will remain in the focus for the next few years. In a short-term, the research focus is on stacking and vehicle integration of existing systems. For the mid- and long-term vehicle generations continuous R&D effort is needed to achieve the required utilization of advanced Li-ion batteries (3rd generation) and solid-state batteries (4th generation).[16]

Further 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.[17]). It might be possible to develop a rechargeable battery technology utilizing ambient air as the oxidizing material in the battery, thus enabling an order of magnitude increase in battery energy density. Others like mechanical energy storages (e.g. flywheels) and super caps can achieve similar effects as batteries and might be used in stationary systems (e.g. to allow fast charging in locally weak grids) but will not play an important role in mass-production vehicles.

In the past years, batteries for automotive applications have been improved tremendously, however fur-

[13] https://www.charin.global/technology/mcs/, retrieved 8 June 2022

[14] https://www.sae.org/news/2020/05/chademo-3.0-to-harmonize-global-ev-quick-charging-standards https://en.wikipedia.org/wiki/ChaoJi, retrieved 8 June 2022

[15] https://eucar.be/wp-content/uploads/2019/08/20190710-EG-BEV-FCEV-Battery-requirements-FINAL.pdf, retrieved 8 June 2022

[16] NPE (2016). Roadmap Batteriezellfertigung in D | EBA (2018). European Battery Cell R&I Workshop 11-12 Jan 2018, Final Report | expert interviews

[17] EBA (2018). European Battery Cell R&I Workshop 11-12 Jan 2018, Final Report

ther R&D for improvement is mandatory to achieve the set goals in performance, efficiency, and cost. The aims for all battery technologies are improving the energy content at a higher voltage level, the power-to-energy-ratio, achieve new levels of geometrical and structural integration and reducing costs whilst increasing efficiency, durability (cycle stability) and safety.

Especially for the topic of safety, there are still several approaches to achieve the same objective since (traction) batteries in automotive applications are quite new. 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).

Key activities in R&D for all electric energy storage technologies for vehicles are concentrated in the areas of:

1. Optimized and new battery technology generations
    - Advanced Li ion – 3rd generation
    - Solid state Li ion – 4th generation
    - Energy management on subsystem and system of system's level
    - Integration of real and virtual sensors
    - Cycle stability
2. Optimization of the battery cell and pack integration
    - Design of advanced battery packs based on new cell formats (e.g. 4680)
    - Battery pack safety / "no propagation pack" based on midterm upcoming up Li-ion cell technologies
    - Pack engineering for improved recyclability
    - Assembly and joining process technologies
3. New methods and materials to improve performance and cost (needed for 1. and 2.)
    - New integrated modelling and simulation methods
    - New statistical testing methods
    - Material research
    - Process equipment development

The R&D topics listed under "3. New methods and materials" need to be part of both R&D "programmes" dealing with "1. Optimized and new battery technology generations" and "2. Optimization of the battery cell and pack integration".

Advanced mechanical and chemical **modelling methods and simulation** tools allow to draw conclusions from battery cell level to systems level 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 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 on cell as well as on pack or system level to improve basic characteristics of future batteries and help to achieve the performance, efficiency, weight, and cost goals.

Battery Technologies

Advanced Li-ion (3rd generation), solid state batteries (4th generation) as well as long-term 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.

The following steps are necessary to further improve advanced Li ion battery technology (3rd generation):

- Advanced Li-ion batteries with enhanced safety behaviour
- Improved cyclability and operational lifetime, whilst maintaining competitive performance for cost, energy and power density
- Improved sustainability and recyclability
- Preparation for industrial scale-up of manufacturing

Very high R&D effort is expected on battery cell level, especially for the replacement of scarce resources like 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).

The following steps are necessary to push solid state battery technology (4th generation):

- Interface stability vs Li metal to enable Gen 4 – currently TRL 2-3; TRL 6-7 is needed (best case 3-5 years)
- Li ion transport/mobility in solid electrolyte at similar level to liquid – 5-10 years at commercial level (TRL 6+)
- For Polymer (hybrid) electrolyte development to TRL 6+:
    - Stability beyond 4.3 V vs Li/Li+ (4-6 years)
    - Ionic conductivity increase by 30-40 % (4-6 years)
    - Establishment of an uniform processability/manufacturing method (3-4 years)
- For ceramic/oxide electrolyte development to TRL 6+:
    - Uniform deposition method onto electrodes and electrode penetration (4-6 years)
    - Stability against ambient conditions (3-5 years)

   - Cost reduction (needed time depends on material and process developments)
- For sulphidic electrolyte development
   - Uniform deposition method established (2-4 years)
   - Reduction of health and safety implications (H_2S generation) (4-6 years if at all)
- Large scale Li metal/electrode production for generation 4b (4-6 years)
- Stable Li deposition process for Gen 4c (anodeless cells with Li being deposited in situ)
- Cell design considerations for Gen 4 materials (3-5 years, depending on electrolyte technology used)

Energy Storages

Advanced Li-Ion Batteries (3rd Generation) Cells & Moduls

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

type of project required

short-term until 2025	**medium-term** 2025-2030	**long-term** 2030+
High voltage on pack level with Li-Ion (NMC, LTO, LFP), TRL2022 8-9	High voltage on pack level with Li-Ion (NMC, LTO, LFP), TRL2022 8-9	
Avoiding toxic materials and scarce resources (e.g. Co), TRL2022 8-9	Avoiding toxic materials and scarce resources (e.g. Co), TRL2022 8-9	Avoiding toxic materials and scarce resources (e.g. Co), TRL2022 8-9
Highly safe battery, TRL2022 5-9	Highly safe battery, TRL2022 5-9	
Thermal management (reduced temperature sensitivity), TRL2022 4-8	Thermal management (reduced temperature sensitivity), TRL2022 4-8	Thermal management (reduced temperature sensitivity), TRL2022 4-8
Battery management system and battery diagnostics, TRL2022 8-9		

Energy Storages

Solid State Batteries (4th generation) Cells & Moduls

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

type of project required

short-term until 2025	**medium-term** 2025-2030	**long-term** 2030+
Cell design (material optimization, producibility, low carbon footprint ...), TRL2022 2-3	Cell design (material optimization, producibility, low carbon footprint ...), TRL2022 2-3	Cell design (material optimization, producibility, low carbon footprint ...), TRL2022 2-3
Multiscale modelling (material, cell & system level, processing ...), TRL2022 2	Multiscale modelling (material, cell & system level, processing ...), TRL2022 2	Multiscale modelling (material, cell & system level, processing ...), TRL2022 2
Manufacturing processes, research and production pilot lines, TRL2022 2-4	Manufacturing processes, research and production pilot lines, TRL2022 2-4	Manufacturing processes, research and production pilot lines, TRL2022 2-4
Battery design, processes & strategies for recycling and 2nd life, TRL2022 2-4	Battery design, processes & strategies for recycling and 2nd life, TRL2022 2-4	Battery design, processes & strategies for recycling and 2nd life, TRL2022 2-4
Material research (conductivity, electro-chemical stability, usable at temperatures up to and above 100°C, sulphide solid state electrolytes, lower toxicity, ...), TRL2022 2	Material research (conductivity, electro-chemical stability, usable at temperatures up to and above 100°C, sulphide solid state electrolytes, lower toxicity, ...), TRL2022 2	Material research (conductivity, electro-chemical stability, usable at temperatures up to and above 100°C, sulphide solid state electrolytes, lower toxicity, ...), TRL2022 2
Highly safe battery, TRL2022 5-9	Highly safe battery, TRL2022 5-9	
Thermal management (reduced temperature sensitivity), TRL2022 4-8	Thermal management (reduced temperature sensitivity), TRL2022 4-8	Thermal management (reduced temperature sensitivity), TRL2022 4-8
Battery management system and battery diagnostics, TRL2022 8-9		

Energy Storages

New Battery Technologies: Cells and Moduls

higher energy content / power-to-energy ratio / efficiency / durability / safety / cost / integration / resource availability

type of project required

short-term until 2025	**medium-term** 2025-2030	**long-term** 2030+
Metal-oxygen (metal-air) batteries, Mg-Ion batteries etc. (high energy applications-range), TRL2022 1-3	Metal-oxygen (metal-air) batteries, Mg-Ion batteries etc. (high energy applications-range), TRL2022 1-3	Metal-oxygen (metal-air) batteries, Mg-Ion batteries etc. (high energy applications-range), TRL2022 1-3
Highly integrated safe battery, TRL2022 1-3	Highly integrated safe battery, TRL2022 1-3	Highly integrated safe battery, TRL2022 1-3
Battery diagnostics, TRL2022 1-3	Battery diagnostics, TRL2022 1-3	Battery diagnostics, TRL2022 1-3
		Battery management system, TRL2022 1-3
		Redox flow, TRL2022 1-3

Optimization of cell and battery integration/packaging in the overall vehicle structure

An additional approach to increase the total installed energy (more useable energy for higher vehicle mileage) of a vehicle apart from cell chemistry development, is the optimization of the battery cell and pack integration approach. Current optimization efforts are labelled as Cell-to-Pack (C2P) and upcoming investigations are called Cell-to-Chassis or Cell-to-Vehicle (C2C / C2V). The C2P approach (which is now entering the mass market) already optimizes the battery pack itself as a component: the cell modules are formed to larger cell arrays / cell clusters to create a better space utilization of the given battery packaging space inside the vehicle. The cell cluster housings/structure are omitted/reduced while still maintaining the electrical and structural functionalities and performance. This approach allows to save the weight and better utilise the space, which leads to a higher volumetric/gravimetric energy density on pack level.

C2C concept is a future concept (>2025), which reevaluates the integration of the battery pack into the vehicle's underbody: the battery pack is no longer a standalone / separate component anymore. In fact, it will be a combined integrated unit of the chassis. The concept behind this development is to consider/treat battery and chassis/underbody as one component, to further increase installed energies, reduce overall complete vehicle part costs and weight e.g. by removing redundant structures, less needed packaging space and better Z-stack behaviour etc.

For systems containing cylindrical cells the trend goes towards larger cells, e.g. the 4680 format. Compared to today's 2170 this size translates to an increase of around 5 times in volume and an even larger increase in stored energy because of more active material compared to inactive cell parts. This significant increase demands for major adaptions in mechanical pack design including safety measures and cooling strategy. These activities can go hand in hand with increasing the safety with the ultimate goal of a no-propagation pack, meaning a battery system where a cell in thermal runaway does not trigger further runaways. A redesign in packaging, venting channels and safety vents, flame distance and barriers are required with support of simulation and testing for optimization and verification

Nevertheless, it should not be ignored that the current development process will also change because of such highly integrated solutions, for example validation strategies, regulations etc. Further, the decision to build a battery electric vehicle using such C2C vehicle approach must be taken much earlier within the entire value chain and thus affects larger parts of the complete value chain.

For the successful integration of the batteries into the vehicle resp. the electric HV circuit, safety elements play a vital role – namely to achieve the requested ASIL (automotive safety integration level) standard in the emergency shut down. Safe separation of the high energy amount stored in the battery as well as safe discharge of energy storages in the electric HV circuits needs to be managed. R&D is needed to achieve the performance levels for those elements regarding short circuit currents (up to more than 30 kA) and circuit inductances (up to > 100 nH) for the steadily increasing battery energies (> 100 kWh) and voltages up to 1250 V (with potential to 1500 V in the long-term). New solutions are needed for high performance cars and electric trucks.

Electric Components

Effects on system costs, safety (torque accuracy, cyber security, warranty), package, power density and efficiency can be achieved by <u>further developments of the electric motor and inverter.</u> Advanced electric motor design, e.g. new winding types, advanced magnet materials for less Heavy Rare Earth Element (HREE) usage and recyclability, advanced cooling flu-

*a wide range of TRL is stated here since these materials already are implied in the market but further research is still necessary taking into account circular economy – p.e. research on new sustainable materials with the requested properties

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Energy Storages

New Methods and Materials to improve Performance and Cost

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

type of project required

- Battery design, processes & strategies for recycling and 2nd life, TRL2022 5-7
- Advanced processing technologies, production pilot lines, TRL2022 4-7
- Battery design, processes & strategies for recycling and 2nd life, TRL2022 1-3
- Cycle stability also regarding C2C, TRL2022 4-6
- New integrated Modelling and simulation Methods, TRL2022 5-6
- New statistical testing methods, TRL2022 3-5
- Material research, TRL2022 3-8*

*a wide range of TRL is stated here since these materials already are implied in the market but further research is still necessary taking into account circular economy – p.e. research on new sustainable materials with the requested properties

ids, novel insulation techniques, advanced and direct cooling systems for stator and rotor active parts, retention sleeves, advanced sealing materials, motor topologies for optimized space utilization and increased motor-inverter-integration offer high potentials to decrease the overall EDU (Electric Drive Unit) costs and improve furthermore system efficiency with direct impact in driving range by same battery capacity. Inverters are obligatory for EDU as they provide the necessary control strategy to run the E-Motor and bring the correct torque to the wheel. Highly integrated electric motors with adequate (high) revolution speeds may provide the required performance with lower weight and less space requirements if the resulting higher temperature level can be handled accordingly.

The right cooling is not only significant for the E-Motor and Inverter but also for the whole EDU. Therefore, extensive research has to be done on that, taking into consideration 3 in 1 or even 5 in 1 architecture. Even the cooling strategy of the whole BEV depends on this with massive impact on costs and durability. Research needs are evident in heat exchange technologies, novel multi-material composites, fluids as well as CFD (Computational Fluid Dynamics) simulation to predict and control temperature distribution. Exact knowledge of temperature pattern over cycle load and peak are important for design and durability and serve as an input for the battery management software. Therefore, research is needed.

To transmit torque from the E-Motor to the wheels with a cost efficient, quiet, and compact transmission and high integration into the E-Motor, an in-depth engineering effort is needed. Especially the 3 in 1 architecture asks for an overall optimized design of E-Motor, inverter and transmission unit, as every single subsystem affects the other. Considering the indefinite amount of use cases and cycle loads worldwide; tons of EDU possibilities are existing but only one fits to the vehicle requirement.

Control strategies for EDUs are mostly related to known industrial applications, but with incredible room available for further innovation. New control strategies are not only necessary to gain the potential benefit of new MOSFET and IGBT power modules but also for new functions implemented on the inverter. All software and system innovation have to be tested on specific test benches and demonstrator vehicles. To reduce the design phase time simulation tools must be innovated and engineered accordingly. The cost intensive testing of electrified powertrain can only be tackled by using verified simulation tools, which are not available yet.

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

The term "Power Electronics" summarizes the inverter / converter, DC-DC converter and on-board charging unit. New materials, "self-learning" inverters and high-volume production will reduce costs and create added value. Extensive research on manufacturing, simulation and testing have to be done for SiC and GaN power modules, which offers some efficiency benefit and to target the cost factor. High frequency switching equally demands research on motor simulation methods for including parasitic losses and insulation stability. Safety circuit minimized parasitic loss topologies, EMC (Electro-Magnetic Compatibility) and passive power electronics components (fuses, resistors, capacitors, inductors), which can cope with the high energy density, automotive safety and cost requirements, need further development. Advanced cooling, joining and EDU packaging (motor, inverter and gear-box) technologies to harvest the full potential of wide band gap semiconductors also need further investigation.

