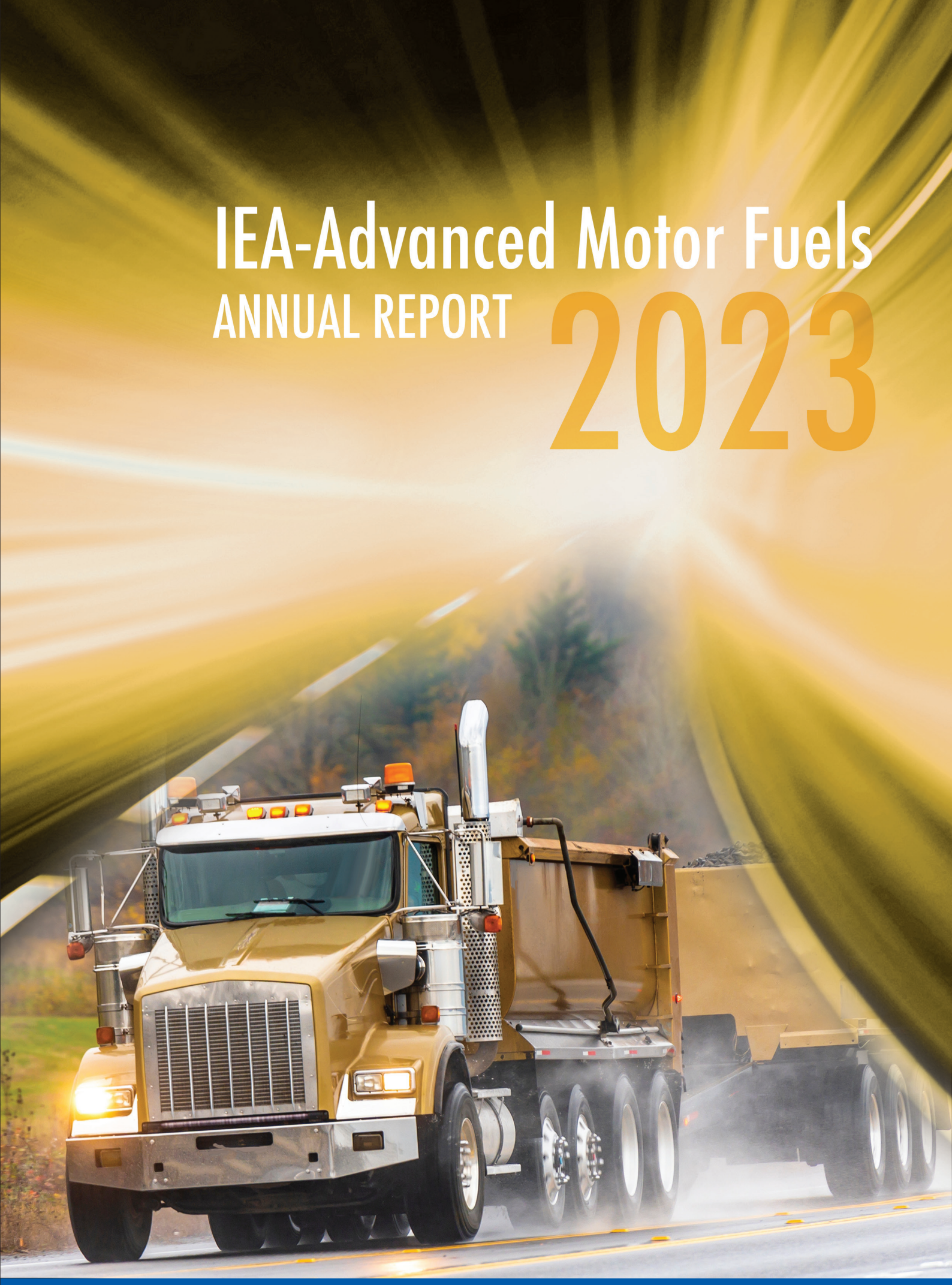
IEA-Advanced Motor Fuels
ANNUAL REPORT 2023



Technology Collaboration Programme
by IEA

Chairpersons Message – AMF 2023

Jesper Schramm, Chair of the AMF TCP

The Technology Collaboration Programme (TCP) on Advanced Motor Fuels (AMF) aims to reduce greenhouse gas emissions and local air pollutant emissions from the transport sector while ensuring the availability and affordability of transport fuels. The AMF TCP serves to inform and advise with updated knowledge and information about transport fuels. Our activities consist mainly of developing collaborative tasks, for which member countries combine their activities and skills to advance mutual goals. Our newsletters share this objective, providing short updates on the global and local situation.

Transportation sectors around the world are changing, and many countries no longer support development of combustion engines as a power source for road transportation. The AMF-TCP has had to adjust its activities to follow this trend.

Electric vehicles are expected to replace combustion engine vehicles in many countries, but not in all parts of the world. One of AMF's important tasks is to compile and disseminate information about such differences from region to region. Representatives from Brazil, a newer AMF member country, for example, pointed out at our last Executive Committee meeting that it will be expensive to build new infrastructure to provide additional electricity for transportation, and Brazil must prioritize its investments to address challenges related to poverty, education, public health care, jobs creation, infrastructure, and electricity access that still exist across the country, beyond the relevant presence of renewable fuels in the Brazilian transport sector.

Other forms of transportation will depend on advanced motor fuels, as the following important examples illustrate:

- Truck companies are preparing future vehicles for long-haul transportation that runs on hydrogen in combustion engines.
- The International Energy Agency's (IEA's) Net Zero Emissions by 2050 Scenario forecast predicts that more than 50% of marine transportation will be based on ammonia in 2070.
- Application of sustainable fuels is probably the only way forward to reduce greenhouse gas emissions from aviation.

