C R&D Challenges: Fuel Cell Electric Vehicle and H_2 2024+

This Position paper's focus is on R&D requirements of fuel cell technology for electric vehicles and renewable H_2. Regarding H_2, production from non-fossil sources as well as distribution, storage and H_2 refueling stations (HRS) are addressed here. H_2 combustion can be found in chapter D R&D Challenges: Hybrids and Sustainable Fuels 2024+.

C.1 Requirements on Technology Development and Research Demand

H_2 and fuel cell technology in Austria offers the opportunity to implement the energy transition faster and more efficiently, to expand and use the country's own renewable resources in addition to the import of renewable H_2 to make an important contribution to greenhouse gas reduction, air pollution control and noise protection - especially in metropolitan areas. Additionally, the external trade balance can be improved while creating higher added value as well as new jobs in Austria. Although this position paper focuses on the automotive sector with on- and off-road vehicles including non-road mobile machinery, other mobility sectors such as aviation and inland/maritime shipping will also benefit from the research addressed in this section.

To harness these advantages of fuel cell and H_2 technologies in and for Austria, this technology needs political support and investments in grants, technical assistance and R&D tools, also including measures for market ramp-up. These are recommendations for actions for the period up to 2026:

- Strengthening Austria as a location by building up H_2 and fuel cell industry
- Increase of research funding for H_2 and fuel cell technologies and create a specialized funding instrument with a separate budget focused on R&D of all types of electrolyzers, H_2 on-board storage and fuel cells
- Accelerated expansion of renewable electricity generation for H_2 production
- Certification system for green H_2 - as H_2 generated by renewable energies
- Decentralized / regional approach to enable use, grid system release and balancing
- Simplified and standardized approval procedures for H_2 refueling stations and facilities
- Expansion of the H_2 refueling infrastructure for cars, buses and trucks
- The weight potential of fuel cell trucks compared to BEV trucks should be promoted in view of the increasing overall traffic.
- Incentives (e.g. CAPEX (Capital Expenditures) tax and long-term amortization and OPEX (Operational Expenditures) tax type, toll) for the fleet development of fuel cell vehicles that compensate the current additional costs compared to conventional drives
- The Austrian H_2 Strategy should strengthen the role of mobility in R&D and in the roll-out of H_2 with measures for infrastructure and vehicles implementation for a wide-field of applications (passenger cars, light duty vehicles, heavy duty trucks, busses, trains, aviation, off-road applications etc.)
- A specialized funding instrument with a separate budget focused on H_2 mobility applications should be installed by the government
- Support for building up references with industrial relevance (fleet size, high number of hours of operation etc.) for various applications in the field and real-world environment

C.2 Position

Green H_2 enables an integrated, efficient and socially sustainable energy system. To achieve the climate goals agreed in Paris in 2015, our energy system must be **carbon-neutral and defossilized**. As a result, EU has defined 2050, Germany 2045 and Austria 2040 as target years for achieving climate neutrality. Green electricity and green H_2 are zero-emission and carbon-free energy sources for this **energy transition**. They allow climate-neutral product cycles and offer a significantly higher level of efficiency and thus lower energy consumption compared to conventional systems. **H_2 is the key to expanding renewable electricity production** from wind, water and sun, as excess energy is used, and long-term and efficient energy storage is made possible. H_2 enables the different energy and usage sectors (household, industry, and mobility) to be interwoven, and at the same time offers the necessary flexibility and grid stabilization for energy systems with a high proportion of renewable energy. As the future energy system relies more heavily on renewables, H_2 will also play a growing role in integration and storage of renewable electricity. H_2 allows to store and transport renewable energy efficiently over extended periods of time and is therefore a key enabler of the transition to renewable energies. Hence, it will also be available in enormous quantities **for mobility**. Fuel cell electric vehicles in combination with H_2 are offering a possibility for a completely decarbonized mobility system and are perfectly suitable when criteria like long range, high-power, high-energy consumption and fast refueling are targeted.

The European Commission's timetable earmarks net-zero **greenhouse gas** emissions **in 2050**. For this, the conversion of the transport sector from currently over 90% fossil-based mobility to electromobility offers the greatest prospect of success. Action is needed for on-road and off-road vehicles (e.g. 2-/3-wheelers, passenger cars, commercial vehicles incl. heavy/long-distance traffic and off-road applications). The on-board storage of H_2 in a high-pressure or cryogenic storage system enables significantly higher power densities and therefore higher ranges can be achieved with short refueling times (within similar time requirements as for conventional fuels). For high performance and long ranges, what is of crucial importance for electromobility for heavy/long-distance transport, electromobility with **Fuel Cell Electric Vehicles (FCEVs)** offers the drive concept of choice. H_2 fuel cell vehicles are **locally emission-free** electric vehicles. In particular, **electric vehicles with PEM** (polymer electrolyte membrane) **fuel cells** in combination with **green H_2** are of essential importance because they feature **lowest greenhouse gas emissions (GHG)** of all vehicle concepts over the entire life cycle when high driving range is required (production, operation, recycling).[13,14] Moreover, fuel cell vehicles feature potential to achieve competitive costs at high production volumes[15, 16] and guarantee ecological advantages regarding rare resources as well as recycling and low emissions of the whole life cycle. However, high improvement potentials especially concerning overall efficiency, costs, industrialization, materials etc. are still existing.