High Power Systems with up to 1250 V voltage level [18] for passenger cars and especially for commercial vehicles (with a potential voltage level of up to 1500 V [19]) open the window for ultra-fast charg-

[18] https://www.charin.global/technology/mcs/retrieved 8 June 2022

[19] https://www.sae.org/news/2020/05/chademo-3.0-to-harmonize-global-ev-quick-charging-standards, retrieved 8 June 2022
https://en.wikipedia.org/wiki/ChaoJi, retrieved 8 June 2022

Legend

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

ing up to the MW range. This is enabled via the wide bandgap power modules. Research is necessary on the motor level and the electric circuit level (insulation, EMC, passive components) in order to deal with these high voltages in the EDU package. Further, cost reductions are necessary in the production of all electric powertrain components, enabling for a high number of end users to afford and utilize the benefits of these technologies and reach the requested CO_2 target goals., To decrease the costs continuously is a general obligation for the manufacturing. Therefore, innovation, applied research and development in the field of production technologies are required.

Vehicle Control Unit – Hardware and Software

The trend towards connected systems and the fast technical progress of driver assistance functions will lead to an extending high data exchange between toady's independently developed and operating control units (e.g. propulsion, braking, steering, charging, etc.). A more cross-domain thinking, centralized and integrated approach will be essentially required, starting in the first step with an integration of established powertrain domain functions in one control unit (e.g. motion controller) and in the long-term towards an extensive function aggregation in a powerful central vehicle computer.

Today, a vehicle is in its best condition when it leaves the factory. But in the future, software can be continuously optimized within the limits of the hardware. This means that the vehicle can even improve after leaving the factory. For example, through updates to the vehicle features and upgrades and improvements. Software solutions will therefore become the key feature that vehicle manufacturers and fleet operators use in the future to set themselves apart. This paradigm shift is made possible in the first place by the separation of hardware and software.

To enable these future steps high research in development effort is required such as:

- Hardware with increased processing power and storage capacity for the introduction of new features, which use machine learning and deep learning methods e.g. for a higher levels of ADAS.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Electric Components

Electric Motor

efficiency / cost / safety / reliability / high volume production / thermal stability type of project required

type of project required

- Advanced materials (e.g. electric sheet, magnet), TRL^{2022} 3
- Manufacturing processes (e.g. electric metal stacks, winding assemblies) for the automotive industry, TRL^{2022} 4-6
- Speeds > 20.000 rpm (e.g. bearing, seal, magnet fixation, retention sleeves), TRL^{2022} 2-6
- Heavy Rare Earth Element (HREE) free or non-permanent-magnet concepts, material recyclability, TRL^{2022} 3-6
- Advanced motor topologies (e.g. in-wheel motors, disc shape motors), TRL^{2022} 5-7
- Transmission (e.g. reduction gear, 2-speed, NVH), TRL^{2022} 6-9
- Cooling concepts (e.g. direct slot cooling, embedding, direct active part cooling), TRL^{2022} 3-5
- Testing and validation, TRL^{2022} 4-6
- Motor adaption to HF-switching, TRL^{2022} 2-3

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Electric Components

Motion-, Drive- or Powertrain-) Control, Software & Hardware

control units that serve as integration platforms, hosts for demanding applications, and connectivity hubs.

type of project required

- Motion/Drive-Controller hardware powerful for future demanded applications and extended use of AI methods, TRL^{2022} 4-7
- Software integration platforms efficient for function fusion, demanding applications (AD, model-based control), and connectivity hub, TRL^{2022} 3-6
- Software applications and -services for continuous and active software maintenance over live time (continuously maintained vehicle), TRL^{2022} 4-7
- Enlarged use of AI methodology and digital twins for predictive and model-based control functions and component maintenance, TRL^{2022} 4-7
- New testing and validation methodologies und systems (e.g. continuous testing, SiL), TRL^{2022} 4-7

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Electric Components

Inverter, Power Electronics

efficiency / cost / safety / reliability

type of project required

- Increase packaging density by e.g.integration in motor or e-axle, TRL^{2022} 7
- Utilization of wide-bandgap semiconductors (cost efficient, high temperature operation, lifetime, minimized parasitic losses, safety circuit) in advanced EDUs, TRL^{2022} 5
- Increase performance of passive electronic components capacitors, inductors, resistors, fuses high power density, less space requirements, cost efficient, TRL^{2022} 6-9
- Assembling and joining technologies for high volume production including disassembling and recyclability, TRL^{2022} 6
- Functional integration to increase packing density and reduce cost (e.g. active HV-discharge, high speed safety, new cooling concepts), TRL^{2022} 6
- Self-learning adaptive algorithms and next generations of model-based control, TRL^{2022} 4
- New materials (e.g. printed circuit boards, housings, capacitors) and their recyclability, TRL^{2022} 4-6
- Application of power electronics for measurement and test systems with mixed operation of simulation models and real test beds, TRL^{2022} 5-8

- Flexible software integration platform, enabling a cost optimized cross-domain integration of functions developed in different environments/ domains.
- Multi-ASIL (Automotive System Integration Level) capability on one hardware, integration, and execution of applications with different safety requirements (ASIL classification).
- Secure data and loop analysis consisting of the data preparation in the vehicle, analysis of transmitted data on a cloud server as well as the reprogramming of resulting adjustments of parameter or the exchange of complete software packages.
- Use of AI methods such as machine learning, deep learning, as well digital twins for predictive component diagnosis and maintenance.

Charging Technologies

The focus of this technology roadmap is clearly the vehicle. Nevertheless, charging is not only an infrastructure topic but also effects the vehicle, which has to fulfil necessary requirements, especially for fast charging.

The development and vehicle integration of efficient charging technologies is critical to the success of battery electric vehicles. Conductive charging systems (with plugs) are available with global different standards (interfaces) and have already been partially introduced to the market. Inductive charging is seen as a medium to long-term charging technology for improved end customer comfort. Since the efficiency of such systems is still too low and the effects of magnetic fields on the human body and the environment are still unknown, further investigation and R&D effort is needed. Alternatives for an improved end-customer friendly charging functionality can be realized with automated conductive charging systems, which have been demonstrated as first concepts with major R&D demand for industrialization and integration in a series development vehicle.

Finally battery swapping systems would also be an end customer friendly charging approach, but require a high level of standardization, which affects OEMs in their freedom of design and business case (warranty issues) and weakens the consideration of treating the battery and chassis/underbody as one component, to further increase installed energies, reduce overall complete vehicle part costs and weight (see chapter "Optimization of cell and battery integration/ packaging in the overall vehicle structure"). 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 not legally clarified in the EU. Consequently, for A3PS members, battery swapping systems are not worth-while for common use. The production of battery and charging systems has a high potential to create added value in Austria.

(Ultra) Fast charging (charging with high current over a longer time period) is a functional improvement to shorten the charging time. However, fast charging requires sophisticated knowledge in switching mode, reliable and affordable power modules and durable insulation technologies. Thermal management and its implementation in the overall vehicle operating strategy is key to use the potential of fast charging. This means in detail the pre-conditioning of the battery in order to prevent overheating or to prepare for upcoming high-power charging demands under cold weather situations in order to prevent and overcomea reduction of the battery's durability and a loss of efficiency of the charging process itself. Besides, fast charging presents major challenges to satisfy the high-power demand while keepingthe stability of the grid. One approach to overcome grid restraints is to use buffering batteries in the charging stations – first solutions are already available on the market. However, fast charging technologies and their widespread availability help to meet users' range anxiety and might be a solution to limit the battery weight in commercial (regional) vehicles. Therefore, an improved charging infrastructure is crucial. For commercial vehicle appli-

Legend

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

cations the charging powers are expected to increase to the MW (MegaWatt) range, which still have the need to improve the efficiencies beyond 95 %.

Next to the availability of charging infrastructure the authentication and payment procedure itself is still a big global issue to be solved. Therefore, standardized procedures and protocols need to be developed and implemented. ISO 15118-20:2022[20] is the standard forVehicle-to-Grid (V2G) communication interface. PnC (Plug and Charge) still faces challenges despite an existing standardization[21].

Smart Charging / Bidirectional Charging:

The bidirectional charging (BDC) standard ISO15118 enables the integration of electric vehicles into the power grid. EV's with charging flexibility via smart charging and bidirectional energy flow solutions (V2G, V2H, V2B, etc.) can reduce investments in the electric grid, prevent grid overloading, system instability and voltage drop issues.

Today, there are some prototype implementations for a sustainable market launch of smart charging and V2G services, a high R&D effort is still required.

Main development areas and challenges are:

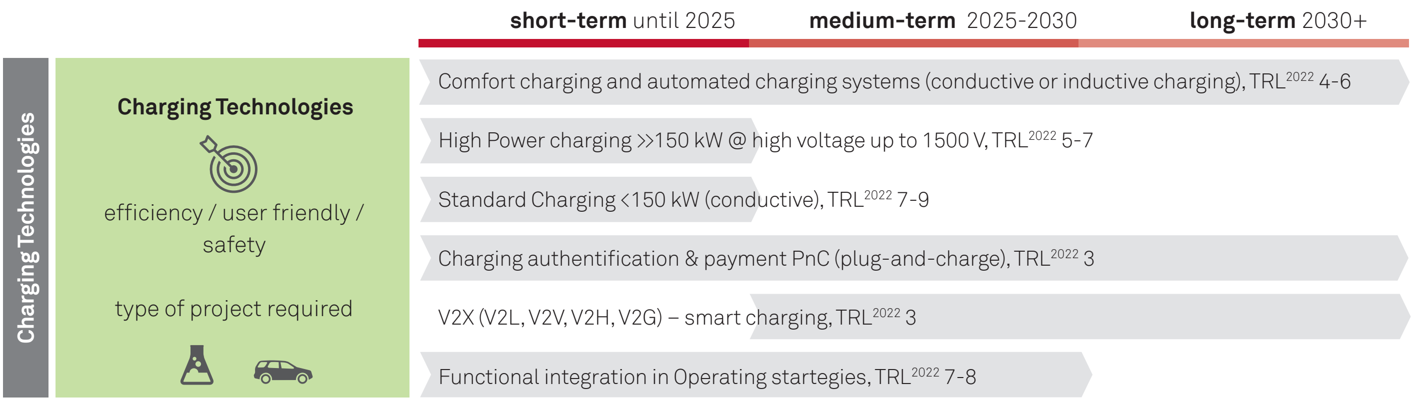
- Cost-efficient bi-directional charging components are needed to maximize the efficiency of the whole energy system.
- Interoperable end-to-end smart charging and V2X services across EVs, service providers and energy networks, in order to be widely deployed and accepted in the market.
- Efficient smart energy management (grid) functions and flexibility services, using accurate forecasts via real-time data from EVs and EV users.
- Intelligent optimization algorithms with lower computational complexity to determine a reliable short-term forecast based on reliable real data such as vehicle location, battery capacity, EV user's acceptance. The execution time of the algorithms is crucial as the problem must be solved within appropriate time constraints for a big number of EVs
- Enabling the communication with fleets of moving EVs and real-time interaction with users.
- Develop more reliable models for battery degradation and cost implications due to frequent charging and discharging cycles required by bidirectional V2G implementation, (electro-therma and aging modelling).

The following charging functionalities shall be enabled to utilize the potential contributions of a high number of vehicle batteries for load distribution, peak buffering and in the long run for supporting the grid stability. All They are all designated as vehicle to "X" (V2X) functions, which are already known and an upcoming technology approach, which must be considered for different charging functionalities.

- V2L: vehicle to load can provide an electrical interface from the vehicle to any standard electrical device.
- V2V: vehicle to vehicle could transfer energy from one vehicle to another.
- V2H: vehicle to home as an important functionality to be used as back-up power supply or buffer battery in combination with advanced intelligent (smart home) electric systems .
- V2G: vehicle to grid finally could be a big infrastructure topic / business to support net stability and or supporter for grid power management (e.g. peak shaving).
- V2H and V2G concept and solution development needs the involvement of grid companies and could be a topic for a preliminary "Sondierungsstudie" in order to define detailed Research and Development needs.

[20] https://www.iso.org/standard/77845.html, retrieved 8 June 2022

[21] https://www.auto-motor-und-sport.de/tech-zukunft/mobilitaetsservices/plug-and-charge-einfach-laden-probeleme/,retrieved 8 June 2022



Fuel Cell Technologies

Fuel Cell Technologies

Fuel cells are electrochemical energy converters, which directly convert the chemical bound energy of a fuel (often hydrogen) with high efficiency into electricity. This conversion process is completely free of pollutants, green-house gases and noise emissions. Fuel cells are generally very resource-efficient energy converters. The by-product heat can be used for heating purposes in addition to the use of electricity, which further increases the efficiency of use. Hence, fuel cells are an energy- and resource-efficient option for electrification of transport. Huge progress has been achieved by research and development in the last decades. Actually, two main technologies of fuel cells are used or near-to-market for automotive and other transport applications. On the one hand, the Polymer Electrolyte Membrane or often Proton Exchange Membrane fuel cell (PEMFC) and on the other hand, the Solid Oxide Fuel Cell (SOFC). PEMFCs operate at low temperature ranges (e.g. 50°C to 80°C) and are therefore suitable for FCV or REX. FEMFCs are using a special polymer membrane as electrolyte for conducting protons. The SOFC has a solid oxide or ceramic electrolyte and operates at high temperature levels between 600°C and 1000°C. Due to the high system temperatures, SOFCs are too slow for direct drives and are only suitable as APUs. Both technologies, PEMFC and SOFC offer a great synergy potential also with their respective electrolysis technologies, the polymer electrolyte membrane electrolysis (PEMEC) and the solid oxide electrolysis cell (SOEC). Therefore, these technologies are also discussed in this roadmap in the section of energy carriers.

During the last years, great technological progress has been achieved. With PEMFCs, costs have been reduced by more than 90%, catalyst loading has been reduced by around 80%, the durability and the specific stack power density increased by more than a factor of 4 etc. This progress results in many ongoing vehicle developments and underlines the role of fuel cells in mobility to enable defossilization and electrification at the same time. Generally, fuel cell vehicles (FCV) usually consist of a hybrid powertrain with a battery and a fuel cell, which offers synergies between the production of BEVs, Hybrid Electric Vehicles (HEV) and FCVs. There are already some hydrogen fuel cell applications that have proven to be close to market maturity. FC material handling vehicles, FC buses and – to a lesser degree – FC passenger cars, have been successfully developed, demonstrated and already been deployed with limited further subsidies needed. In addition to that, huge efforts are actually made to develop fuel cell powertrains for Light-Duty Vehicles (LDV) and Heavy-Duty Vehicles (HDV).

Nevertheless, these developments are not sufficient to meet the ambitious emission reductions in transport. We still need to further research, develop and prove solutions in many sectors such as heavy-duty vehicles, off-road and industrial vehicles, trains, shipping, and aviation. Such solutions can be based on the transfer of technical knowledge already gained in FC passenger cars and FC buses, while cost reductions and higher efficiencies can be achieved by scaling and by process integration, improving the competitiveness of these technologies with a roll down effect, e.g. by platform approaches of FC modules across sectors. Several technology routes still need further improvements, especially in the context of reducing costs, increasing efficiency, and increasing durability, in order to make them competitive with other technologies. These include:

- Improvement of main technology building blocks that can be applied across a range of different transport applications, amongst which are fuel cell stacks and hydrogen storage systems
- Adapting fuel cell systems from other vehicles (urban buses / cars) for LDV and HDV
- Delivering the technological and know-how basis for production and quality control
- Producing components for rail applications (e.g. freight and shunting locomotive)
- Adapting FC components to waterborne transport, and developing next generations based on learnings from first demonstrations as well as developing on-board hydrogen storage systems and FC technologies specifically adapted for aviation

Especially in the case of hydrogen-based transportation, the competitiveness of hydrogen technologies is dependent on research and innovation breakthroughs, on production volumes of vehicles and components and on the price and availability of hydrogen as a fuel. Therefore, actions aimed at stimulating a broad rollout of FC vehicles around Europe are equally important to research and innovation actions, for hard to electrify sectors, to drive the Total Cost of Ownership (TCO) of the FC vehicles down. Austrian companies, research institutions and universities are engaged in the field of fuel cell technologies and their respective test and validation systems since decades. Due to the beginning ramp up phase of fuel cell and hydrogen technologies, A3PS members expect even tougher international competition in research and industry and therefore more instruments to strengthen the Austrian community are needed.