AMF has been discussing a "white paper" task proposal about the "Future Role of Combustion Engines and Sustainable Fuels" to get an overview of the situation. This proposed task will also be an important basis for AMF's future role and activities. The white paper task is expected to begin in 2024, and discussions have begun with other TCPs (Sustainable Combustion, Bioenergy, and Hydrogen) to make the task a common activity.

In October, we had a fruitful common meeting in Leipzig with participants from the AMF TCP and the Bioenergy TCP Task 39. The discussions there identified the top scorers of interest overlap as follows:

- The white paper on the future role of combustion engines and sustainable fuels
- Sustainable aviation fuels and marine fuels
- Life-cycle analysis certification schemes

I believe that AMF will focus increasingly on the end-use aspects of hydrogen application, as well as the topics listed above.

I am confident that AMF will define the path forward in close collaboration with other TCPs. AMF is about to present the next strategic work plan for the years 2025–2029. The request-for-extension procedure is ongoing and will be finished during 2024. The final plan is a result of intensive discussions that have taken place at the Executive Committee meetings and other collaboration meetings and will reflect considerations like those listed above.

Vision

Advanced motor fuels, applicable to all modes of transport, significantly contribute to a sustainable society around the globe.

Mission

The mission of AMF is to advance the understanding and appreciation of the potential of advanced motor fuels toward transport sustainability. We provide sound scientific information and technology assessments facilitating informed and science-based decisions regarding advanced motor fuels at all levels of decision-making.

Highlights of Advanced Motor Fuels

Kim Winther, Subcommittee Strategy & Technology Chair

While Russia's war on Ukraine impacted energy markets severely in 2023, it also served as a catalyst for many nations to double down on clean energy transitions to improve security, sustainability, and independence from imported fossil fuels over the longer term.

AMF continued its string of physical meetings, reducing these to one per year due to high travel costs and restrictions caused by the aftermath of Covid. The 2023 meeting was hosted by Germany and had participation from most of the member countries. During this meeting, the synergies between biofuels and Power-to-X was among the focal points.

Ammonia engines have progressed significantly in 2023; for example, the four-stroke Wärtsilä 25 engine is now commercially available, and the MAN ME-LGI two-stroke ammonia engine was successfully tested. In 2023, ammonia bunkering and service-tank facilities were added with all auxiliary systems. Korean Hyundai (.HD HHI-EMD) expects to deliver a 6X52DF-A ammonia engine for an inaugural ammonia-powered vessel in early 2025. Several universities and independent research firms also reported progress on experimental setups that will accelerate future development of ammonia engines.

Hydrogen engines continued to gain interest in 2023. Cummins unveiled its new 15-liter, fuel-agnostic engine, noting that the single platform can support various fuel types, including hydrogen, natural gas, and diesel. Deutz added the new TCG 7.8 H2 hydrogen combustion engine, and Kubota showed a new 3.8-liter hydrogen engine. Kohler Engines introduced hydrogen technology with its new KDH Engine.

The Haru Oni project in Chilean Patagonia (initiated by German sports car maker Porsche) is now fully operational. The first batch of renewable gasoline was shipped to Germany in 2023 for further testing.

Marine fuels stay high on the AMF agenda. The 2023 introduction of the Laura Mærsk demonstrated the viability of using carbon-neutral fuels like e-methanol to significantly reduce emissions from the shipping industry. The vessel was hailed as a major milestone in making global maritime trade more sustainable.

Because sustainable fuels for the aviation industry have now become a priority of AMF, we initiated a followup to Task 63 "Sustainable Aviation Fuels." Besides organization, pricing, and CO_2 accounting, AMF will also explore the non-CO_2 effects (e.g., contrail formation) associated with flying on renewable fuels.

AMF continues to monitor developments across the globe in search of the best advanced fuel topics to address in the coming years.

Annual Report 2023 Production Notes

This Annual Report was produced by Kevin A. Brown (project coordination/management), Mary Fitzpatrick (editing), Lorenza Salinas (document production), and Sonya Soroko (cover design) of Argonne National Laboratory.

Contributions were made by a team of authors from the Technology Collaboration Programme on Advanced Motor Fuels (AMF), as listed below.

Country reports were delivered by the Contracting Parties:

Austria	Austrian Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK)
Brazil	Energy Research Office (EPE)
Canada	Environment and Climate Change Canada
China	China Automotive Technology and Research Center (CATARC)
Denmark	Technical University of Denmark (DTU)
Finland	The Technical Research Centre of Finland (VTT)
Germany	Agency for Renewable Resources (FNR)
India	Ministry of Petroleum and Natural Gas
Japan	• National Institute of Advanced Industrial Science and Technology (AIST) • Organization for the Promotion of Low Emission Vehicles (LEVO) • National Traffic Safety and Environment Laboratory (NTSEL)
Republic of Korea	Korea Institute of Energy Technology Evaluation and Planning (KETEP)
Spain	Institute for Diversification and Saving of Energy (IDAE)
Sweden	Swedish Transport Administration (STA)
Switzerland	Swiss Federal Office of Energy (SFOE)
USA	U.S. Department of Energy (DOE)

Task reports were delivered by the respective Task Managers and Responsible Experts:

Task 28	Information Service and AMF Website	Dina Bacovsky
Task 60	The Progress of Advanced Marine Fuels	Kim Winther
Task 61	Remote Emission Sensing	Åke Sjödin
Task 62	Wear in Engines Using Alternative Fuels	Jesper Schramm
Task 63	Sustainable Aviation Fuels	Doris Matschegg
Task 64	E-Fuels and End-Use Perspectives	Zoe Stadler
Task 65	Powertrain Options for Non-Road Mobile Machinery	Rasmus Pettinen

Currency values in the Country and Task reports rely on the exchange rate at the time of print publication, with the exception of Switzerland's Country report, which uses the mean value of the FTA (Swiss Federal Tax Administration) that is valid during the reporting period.