The promising application of high-temperature fuel cells (SOFCs), which can be run with H_2 or other renewable fuels, could be used in heavy-duty road and rail vehicles as well as in ships. In any case, every fuel cell vehicle is an electric vehicle. The fuel cell permanently delivers electric power to the high-voltage buffer battery that can be kept much smaller than for pure battery electric vehicles. This synergy allows a favorable vehicle operation including the recuperation of braking energy.

With a small amount of refueling stations, H_2 enables nationwide coverage. **H_2** is safely stored at the refueling station and, as with fossil fuels, high refueling capacities are possible. For a nationwide supply of **H_2** there are **significantly lower infrastructure investments** than for battery electromobility, which require a higher number of charging stations.[17]

Power-to-X: PEM-electrolyzers, powered by renewable energy sources, allow the production of enormous amounts of green H_2, which may be used for the conversion of CO_2 to e-fuels, e-methanol and e-methane as well as for the synthesis of ammonia. Additionally, the combination of high-temperature electrolysis[18] of H_2O or co-electrolysis of CO_2 and H_2O with suitable processes allow the production of green energy carriers with high efficiency. Required are powerful and aging resistant catalysts, but also innovative LOHC-materials, and efficient polymer- und ceramic membranes for the purification of H_2. Solid oxide electrolysis cells (SOECs, PCECs) need new oxygen and proton-conducting

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[13] Umweltbundesamt: *Ökobilanz alternativer Antriebe*, 2018.

[14] Fraunhofer ISE: *„Treibhausgas-Emissionen für Batterie- und Brennstoffzellenfahrzeuge mit Reichweiten über 300 km“*, 2019.

[15] Salman, P.; Wallnöfer-Ogris, E.; Sartory, M.; Trattner, A. et al., "*Hydrogen-Powered Fuel Cell Range Extender Vehicle – Long Driving Range with Zero-Emissions*," SAE Technical Paper 2017-01-1185, 2017, doi:10.4271/2017-01-1185.

[16] Thompson et al: *Direct hydrogen fuel cell electric vehicle cost analysis: System and highvolume manufacturing description, validation, and outlook*, Journal of Power Sources 399 (2018) 304–313, Elsevier, 2018.

[17] Robinius, M.; Linsen, J.; Grube, T.; Reuß, M.; Stenzel, P.; Syranidis, K.; Kuckertz, P. & Stolten, D. (2018): *Comparative Analysis of Infrastructures. Hydrogen Fueling and Electric Charging of Vehicles*

[18] Sitte, W.; Merkle R., (Eds.), *High Temperature Electrolysis - From Fundamental to Applications*, IOP-Publishing 2023

ceramic materials (electrodes, electrolytes) with reduced amount of critical raw materials (rare earths) but increased power density and long-term stability, also for operation at lower temperatures.

In general, there is a strong need for research and development of scalable electrolysis (incl. efficient auxiliary units), powered by renewable energy sources like wind, solar or hydropower. Regional and local production of green H_2 and other energy carriers by electrolysis will significantly contribute to supply H_2 refueling stations and pipelines.

Location Austria: Austrian industry, research institutes and universities have been active for a long time in research and development of fuel cell and H_2 technologies. Now, developments must be continued, accelerated and results need to be transferred to the market. Overall, the H_2 fuel cell is the appropriate zero-emission technology for Europe and especially for Austria, because the existing expertise, the production technologies, the industrial and economic sectors as well as the available resources offer ideal conditions for this technology. The training and teaching of this subject area must also be pushed further. In addition to courses, academic theses are an excellent way to create best training in this field and to support research.

Specific **research demand** for FCEVs primarily pertains to the further reduction of **costs** and the further increase in **lifetime** and **efficiency**. In addition, the entire production, distribution and user chain based on renewable energies must be optimized regarding maximum efficiency and lowest costs. There is a **need for research funding** for all types of fuel and electrolysis cells, from cell and stack level to complete systems, vehicle concepts, system concepts, H_2 storage technologies and development tools, as well as measurement and testing technology, and the establishment and expansion of the laboratory infrastructure required for this. In addition to R&D, support for building up references with industrial relevance (fleet size, high number of hours of operation etc.) for various applications in the field and real-world environment is urgently needed.