The strategy for the development of the transport fuel cell system components will continue to pursue three overarching goals: cost reduction, increased performance (also efficiency) and lifetime. Advancements in this domain will be beneficial to all transport applications regardless of their current state of the art. Sustainability, recycling and eco-design are also important principles that will play a role in the development of components.

Fuel Cell Vehicle Concepts

In order to fully unlock the potential of hydrogen technologies and introduce them as a mainstream means of decarbonisation in all transport modes, vehicle prices will need to evolve towards the prices of vehicles in use today. This in turn requires a reduction in the cost of the powertrain components – the "technology building blocks" – the fuel cell stacks, the supporting Balance of Plant (BoP), which makes up the "fuel cell system" and the on-board hydrogen storage system. Cost reduction in these components will be driven by a combination of technology development and volume of deployment. Embedding the concept of modularity in the development of components and BoP will also be important to reach mass production efficiently. Modular systems will be adapted to the specific needs of each transport modes, while avoiding the re-engineering of components and systems hence allowing the attainment of mass production dynamics despite the low number of units deployed in different transport modes at early stage.

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 obstacles 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 powertrain design, fuel cells operate at power levels from 15 to 30 kW for range extender vehicles, APU (Auxiliary Power Unit) applications and Combined Heat and Power (CHP) applications up to 100 kW and more power for "pure or fuel cell dominant" fuel cell vehicles. Fuel Cell range extender vehicles are battery electric vehicles with fuel cells for maintaining charge for discharged battery. In "pure or fuel cell dominant" fuel cell vehicles, the fuel cell provides the total amount of electrical drive energy. A small battery (1-2 kWh for passenger cars) or supercapacitors are required to buffer highly dynamic load changes and peak performances.

In the heavy-duty sector, the use of PEM fuel cells in city buses is considered an early commercial market. In addition, hydrogen storage and refuelling will follow new standards with pressure levels of up to 700 bar in the short term. 700 bar is the standard for passenger vehicles and very likely most suitable for heavy-duty trukcs, especially for long-distance applications. For buses and trains, 350 bar is more likely due to packaging and lower range requirments. Costs are the main drivers and LH_2 is also discussed as an option for HDV.

Key applications & load cycles of FCVs are:

- Passenger cars and light duty vehicles (30 – 100 kW continuously [cont.], 5-8 kh lifetime target)
- Medium and heavy-duty trucks (100 – 300 kW cont., >30 kh lifetime target)
- City bus (30-60 kW cont., >30 kh lifetime target)
- Coach (80 – 120 kW cont., >30 kh lifetime target)
- Train (250+ cont., >30 kh lifetime target)
- Gensets (50+ cont., >10 kh lifetime target)
- Special applications (constructiosn & agricultural equipment, municipal, >10 kh lifetime target)

Powertrain configurations & vehicle level architectures:

- REX
- Mid-size
- FC dominat

Intelligent and adaptive operating strategies are particularly important for fuel cell electric vehicles to both minimize component degradation and maximize efficiency throughout the vehicle's lifetime. On the one hand, a significant contribution can be expected from predictive control methods that take into account forecasts of e.g. route, traffic, weather, etc. On the other hand, adaptive concepts are required that adjust the operating strategy during operation to the current state of health of the components (battery, fuel cell stacks) to optimize lifetime and/or total cost of ownership. Therefore, energy management and thermal management have to be adapted online in order to avoid premature aging of specific components. In this context, for heavy-duty applications, modular fuel cell systems also play a decisive role. Such systems with multiple independently operated fuel cell stacks achieve higher efficiency and reliability. They provide additional degrees of freedom in optimizing and predictively adapting the operating strategy.

An essential prerequisite for the adaptation and optimization of the operating strategy is the determination of the health status and prediction of the degradation of the components. Future vehicles will continuously transmit their operating data (e.g. battery health parameters) over the air to a central unit, and more accurate degradation models can be parameterized with the available data. However, on-board diagnostic systems are needed that use such aging models and virtual sensors to predict remaining life at a given load demand.

The main research needs for fuel cell vehicles can be summarized as follows:

Legend

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

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Fuel Cell Vehicle Concepts

Fuel Cell Vehicle Concepts

NVH optimization / increase customer acceptance

type of project required

- Demonstration activities of vehicles and infrastructure (public transport, fleet applications …), TRL2022 5-7
- Passenger cars, TRL2022 6-8
- Heavy duty applications (trucks), TRL2022 5-6
- Fuel cell dominant concepts, TRL2022 6-8
- Fuel cell range extender concepts (SOFC, PEM), TRL2022 4-6
- Public awareness, TRL2022 4
- Life cycle analysis of vehicle concepts, TRL2022 4-6
- Special vehicles (tractor, industrial trucks, sport vehicles), TRL2022 4-6
- Functional safety, TRL2022 6-8
- Improved thermal management with focus on heavy-duty, TRL2022 4-6
- Adaptive operation strategies and on-board diagnostics (e.g. life time monitoring), TRL2022 4
- Onboard-usage of waste-energy (e.g. recovery of pressure energy), TRL2022 4

Polymer Electrolyte Membrane Fuel Cells

PEM fuel cell components are now developed to the point where they can be used in small series for normal vehicle customers in terms of operational reliability and cost. The challenge now is to reduce costs through a combination of increased production volumes and technology development to improve and automate production techniques, reduce material costs per unit of production (especially the cost of precious metals used as catalysts in fuel cells), and improve design at the stack level (e.g. catalyst layers) and BoP components of the system (e.g. cathode sub system). Synergy effects in terms of technology and upscaling are being considered for LDV systems and expected for other areas of HDV applications such as railways, shipping, or aviation (where the performance ranges are comparable to HDVs). Regarding the next generation of fuel cell vehicles, the focus is put on the replacement of noble metal catalysts in the fuel cell.

Low TRL research activities will drive the development of next generation components, which is the necessary step to further progress towards the full competitiveness of fuel cells for road applications both in terms of cost and performance. The main objectives of this technology area will be the following:

- Improving overall system performance for fuel cell stack technology in terms of power density, energy efficiency, operating temperature, reliability and durability
- Improvements in design, health monitoring and manufacturability of core components for fuel cell stacks and on-board storage technology
- Optimisation of stacks for higher performance, durability and reliability incl. game changing concepts on core components and new methods for stack and system state-of-health monitoring
- Improving operating strategies on subsystem (anode, cathode, cooling, HV/LV electric and safety system) and system level including start-up (e.g. start-up dynamic, freeze start), operating (e.g. operating stability, recoverable degradation) and shut down processes (e.g. hydrogen protection time, freeze start)
- Adaptive control strategies for reduced degradation
- Reduce costs via reduction or replacement of PGM loadings and due to application of innovative manufacturing processes (e.g. resulting in function integration) on stack and system level
- Simplification of the FC system design (in particular for heavy-duty applications) in order to reduce the number of parts and foster the emergence of standard components, interfaces and system configurations hence improving their manufacturability
- Developing low-cost concepts and improving manufacturability and recyclability (processes, automation, quality control tools, in-line and end-of-line diagnostics)
- Sustainability and environmental impact reduction by using materials with improved recyclability on component, material, and energy level as well as reduction of pollutants and materials with high environmental impact
- Extending the EU leadership on FC production from automotive to maritime and aviation, given the high pressure for decarbonisation of these sectors.

Innovation on components level and in the system:
- Endurable and dynamic hydrogen concentration monitoring sensors and methods under real-world conditions
- Virtual sensors and state-of-health monitoring

Development of design tools, analysis & characterization methods
- Advanced system simulation and design methods with capability to predict dynamic behaviour, instability phenomenon in anode and cathode subsystem, reversible and permanent degradation, freeze start, etc.
- Accelerated stress test methods on single cell, short-stack, and system level
- Anode and cathode degradation mechanisms, factors (poisonous substances) and mitigation
- System characterization & end-of-line testing

The main research needs for PEM fuel cells can be summarized as follows:

PEM Fuel Cell Systems

PEM Fuel Cells (for REX-FCV and and full hybrid FCV / synergies with PEM-electrolysis)

Power density / efficiency / endurance & lifetime / operating stability & dynamics / cost reduction / recyclability & environmental impact

type of project required: (material) fundamental research, industrial research, experimental development

Research need	**short-term** until 2025	**medium-term** 2025-2030	**long-term** 2030+
New cell materials (lifetime, operation temp., environm. impact) & PGM reduction, TRL^{2022} 2-7	x	x	x
Reduction of noble metal catalysts, TRL^{2022} 7	x	x	
Sustainability & environmental impact, TRL^{2022} 3-8	x	x	x
Low-cost materials & innovative production methods (function integ.) in the BoP, TRL^{2022} 7-8	x		
FC process innovation (e.g. freeze start, degradation red., dynamic & stability), TRL^{2022} 6-8	x	x	
Subsystem & component innovation (anode, cathode, cooling, HV/LV electr.), TRL^{2022} 5-8	x	x	
Media conditioning (e.g. charging, humidifying), TRL^{2022} 5-7	x	x	
Medium temperature fuel cells (>80°C), TRL^{2022} 5-7	x	x	x
Innovative FC control strategies (adaptive & self-learning, virtual sensors, regenerative degradation, etc.), TRL^{2022} 4-9	x	x	x
Dynamic behavior (controls, calibration, optimization), TRL^{2022} 7	x	x	
Specific thermal management, TRL^{2022} 7-8	x	x	
Degradation mechanism, poisonous substances & mitigation, TRL^{2022} 2-6	x	x	x
Cost engineering (production technologies, novel materials, simplification ...), TRL^{2022} 2-6	x	x	x
Hydrogen gas quality (impact on degradation ...), TRL^{2022} 4	x	x	
Production technologies, quality control and recycling (understanding the interaction of production with functionalities and key figures), TRL^{2022} 4-6	x	x	x
Advanced monitoring, characterisation & data analysis for lab, field & EoL testing, TRL^{2022} 4-7	x	x	x
Accelerated stress testing, TRL^{2022} 3-5	x	x	

Solid Oxide Fuel Cells

In order to reduce the use of the EU-defined "critical raw materials", more R&D is required in the field of lightweight SOFC stack components, qualified catalysts and high temperature electrolysis (SOEC) – for instance through recycling, reducing or avoiding the use of rare earth elements. This is of special importance, since electrolysis is an important route to produce green hydrogen. R&D activities are required for the development of new low-cost materials with high durability as well as on the improvement of the BoP components of SOFC systems.

For automotive applications (incl. REX concepts), increasing the dynamics and reducing the time of the start-up phase is important. This is also has to be investigated and solved through R&D activities.

Legend

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

SOFC for FCV

SO Fuel Cells (synergies with CHP and SOEC)	**short-term** until 2025 / **medium-term** 2025-2030 / **long-term** 2030+
efficiency / endurance / life-time / cost reduction	Internal hydrocarbon reforming (catalysts), TRL^{2022} 2-3
type of project required	Improved gas and thermal management, TRL^{2022} 4-5
	Reduction of operating temperature of fuel processing and electrochemical conversion, TRL^{2022} 1-3
	Increased specific power and durability by introduction of novel cell components without or with low content of critical raw materials as well as optimized design, TRL^{2022} 2-4
	Protonic Ceramic Fuel Cells (PCFCs), TRL^{2022} 2-3
	Improved interconnects and coatings with appropriate Cr-retention capability for lower operating temperatures, TRL^{2022} 3-5
	Improved monitoring and diagnotic tools for cells and stacks, including degradation and failure modes, TRL^{2022} 2-4
	Metal Supported Cell (MSC) for APU and REX with improved cold-start behaviour, TRL^{2022} 4-6
	Novel production technologies for improved recyclability of cells and stacks, TRL^{2022} 3-5
	Improving efficiency, durability, and costs of BoP components, TRL^{2022} 2-4

AEMFC for FCV

AEM Fuel Cells	**short-term** until 2025 / **medium-term** 2025-2030 / **long-term** 2030+
efficiency / endurance / lifetime / cost reduction	Anion exchange membranes for higher current density and higher lifetime, TRL^{2022} 2-3
type of project required	PGM-free electrodes, TRL^{2022} 3-4
	Develop AEM stack technology and production, TRL^{2022} 3-4
	Understanding root cause of AEM degradation, TRL^{2022} 2-4

Anion Exchange Membrane Fuel Cells

In order to solve cost issues of existing fuel cell technologies like PEMFC, research on relatively inexpensive hydrocarbon-based polymers and Anion Exchange Membrane Fuel Cells (AEMFCs), to which non-PGM catalysts can be applied, is being actively conducted. The less corrosive alkaline media enables the use of inexpensive non-precious metal catalysts such as Ni on the anode side or Ag on the cathode side.

AEMFCs theoretically offer high potential for energy and resource efficiency. However, the high degradation and the lack of qualified Anion Exchange Membranes (AEMs) greatly hindered the development of AEMFCs. Especially Austria provides comprehensive competence in the area of Ni-based and PGM-free catalysts and therefore the technology should be of interest in this regard.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

On-Board Hydrogen Storage

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

type of project required

- Ionic liquids and LOHC, TRL[2022] 2-3
- New sensor technologies for production and lifetime monitoring for components, TRL[2022] 2-4
- New sensor technologies for lifetime monitoring for components and systems (synergies with production / model-based prediction), TRL[2022] 2-4
- Joining technology (tubes, fittings), TRL[2022] 6-7
- Break through H_2 storage materials and concepts, TRL[2022] 1-3
- Solid state storages, TRL[2022] 3
- Fiber technology (impregnation ...), TRL[2022] 3
- Freeform hydrogen tank, TRL[2022] 2
- Liner production, TRL[2022] 4-6
- Legislation, regulations, codes and standards (RCS), including technical safety standards and standards for fueling and interfaces to HRS infrastructure, TRL[2022] 4-8
- LHSS hydrogen supply pressurization system, TRL[2022] 2-4
- Recycling and/or re-use of composite hydrogen storage systems, TRL[2022] 4
- Bio-based carbon fibre as raw material for composite HSS (Hydrogen Storage Systems), TRL[2022] 2-4
- Matrix-free compressed vessels (without resine), TRL[2022] 4

On-Board Hydrogen Storage

On-board Hydrogen Storage

Volume production and technology developments will also play a similar role for hydrogen storage systems, both gaseous and liquid. Further technology development programs are needed to ensure that the core technology makes progress towards the lower bound of the cost targets. Moreover, the gaseous Compressed Hydrogen Storage Systems (CHSS) requires research to reduce the LCA emissions of the carbon fibre. In parallel, market introduction programs are critical to stimulate the market and mature the technology along the cost curve.

Actual fuel cell vehicles are equipped with hydrogen storage systems with a pressure level of up to 700 bar. However, there are various technical options for storing hydrogen on board of a vehicle and feeding it into the propulsion system. Very strong R&D efforts are required to develop hydrogen storage systems that achieve high storage densities at lower levels of pressure while reducing their costs as well as their carbon footprint. E.g. LHSS (Liquid Hydrogen Storage Systems), CcHS (Cryo-compressed Hydrogen Systems), LOHC (Liquid Organic Hydrogen Carriers).

