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

2) Continuous development of sustainable fuels - including the efficient production of H_2 from renewable electricity sources and CO_2, or from synthesis gas e.g. by co-electrolysis of H_2O and CO_2.
3) Upgrade of biogas to fully convert biogenic carbon to biofuels.
4) Continuous research on energy efficient, low cost and aging resistant catalysts
5) Technology research and development on hybrid transmissions to achieve highest powertrain operation efficiency.
6) Overall efficiency improvement of ICE in combination with sustainable liquid and gaseous fuels, particularly H_2.

D.2 Essential Legal Framework

To facilitate the deployment of sustainable fuels and hybrid powertrains, policymakers are encouraged to:

- Create an EU-wide legislative framework and directives for rapid implementation of an efficient and climate neutral mobility, enabling the EU-industry the introduction of new technologies resulting from R&D activities described in this position paper.
- Adapt legislation, taxation, codes, and standards, as well as powertrain technologies to allow higher biofuel blends.
- Provide incentives for production or supply of sustainable fuels.
- Adapt the (EU-wide) CO_2-regulation to include well-to-wheel GHG emission benefits using renewable energy carriers (biofuels and RFNBOs). This would allow the automotive industry to consider renewable fuels in their targets and would thus encourage the adaptation of ICEs to higher blends of renewable fuels.

These frameworks (i.e., legislation and regulations) should be based on the actual GHG reduction, without favoring specific technologies. This actual GHG reduction depends on the carbon intensity of the energy carriers (fuels and electricity) used and the actual use of these energy carriers in the related vehicles, e.g. plug-in hybrid vehicles that are never charged but always run on fossil fuels do not provide actual GHG emission reductions.

These frameworks also need to be long-term, since otherwise there is great uncertainty for customers and especially for industry and companies. Industry is prepared to make innovative long-term investments, even if very expensive, but these can only be made on a sound basis.

D.3 Life Cycle Assessment and Circular Economy

A key factor for Life Cycle Assessment (LCA) of hybrid vehicles is the energy demand and efficiency throughout the vehicle's entire lifetime - from production via operation to recycling. While research focuses on increasing system efficiency, LCA must consider a "bigger picture", e.g. considering the effect of the additional weight of hybrid vehicles on energy consumption in real world driving.

LCA of biofuels and RFNBOs based on carbon capture and utilization involves a wide range of supply chains of different types of biomass, biomass conversion processes, renewable electricity, H_2production, CO_2-sources and separation technologies. LCA-results are therefore highly influenced by the CO_2-source and the degree of process integration and system efficiency. On top of traditional LCA, also dynamic LCA should be conducted, to assess the impact of EU-wide deployment of sustainable fuels and hybrid powertrains.

In a future fully circular economy, all developments must aim for zero waste, i.e. the recycling and reuse of all materials. Therefore, research is needed to achieve closed-loop materials cycles of future products.

D.4 Research Requirements

The research requirements listed below are expected to be most relevant within a short-term perspective (2024-2026).

A more extensive list of research requirements including mid-term (2025-2030) and long-term (2030+) topics can be found in the A3PS Roadmap “Austrian Roadmap for Sustainable Mobility – a long-term perspective, Version 2022 (https://www.a3ps.at/a3ps-roadmaps).

D.4.1 Hybrid System

- New hybrid topologies
  - Increase of efficiency and thus reduce GHG emissions
  - Development of solutions at optimal costs

- Electrified and on-demand-driven auxiliary units
  - Efficient air conditioning compressor, power steering pump, components of the air management (charging) system
  - Electric machines for electric auxiliary units including control – especially powerful units for commercial vehicle applications

- Energy management (including thermal management)
  - Avoiding cold start losses (heat storage, heat encapsulation)
  - Thermal conditioning of the exhaust gas after-treatment system
  - Optimizing electric energy management of hybrid powertrain systems
  - Thermodynamic waste heat recovery (Rankine cycle, thermo-chemical and thermo-electric heat recovery)
  - Optimal predictive thermal control (e.g. predictive cooling)
  - Combined control of heat and power flux
  - Adaptation of the operating strategy to optimize the lifetime of the hybrid system (e.g. the battery)

- Control of the hybrid system
  - Optimal operating strategy and control of hybrids using connectivity Car2X - X2Car (e.g. hybrid system on navigation system); Monitoring and service optimization
  - Software for component control and system control
  - Fast modeling methods and fast, automated control and diagnosis system parameterization
  - Combined physical-mathematical / phenomenological modeling
  - Efficient validation of complex drive systems
  - Automated operating and cutting-edge control strategies
  - Development tools & methodologies (e.g. “simulation on molecular level”)