C.3 Life Cycle Assessment and Circular Economy

Life Cycle Assessment (LCA) of FCEVs involves a range of influencing factors, such as H_2 production (incl. use of co-products oxygen and heat as well as 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 H_2 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. During the life cycle increasing requirements on service, repair and upgrading demands need to be considered to optimize resource and energy usage over lifetime and beyond. End-of-life aspects include vehicle and fuel cell recycling as an essential 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. In general, a detailed circular economy approach must be developed for FCEVs.

C.4 Research Requirements

The H_2 and fuel cell technologies are now in a process of accelerated development, showing that there is considerable need for research and development with respect to optimization in the long term, particularly in terms of costs, lifetime and efficiency. The research and development needs of the near future (2024-2026) include the following topics (alphabetical order):

- Development tools, measuring and testing technology
    - Optimized test procedures and test benches for all types of fuel cells, electrolyzers and H_2 storage technologies and their BoP (balance of plant) components
    - Simulation tools and development methods
- Electrolysis (all types) - cell, stack, system and systems powered with renewable energies
    - Efficient production technologies for PEM electrolyzers for efficient production of green H_2 powered by electricity from renewable sources

    - Energy efficient, low cost and ageing-resistant catalysts for the efficient conversion of green H_2 and CO_2 to e-fuels
    - Ageing resistant and low-cost oxygen and proton conducting ceramic materials with reduced amount of critical elements for solid oxide electrolysis of H_2O or co-electrolysis of H_2O and CO_2 for the efficient production of e-fuels
    - Process management and control
    - Inexpensive and efficient auxiliary units (BoP components)
    - H_2 purification and distribution for mobile applications
    - Optimize coupling of electrolysis with downstream synthesis for renewable fuel production (e.g., e-fuels, e-ammonia, e-methanol, SNG (synthetic natural gas), …) in terms of efficiency, scalability, lifetime and durability
- Fuel cell (all types) - cell, stack and system
    - Materials and production technologies
    - Process management and control
    - Affordable and efficient auxiliary units (BoP components)
    - Improving the tolerance of future fuel cell systems to H_2 quality, as this can eliminate the requirements for refueling with H_2 and the sometimes-complex cleaning, for example when connecting H_2 filling stations to an H_2 pipeline network.
- Fuel cell vehicles for various applications ranging from passenger cars via commercial vehicle to off-road vehicles
    - Fuel Cell system optimization in terms of efficiency, lifetime, and durability
    - System and vehicle integration - spatial and functional integration
    - Thermal and energy management
    - Control and regulation of the entire drivetrain (battery, power electronics etc.)
    - Evaluation of crash situations (Emergency Response Management)
    - LCA, Recycling Concepts, Life cycle optimization
    - Impact of new Eco-design Regulation
    - Establishment of an independent legal regulation for the periodic technical monitoring of H_2 vehicles and their H_2-specific components.
- Functional Integration and secure packaging
    - Development of crash models of relevant storage and fuel cell systems
    - LCA, Recycling Concepts, Life cycle optimization
    - Impact of new Eco-design Regulation
- H_2 refueling infrastructures for all vehicle categories
    - Process management
    - Safety-related communication between HRS (Hydrogen Refueling Stations) H_2 powered vehicles
    - Logistics (distribution and storage of H_2)
    - More reliable and efficient components and systems
    - Rapid H_2 refueling (“dynamic-data” H_2 fueling) and the associated upgrade of components and controls
    - Focus on the development of cost optimized H_2 tank system components
    - Studies on the creation of uniform approval guidelines and requirements for HRS in Austria
- H_2 storage technologies for mobile and stationary applications

        - Materials and production technologies
        - Inexpensive components with low carbon footprint
        - Technologies to provide higher fuel supply pressure if required
- Laboratory infrastructure for research and development work including real-gas, real-size testing infrastructure for H_2 systems and components with focus on supplier industry

C.4.1 Requested National Funding Instruments for "Fuel Cell Electric Vehicle and H_2"

The topics defined above follow the specific strengths of the Austrian R&D community in this field. Nationally funded research programs should help to further strengthen this expertise and ability, 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 a 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 existed in the past and should also be realized in the future as a preferred platform 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, industry-related research for knowledge transfer)
- Flagship Projects (industry-related research for knowledge transfer)
- R&D infrastructure funding (support of laboratory infrastructure)
- Infrastructure funding for demonstration and implementation of large fleets
- Funding for participation: creation of an EU-wide legislative framework as well as directives and standards
- High TRL research – market launch and fleet testing

While there is no question that H_2 -powered vehicles in near future need to run exclusively on H_2 from sustainable production, this requirement is often a hurdle for R&D projects, as green H_2 is not yet available everywhere. It would therefore make sense not to see this regulation as a basic requirement for funding R&D projects if H_2 from renewable sources is not available.