On board storage technology:

- Development of new materials for high-pressure tanks and fast refuelling enhancing the properties of the liner and targeting cost reduction of the reinforcement
- Development of novel storage concepts to improve storage density (conformability), including solid carrier, pressurized tank, and liquid cryogenic hydrogen
- Development and validation of integrated mounting concepts, safety by design and innovative manufacturing and quality control techniques
- Integration of low cost and reliable safety sensors for structural health monitoring and fire detection.

The main research needs for On-Board Hydrogen Storage can are summarized in the table above.

Legend

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

Cross-Cutting R&D topics

While cross-cutting issues such as knowledge management or communication activities are required for market introduction, several specific research and development supporting activities in the area of testing and validation are still needed to expand and strengthen Austria in the hydrogen sector. This comprises:

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Test & Validation

Test & Validation

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

type of project required

- HiL (Hardware in the loop) and on-board real world analysis, TRL^{2022} 4 -7
- Long-term tests under real conditions and accelerated stress tests (AST), TRL^{2022} 4-5
- Automated measurement and test environment for components and systems, TRL^{2022} 5 - 7
- High pressure test bed incl. refuelling infrastructure, TRL^{2022} 7-8
- Model based development and xiL testing, TRL^{2022} 2-5
- Gas analytic (e.g. N_2/H_2 in anode/anode loop, CO/CO_2 at stack cathode outlet), TRL^{2022} 6
- End of Line (EoL) test systems (fuel cell, tank, valves ...), TRL^{2022} 3-6
- Virtual validation, TRL^{2022} 2-4
- Mechanical stress tests, TRL^{2022} 5-6
- Analysis methods for hydrogen gas quality, TRL^{2022} 5-6
- Liquid hydrogen test bed incl. refueling infrastructure, TRL^{2022} 4-5
- Simulation of two-phase liquid processes and electrostatic behaviour à add to chart V&V, TRL^{2022} 4

Production and Industrialization of Fuel Cell Components and Vehicles

The overarching goal of this focus area is to contribute to the aim that the hydrogen sector becomes a sustainable and circular sector supporting the Austrian and EU strategy on energy system integration and to contribute towards the achievement of the Sustainable Development Goals and the objectives of the Paris Agreement. To improve sustainability and circularity, key focus areas for development are complete and integrated LCA tools, enhanced recovery of PGMs/CRMs (Platinum Group Metals/critical raw materials) including per- and polyfluoroalkyl substances (PFAS) based ionomers and membranes, development of recycling integrated processes, and development of eco-design guidelines and eco-efficient processes. Thus, the specific objectives in this area are:

- Develop industrialization and automation processes to reduce costs of fuel cell and hydrogen components
- Develop life cycle thinking tools addressing the three dimensions of sustainable development: economic, social, and environmental
- Develop eco-design guidelines and eco-efficient processes
- Develop enhanced recovery processes in particular for PGMs/CRMs and per- and polyfluoroalkyl substances.

To this end, further research is needed to develop reliable methodologies for assessing the environmental, economic and social impacts of hydrogen-based technologies and their associated value chains, including their full life-cycle environmental impacts (including "water balance" impacts), circularity and sustainability. Furthermore, securing the supply of critical raw materials in parallel to material reduction, substitution, reuse, and recycling needs to become a core part of the value chain to foster a more circular economy.

Further research to optimise the recycling technology for PEMFC and SOFC, such as for noble metals and critical materials is needed, including perfluorosulfonic acid membranes and ionomers from components used in these processes. Learnings from this work should be able to be scaled-up towards market deployment.

PEM and Alkaline Electrolysis (PEMEL, AEMEL, and AEL), Polymeric Fuel Cells (PEMFC), and Storage materials recycling processes will be developed by transferring current industrial processes already in place for other different value chains than hydrogen. In this regard, the recycling of the different components of the hydrogen value chain will need to be addressed to optimise systems components and increase sustainability and circularity.

Production and Industrialization of Fuel Cell Components and Vehicles

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Fuel Cell & Component Production

cost reduction / high volume production technologies

type of project required: industrial research, experimental development, demonstration

- Developing new manufacturing technologies (cell, stack and BoP components), TRL^{2022} 4-6
- Innovative sensors and actuators, TRL^{2022} 3
- Production processes including automation and semi-automation to improve production speed, TRL^{2022} 4
- Real-time quality control in the manufacturing process, TRL^{2022} 3-4
- 2nd Life of fuel cell vehicles, TRL^{2022} 3-4
- Recycling of fuel cell vehicles, TRL^{2022} 4
- Controll units (possibility of using AI and other emerging digital technologies to improve the manufacturing and /or maintenance), TRL^{2022} 3-8
- Creation of Austrian seamless supply chain for fuel cell and BoP Components, TRL^{2022} 3-8
- Production and recycling of fuel cells, TRL^{2022} 4-6
- Manufacturing machines and R&D equipment like test benches and measurement technologies, TRL^{2022} 3-4

Legend

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

Hybrid Automotive Powertrains

Hybrid Automotive Powertrains

The European grid is currently supplied only 60 % from low CO_2 sources and 40 % fossil, with a coal share of about 45 %. In any case, the grid expansion with green power plants must be caarried out faster than the increase in grid consumers, otherwise **every new consumer** will have to be supplied by fossil fuel power plants and **will cause additional significant CO_2 emissions**. As a result, the most important goal of the energy transition – to run the European grid entirely on renewable energy – is moving further and further away. This fact can be counteracted by transport, which will be dominantly powered by Internal Combustion Engines (ICE) until well beyond 2030, by obtaining significant fuel consumption and fossil CO_2 reduction without disadvantages for the users via two approaches: fuel consumption reduction by (i) optimizing ICE's with or without an electric powertrain (hybrid vehicles), and (ii) green gaseous and liquid fuels.

Hybrid powertrains allow the combination of the advantages of pure electric propulsion, e.g. highly efficient torque generation with E-motors as well as recuperation and storage of break energy, with that of ICE driven vehicles, e.g. conversion of the chemical energy of a liquid energy carrier into kinetic energy in a robust device of highest power density insensitive against fuel impurities. Obviously, such energy converters have to fulfill all – also future – emission standards and are, thus, fully environmentally compatible. Such powertrain systems can be used throughout the entire transition phase from fossil dominated to purely sustainably generated energy carriers. Hybrids are ranging from micro-hybrid systems with dominant torque generation by the ICE to powertrains where torque is completely generated by one or more E-motors and the ICE being coupled to a generator is providing the average driving power only.

Hybrid, battery-electric and fuel-cell-electric powertrains are sharing many components such as E-motors, power electronics, energy buffers (batteries etc.) and subsystems such as e-axles. Hence, all R&D needs and objectives related to these component and subsystems are elaborated in full detail in the BEV section of this roadmap.

Sustainable Combustion Engines

Internal combustion engines will remain the main power unit in conventional and in hybrid powertrains also beyond 2030. The fastest way to reduce CO_2 emissions from traffic is the reduction of fossil fuel consumption by either increasing the efficiency of the vehicles drivetrain or by using hydrogen or other gaseous and liquid energy carriers generated from renewable primary energy sources. However, there is still a lot of potential for improvement if an ICE is operated in a hybrid powertrain. Fuel consumption can be further reduced by 20% or more due to special operating conditions, with additional variability, mechatronic subsystems and the application of new materials for further friction reduction. This means, a peak efficiency of 50% and more is a target for ICEs. Further, even if CO_2 neutrality is achieved via defossilized energy carriers, the combustion processes have to be developed towards "zero-impact exhaust emissions" (no particles, NO_x and other toxic emissions).

Further, since the ICE will be operated in the future with C-neutral energy carriers such as synthetic fuels as well as H_2 and in a substantially different way (peak shaving, load point shifting, start/stop etc.) in hybrid (compared to a pure thermodynamic powertrain), dedicated combustion engines as "fuel converters", a further reduction of emissions and fuel consumption can be realised. Such fuel converter applications open the doors for R&D and new products in (i) waste heat recovery, (ii) electrical energy storage, and (iii) ICE development when the ICE is operated at only a single load point supplying power to the electric drivetrain and electric energy storage via a generator.[22]

(i) A waste heat recovery system will achieve optimum efficiency in converting exhaust gas energy from the ICE into electricity when the combustion has a known exhaust gas temperature and energy content. Reliable, cost-effective and highly efficient technical solutions must be found. Such waste heat recovery systems could be used then also for other applications in e.g. industrial production.

(ii) Relatively small storage capacities are needed in such serial and electrical powerful hybrids to provide high power during braking and acceleration. Electric storage systems capable of C-rates of 10 to 20 for a few hundred thousand cycles with a depth of discharge of 80 % are needed but not yet fully developed and require public funding to provide optimal solutions. Such storage systems can also be used in fuel cell powertrains where they are needed to recuperate the braking energy and to shave off power peaks of the fuel cell.

(iii) An ICE operated as a fuel converter in a single load point at peak efficiency and minimum emissions has a different requirement profile for the ICE than "classic" hybrid vehicles. The power output of the combustion engine is much lower than that of "classic" hybrids and much lower than the power of the electric drivetrain. The ICE, together with the waste heat recovery system and the generator, forms the fuel converter and its power is set to a value to obtain

[22] G. Brasseur, „Hochwirkungsgrad Hybridantrieb für nachhaltige Elektromobilität", open access doi:10.1553/0x003b46cd, Austrian Academy of Sciences, Feb. 5, 2020, pp. 1-36.

a specific permanent maximum speed on a highway. It could be replaced in the future by a fuel cell able to be operated on liquid fossil or synthetic green fuels.

In the field of commercial vehicles, the R&D focus is on hydrogen and synthetic fueled engine concepts.

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 behaviour.

The main development routes are:

- Fuel/gas preparation, ignition and combustion systems for hydrogen and climate-neutral energy carriers for different engine processes (port-/direct-injection)
- Exhaust gas after treatment considering all types of climate-neutral energy carriers (focus on DeNOx, PF (Particle Filter) incl. emissions caused by lubrication oil
- Structural optimization (new materials, advanced joining technologies, high-strength, functional materials) incl. resistance against new gaseous and liquid fuels
- Advanced hybrid systems with extended pure electric range
- CE powertrain with eDriveline Systems (eTransfer Case, electrified axle drive front and rear)
- Minimization of friction losses (new materials and surface structures)
- Thermal management (heat storage, reduction of heat losses, waste heat recovery)
- Transmission optimization (high reduction gears, alternative lubricants for friction reduction, clutch & actuators, axle drive incl. differential, hybrid materials, joinings, thermal management)
- Development tools and methodologies (simulation & control platform/development)

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

ICE for Hybrid Powertrains

ICE Technologies

Zero-impact emissions and significant efficiency improvement (eta>50%)

type of project required

- Low-pressure port/direct injection H_2 engine (H_2-injector, tank/gas pressure for PFI/DI, ignition system, combustion stability, avoidance of backfiring/anomalies, safety of H_2 engines), TRL[2022] 6-8
- High-pressure direct injection hydrogen-engine (tank/gas pressure, H_2-DI-injector, combustion stability/anomalies, safety of hydrogen DI engines), TRL[2022] 4-6
- Highly efficient compressors, turbines and turbochargers incl. e-blowers mech./electr. compound turbines, TRL[2022] 5-9
- Combustion and aftertreatment systems for hydrogen and climate-neutral/fossil-free energy carriers (e-gas, e-fuel, advanced biofuels, NH3, alcohols), TRL[2022] 6-9
- ICE with special operation strategies (incl. single point operation), TRL[2022] 5-6
- Reduction of heat losses to the exhaust and to the coolant inside the engine, TRL[2022] 3-5
- Sensors and controllers for high efficient operation (incl. comb. real and virtual sensors, AI based control systems etc.), TRL[2022] 3-8
- High strength functional materials for engines, material resistance against hydrogen and bio-/syn-fuels, TRL[2022] 3-6

Transmission

The transmission (Dedicated Hybrid Transmission) for ICE powertrain is common but with increasing electrification, there is need for further innovation. A dedicated 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 powertrain. (Corresponding research topics are included in chapter "Advanced Thermodynamic Powertrain Technologies".)

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 later (e.g. waste heat of powertrain 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 regarding the vehicle components.

Legend

(material) fundamental research
industrial research
experimental development
demonstration

Clutches will still play an important role in hybrid resp. full electric vehicles. This is for functions like

- clutches for multi speed transmissions (improve efficiency), limited slip differential and torque vectoring to achieve requested vehicle dynamics
- especially for BEV with their high weight (battery), torque limiting clutches (between wheel and E-motor) to prevent mechanical shocks from varying road and load conditions shocks and allow the use of light weight mechanical parts. Therefore friction materials have to be developed to fit the upcoming new environmentally friendly, lowest viscosity (below brake fluid) lubricant generations (e.g. glycol based) often with specified electric properties.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Transmission

Transmission & Components

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

type of project required

- Control strategy including advanced model-based control and functional safety, TRL^{2022} 3-5
- Optimization of friction / thermal management – integration in thermal management in powertrain (fast warm-up / cooling), TRL^{2022} 6-8
- High component and function integration for hybrid transmissions, TRL^{2022} 3-8
- Lubricants and coolants for transmissions, multi-purpose fluids, TRL^{2022} 3-6
- New transmission concepts (aiming at improved costs, quality assurance, reliability, durability, new bearing materials ...), TRL^{2022} 4-8

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Transmission

Clutch, Actuators

efficiency / durability / heat resistance / control strategy / safety

type of project required

- Friction materials and efficient and durable clutch systems (fluid, material, function integration), TRL^{2022} 4-6
- Actuator with higher efficiency, durability and functional safety (cyber security), TRL^{2022} 3-5
- Functional software for higher accuracy and predictive maintenance, TRL^{2022} 4-6

Cross-Cutting Technologies

The following technologies are relevant for the optimization of all types of hybrid powertrains.

Minimizing friction has very relevant potential to reduce CO_2. Therefore, further effort in basic materials research, design, simulation and intensive testing (validation) 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 and jointing technologies are covered mainly by functional integration.