Other sections of this report were delivered by the Chair, the Head of the Strategy & Technology Subcommittee, and the Secretary:

Jesper Schramm	Technical University of Denmark (DTU)	Executive Committee Chair
Kim Winther	Danish Technological Institute (DTI)	Subcommittee Strategy & Technology Chair
Dina Bacovsky, Kerstin Brunbauer	BEST – Bioenergy and Sustainable Technologies GmbH	Secretary, Team & Project Assistance

Contents

Technology Collaboration Programme on Advanced Motor Fuels

The Need for Advanced Motor Fuels
Because internal combustion engines will be the prime movers for the transport of goods and passengers for many years to come, there is a clear need for fuels that:

- Emit lower levels of greenhouse gases (GHGs),
- Cause less local pollution,
- Deliver enhanced efficiency, and
- Offer a wider supply base for transportation fuels.

We also need to understand the full impact of alternative energy solutions from a well-to-wheel perspective and use solid data for decision making.

Our Approach
The Technology Collaboration Programme on Advanced Motor Fuels (AMF TCP) has established a strong international network that fosters collaborative research and development (R&D) and deployment and provides unbiased information on clean, energy-efficient, and sustainable fuels and related vehicle technologies. We intend to:

- Build on this network and continue its fruitful contributions to R&D,
- Strengthen collaborations with other closely related (in terms of topics) technology collaboration programmes, and
- Do a better job of involving industry in our work.

By verifying existing data and generating new data, the AMF TCP can provide decision makers at all levels with a solid foundation for "turning mobility toward sustainability."

Benefits
The AMF TCP brings stakeholders from various continents together to pool and leverage their knowledge of and research capabilities in advanced and sustainable transportation fuels. Our cooperation enables the exchange of best practices and, with our broad geographical representation, allows us to consider regional and local conditions to better facilitate the deployment of new fuel and vehicle technologies.

About the AMF TCP
The AMF TCP is a programme of the International Energy Agency (IEA) that comprises an international group of experts and enables governments and industries worldwide to lead programs and projects on a wide range of energy technologies and related issues (see Section 4a). TCP activities and programs are managed and financed by the participants, which are usually governments. The work program and information exchange, however, are designed and carried out by experts from the participating countries.

Currently, 16 contracting parties from 14 countries participate in the AMF TCP (Japan has designated three contracting parties):

1. Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) (Austria)
2. Energy Research Office (Brazil)
3. Environment Climate Change Canada (Canada)
4. China Automotive Technology and Research Center (China)
5. Technical University of Denmark (Denmark)
6. The Technical Research Centre of Finland (Finland)
7. Agency for Renewable Resources (FNR) (Germany)
8. Ministry of Petroleum and Natural Gas (India)

9. National Institute of Advanced Industrial Science and Technology (Japan)
10. Organization for the Promotion of Low Emission Vehicles (Japan)
11. National Traffic Safety and Environment Laboratory (Japan)
12. Korea Institute of Energy Technology Evaluation and Planning (Republic of Korea)
13. Institute for Diversification and Saving of Energy (Spain)
14. Swedish Transport Administration (Sweden)
15. Swiss Federal Office of Energy (Switzerland)
16. United States Department of Energy (USA)

AMF TCP Management
The AMF TCP is managed by the **Executive Committee**, which consists of one Delegate and one Alternate from each contracting party. These Delegates assess the potential interest of national stakeholders, foster collaboration between country experts and AMF TCP members, and help shape AMF TCP work according to their own country's interests and priorities.

The AMF TCP work program is carried out through **Tasks,** which are projects with defined objectives, a defined work scope, and defined starting and ending dates. These projects can be Task shared, cost shared, or a combination of Task shared and cost shared. Work in specific Tasks is led by Task Managers who participate in Executive Committee meetings to present updates on the progress of work in the Task. They are also responsible for compiling individual contributions and producing the final report.

To support the work of the Executive Committee and enable discussions in smaller groups, two S**ubcommittees** were installed, with a focus on (1) strategy and technology and (2) outreach. The Subcommittees regularly review and — as needed — develop and revise the AMF TCP's strategy, provide new stimuli to encourage technology development, and encourage the participation of new members. Each Subcommittee is headed by one of the experts within the AMF Executive Committee, who leads discussions in the Subcommittee and coordinates the activities of its members.

The **Chair of the AMF Executive Committee** leads all AMF-related work; chairs Executive Committee meetings; and represents the AMF TCP at conferences, workshops, and IEA-related meetings. Several vice-chairs assist the Executive Committee Chair with her/his duties and represent the major regions of AMF contracting parties; currently, these are Asia, the Americas, and Europe.

The AMF **Secretary** is responsible for the daily management of the AMF TCP, organizing Executive Committee meetings, and serving as the main point of contact for Task Managers and new members.

How to Establish Work Priorities
Work priorities for the AMF TCP are established according to the needs of the contracting parties. The goal of the meetings of the Executive Committee, the Strategy Subcommittee, and the Technology Subcommittee is to discuss new developments and identify knowledge gaps and implementation barriers. All delegates are encouraged to propose topics for new Tasks. Whenever three or more contracting parties support a proposal and sufficient funding is raised, a new Task can be established. This system allows for flexible adaptation of the annual work program, continuous development of AMF's scope, and efficient reaction to identified technology gaps or market barriers.

