R&D Challenges: Fuel Cell Electric Vehicle and H_2 2023+

Requirements on Technology Development and Research Demand

Hydrogen and fuel cell technology in Austria offers the opportunity to implement the energy transition quickly and efficiently, to expand and use the country's own renewable resources in addition to the import of renewable hydrogen 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.

In order to harness these advantages of fuel cell and hydrogen 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 2025:

- Strengthening Austria as a location by building up hydrogen and fuel cell industry
- Increase of research funding for hydrogen and fuel cell technologies and create a specialized funding instrument with a separate budget focused on R&D of all types of electrolyzers, hydrogen on-board storage and fuel cells
- Accelerated expansion of renewable electricity generation for hydrogen production
- Certification system for green hydrogen - as hydrogen generated by renewable energies
- Decentralized / regional approach to enable use, grid system release and balancing
- Simplified and standardized approval procedures for hydrogen refueling stations and facilities
- Expansion of the hydrogen refueling infrastructure for cars, buses and trucks
- 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 Hydrogen Strategy should strengthen the role of mobility in R&D and also in the roll-out of hydrogen 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 hydrogen 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

Position

Green hydrogen 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 hydrogen 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. **Hydrogen 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. Hydrogen 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, hydrogen will also play a growing role in integration and storage of renewable electricity. Hydrogen allows to store and transport renewable energy efficiently over long periods of time and is therefore a key enabler of the transition to renewable energies. Hence, it will be also available in large quantities **for mobility**. Fuel cell electric vehicles in combination with hydrogen 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 hydrogen 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 central importance for electromobility for heavy/long-distance transport, electromobility with **Fuel Cell Electric Vehicles (FCEVs)** offers the drive concept of choice. Hydrogen fuel cell vehicles are **locally emission-free** electric vehicles. In particular, **electric vehicles with PEM** (polymer electrolyte membrane) **fuel cells** in combination with **green hydrogen** 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).[8,9] Moreover, fuel cell vehicles feature potential to achieve competitive costs at high production volumes[10,11] 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 operated with hydrogen 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, hydrogen enables a nationwide coverage. **Hydrogen** is safely stored at the refueling station and, as with fossil fuels, high refueling capacities are possible. For a nationwide supply of **hydrogen** there are **significantly lower**

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[8] Umweltbundesamt: *Ökobilanz alternativer Antriebe*, 2018.
[9] Fraunhofer ISE: *„Treibhausgas-Emissionen für Batterie- und Brennstoffzellenfahrzeuge mit Reichweiten über 300 km“*, 2019.
[10] 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.
[11] 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.

infrastructure investments than for battery electromobility, which require a higher number of charging stations.[12]

Power-to-X: PEM-electrolyzers, powered by renewable energy sources, allow the production of large amounts of green hydrogen, 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[13] of H_2O or co-electrolysis of CO_2 and H_2O with suitable processes allows the production of these 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 hydrogen. Solid oxide electrolysis cells (SOECs, PCECs) need new oxygen and proton-conducting 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 hydrogen and other energy carriers by electrolysis will significantly contribute to supply hydrogen 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 hydrogen technologies. Now, developments must be continued, accelerated and results need to be transferred to the market. Overall, the hydrogen fuel cell is the appropriate zero-emission technology for Europe and especially for Austria, because the existing know-how, 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 optimal training in this field and to support research.

Specific **research demand** on 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, hydrogen 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 required.

Life Cycle Assessment and Circular Economy

Life Cycle Assessment (LCA) of FCEVs involves a range of influencing factors, such as hydrogen 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 hydrogen production and use in the fuel cell, the manufacturing of the FCEV propulsion system and related extraction and refining

[12] 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*

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

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 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. In general, a detailed circular economy approach has to be developed for FCEVs.

Research Requirements

The hydrogen and fuel cell technologies are now in a process of accelerated development, indicating 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 (2023-2025) 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 hydrogen storage technologies and their BoP (balance of plant) components
    - Simulation tools and development methods
- Electrolysis (all types) - cell, stack, system and systems coupled with renewable energies
    - Materials and production technologies
    - Process management and control
    - Inexpensive and efficient auxiliary units (BoP components)
    - Hydrogen 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)
- 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 drive train (battery, power electronics etc.)
    - Evaluation of crash situations (Emergency Response Management)
    - LCA, Recycling Concepts, Life cycle optimization
    - Impact of new Eco-design Regulation

- 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
- Hydrogen refueling infrastructures for all vehicle categories
    - Process management
    - Safety-related communication between HRS (Hydrogen Refueling Stations) and FCEV
    - Logistics (distribution and storage of hydrogen)
    - More reliable and efficient components and systems
- Hydrogen 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 hydrogen systems and components with focus on supplier industry

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 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 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 of large fleets
- Funding for participation: creation of an EU-wide legislative framework as well as directives and standards

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

Starting in 2023, an annual volume of 60 M€ is estimated for R&D projects on fuel cell electric vehicles and hydrogen. 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 à 1 M€
- 10 M€ for cooperative R&D projects, experimental development and industrial research: 5 projects à 2 M€
- 30 M€ for Flagship Projects: 3 projects à 10 M€
- 10 M€ for R&D infrastructure (support of laboratory infrastructure)

This **total R&D project volume of 60 M€** should be supported with a **funding volume of about 30 M€** considering an average funding rate of about 50 %.
Additionally to the necessary funding volume for R&D projects we suggest about 40-60 M€ budget for the implementation of fleets and infrastructure.