Improved materials and processes will make it possible to develop new, highly efficient and acoustically optimized transmissions, – e.g. reduction gear sets or coupling elements to reduce drag losses in BEV and hybrid drivetrains. 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.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Cross-cutting technologies

Minimization of Friction Losses

Efficiency

type of project required

- Lubricant, material coating, new materials (e.g. plastics), surfaces structuring (nano structures…), TRL^{2022} 3-8*
- New bearings with new materials and new bearing concepts, TRL^{2022} 3-5
- Low friction sealings, TRL^{2022} 3-5

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Cross-cutting technologies

Thermal & Energy Management

emissions / efficiency / safety, increased functionality

type of project required

- Waste heat recovery (ORC (Organic Racine Cycle), thermo-chemical pro-cesses, thermo-electric conversion etc.), TRL^{2022} 3-5
- Reduction of outer engine heat losses and heat storage (incl. encapsulation), TRL^{2022} 5-7
- Advanced control strategies including AI, self-learning control algorithms, TRL^{2022} 3-4

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Cross-cutting technologies

Development Tools & Methodology

time to market / cost / safety / security

type of project required

- Simulation & control platform / simulation & development environment, TRL^{2022} 4-8**
- Testing systems and measurement technique / manufacturing, EoL testing, TRL^{2022} 4-8
- Model /AI based development tools (joint virtual & real-world tools, digital twins) incl. real time models for XiL-development, TRL^{2022} 3-7
- Real time fully connected design and manufacturing simulation process, TRL^{2022} 3-6

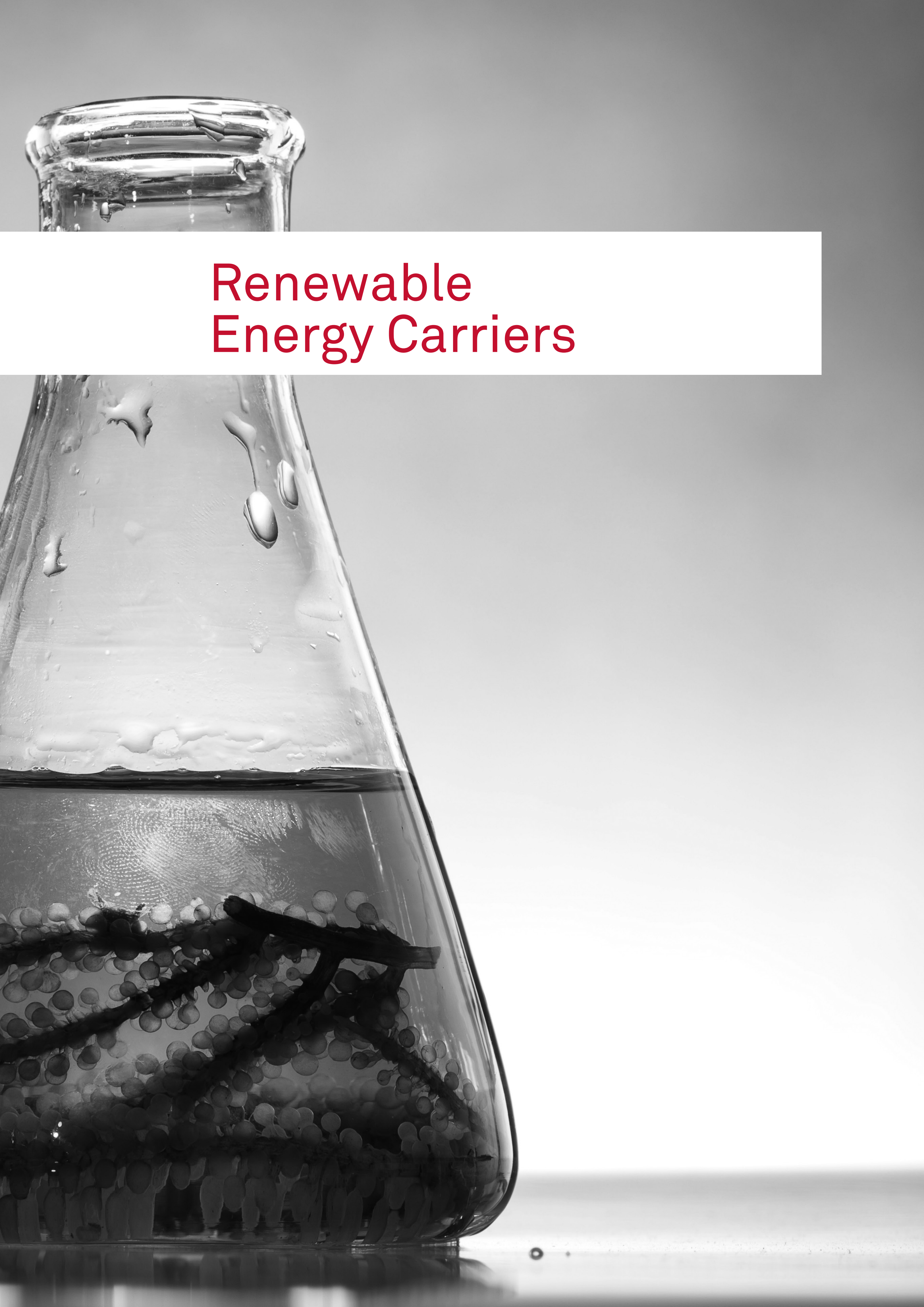
Legend

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

* a wide range of TRL is stated here since these materials already are implied in the market but further research is still necessary taking into account circular economy – e.g. research on new sustainable materials with the requested properties

** a wide range of TRL is stated since this technology profits from overlapping mutual learning: research on fundamentals with applications simultaneously, cross-sector learning

Renewable Energy Carriers



Renewable Energy Carriers

Besides of propulsion technologies, renewable energy carriers play a significant role for sustainable mobility since battery electric vehicles as well as hybrids with ICE and fuel cell electric vehicles need energy carriers, which up today dominantly originate from a fossil feedstock. On the way to a sustainable mobility these energy carriers need to become defossilized. In this roadmap the term "defossilization" is preferred over the more common term "decarbonization" since synthetic gaseous or liquid fuels except of hydrogen (H_2) and ammonia (NH_3) include at least one carbon atom. This carbon is completely climate neutral as long as it is obtained from biomass or other sources where the carbon is kept in a closed cycle (e.g. CO_2 capturing out of the air).

These chemical energy carriers are converted on board of vehicles (but also in other machines such as ships, airplanes or stationary power generators) in thermal and mechanical energy or directly to electric energy in fuel cells. The energy converters considered here are:

- Fuel Cells (FC), where hydrogen (high purity according to ISO 14687-2) but also methanol, ethanol, ammonia and other liquid fuels can be used as an energy carrier
- Compression Ignition (CI) engines where all types of flammable gases (hydrogen, bio-methane, etc.) or liquid fuels (alcohols, ether, etc.), which can form an ignitable mixture are suitable for use. In contrast to a fuel cell, the purity of the fuel is not that important

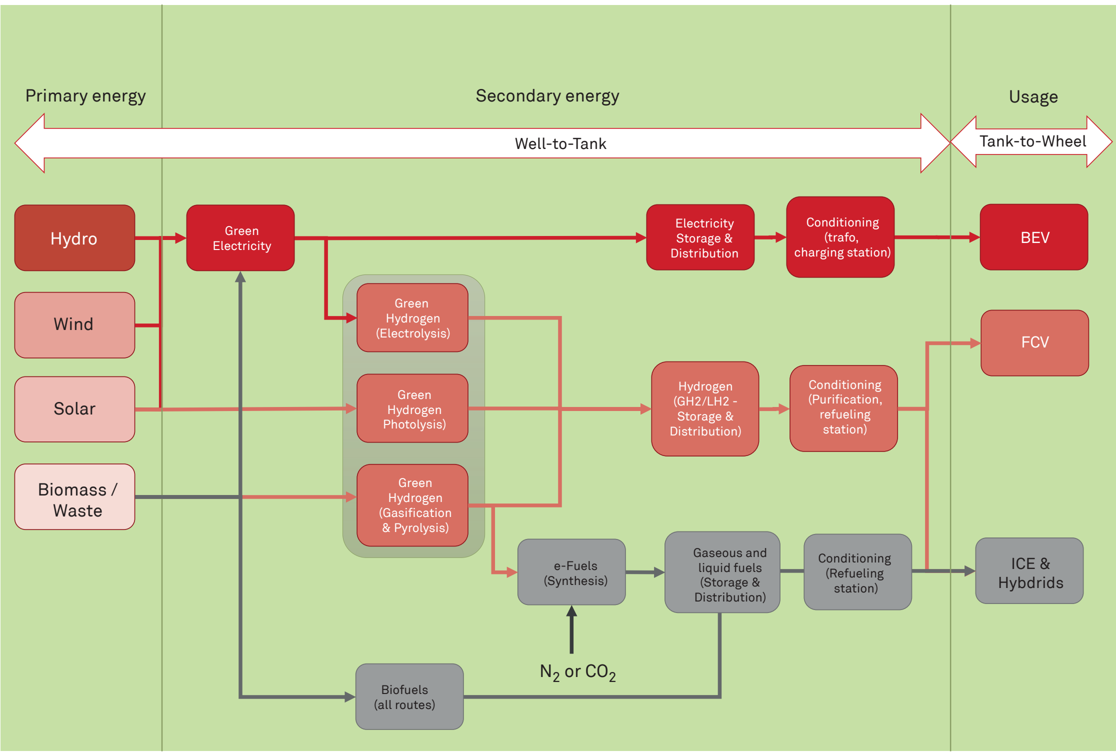


Figure 3: Scheme: Renewable Energy Carriers for Transportation

- Compression ignition (CI) engines, which are characterized by a generally higher efficiency than spark ignition engines. Above all, ignitable fuels such as FAME, HVO, OME, DME are primarily used as energy carriers. Alcohols with additives (e.g. ethanol with an ignition improver) can also be used in modified CI-engines. In dual-fuel diesel engines, any type of liquid (alcohols, ammonia) or gaseous (hydrogen, bio-methane) fuel, ignited with a diesel pilot jet, can be converted into mechanical energy

For the future variety of alternative liquid and gaseous fuels, it is difficult to make a general statement about the combustion and emission behaviour. Rather, it is crucial how well the tuning and adaptation of the engine control to the respective fuel takes place. There is still a considerable need for research in this area regarding:

- Chemical and physical properties of future synthetic bio- and e-fuels and, thus, their combustion behaviour – particularly emission species
- Use in combustion engines with advanced combustion processes (e.g. ultra-lean combustion, homogenous charge compression ignition etc.) and special operation conditions (e.g. single point operation or operation at constant engine speed)

Renewable electricity is important both as an unconditional requirement for e-mobility and to produce renewable hydrogen via electrolysis and e-fuels. Additionally, fuels produced from biogenous feedstock play an important role for defossilization of the transport sector.

Direct use of renewable electricity in battery electric vehicles results in the highest efficiency but electricity is not always produced where or when needed and therefore must be stored and transported. Compared to batteries, energy carriers such as hydrogen and e-fuels have much higher energy densities. Instead of converting them back to electricity when needed, it is more efficient and rational to use these energy carriers directly for combustion or in fuel cells.

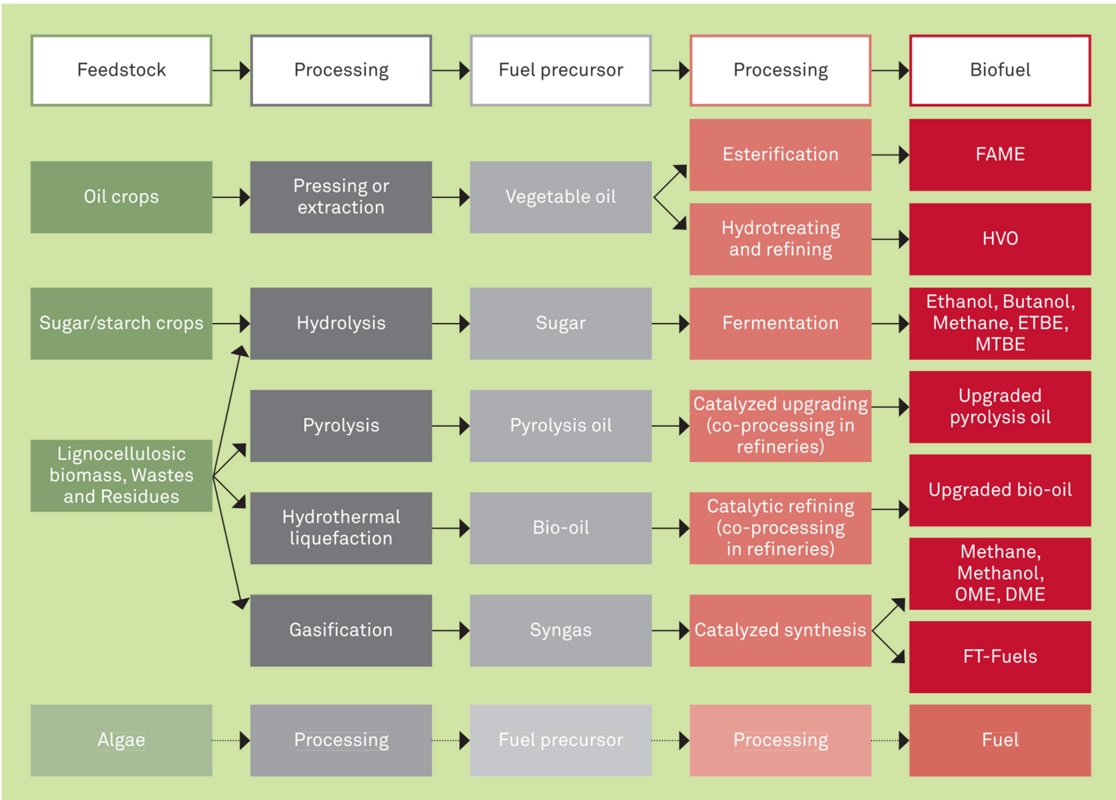
This Roadmap will not go into detail about renewable electricity production and storage. This topic is covered in other publications[23]. The focus in this roadmap is on liquid and gaseous fuels based on biogenous feedstock and/or renewable electricity.

The use of renewable fuels (including renewable hydrogen) in internal combustion engines allows a significant reduction of GHG emissions (down to CO_2 neutral mobility, or even negative emissions in case of carbon capture and storage) for the existing vehicle fleet. Of all options to reduce GHG emissions from road transport, the use of renewable energy has the largest potential.

The importance of hydrogen is also covered in the recently published hydrogen strategy "Wasserstoffstrategie für Österreich"[24], which comes to the conclusion that In areas of mobility that are difficult to electrify, climate-neutral hydrogen is indispensable as a gaseous energy carrier and chemical raw material and represents the most effective path to decarbonization. Analysis of future applications for hydrogen in aviation and the identification of necessary adaptations of the technical, legal and institutional framework are discussed in the Austrian Hydrogen Aviation Study. [25]

In the long-term, optimized combustion engines will still be needed and applied in powertrains for particular applications such as heavy duty or long-distance on/off-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 shall directly contribute to short- and medium-term reductions of GHG and local pollutant emissions. Depending on the GHG emissions from the production pathway, hydrogen and renewable fuels can be more environmentally friendly than systems with all electric powertrains, and additionally offer the advantage to be applicable in the existing infrastructure.

Figure 4: Production Pathways of Biofuels considered



[23] e.g: https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf, retrieved 8 June 2022
https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0576.pdf, retrieved 8 June 2022
https://www.klimafonds.gv.at/wp-content/uploads/sites/16/Technologieroadmap_Energiespeichersysteme2018.pdf, retrieved 8 June 2022

[24] https://www.bmk.gv.at/themen/energie/energieversorgung/wasserstoff/strategie.html, retrieved 8 June 2022

[25] AH2AS-Studie: M. Nöst, H. Friehmelt, M. Friedmann, A. Hauthaler, A. Ottitsch, A. Rautnig, A. Wolfbeisser et.al:"AH2AS - Austrian Hydrogen Aviation Study", study coordinated by A3PS Vienna 2022, in preparation

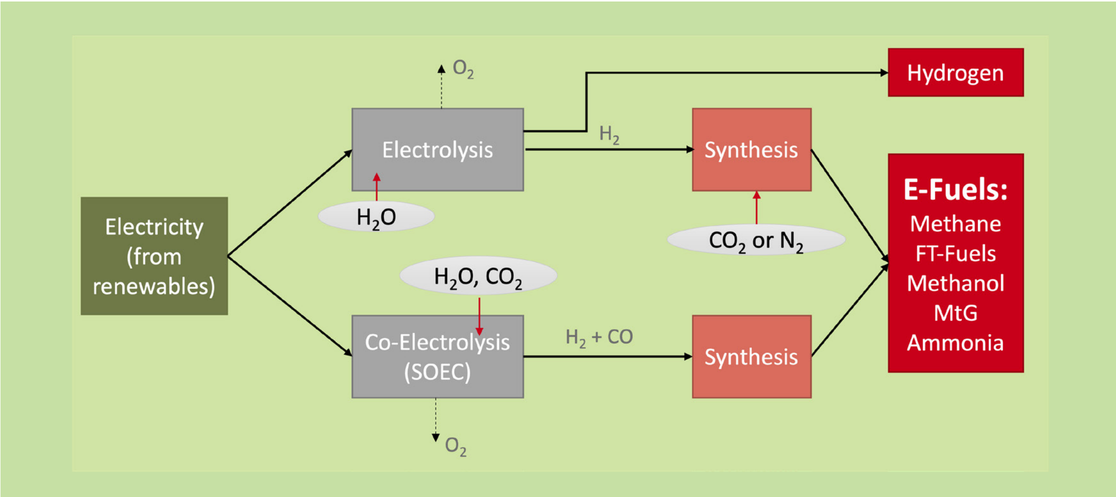


Figure 5: Production Pathways of Hydrogen via Electrolysis and E-Fuels

There is a range of renewable fuels that can contribute to defossilizsation of 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). They can either be used as a substitute or as a blending component.