Current Work Program
Seven projects were ongoing in 2023; two have since been closed:

- Task 28: Information Service and AMF Website
- Task 60: The Progress of Advanced Marine Fuels
- Task 61: Remote Emission Sensing
- Task 62: Wear in Engines Using Alternative Fuels
- Task 63: Sustainable Aviation Fuels
- Task 64: E-Fuels and End-Use Perspectives
- Task 65: Powertrain Options for Non-Road Mobile Machinery

Cooperation with Other TCPs

The following transport-related TCPs are organized in the Transport Contact Group:

- Advanced Fuel Cells
- Advanced Materials in Transportation
- Advanced Motor Fuels
- Bioenergy
- Combustion
- Hybrid and Electric Vehicles
- Hydrogen

AMF actively seeks cooperation with these TCPs. Information exchange is fostered not only through participation in Transport Contact Group meetings, but also by attending other group's Executive Committee meetings, identifying fields of common interest, and participating in the projects of other TCPs.

Ongoing AMF TCP Tasks

2.a
Overview of Tasks

Ongoing Tasks in 2023

Task Number	Title	Task Manager
28	Information Service and AMF Website	Dina Bacovsky
60	The Progress of Advanced Marine Fuels	Kim Winther
61	Remote Emission Sensing	Åke Sjödin
62	Wear in Engines Using Alternative Fuels	Jesper Schramm
63	Sustainable Aviation Fuels	Doris Matschegg
64	E-Fuels and End-Use Perspectives	Zoe Stadler
65	Powertrain Options for Non-Road Mobile Machinery	Rasmus Pettinen

Tasks 60 and 63 concluded in 2023. The final report and key messages for these tasks are available on the AMF TCP website: https://iea-amf.org/. All other tasks will continue in 2024.

2.b
Task Reports

Task 28: Information Service and AMF Website

Project Duration	January 2004 – Continuous
Participants **Task Sharing** **Cost Sharing**	None All contracting parties: Austria, Brazil, Canada, China, Denmark, Finland, Germany, India, Japan, South Korea, Spain, Sweden, Switzerland, United States
Total Budget	EUR 55,000 (USD 59,950)
Task Manager	Dina Bacovsky BEST – Bioenergy and Sustainable Technologies GmbH Email: dina.bacovsky@best-research.eu
Website	https://iea-amf.org/content/projects/map_projects/28

Purpose, Objectives, and Key Question

The purpose of Task 28 is to collate information in the field of advanced motor fuels and make it available to a targeted audience of experts in a concise manner.

Activities

- Review relevant news sources on advanced motor fuels, vehicles, and energy and environmental issues in general. News articles are provided by experts in the Americas, Asia, and Europe.
- Publish three electronic newsletters per year (on average) on the AMF TCP website, and use an email alert system to disseminate information about the latest issues.
  - Issue No. 1 / February 2023
  - Issue No. 2 / April 2023
  - Issue No. 3 / October 2023
  - Issue No. 4 / December 2023
- Prepare an Alternative Fuels Information System that provides concise information on alternative fuels and their use for transport. The system contains information on the performance of cars, effects of fuels on exhaust emissions, and compatibility of fuels with the needs of the transportation infrastructure.
- Update the AMF TCP website to provide information on issues related to transportation fuels, especially those associated with the work being done under the AMF TCP. In addition to providing public information, the website has a password-protected area for storing and distributing internal information for Delegates, Alternates, and Task Managers on diverse topics (e.g., strategies, proposals, decisions, and Executive Committee meetings of the AMF TCP).
- Complete additional activities, including distributing news on social media (beginning in 2020). Follow AMF TCP on LinkedIn and Twitter.

Fuels for cars	Fuels for heavy duty vehicles	Non-road fuels	Marine fuels	Aviation
Task 56: Methanol as Motor Fuel	Task 57: Heavy-Duty Vehicle Evaluation	Task 65: Powertrain Options for Non-Road Mobile Machinery	Task 60 The Progress of Advanced Marine Fuels, report	Task 63 Sustainable Aviation Fuels, report
Task 54: GDI Engines and Alcohol Fuels	Task 53-2: Sustainable Bus Systems (Phase 2) Task 53-1: Sustainable Bus Systems (Phase 1)	Task 50 Fuel and Technology Alternatives in Non-Road Engines	Task 41 Alternative Fuels for Marine Applications, report	
Task 52: Fuels for Efficiency	Task 51: Methane Emission Control	Task 33 Particle Emissions of 2-S Scooters, report		
Task 43 Performance Evaluation of Passenger Car Fuel and Powerplant Options	Task 49 COMVEC – Fuel and Technology Alternatives for Commercial Vehicles	Task 25 Fuel Effects on Emissions from Non-Road Engines, report		
Task 22 Particulate Emissions at Moderate and Cold Temperatures Using Different Fuels, report	Task 37 Fuel and Technology Alternatives for Buses, report			**Lubricants**
Task 12 Particulate Emissions from Alternative Fuelled Vehicles (CNG, LPG), report	Task 17 Real Impact of New Technologies for Heavy-Duty Vehicles			Task 16 Biodegradable Lubricants -Diesel, report -Gasoline, report
Task 5 Performance Evaluation of Alternative Fuel/Engine Concepts, report	Task 8 Heavy-duty Vehicles on Alternative Fuels			

Figure 1. Overview of AMF work on comparisons of advanced motor fuels in different transport sectors

Key Findings

The AMF website and newsletters provide a wealth of information on transportation fuels to experts and interested laypersons.

The website provides background information on the AMF TCP and its participants, access to all AMF publications, details regarding AMF Tasks, and information on fuels and their use in vehicles.

- Delegates to the AMF Executive Committee and Task Managers of AMF Tasks are listed on the website with full contact details and portraits.
- AMF Tasks are briefly described and – where available – final reports and brief key messages are presented. Project descriptions and reports date back to the beginning of AMF in 1984.
- Other publications include AMF annual reports, country reports, newsletters, and brochures.
- Information on specific fuel topics can be found either by searching in the Fuels Information System (Figure 1) or by identifying a relevant Task and checking the related report. Knowledge gained through AMF Tasks is frequently added to the system, making it a reference for experts and laypersons alike.