D.4.2 Sustainable Fuels

- Efficient and “green” (i.e. sustainable) fuel production, on-board storage and fuel use
  - Efficient production of drop-in fuels (biofuels and RFNBOs) to power existing vehicle technologies (and in the current legacy fleet)
    - Efficient production processes of liquid and gaseous energy carriers (e.g. biofuels and RFNBOs), produced from H_2 from renewable electricity sources and CO_2 in view of cost-per-unit impact
  - Low cost and ageing resistant oxygen and proton conducting ceramic materials for solid oxide co-electrolysis of H_2O and CO_2 for the efficient production of RFNBOs, in view of cost-per-unit impact
  - Economic processes for capturing CO_2 from exhaust gases, flue gases, or other sources (no economic solutions exist so far on the medium scale capture)

  - Gasification technologies and other thermal processes to produce biofuels (e.g. gasification of biomass followed by synthesis to liquid or gaseous fuels etc.)
  - Upgrade of biogas to fully convert biogenic carbon sources to e.g. synthesis gas
  - Integration of biofuel production into refineries through co-processing and upgrading of bio-based intermediate energy carriers such as pyrolysis oils, bio-oils and Fischer-Tropsch-liquids
  - Energy efficient, low cost and aging resistant catalysts
  - Adaptation of powertrain systems for the application of higher blends of sustainable fuels
  - Safe on-board storage of sustainable gaseous and liquid energy carriers with high energy density and low specific costs
  - Measurement and analysis techniques for increased quality requirements as well as for online analysis of the gas constituents for optimal setting of the ICE
  - LCA of sustainable fuels and their application in hybrid vehicles

- Material technology for advanced / new fuels
  - Tank / pipe / sealing materials and fuel metering materials
  - Fuel sensors (on and off board)
  - Rapid and efficient H_2 refueling ("dynamic data" H_2 fueling) and the associated upgrade of components and controls

D.4.3 Hybrid Powertrain

- Transmission and clutch technology for hybrid vehicles
  - Variable gear systems
  - Transmissions for high-speed E-machines (including noise reduction)
  - Sinter and coating technologies
  - Lightweight technologies
  - Fast actuators
  - Transmission for highly efficient hybrid topologies
  - Optimal and predictive gear shift control/operation
  - Components and systems for range extender architectures

D.4.4 Thermodynamics of the ICE including Exhaust Gas Treatment

- Combustion technologies for sustainable fuels incl. H_2in compliance with future legal requirements
  - 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)
  - High-pressure direct injection H_2 engine (tank/gas pressure, H_2-DI-injector, combustion stability/anomalies, safety of H_2 DI engines)
  - Optimization of H_2engines in terms of torque and power density, transient operation, efficiency and costs
  - Development and use of "Fully Flexible Direct Injection Systems" for liquid and gaseous fuels
  - New variabilities for efficiency improvements of the engine system
  - Ultimately highly efficient combustion systems aiming at 50 % "plus" efficiency
  - Optimal adaptation of engines to hybrid systems
  - Further NVH reduction of hybrid systems

- Enhanced exhaust gas after-treatment for sustainable fuels in compliance with future legal requirements

    - Elimination of ultra-fine particle emissions
    - Sensors and control systems for RDE (real driving emissions) exhaust gas monitoring
    - Direct emission control
    - Special measures to reduce cold start emissions

- Material technology for engine (and transmission) improvements
    - Improvement of thermal insulation / adiabatic operation
    - Lightweight construction plus the use of new materials
    - Use of sintered components (also for actuators)
    - Reduction of friction and wear (including new bearing technologies especially for future / gaseous fuels …)
    - Design for recyclability, refurbishment, and reuse of materials and components
    - Material, design and production processes for do-no-significant-harm principles

D.4.5 Requested National Funding Instruments for "Hybrids and Sustainable Fuels"

- Low TRL research also including support for RTD work of start-ups and spin-offs
- Co-operative industrial research and experimental development
- Flagship projects
- Funding of demonstration plants, i.e. to produce biofuels or RFNBOs
- Common transnational funding instruments of EU-MS
- High TRL experimental development with focus on vehicle test fleet operations to prepare for industrialization

D.4.6 Estimated National R&D Project Volume for "Hybrids and Sustainable Fuels"

Starting in 2023, an annual[21] volume of 75 M€ is estimated for R&D projects on the hybrid system and powertrain and sustainable fuels. The list below is an assessment of project types needed to cover all topics from basic to applied research, demonstration, fleet testing, field tests and R&D infrastructure:

- 8 M€ low TRL research: 8 projects of 1 M€ each
- 12 M€ for applied & cooperative research: 6 projects of 2 M€ each
- 30 M€ for flagship projects / cluster of flagship projects: 2 projects of 10-20 M€ each
- 10 M€ for high TRL experimental development: 1-2 projects of 5-10 M€ each
- 15 M€ per year for R&D infrastructure

This **total R&D project volume of 75 M€** should be supported with a **funding volume of about 37,5 M€** considering an average funding rate of about 50 %.

Suggested allocation of projects/funding volume to the research areas in this chapter:

1. Hybrid System: 1/5
2. Sustainable Fuels: 2/5
3. Hybrid Powertrain: 1/5
4. Thermodynamics of the ICE including exhaust gas treatment: 1/5

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