A large number of production pathways exist for biofuels and for e-fuels. Figure 4 provides an overview of the production pathways for biofuels considered in this chapter, and Figure 5 provides a schematic representation of the production of e-fuels.

The main driver for the implementation of renewable fuels is the European Renewable Energy Directive 2018/2001/EC, which prescribes that 14 % of all fuels used in each member state in the transport sector shall be based on renewable energy sources by 2030.

Internal combustion engines especially as part of hybrid powertrains will remain an important power unit at least in the period covered by this roadmap and further on applications such as long-distance and heavy-duty vehicles, trains, ships and airplanes. 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).

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

E-Fuels (PtL, PtG) are synthetic fuels, which combine CO_2 as carbon source with renewable hydrogen. CO_2 can be sourced from exhaust gases of industrial processes (integrated energy), from biomass installations, or directly from the 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.

Hydrogen Production via Electrolysis

Hydrogen Generation

The significant increase of renewable energy sources in the power sector will also require the use of energy storage and smart grid solutions capable of handling the variable generation profile.

Hydrogen is an energy carrier that can play a crucial role in closing this spatial and temporal gap as well as addressing these challenges. Hydrogen can be used as a feedstock, a fuel, an energy carrier and an energy storage medium, thus offering numerous applications in the industrial, transport, energy and building sectors. The usage in these various applications can result in faster market penetration of renewable hydrogen, especially during the on-going ramp-up phase. Most importantly, if produced sustainably, it does not cause CO_2 emissions and does not pollute the air when used. It is therefore an important part of the overall solution to achieve the climate neutrality target as fast as possible. Complementing other storage applications, including pump-storage and batteries, as well as smart grid applications, it can serve as a vector for seasonal renewable energy storage. In addition, there is significant potential to repurpose current gas infrastructure for the transport and storage of this hydrogen, which would help achieve the EU‘s climate targets much faster and more economically with existing infrastructure. Further improvements are required especially in cost reduction and efficiency increase for a variety of renewable hydrogen production routes, the main workhorse being electrolysis, supported by other routes exploiting direct sunlight such as thermal dissociation of water using concentrated solar energy or through photocatalysis, biomass/biogas or other biological routes. Today, the most promising way to produce green hydrogen is via electrolysis supplied by green electricity.

Water electrolysis (Alkaline Electrolysis – AEL) has been used to produce hydrogen in industry for nearly a century. Electrolysis has the potential to be a zero-emission form of hydrogen production, if powered by renewables. Electrolysis is key for enabling renewable energy penetration into all sectors, with electrolytic hydrogen being produced at, or transported to, the points of use. Renewable hydrogen produced through electrolysis enables the increased penetration of variable renewable energy into sectors hard to decarbonize like industry, transport, building and heating. However, considerable development of electrolysis technology, cost, performance and durability, connectivity to renewables, water management and the scale of deployment is still needed to achieve this vision. Other technologies such as Anion Exchange Membrane Electrolysis (AEMEL) and Protonic Ceramic Electrolysis (PCEL) as well as reversible electrolysis and co-electrolysis will contribute to technology progress, widening the impact to the energy and industrial sectors.

Hydrogen production via electrolysis is currently more expensive than via other methods due to the high capital costs of the electrolysis and dependence on electricity costs. The key objectives are:

1. Reducing electrolysis CAPEX (Capital Expenditures) and OPEX (Operational Expenditures)
2. Improving dynamic operation and efficiency, with high durability and reliability, especially when operating dynamically
3. Increasing current density and decreasing footprint
4. Demonstrate the value of electrolysis for the power system through their ability to provide flexibility and allow higher integration of renewables;
5. Ensure circularity by design for materials and for production processes, minimising the life-cycle environmental footprint of electrolysis
6. Increasing the scale of deployment
7. Improved manufacturing for both water and steam electrolysis

Future cost reductions and increased lifetime in the different electrolysis technologies may be realised through new materials/manufacturing processes/concepts as per the priorities below.

- Generic for all electrolysis: develop new electrodes and membranes, reducing / free of Critical Raw Materials (CRMs) and reducing / without per- and polyfluoroalkyl substances in order to avoid in the medium- to long-term their use in different materials or components such as electrocatalysts, MEAs (Membrane Electrode Assembly), etc., as well as novel and breakthrough cell design, to increase the current density, while improving their lifetime and efficiency, develop low-cost metallic materials coatings and seals, develop and validate integrated mounting concepts, thermal management and innovative manufacturing processes
- Development of novel catalysts (low PGM, non-PGM, bioinspired) for water electrolysis)
- Minimisation of environmental impact / aim for circularity (energy, resources/material, recyclability)
- AEL: develop more compact stack design, reach high current density without noble metals, 3D electrodes, pulsed voltage
- PEMEL: Reduce precious metals content in catalysts and consider recycling, develop PGM-free catalysts, develop new/advanced membranes, reduce gas crossover while increasing current densities and operating pressures
- SOEL: pressurised stack, improved hydrogen or syngas purity at exit of stack; new materials and stack designs and use of advanced manufacturing techniques
- AEMEL: improved materials, new membranes, reduction of KOH concentration, increase scale/capacity, aiming for waste minimisation / circularity
- PCEL: planar or tubular cells of improved materials and optimised design and performances in view of scaling up to hundreds of kilowatts size
- Others: investigate the possibility of non-pure water electrolysis.

Several concepts for reducing electrolysis costs and improving technical key performance indicators have been demonstrated in the laboratory. This area can support promising applications identified through the research programme suggested above as well as:

- Improve cell design for high performance and increase cell/stack robustness through improved thermal and process-flow management
- Develop larger area cells/stacks components with adequate manufacturing quality for high power systems
- Consider innovative system designs and improved balance of plant components to reduce parasitic losses and reduce cost (e.g. purpose-built rectifiers, integrated cooling systems, electrical heaters and heat-exchangers), when relevant in optimised electrical integration with renewables;
- Develop tools and methods for monitoring, diagnostics and control of electrolysis systems
- Develop high pressure stacks to avoid/reduce the need for downstream compression or alternative compression techniques (e.g. electrochemical)
- Consider original concepts like reversible operation (electrolysis, fuel cell) and co-electrolysis (to produce syngas)
- Explore the options for utilising by-product oxygen and waste heat
- Develop new stack and balance of plant (BoP) designs adapted to several end uses, e.g. coupling

Legend

(material) fundamental research
industrial research
experimental development
demonstration

with renewables in remote areas and related constraints
- Develop automation and quality control processes for production of large volumes of cell/stacks components
- Demonstrate at the MW range the alternative electrolysis technologies – AEMEL and PCEL;
- Provide a compelling economic and environmental case for key applications e.g. feedstock for industries, transport, energy storage, heat and power
- Operate with variable load and adequate flexibility to be coupled with renewable energy
- MW scale direct coupling to renewable generation (both on- and off-grid) including offshore hydrogen production, aiming at identifying the best system configuration to reach competitiveness
- Integrating large scale electrolysis (50-200 MW) into industrial production plants, demonstrating dynamic operation
- Renewable hydrogen (both on and off-grid) for refining crude oil into complex fuels (e.g. kerosene/jet fuel)
- Ammonia and methanol production with renewable hydrogen (both on- and off-grid) to decrease GHG emissions and managing energy loads
- Production of synthetic petrochemicals (e.g. olefins, BtX and syngas) using renewable hydrogen (both on and off-grid)
- Demonstrate the ability of renewable hydrogen (both on and off-grid) as a reducing agent in iron and steel production (replacing fossil fuels such as coke and natural gas)
- Consider industrial applications where oxygen and electrolysis waste heat could also be exploited besides renewable hydrogen (both on and off-grid).

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Hydrogen Generation

PEMEC

efficiency / endurance / lifetime / cost reduction

type of project required

- reduce precious metals content in catalysts and consider recycling, TRL^{2022} 4-5
- develop PGM-free catalysts, TRL^{2022} 2-4
- develop new/advanced membranes also for higher operation temperature, TRL^{2022} 2-4
- innovative system designs and improved balance of plant components to re-duce parasitic losses, TRL^{2022} 3-4
- diagnostics of state of health, TRL^{2022} 3-4
- improved high pressure stack and systems, TRL^{2022} 4
- manufacturing and industrialization of systems up to GW range, TRL^{2022} 4

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Hydrogen Generation

SOEC

efficiency / endurance / lifetime / cost reduction

type of project required

- Increased specific power density and durability by introduction of novel cell components without or with low content of CRM as well as optimized design for hydrogen production, TRL^{2022} 2-4
- Protonic Ceramic Electrolysis Cells (PCECs), TRL^{2022} 2-3
- Increased specific power density and durability by introduction of novel cell components without or with low content of CRM and optimized design for co-electrolysis of H_2O and CO_2 for PtX, TRL^{2022} 2-4
- Improved interconnects and coatings with Cr-retention capability for lower operating temperatures, TRL^{2022} 2-3
- Improved monitoring and diagnostic tools for cells and stacks, including degradation and failure modes, TRL^{2022} 2-4
- Metal supported solid oxide and protonic ceramic electrolysis cells, TRL^{2022} 2-4
- Novel production technologies for improved recyclability of cells and stacks, TRL^{2022} 3-5

Hydrogen Storage and Distribution

As explicitly mentioned in the EU Hydrogen Strategy, it is essential that hydrogen becomes an intrinsic part of an integrated energy system. For this to happen, hydrogen will have to be used for daily and/or seasonal storage providing buffering functions, thereby enhancing security of supply in the medium-term. The strategy also calls for an EU-wide logistical infrastructure that needs to be developed to transport hydrogen from areas with large renewable potential to demand centres across Europe. A pluralistic approach with respect to the technologies that will be investigated and supported is envisaged, to have a complete set of technologies that can serve as building blocks of the EU-wide logistical infrastructure.

Hydrogen Refuelling Stations

Due to their high operational flexibility and relatively short refuelling time compared to electricity charging, FC heavy-duty vehicles are particularly suited for long-haul operations. However, in order to have a viable case for the widespread use of FC Heavy-Duty Vehicles (HDV), it will be essential that there is an EU-wide network of publicly accessible HRS. Furthermore, the larger heavy-duty fuelling applications such as buses and trains will require very reliable, high capacity stations capable of delivering many tonnes each day. To address this, the revision of the Alternative Fuel Infrastructure Regulation, requires one hydrogen refuelling station available every 150 km along the TEN-T (Trans-European Transport Network) core network and in every urban node. Synergies with CEF (Connecting Europe Facility) must support the roll-out of road HRS. European support is envisaged alongside Member State support for a large HRS deployment in Europe.

To date, most existing HRS are dedicated to the use of passenger vehicles and cannot be used by heavy-duty trucks due to different technological requirements for filling up the much larger truck tanks. However, the increasing number of stations is promising, and the existing foundation of HRS in Europe could partly be upgraded for truck-specific refuelling soon. As refuelling infrastructure is adjusted to meet the needs of heavy-duty trucks, more demonstration projects become feasible, providing a foundation for larger scale commercial deployment.

European manufacturers dominate the global supply of hydrogen stations. Furthermore, Europe has a larger deployment of hydrogen stations compared to any other region, which provides greater experience in the operation and support of these stations than elsewhere. This positions Europe to be a long-term leader in the supply of stations worldwide. Based on the experience from the HRS deployment so far, there are significant issues with publicly accessible stations, which can all be resolved over the coming years:

- The costs of the refuelling stations are high (both CAPEX and OPEX), which creates a challenge in creating a competitive refuelling station business model, particularly in the early years when utilisation is low
- The station availability is currently too low. This creates issues for customers who cannot rely on their hydrogen supply and can be particularly problematic for HDV users. This situation will be partly resolved through increased throughput at the stations but will also benefit from improved components (particularly compressors and dispensers)
- The permitting and construction process is too long – leading to a need to improve standardisation, technical certification and also levels of education and awareness amongst regulators
- The design of the HRS is heavily influenced by the respective fuelling protocols, which need to be jointly developed with vehicle manufacturers to allow a safe and reliable refuelling. Regarding maturity, refuelling protocols for Light Duty Vehicles (LDV) will be in place more readily, while for heavy-duty vehicles there is an urgent need for their quick development in order to enable the massive deployment of HDV foreseen by 2030
- In addition, there is technical work, which needs to be done to develop and optimise concepts for high capacity refuelling for heavy-duty vehicles and vessels, as well as to facilitate the use of renewable hydrogen, e.g. produced onsite by electrolysis or biomass. Heavy-duty transport is expected to be a relevant driver for HRS deployment
- Finally, there is a lack or limited availability of existing cross-border infrastructure and cooperation.

Research actions should be:

- Better interfacing technology is required between hydrogen vehicles and HRS to ensure optimal (and safe) fueling protocols
- Increasing flexibility and enabling low inlet pressure are necessary to support the use of renewable hydrogen produced on-site
- Specific components are currently missing and need to be developed to contribute in the HRS schedule e.g.: heavy-duty nozzles and flexibles, chillers for heavy-duty purposes, multipurpose refuelling protocols
- Development of new approaches to decrease overall HRS footprint
- Develop high throughput stations for large scale vehicles (ships, fleets of trains, large fleets of buses or trucks), including higher than 1000 kg/day capacity and individual fills in excess of 200 kg (in less than 20 minutes);
- Reduction in the CAPEX and OPEX of high capacity HRS through integrating innovative technological components – development work here would focus on how to integrate those components;
- Facilitate the use of locally produced renewable hydrogen, e.g. by enabling low inlet pressure and flexible operation for variable RES (Renewable Energy Sources).

Legend

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

- Standardise and industrialise heavy-duty HRS equipment and components
- Increase the reliability, safety and availability of heavy-duty HRS equipment and infrastructure for all road vehicles
- Deployment of high throughput stations (multi-ton/day) for large scale ships, fleets of trains or large fleets of buses and trucks
- Support improved efficiency and minimisation of boil off during hydrogen transfer and distribution at a HRS based on liquid hydrogen
- Explore novel business models, for example, on-demand hydrogen refuelling and compact hydrogen mobile stations

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Hydrogen Generation, Storage and Distribution

Hydrogen Generation

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

type of project required

- Low temperature electrolysis (PEMEC), TRL[2022] 3-8*
- High temperature electrolysis (SOEC), TRL[2022] 3-4
- Central and de-centralized hydrogen production concepts, TRL[2022] 4-6
- Refuelling stations (reliability, costs, official verification ...), TRL[2022] 5-6
- Optimization of energy supply – linkage of electricity and gas grid, TRL[2022] 4-6
- Compliance of hydrogen quality over entire supply chain, TRL[2022] 7-8
- High pressure electrolysis, TRL[2022] 4-5
- Integration of various hydrogen sources via compatibility of transport modes of hydrogen, TRL[2022] 4-6
- Liquid Hydrogen (LH_2), TRL[2022] 4-6
- AEM electrolysis, TRL[2022] 4-6
- Develop high throughput stations and the supply chain for large scale roll-out with focus on heavy duty, TRL[2022] 3-5
- Reduction of footprint CAPEX and OPEX of HRS and improvement of efficiency, TRL[2022] 3-5
- Advanced compression concepts (electrochemical processes, thermal processes), TRL[2022] 3-4
- Feed-out and purification of hydrogen on-site at HRS, TRL[2022] 3-4

* wide range of TRL because of different generations of PEMFC; PEMFC are already applied in the market but a new generation of PEMFC, which require less PGM still requires fundamental research

E-Fuels based on Hydrogen produced via Electrolysis

Examples of PtL processes included the production of hydrocarbons via the Fischer-Tropsch (FT) process and the production of methanol, and the resulting fuels, e.g. MtG (Methanol-to-Gasoline), can be used as full substitutes or blends. PtG (methane) can be produced via the Sabatier process, 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.