Newsletters are typically around 12 pages and are provided electronically (subscription is possible via the website). Topics covered are as follows:

- Demonstration/Implementation/Markets
- Policy/Legislation/Mandates/Standards
- Spotlights on Aviation, Shipping, and Asia
- IEA and IEA-AMF News
- Publications
- Events

AMF posts around one item per week on Twitter and LinkedIn. Items focus on statements from AMF Task reports and Task key messages, and they also promote the AMF newsletter.

Publications

In 2023, the AMF TCP published four electronic newsletters, posted to the AMF TCP website and distributed it through the national networks of the AMF Delegates.

The Fuels Information System is available on the AMF TCP website. The AMF TCP website is updated frequently with information from Tasks and Executive Committee meetings.

Task 60: The Progress of Advanced Marine Fuels

Project Duration	November 2019–October 2023
Participants **Task sharing** **Cost sharing**	 Austria, Canada, China, Denmark, Finland, Korea, Sweden, Switzerland, and USA Methanol Institute, USA
Total Budget	EUR 1,795,000 (USD 1,980,700)
Task Manager	Kim Winther Danish Technological Institute Email: kwi@teknologisk.dk
Website	https://www.iea-amf.org/content/projects/map_projects/60

Purpose, Objectives, and Key Question

In 2013, AMF released its first Task report on marine fuels (Task 41) highlighting the fact that no alternative fuel option existed that did not add significant costs or pose other serious impediments. The preferred marine fuel, heavy fuel oil (HFO), was soon to be banned or restricted due to its high sulfur and fossil carbon content. Recent developments, however, have highlighted several new fuel options that should be assessed.

Task 60 seeks to answer the following key question: How can new forms of advanced marine fuels contribute to carbon-neutral shipping in the future?

Activities

The final report was finished, and a hybrid conference was held on June 20, 2023, in Copenhagen.

Key Findings

The key findings of this task are as follows:

- Ultra-low-sulfur marine fuel has become available in adequate quantities around the globe, contributing significantly to a reduction in marine sulfur emissions.
- Liquefied natural gas (LNG) as a fuel has seen a big surge in both number of ships and total amount of LNG used for shipping, reducing both sulfur and black carbon emissions.
- Scrubber installations have also surged since the introduction of the International Maritime Organization (IMO) 2020 sulfur cap. Scrubbers effectively capture sulfur but, depending on operation, are less effective in mitigating black carbon. Open-loop scrubbers are prohibited in China.
- Emissions of black carbon can be effectively mitigated through the use of advanced fuels such as methane, ammonia, hydrogen, or methanol.
- The global nitrogen oxide (NO_x) regulation applies only to new ships and has no effect on existing ships. To reduce NO_x pollution from older ships, local enforcement, differentiated harbor taxes, and incentivized retrofit programs are needed.
- Biofuels produced by means of fast catalytic pyrolysis or hydrothermal liquefaction are potentially promising drop-in fuels.
- Methanol dual-fuel engines are becoming an accepted option for new ships.
- Hydrogen engines are still new to the market.
- Ammonia engines are still in the research and development phase.
- Many different fuel production pathways should be considered from a well-to-wake perspective when assessing climate impact.
- Carbon capture technology is important for the decarbonization of the shipping industry.
- Electrification may be the best option for short sea shipping

Publications

A final report and the key messages for Task 60 are available on the AMF TCP website.

Task 61: Remote Emission Sensing

Project Duration	May 2020–May 2024
Participants **Task sharing** **Cost sharing**	 China, Denmark, Finland, Sweden, Switzerland None
Total Budget	EUR 210,000 (USD 229,165)
Task Manager	Åke Sjödin IVL Swedish Environmental Research Institute Email: ake.sjodin@ivl.se
Website	https://www.iea-amf.org/content/projects/map_projects/61

Purpose, Objectives, and Key Question

The objective of this task is to evaluate and propose methods for using remote emission sensing (RES) — for policy purposes, as well as for direct enforcement — to detect high-emitting/gross-polluting vehicles in real-world traffic.

The project will comprise all vehicle categories (i.e., passenger cars, light-duty commercial vehicles, heavy-duty trucks, buses, and motorcycles) running on commonly used combustion fuels (i.e., petrol, diesel, and compressed/liquefied natural gas [CNG/LNG]) designed to meet all adopted legislative emission limits (e.g., Euro 1/I–Euro 6/VI). Special attention will be paid to high-emitting vehicles designed to meet the most recent emission standards, such as Euro 6. Target pollutants will be nitrogen oxide (NO_x) and particulate matter (PM).

The project aims to evaluate and compare the performance and applicability of the following main types of RES technologies to identify high-emitting vehicles:

- Conventional RES (Type 1 RES): Technologies already offered on the market by commercial providers for emission measurement.
- Point sampling RES (Type 2 RES): Similar to Type 1/conventional RES but still under development (i.e., not yet commercialized), Type 2 RES demonstrates the best advantage for measuring PM emissions (both number and mass).
- Plume chasing RES (Type 3 RES): While Type 3 RES cannot measure emissions from as many vehicles as Types 1 and 2, the measurements are longer duration, making this type more useful for pinpointing high emitters.

The project will make use of existing RES datasets in Europe and China, as well as new datasets from upcoming RES measurement campaigns until early 2023.