C.4.2 Estimated National R&D Project Volume for "Fuel Cell Electric Vehicle and H_2"

Starting in 2023, an annual[19] volume of 65 M€ is estimated for R&D projects on fuel cell electric vehicles and H_2. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration and R&D infrastructure:

- 10 M€ for cooperative projects of oriented basic research: 10 projects of 1 M€ each
- 15 M€ for cooperative R&D projects, experimental development and industrial research: 5 projects of 2 M€ each
- 30 M€ for Flagship Projects: 3 projects of 10 M€ each
- 10 M€ for R&D infrastructure (support of laboratory infrastructure)

This **total R&D project volume of 65 M€** should be supported with a **funding volume of about 32,5 M€** considering an average funding rate of about 50 %.
Additionally, to the necessary funding volume for R&D projects we suggest about a
40-60 M€ budget for the implementation of fleets and infrastructure.

[19] for projects granted within one year – project/funding volume for the whole project duration

D R&D Challenges: Hybrids and Sustainable Fuels 2024+

This Position paper summarizes the R&D requirements of hybrid powertrains incl. hydrogen combustion engine (H_2 ICE) fueled with sustainable liquid and gaseous fuels, i.e. incl. "green" H_2. H_2production from non-fossil sources as well as distribution, storage and hydrogen refueling stations (HRS) are addressed in chapter C R&D Challenges: Fuel Cell Electric Vehicle and H_2 2024+.

D.1 Trends on Technology Development and Research Demand

Although this position paper focuses on the automotive sector with on- and off-road vehicles including non-road mobile machinery, other mobility sectors such as aviation and inland/maritime shipping will also benefit from the research addressed in this section - particularly on sustainable fuels sustainable aviation fuels (SAF), sustainable fuels for ships).

Hybrid powertrains fueled **with sustainable, renewable liquid and gaseous fuels incl.** H_2– i.e. biofuels and so-called RFNBOs (renewable fuels of non-biological origin)[20] – are highly efficient and very well suited for applications where long ranges and short refueling times are of major importance. Small batteries and largely mechanical components of hybrid powertrains lead to a low environmental impact during production and recycling. As a result, hybrid powertrains can very effectively contribute to achieving climate-neutral mobility.

Therefore, research must focus on further improvements of hybrid powertrain and vehicle efficiency and at the same time on fuels with low pollutant emissions and low (fossil) carbon intensity in the life cycle. Such improvements directly contribute to the reduction of GHG and pollutant emissions in the short and medium term. Today, vehicles powered by sustainable chemical energy carriers (renewable liquid and gaseous fuels and H_2) can achieve as low GHG emissions as electric vehicles based on the current carbon intensity of national electric power generation mix. Another important aspect of liquid sustainable fuels is that they can be used in existing vehicles as part of the existing fuel supply infrastructure, and their use has an immediate positive impact on the GHG balance. In addition, the use of H_2in internal combustion engines (ICE) (as well as turbines) – in pure ICE and hybrid powertrains can help to increase the demand for H_2 as a transport fuel in the near future. This could make a H_2network and H_2refueling stations economically viable much sooner.

Fuel-side measures have a high potential for reducing GHG emissions. Firstly, there is the possibility to increase blending ratios of conventional biofuels such as FAME biodiesel and ethanol, leading to immediate further reduction of GHG emissions. Secondly, sustainable advanced biofuels can be based on a broader biological raw material basis and, unlike sugar, starch, oils, and fats, are not in competition with food and feedstock production. Residues from agriculture and forestry, industrial residues and waste can be used as raw materials. These fuel paths open new regional value creation potential. However, the corresponding production technologies still need to be developed to market maturity through appropriate R&D and demonstration activities. And finally, RFNBOs, e.g. H_2 as well as e-fuels from renewable electricity and renewable carbon sources can also be made available as high-quality energy carriers for engines. While these technologies are already quite developed, the respective fuels are not yet commercially produced.

In summary, the following specific research needs for product development for the European and global market (to strengthen the European competitiveness and the European exports) can be identified for the years 2024+:

1) Efficiency improvement of the powertrain system by all kinds of hybridization including range extender architectures with ICEs along with intelligent operating strategies for matching current and future emission standards, optimal and predictive thermal and energy management, waste heat utilization (e.g. on-board fuel reforming from waste heat recovery) and loss reduction through electrification of auxiliary units.

[20] https://energy.ec.europa.eu/publications/delegated-regulation-union-methodology-rfnbos_en, retrieved 8 May 2024