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

E-Fuels

E-Fuels (PtL, PtG)

Pilot plants or demonstration units

type of project required

- Demonstration of small to medium scale PtL/PtG gas units, integration in AD plants, or other CO_2 sources, TRL[2022] 4-6
- Development of units or processes with higher efficiency for PtX, like low temperature rWGS reactor, TRL[2022] 4-6
- Technologies to separate CO_2 from the atmosphere, TRL[2022] 3
- First Commercial E-Fuels Facility, TRL[2022] 5

Biofuels

Biofuels are fuels, which are produced through contemporary processes from biomass, rather than by the very slow geological processes involved in the formation of fossil fuels, such as oil.

Advanced biofuels, also known as 2nd generation biofuels, are fuels that can be manufactured from various types of non-food biomass. Conventional biofuels, also known as 1st generation biofuels, are made from sugar-starch feedstocks and edible oil feedstocks, which are generally converted into bioethanol, biodiesel, respectively. Advanced biofuels are made from different feedstocks and therefore may require different technology to extract useful energy carriers from them.

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 at the demonstration stage. 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. Ethanol with 5% ignition improver and lubricant additive is referred to as ED95 ethanol diesel and is suitable for use in modified diesel engines.

Methanol can be used in various blends with gasoline[26], or further processed into MTBE. Generally, methanol combustion shows low emissions of carbon monoxide, hydrocarbons, nitrogen oxides and particles, 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 NOx-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 NOx-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.

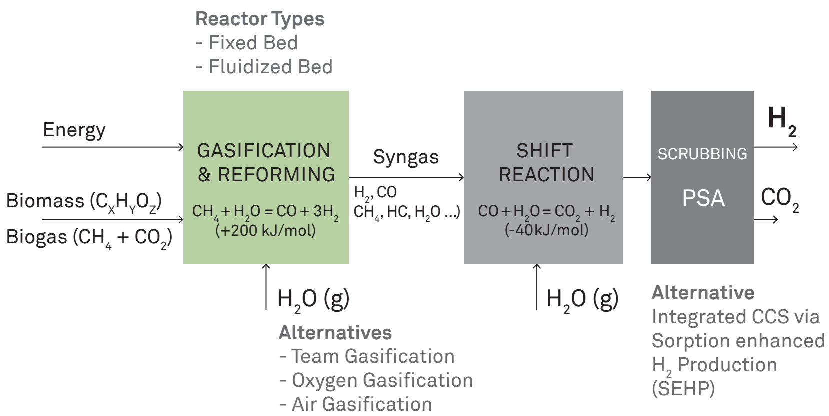
Bio-Methane can be produced from various sources of biomass via two different pathways (fermentation or gasification). In any case, after upgrading, the resulting product is methane of a quality similar to that of natural gas. Bio-Methane can be blended at any ratio with or fully substitute natural gas.

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 by-product 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.

Hydrogen from Biomass: For the conversion of biomass to (green) hydrogen the following paths are from interest for the industry:

[26] https://iea-amf.org/content/fuel_information/methanol, retrieved 8 June 2022

Figure 6: Scheme H_2 Production Process via Thermal Gasification of Biomass



Legend

(material) fundamental research

industrial research

experimental development

demonstration

1) Thermal Gasification,
2) Production of Biogas (Methane Fermentation) and Steam Reforming,
3) Biological H_2 Production via Bacteria,
4) Electrochemically assisted Production.

ad 1): Thermal Gasification & Reforming Process, characterized through an Endothermal process, Gasification using Steam, Oxygen within the Biomass supports the endothermic Process, Water Gas Shift Reaction to increase H_2 Output is seen with very high potential.

Algae-based biofuels, which are also referred to as 3rd generation fuels 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 focus on higher value products. Even though algal biomass is still far from the market, motives for the continuation of the research are high yields per area, which can theoretically be achieved, the possibility of production on unused land including coastal sea areas and medium to long-term opportunities for Austrian technology suppliers.

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-crude 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.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Biofuels

Fischer-Tropsch fuels from biomass

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

type of project required

- Utilization of waste materials as feedstock, TRL^{2022} 6
- Energy-efficient syngas cleaning for FT synthesis, TRL^{2022} 7
- Demonstration of gasification and FT synthesis at large scale, TRL^{2022} 7
- First commercial-scale gasification and FT synthesis facility, TRL^{2022} 7

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Biofuels

Methane via anaerobic digestion

commercial decentralized systems (pilot plant available)

type of project required

- Cryogenic upgrading unit connecting several AD plants in remote areas, TRL^{2022} 4-6
- Integration of PtG units in decentralized AD plants, TRL^{2022} 3-6

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Biofuels

Hydrogen and Methane via gasification

commercial decentralized systems (demo plant available)

type of project required

- First commercial-scale gasification and methanation facility, TRL^{2022} 8
- Hydrogen production via thermal gasification and steam reforming, TRL^{2022} 6-8

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Biofuels

Algae-based fuels

bring down the cultivation, harvesting and processing costs

type of project required

- LEnhanced productivity of known algae species, TRL^{2022} 6
- Enhanced stability of algae cultures, TRL^{2022} 6
- Cultivation of algae species with higher fatty acid content, TRL^{2022} 6
- Cultivation of mixed species cultures for higher stability and productivity, TRL^{2022} 6
- Reduction of production costs / production in biorefineries that produce high-value products along with fuels, TRL^{2022} 6
- Target algal biomass as product to stimulate mass production, TRL^{2022} 6
- Integration of algae biomass production with downstream processes, TRL^{2022} 6
- Zero waste production / biorefinery concept, TRL^{2022} 6
- Adaptation of regulations, guidelines and standards to the cultivation, pro-cessing and utilization of microalgae, TRL^{2022} 6

short-term until 2025 | **medium-term** 2025-2030 | **long-term** 2030+

Biofuels

Co-processed fuels

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

type of project required

- Hydrotreating & upgrading of FT-waxes, pyrolysis oil, or other biocrudes (products from HTL or APR), TRL^{2022} 3-6

Legend

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

Advanced Powertrain Integration Technologies on Vehicle Level

Advanced Powertrain Integration Technologies on Vehicle Level

Aside from advanced powertrain technologies treated in the previous chapters, this chapter focuses on technologies on vehicle level, which considerably influence the vehicle performance, fuel consumption, efficiency and environmental impact. Beside electrification, digitalization rises as new challenge.

Digitalization and digital twinning are key to enable predictive control and bringing components and systems close to their limits, without having to consider production tolerance-based safety margins. Special emphasis will be put on these aspects in this updated version of the roadmap.

On the other hand, some topics – although considered as extremely relevant for automotive research – have been excluded from this roadmap (although they have been treated in a previous version). These topics are:

- Advanced human machine interfaces providing the information individually and context-based: this is relevant for safety but could also be beneficial from an energy efficiency point of view (e.g., nudging energy efficient driving)
- Traffic flow optimization: relevant for energy efficiency and pollutant minimization
- Comfort related topics (except thermal comfort, which has a clear impact on energy efficiency): noise, haptic comfort etc. are relevant in automotive industry but are not considered in this roadmap
- Vehicle automation and autonomy: extremely relevant with high need of funded research, but not considered in this roadmap since the weight is more on the safety aspect than on the efficiency aspect

ADAS is thought along in this roadmap when directly relevant to the powertrain. The whole field of ADAS would break the mould of this roadmap since we shouldn't consider only the vehicle level but also the infrastructure. Automated vehicles usually are not autonomous but connected and a holistic approach of ADAS always includes both vehicle and infrastructure.

This chapter is structured as follows:

1. Methodology, development tools and measurement
2. Advanced auxiliaries, components and systems enabling energy savings
3. Advanced vehicle control systems
4. Lightweight design and materials

Methodology, Development Tools and Measurement

Advanced "Methodologies, Development Tools & Measurement", is the basis for efficiently designing powertrains and systems of the future and control them during operation adaptively (according to their individual and current state). Hence, a digital representation of individual components and systems is needed to predict their behaviour, predict maintenance needs and foresee degradation effects.

To retrieve information that is necessary to feed digital twins during operation, new affordable and sometimes higher precision drift-stable sensor technologies are required that could be augmented with virtual sensors in the control loop.

How this information is further processed (with the help of AI methods and machine-learning) in an energy-efficient way is challenging and will not be possible with traditional computing architectures: Edge-Computing, cloud-computing and neuromorphic architectures will be needed as foundation.

On computing level new paradigms have to be considered (edge / cloud / neuromorphic), which enable fast energy saving computation of huge amounts of data that are used for building data-driven models for digital twins.

Considering life-cycle aspects, re-use and recycling, this circular economy requires standardized LCA procedures and data that can be implemented in tools providing context-based information to the designers of new systems.

Overarching above mentioned topics is a system of systems engineering approach, which enables to analyse and optimize complex systems that are composed of several systems. A system of systems approach will lead to more complex systems that are performing better than just the sum of single systems. A methodology for system of systems approach is still incomplete and has to be developed.

For this system of systems approach it is absolutely necessary that standardized methods are developed that tackle the whole process from

- Data generation: what data is necessary, in which quality to retrieve the desired information (AI and machine learning cannot compensate for inadequate, incomplete or wrong data)
- Virtual Approval:
  - design of adequate ODDs (Operating Design Domains) on component, system and system of systems level;
  - quantification of uncertainty

The table on the next page provides an overview:

Advanced Powertrain Integration Technologies on Vehicle Level

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Development Tools, Methodologies, Measurement and Test

Enabling significant energy efficiency increase, considering circular economy and life-cycle

type of project required

- Digital twin of energy systems (enabling operation close to limits and prediction), TRL^{2022} 7
- Standardized LCA methods and data, TRL^{2022} 9
- Methods for LCA and circular economy in the design phase, TRL^{2022} 8
- Local/multi-physical data driven modelling, virtual sensors, TRL^{2022} 7
- Computing: neuromorphic, edge, cloud, TRL^{2022} 6
- System of Systems Engineering, TRL^{2022} 8

Advanced Auxiliaries, Components and Systems enabling Energy-Savings

Energy and Thermal Management: Trustworthiness for range prediction and charging of electrified vehicles have to be increased. Retrieving relevant vehicle information – such as state of charge, and state of health of the battery and information concerning the trip are crucial to plan charging with the power needed to complete the trips in the desired time, while taking into account time-dependent available power at charging stations. This requires the knowledge of the demand of other drivers, a decent information and control system and also information about the actual state of the distribution grid. Power losses that occur during the charging process shall be transferred to other systems, where these heat losses can be used effectively. Prediction of the behaviour and predictive control of components is crucial for increasing energy efficiency on system level. While the predictive control has been demonstrated in several applications, digital twins of components and retrieving information on traffic and road conditions for the upcoming kilometres offer a high potential to increase energy efficiency. Predicting the thermal comfort of passengers in battery electric vehicles is key for reliable range prediction (especially in winter). For new battery concepts thermal conditioning like Cell-to-Pack design with highly efficient and highly thermal uniformity concepts like dielectric fluid immersion cooling with focus on long-term stability has to be ensured.

Advanced Powertrain Integration Technologies on Vehicle Level

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Energy and Thermal Management

efficiency / optimum use of avail-able energy

type of project required

- Access to relevant vehicle information for charging in cooperation with Cooperative, Connected Automated Mobility (CCAM), TRL^{2022} 3-7
- Predictive energy/thermal management of cabin and powertrain components, TRL^{2022} 5-8
- Silent cooling and heat loss recovery during High Power Charging (HPC), TRL^{2022} 5-7
- Operation of components closer to thermal limits, TR^{2022}L 4-9
- Thermal Conditioning of new battery concepts, TRL^{2022} 4-8

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 powertrains (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 powertrains 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.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Advanced Powertrain Integration Technologies on Vehicle Level

Heating, Ventilation and Air-Conditioning (HVAC)

efficiency (range) vs. comfort and power / integration / self-adaptive control

type of project required

- High-Performance battery Cooling during high power charging (HPC), TRL^{2022} 5-9
- Local cabin conditioning and surface heating, TRL^{2022} 3-5
- Heat pump system for HVAC, TRL^{2022} 7-9
- Self-adaptive (AI-supported) comfort based HVAC control, TRL^{2022} 3-5
- Predictive maintenance, TRL^{2022} 5-8

Innovative "Regenerative Braking Systems, particle free braking" 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.

short-term until 2025 **medium-term** 2025-2030 **long-term** 2030+

Advanced Powertrain Integration Technologies on Vehicle Level

Regenerative Braking Systems

efficiency / reducing particles / braking comfort

type of project required

- High performance 4-wheel regenerative braking system for optimal energy recuperation, TRL^{2022} 5-7
- Reducing particles / braking comfort, TRL^{2022} 5-6
- Energy recuperation / actuators, TRL^{2022} 7-9

High power energy storages offer a high potential in terms of GHG reduction when combustion engines are used in the powertrain. These storage systems can be

- Supercaps
- Electro-mechanical storage systems or
- Dedicated high power batteries

Legend

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

		short-term until 2025	**medium-term** 2025-2030	**long-term** 2030+
Advanced Powertrain Integration Technologies on Vehicle Level	**High-Power Storage Systems** efficiency / optimum use of available energy / remote energy supply type of project required	Supercaps, TRL[2022] 6		
		Electro-mechanic storage, TRL[2022] 6		
		Dedicated high-power post Lithium batteries, TRL[2022] 4		

Advanced Vehicle Control Systems, and Software

Advanced control methods for vehicle powertrains (e.g. fuel cell hybrids) that both minimise component degradation and maximise efficiency are crucial. For example, predictive control schemes that consider forecasts on e.g. route, traffic, weather, etc. are necessary. State-of-health monitoring systems (virtual sensors) as well as adequate new sensors to measure the operating conditions (e.g. in batteries or fuel cells) without negatively influencing their operation are required. Future vehicles will continuously provide their operational data (e.g. battery health parameters) to a central unit over the air. This enables new opportunities to evaluate the performance of a whole vehicle fleet in real-time. Adjustments to battery degradation models and associated operation strategies can be fed back to the vehicle fleet. Thus, adaptive control strategies could be implemented on the fleet level, optimising component lifetimes, emissions and efficiency on the go, without the need for maintenance downtime.

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.

Increasing number of sensors in vehicles to cope with new challenges, like environmental perception, measurement of components and system states for control functions and the future use of trustworthy digital twins require the efficient use of sensing equipment on board.

Automated driving functions of SAE Levels 3 to 5 will enable the driver to give the driving task to the vehicle to increase safety, comfort as well as efficiency of traffic and transport. However, a prerequisite for this is that the driving functions are objectively verified to an unprecedented extent. Currently, there is no method that allows to perform the associated verification process at a reasonable cost to the industry. In scientific literature, there are approaches available that propose incredible real driving testing distances, but such efforts are not feasible in industrial projects. Therefore, new innovative smart approaches consisting of virtual methods, real-world testing and combination of both must be found that allow a holistic verification of the automated driving functions on complete vehicle level. For the use of such new approaches in industrial vehicle development it is important that these new methods can be performed with the available resources to ensure safe and comfort orientated operation of automated vehicles, whether they are developed for public traffic or for special applications on restricted areas.