The general outcome of Task 61 will be an independent comparison and evaluation of the performance of various RES technologies, focusing on their ability and usefulness to detect excess-emitting vehicles for direct enforcement, as well as emissions legislation and air pollution policy. The project will provide proposals on how RES can be practically applied for these purposes, covering both existing and future in-use fleets. The project's final report will include the following:

- An "up-to-date" view of the real-world emission performance of European and Chinese in-use fleets, demonstrating the impact of current emissions legislation on the real-world emissions of vehicle categories — grouped by emission standard, vehicle manufacturer, engine family, etc., to reveal eventual gaps between on-road emissions and legislative emission limits.
- A comparison and evaluation of the performance of various RES technologies to accurately measure on-road emissions, and particularly to accurately pinpoint high- or excess-emitting vehicles on an individual vehicle level and on a vehicle model or engine family level.
- Proposals on how RES can be practically used to detect high-emitting vehicles for direct enforcement purposes as well as to monitor real-world emissions for emission legislation and air pollution policy purposes.

Activities

WP 1: Collection and consolidation of existing data
No further data were collected for Task 61 during 2023. The most recent consolidated data were already collected during the various RES measurement campaigns carried out in Europe and China in 2022 and reported in the AMF 2022 Annual Report. This goes also for the related portable emissions measurement sampling (PEMS) measurements and exhaust plume simulations. A milestone for European RES data was the launch of the new database developed for the City Air Remote Emission Sensing (CARES) project, finalized in June 2023 and partly open to the public. The number of (attempted) emission measurements stored in the database has exceeded 2.4 million. The new database contains RES Type 1 and 2 data.

WP 2: Comparison and evaluation of the performance of different RES technologies
The summary report of the three city demonstration measurement campaigns in the CARES project was published in 2023, providing an overview of the results from measurements collected using RES type 1, type 2, type 3, and PEMS [1] in Milan, Krakow, and Prague/Brno.

Several scientific papers providing more extensive and detailed comparisons and evaluations of RES Types 1, 2, and 3, based on the measurements carried out in the CARES project, were prepared and submitted to scientific journals in 2023 or early 2024 [2, 3, 4].

WP 3: Evaluation of using RES to detect individual high-emitting vehicles for enforcement
Based on both the test track and real-world setting measurements in the CARES project, we completed extensive work to evaluate the potential of RES Types 1, 2, and 3 to accurately detect individual high-emitting vehicles for both NO_X and particulate matter for both light- and heavy-duty vehicles, representing newer vehicles than Euro 4 [4, 5, 6].

WP 4: Evaluation of using RES for emission legislation and air pollution policy purposes
We used the RES Type 1 data collected in the city demonstration measurement campaigns during the CARES project to analyze the emissions performance of petrol, diesel, and LPG/CNG passenger cars by Euro standard and by engine family up to Euro 6d [1, 7].

WP 5: Project coordination and management, synthesis, reporting, and dissemination
In 2023, we reported activities and progress in Executive Committee meetings 65 and 66. Six Task 61 work meetings were arranged in 2023, the majority focusing on preparation of the final Task 61 report during the fall.

Key Findings

- RES type 1, 2 and 3 data agree well with each other — as well as with PEMS — for NO_X, but less well for PM, for which RES type 1 deviates from the other methods, especially for vehicles equipped with diesel particulate filters (i.e., vehicles with very low particle emissions). The agreement for NO_X for RES Type 1, Type 2, and PEMS can be seen in Figure 1.
- Applied in the right manner, all three types of RES are capable of detecting individual high-emitting vehicles with regard to both NO_x and PM emissions; however, for RES Types 1 and 2, single measurements are not sufficient to avoid significant errors.
- RES Type 1 seems best applied for exploring the efficiency of and compliance with light-duty vehicle emissions legislation, in particular for NO and for evaluating air pollution policies related to road transport, such as the way to design and assess the impact of Low Emission Zones.
- REST Type 2 seems best applied for evaluating PM emissions and identifying vehicles equipped with non-functional or not fully functional diesel particulate filters.
- RES Type 3 seems best applied for detecting heavy-duty vehicles with failing selective catalytic reduction (SCR) systems.

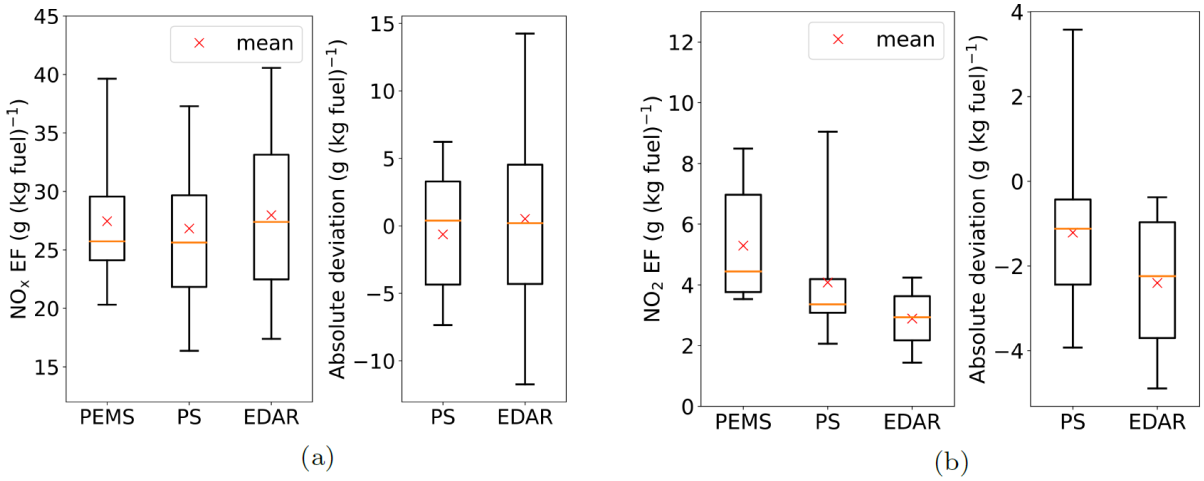


Figure 1. (a) Comparison of NO_x-fuel-based emission factors (EFs) measured with PEMS, RES Type 2 (point sampling [PS]) and RES Type 1 (emissions detection and reporting [EDAR]). Left: Boxplots of the EFs. Right: Deviation of PS and EDAR measurements compared to PEMS. (b) Comparison of fuel-based NO_2 EFs measured with PEMS, PS, and EDAR. Left: Boxplots of the EFs. Right: Deviation of PS and EDAR measurements compared to PEMS.