Legend

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

Advanced Vehicle Control System		**short-term** until 2025 / **medium-term** 2025-2030 / **long-term** 2030+
	Sensors Efficiency, extended lifetime type of project required	Sensor Fusion (including quantification of uncertainty), TRL^{2022} 6-9
		Virtual Sensors (including quantification of uncertainty), TRL^{2022} 5-8
		Drift Stable multi-physical Quantum Sensors, TRL^{2022} 2-5
		Multi-use of sensors, TRL^{2022} 3-5
		Sensor Modelling and Digital Twinning, TRL^{2022} 3-7

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 powertrains, including the operating strategy.

For xCUs virtual validation will become increasingly important, when over-the-air software updates should become reality. Modular software functions that can be validated in respective (well-designed) ODDs will be essential for virtual validation.

V2X capable on-board units will still have to be validated in real-world traffic.

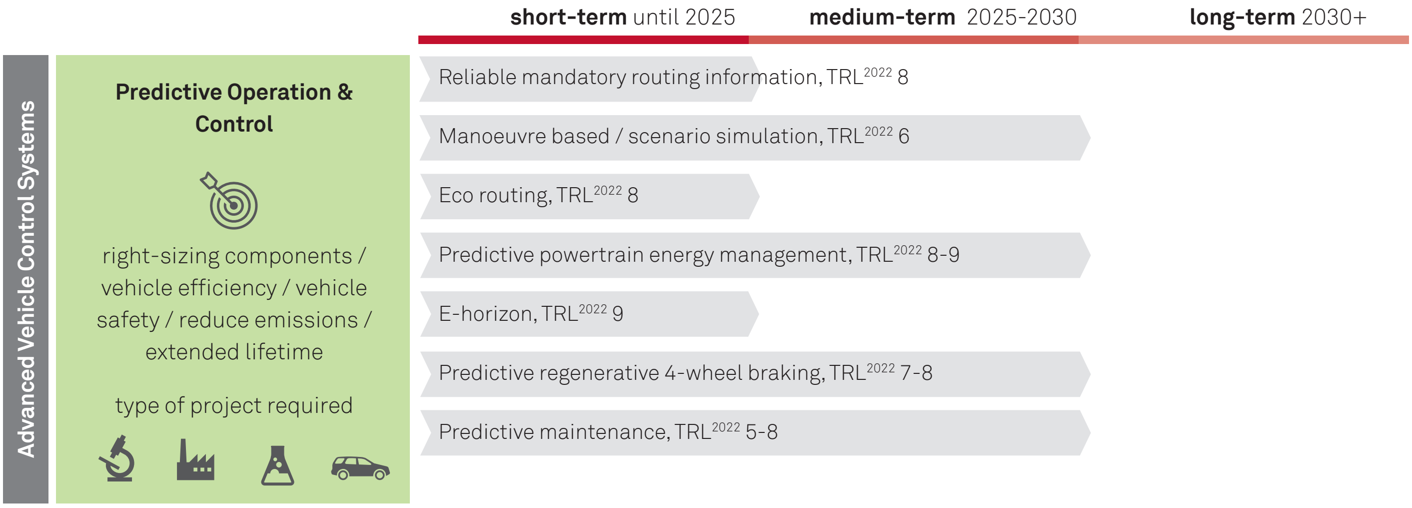
Zone controllers are emerging in the automotive industry as nodes or hubs that solve zone specific tasks, which decreases cabling effort and weight. For these zone controllers to work in a complex system-of-systems self-X capabilities are mandatory (X stands for monitoring, diagnosis and possibly taking over control tasks from other not functional controllers).

Multi-core controllers are needed to handle complex (sometimes model-based) control functions; however their price is still hindering their use in automotive industry. New emerging neuromorphic architectures (e.g. dedicated in distributed environments to deal with specific computing tasks) will be essential for reliable and complex computing in future architectures.

Advanced Vehicle Control System		**short-term** until 2025 / **medium-term** 2025-2030 / **long-term** 2030+
	xCU incl. Software efficiency / emissions / security / safety type of project required	Virtual xCU: virtual validation (incl. model validation and generation of digital twins), enhancement of FMI/FMU, TRL^{2022} 4
		V2X capable on-board units (road-side units) – validation in traffic management, TRL^{2022} 8-9
		Modular software function, TRL^{2022} 4-6
		Self-X of zone-CUs, TRL^{2022} 5
		Multi core controller and neuromorphic architectures, TRL^{2022} 4-6

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. Predictive maintenance is becoming increasingly important when fail-safe operation of relevant drivetrain components is considered but also degradation effects that can affect efficiency of the entire system.

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



Lightweight Design and Materials

Lightweighting is a key technology and a cross-cutting issue, which itself requires more attention in research and development instead of being only enabler of other topics like low-emission mobility. In today's world, lightweight construction must be sustainable, smart and affordable in order to be able to support the European goals of the green deal or national aims as e.g. from the Mobilitätsmasterplan 2030. For the focus area of A3PS, this means on the one hand, the lightweight vehicle design to minimize energy consumption through reduced vehicle weight and thus extending the range of the vehicles. On the other hand, lightweight construction is of particular relevance for future, new propulsion systems and their components. The basic idea of lightweighting, to use constructions and materials with better mechanical properties at a lighter weight is still valid. Thus, further topics are still the improvement of high-strength materials and new lightweighting alloys, such as Aluminium, Magnesium, etc. for engines, transmissions, electric components and of course the whole chassis. In addition, new alloying/material concepts like the "one-alloy/material-fits-all" approach is one of the most promising technological options that make subsequent recycling more efficient and save resources during production. In this way, the issues of recycling and circular economy, which are no longer negligible nowadays, are considered by means of modern materials in the powertrain. In addition to this material approach, the consistent pursuit of functional integration to drastically reduce the number of components and expand the tasks of structural components, for example, is a promising approach. Additive manufacturing is a key technology that enables the production of these complex, function-integrated components. To further increase the sustainability of lightweight construction, it is necessary to design the function-integrated components and constructions in such a way that they are suitable for repair/reuse/recycling (including even automated dismantling) and thus enable a longer service life and circular economy. With all these new materials and components in the powertrain, it must be considered that the joining techniques also meet the new requirements and must therefore also be adapted and optimized in additional research projects. However, all these approaches are only promising if the energy content (or the CO_2 footprint) in the material and the resulting lightweight construction are also considered and reduced. An additional focus should be laid on an overall cost-benefit view, including economic and ecological factors.

Legend

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

		short-term until 2025 / **medium-term** 2025-2030 / **long-term** 2030+
Lightweight Design	**Lightweight Construction / Materials** efficiency / mass reduction / manufacturing / costs / recycling type of project required	High performance lightweight materials incl. "one-alloy/material fits all" approach, TRL^{2022} 2-5
		Reduced number of components, TRL^{2022} 6-7
		Highly integrated components, TRL^{2022} 2-5
		Additive Manufacturing, TRL^{2022} 2-7
		New advanced joining technologies, TRL^{2022} 3-4
		New simulation methods for material design and material performance, TRL^{2022} 3-7
		Non-destructive testing methods and material characterization, TRL^{2022} 3-8
		Suitability for repair / reuse / recycling / circular economy of materials, TRL^{2022} 4-7

Challenges

Technology-related challenges in the core areas powertrain, 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 powertrain systems the 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 powertrain 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 powertrain concepts require innovative, intelligent production methods in order to produce efficiently and in a cost-saving 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 powertrain 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 powertrain, it is necessary to introduce companies mainly from the electronics sector to the automotive industry.	**Qualification process** To meet the high demands in the automotive industry, an appropriate qualification process must be established.
Ensure product quality and market-led product cycles New powertrain systems must meet all criteria such as functional safety, high product quality and efficiency. At the same time, sufficient short develop-ment times are required already at the first launch.	**Development of new simulation tools and measurement techniques** For new powertrain systems integrated tool chains need to be developed from simulation to series testing.
Control and regulation technology Future powertrain 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 measurable values for energy and resource efficiency as well as for the overall energy consump-tion (LCA, cradle-to-grave, weel-to-wheel). Development of standardized evaluation methods and tools.
Reduce development time	**Simulation and Software** Software tools are needed to support technical potentials.
Harmonization 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.	**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.

Research Requirements and Funding Instruments

To intensify long-term research and development in all areas addressed within this roadmap, companies and R&D institutions 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. 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.

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
- Differentiated funding rates from research to demonstration projects
- 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 – without any claim to completeness:

- **EARPA** (European Automotive Research Partners Association)
  https://www.earpa.eu/earpa/home

- **ERTRAC** (European Road Transport Research Advisory Council)
  https://www.ertrac.org

- **EUCAR** (European Council for Automotive R&D)
  https://www.eucar.be

- **FCH-JU** (Fuel Cells and Hydrogen Joint Undertaking)
  https://www.fch.europa.eu

- **IEA** (International Energy Agency)
  https://www.iea.org

- **IPHE** (International Partnership for Hydrogen and Fuel Cells in the Economy)
  https://www.iphe.net

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

Requested national funding instruments

The topics defined in this Roadmap follow the specific strengths of the Austrian R&D community in this field. Nationally funded research programs should help to further strengthen this know-how and expertise, thus preparing the path for successful participation in European programs such as Clean Hydrogen Europe, the Hydrogen IPCEI or the European Clean Hydrogen Alliance. National programs should also serve as basis for the development of products to be produced in Austria following up EU funded projects.

Existing national programs such as the Mobility of the Future, the Energy Model Region WIVA P&G or the Energy Research Program have been in the past and should be in the future a preferred environment for projects using the following instruments:

- Cooperative projects of oriented basic research
- Cooperative R&D projects, experimental development and industrial research (Fundamental research with low TRL for knowledge expansion)
- Flagship projects (Industry-related research for knowledge transfer)
- Infrastructure for demonstration plants
- R&D infrastructure funding (Support of laboratory infrastructure)
- Funding for participation (Creation of an EU-wide legislative framework, directives and standards)
- Low TRL research (Basic research)
- Funding of demonstration plants (e.g. to produce biofuels, e-fuels or other synthetic fuels)

List of Acronyms

AD	Autonomous Driving
ADAS	Advanced Driver Assistance Systems
AEL	Alkaline Electrolysis
AEM	Anion Exchange Membrane
AEMEL	Anion Exchange Membrane Electrolysis
AEMFC	Anion Exchange Membrane Fuel Cells
AI	Artificial Intelligence / Alcohol Interlock
APU	Auxiliary Power Unit
ASIL	Automotive Safety Integration Level
AST	Accelerated Stress Tests
BEV	Battery Electric Vehicle
BMK	Federal Ministry Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology
BoP	Balance of Plant
BtX (BtL, BtG)	Biomass-to-X (X = Liquid or Gas)
C2C	Cell-to-Chassis
C2P	Cell-to-Pack
C2V	Cell-to-Vehicle
CAPEX	Capital Expenditures
CcHS	Cryo-compressed Hydrogen Systems
CEF	Connecting Europe Facility
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CI	Compression Ignition
CHSS	Compressed Hydrogen Storage Systems
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2 eq	CO_2 equivalent: a unit of measurement that is used to standardise the climate effects of various greenhouse gases
CRM	Critical Raw Materials
CU	Control Unit
CV	Commercial Vehicle
DI	Direct Injection
DC	Direct Current
$DeNO_x$	Denitrification (Elimination of NOx)
DME	Dimethyl Ether
EC	European Commission
EDU	Electric Drive Unit
EMC	Electro-Magnetic Compatibility
EoL	End-of-Line/End-of-Life
ERTRAC	European Road Transport Research Advisory Council
EUCAR	European Council for Automotive R&D
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
FCH-JU	Fuel Cells and Hydrogen Joint Undertaking
FCEV	Fuel Cell Electric Vehicle
FCV	Fuel Cell Vehicle
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Unit
FT	Fischer-Tropsch
GH_2	Gaseous Hydrogen
GHG	Greenhouse Gas
H_2	Hydrogen
HC	Hydrocarbon
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
HiL	Hardware in the Loop
HPC	High Power Charging (HPC)
HREE	Heavy Rare Earth Element
HRS	Hydrogen Refuelling Station
HSS	Hydrogen Storage Systems
HV	High Voltage / Heavy Vehicles
HVAC	Heating, Ventilation and Air Conditioning
HVO	Hydrogenated oder Hydrotreated Vegetable Oils
ICE	Internal Combustion Engine
IEA	International Energy Agency
IGBT	Insulated-Gate Bipolar Transistor
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IPCEI	Important Projects of Common European Interest
ISO	International Organization for Standardization
JRC	Joint Research Centre
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LCSA	Life Cycle Sustainability Assessment
LDV	Light Duty Vehicle
LFP	Lithium Ferrophosphate
Li	Lithium
LOHC	Liquid Organic Hydrogen Carriers
LHSS	Liquid Hydrogen Storage Systems
LH_2	Liquid Hydrogen
LTO	Lithium Titanate Oxide
LV	Light Vehicle
MEA	Membrane Electrode Assembly
Mg	Magnesium
MOSFET	Metal Oxide Semiconductor Field-Effect Transistors
MSC	Metal Supported Cell
MtG	Methanol-to-Gasoline
MW	Megawatt
N_2	Nitrogen
Na	Natrium
NMC	Nickel Manganese Cobalt
NO_x	Mono-nitrogen oxides (NO and NO_2)

NVH	Noise, Vibration and Harshness
ODD	Operating Design Domains
OEM	Original Equipment Manufacturer
OME	Oxymethylene Ether
OPEX	Operational Expenditures
ORC	Organic Rankine Cycle
PCEL	Protonic Ceramic Electrolysis
PCEC	Prononic Ceramic Electrolysis Cell
PCFC	Protonic Ceramic Fuel Cell
PEM	Polymer Electrolyte Membrane
PEMEL	Polymer Electrolyte Membrane Electrolysis
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PF	Particulate Filter
PFAS	Per- and polyfluoroalkyl substances
PGM	Platinum Group Metals
PHEV	Plug-in Hybrid Electric Vehicle
PFI	port fueled injected
PM	Particulate Matter
PnC	Plug-and-Charge
PtX (PtL, PtG)	Power-to-X (X= Liquid or Gas)
R&D	Research and Development
RCS	Regulations, Codes and Standards
RES	Renewable Energy Sources
REX	Range Extender
SAE	Society of Automotive Engineers
SI	Spark Ignition
SOEC	Solid Oxide Electrolyser Cell
SOEL	Solid Oxide Electrolysis
SOFC	Solid Oxide Fuel Cell
TCO	Total Cost of Ownership
TEN-T	Trans-European Transport Network
TRL	Technology Readiness Level
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2L	Vehicle-to-Load
V2V	Vehicle-to-Vehicle
V2X	Communication from vehicle to X (e.g. Vehicle, Infrastructure, …)
WGS	Water-Gas-Shift
WtW	Well-to-Wheel
xCU	Any Control Unit
xiL	Model, software or hardware in the Loop

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A3PS – Austrian Association for Advanced Propulsion Systems

The **A3PS** is the **strategic partnership** between the Austrian technology policy, industry and research institutions.

The **A3PS** stimulates the development of advanced propulsion systems and energy carriers – to build up common competence and to accelerate market launches.

The **A3PS** addresses **all advanced drive train technologies** with contributions to the improvement of energy efficiency and reduction of emissions supporting the whole innovation cycle (research, development, deployment).

Media owner and editor

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Österreichische Plattform zur Förderung von
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Energieversorgung und -speicherung

Phone: +43 (0)1 8904906
E-Mail: office@a3ps.at
Web: www.a3ps.at

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