Main Conclusions

- There are many valid and promising applications of RES. Considering that the three different types have complementary features, they may well be applied in assembly, not only as single systems.
- To identify tampered vehicles, RES may be the only option but would require a shift from some of today's focus on periodic technical inspections (PTIs) to roadside inspections, in which case, all types of RES have proven capable of drastically increasing officials' efficiency in catching gross polluters.
- RES technologies and associated pollutant measurement and auxiliary instruments are continuously being further developed to improve performance and meet new challenges to reduce road vehicle emissions.

Publications

1. Bernard, Y., et al. (2023) *CARES deliverable D3.4 – Summary Report: Partner City Measurement Campaigns*.
2. Knoll, M., M. Penz, C. Schmidt, D. Pöhler, T. Rossi, S. Casadei, Y. Bernard, Y., Å. Hallquist, Å. Sjödin, and A. Bergmann (2023) "Evaluation of the point sampling method and inter-comparison of remote emission sensing systems for screening real-world car emissions." Manuscript submitted to *Science of the Total Environment* (accepted for publication 12 March 2024).
3. Knoll, M., M. Penz, H. Juchem, C. Schmidt, and D. Pöhler, A. Bergmann (2023) "Large-scale automated emission measurement of individual vehicles with point sampling." Preprint in *Atmospheric Measurement Techniques, The European Geosciences Union*.
4. Schmidt, C., D. Pöhler, S. Schmitt, J.P. Lollinga, Q. Vroom, R.N. Gijlswijk, N.E. Ligterink, M. Knoll, F.J. Naomi, D.C. Carslaw, M. Vojtíšek, M. Pechout, and U. Platt, (2023) "Optimisation and Validation of Plume Chasing for Robust and Automated NO_x and Particle Vehicle Emission Measurements." Manuscript submitted to *Atm. Env. X 2024*.
5. Borken-Kleefeld, et al. (2023) *Final Report on high-emitter & clean vehicle identification*.
6. Sjödin, Å., et al. (2023) *New knowledge on high-emitters and on-road emissions from the H2020 CARES project*. Task Force on Emission Inventories and Projections Annual Meeting, Oxford, April 2023.
7. Bernard, Y., et al. (2023) *Real-world emission factors and impact of low-emission zones*.

The final Task 61 report will be made available for download on the website in the late spring/early summer of 2024.

Task 62: Wear in Engines Using Alternative Fuels

Project Duration	January 2022–June 2024
Participants **Task sharing** **Cost sharing**	China, Denmark, Finland, Germany
Total Budget	In-kind contributions corresponding to > EUR 150,000 (USD 162,620)
Task Manager	Jesper Schramm DTU – Technical University of Denmark Email: jessc@dtu.dk
Website	https://iea-amf.org/content/projects/map_projects/62

Purpose, Objectives, and Key Question

Alternative fuels have been intensively introduced in transportation sectors in recent years. While some of the wear caused by these fuels can be seen initially, the problems really become clear after years of application. The goal of this task is to identify and present an overview of potential wear issues to prevent major surprises in the future.

We will evaluate excess wear in **internal combustion** engines caused by **the use** of alternative fuels. The objectives are to review ongoing related projects in the member countries and conduct a general literature review to evaluate which engine wear problem that can be foreseen with future application of alternative fuels.

The key questions to be addressed are as follows:

- How severe are the problems associated with use of alternative fuels?
- What is the expected increase in engine wear caused by these fuels?
- What can be done to solve these problems?

Activities

General literature review

We will complete a general literature review for alternative fuels, focusing on those relevant to ongoing studies related to engine applications in the countries involved in the task: methanol, ammonia, and bio-oils, among others.

In the literature review, we will compile the available information and report it in a structured way that supports future application of alternative fuels.

On-line seminars

Activities related to engine wear are ongoing in the involved AMF countries. These studies will be communicated through presentations from the responsible “activity” persons (or other designated people) at frequent seminars. The results from the seminars will provide a background for the literature review report.

Key Findings

The results will be published in a report that will be delivered at the end of the project period. In addition, the results will be published at international conferences and journals.

Main Conclusions

The project results will identify and add to the understanding of the high degrees of wear caused by use of alternative fuels in engines used in the transportation sector.

Publications

None so far.

Task 63: Sustainable Aviation Fuels

Project Duration	November 2021–April 2023
Participants **Task sharing** **Cost sharing**	Austria, Brazil, China, Denmark, Germany, Switzerland, USA
Total Budget	EUR 200,000 (USD 216,848)
Task Manager	Doris Matschegg BEST Bioenergy and Sustainable Technologies GmbH Email: doris.matschegg@best-research.eu
Website	https://iea-amf.org/content/projects/map_projects/63

Purpose, Objectives and Key Question

Sustainable aviation fuels (SAFs) have the potential to reduce greenhouse gas (GHG) emissions from the aviation sector. However, this potential remains largely untapped because such fuels currently represent only 0.05% of total jet fuel consumption. The aim of Task 63 is to lay the foundation for collaborative research, development, and demonstration (RD&D) work on SAFs within the AMF TCP. Thus, the Task focuses on identifying stakeholders and experts, assessing the national situations of the participants, and facilitating information exchange regarding the primary obstacles to adopting SAFs. The Task will address biofuels as well as e-fuels.

Activities

Activities associated with Task 63 include a comprehensive description of the international status of SAFs, an analysis of the concrete situation in some Task member countries, highlighting of best practice examples, and identification of international stakeholders.

Status quo

- Approved technology pathways and those in the ASTM certification process: description of certified technologies and those for which certification applications have been submitted, feedstocks and products, technology readiness levels (TRLs), production costs, and GHG emissions over the life cycle of the technology.
- Production facilities: overview of facilities in operation, under construction, or planned; current and projected production capacities; and technology providers.
- Application of SAF: airports that supply SAFs, airlines that use SAFs, announced supply agreements, announcements by aircraft manufacturers.
- Legislation: national and European Union (EU) commitments and international announcements and agreements.
- SAFs in the energy system: global demand, relation to other transport sectors and other energy-intensive sectors, and projected development.

National assessments

- Identification of current and potential national actors from research, industry, and administration along the value chain (e.g., feedstock suppliers, conversion technologies providers, aviation fuel suppliers, aviation fuel consumers, aviation original equipment manufacturers [OEMs], energy providers, bioenergy research centers, academia).
- Qualitative assessment of the national feedstock potential (considering competing use and trade) for the production of SAFs from biomass, wastes, residues, and electrolysis hydrogen and comparison of production potential with demand.
- Analysis of national strengths based on raw material availability, technological expertise, and willingness to implement on the part of the actors involved.
- Analysis of the current legal framework and announced new regulations with regard to their impact on national climate targets.
- Identification of challenges and opportunities along the value chain with regard to the market introduction of sustainable aviation fuels.

Best practice examples

- Compilation of jointly selected examples of successful production and application of SAFs so that other stakeholders in the field (e.g., airports, airlines, kerosene providers) can learn from them.
- Presentation of best practice examples through a series of three online seminars with different thematic focus (Feedstocks & Conversion, Supply & Operation, and Markets & Policy) during which successful actors will describe how they have implemented the production or application of SAFs, the challenges they have faced, and the strategies they implemented to overcome them.
- Posting of the seminars, as well as the presentations, online to make their findings as accessible as possible.
- Summary of the lessons and recommendations for action derived from the examples in a report. Preparation and sharing of best practice fact sheets online.

Key Findings

Because Task 63 lays the foundation for collaborative research, the findings were broad rather than specific. Key findings of Task 63 include the following:

- The primary barriers for implementing SAFs include (1) feedstock limitations, as well as competition with other sectors for certain feedstocks and certain regions; (2) high production costs and, due to limited market capacities, significantly higher market prices for SAFs compared with conventional jet fuel, and (3) a lack of clear international regulations and alignment between them (e.g., EU Emissions Trading System [EU-ETS] and Carbon Offsetting and Reduction Scheme for International Aviation [CORSIA]).
- Biogenic SAFs are essential for decarbonizing the aviation sector, especially in the short term. The hydroprocessed esters and fatty acids (HEFA) process is currently the main pathway, but until 2030, gasification with a subsequent Fischer–Tropsch synthesis (gasification-FT) and alcohol-to-jet (ATJ) will produce significant amounts of SAFs. The power-to-liquid (PtL) process will take longer to be fully commercial. However, all SAF technology pathways are needed to achieve the targets of the sector.
- Scaling up SAF capacities requires huge investments and risk sharing among stakeholders. Offtake agreements are one possibility for airlines to support SAF producers while securing their SAF supply. The number of offtake agreements has increased sharply in recent years, and this trend is expected to continue.
- SAF availability is very limited at the moment, but the EU and USA for example have very ambitious plans for capacity increase (e.g., ReFuelEU Aviation, U.S. Aviation Climate Goal). Worldwide, there are six production facilities in operation, with Neste as the market leader. In the USA, the production forecast for 2027 is about 60 times higher compared with 2022 levels.
- Although the EU shares a common (proposed) framework, strategies among member states vary (e.g., strong focus on e-fuels in Germany and Denmark).
- SAF blending is not a technological issue (even in the case of multi-blending), but an administrative one. There are three methods for SAF delivery: segregated delivery, mass balance, and book and claim. While the book and claim mechanism seems the most practical, it does not support reducing regional non-CO_2 effects.

Main Conclusions

Although SAF production technologies (other than hydrotreatment) have yet to be further developed and deployed, neither production technology nor technical issues when operating aircraft on SAF is seen as the main challenge. Implementing SAF use is primarily an economic challenge, rather than a technical one.

Publications

- Final report
- Key messages
- Presentations of national workshop (German)
- Recordings and presentations of online seminars
- Presentations of international workshop

Task 64: E-fuels and End-Use Perspectives

Project Duration	May 2022 – April 2024
Participants **Task sharing** **Cost sharing**	 Brazil, China, Denmark, Finland, Germany, Japan, Switzerland, USA None
Total Budget	EUR 200,000 (USD 216,844)
Task Manager	Zoe Stadler Eastern Switzerland University of Applied Sciences Email: zoe.stadler@ost.ch
Website	https://iea-amf.org/content/projects/map_projects/64

Purpose, Objectives, and Key Question

The focus of Task 64 is an informative exchange about the production and application of different e-fuels and the corresponding regulatory framework and standards. The output of the task is a concise report addressing the following topics:

- Demo sites/pilot programmes: Consideration of demonstration sites in different countries that focus on the development and improvement of e-fuel production technologies, including consideration of technology pathways, technological maturity, and case studies.
- Carbon dioxide (CO_2) and hydrogen (H_2) resources: Examination of the availability of CO_2, water resources, and electricity sources in different countries, with assessment of national feedstock potential for e-fuel production.
- Application side: Experiences and challenges in the application of e-fuels, especially regarding the use of e-fuels in aviation, maritime, and road transport.
- Regulations and standards: Norms, standards, and/or regulations for the use of e-fuels in various countries, including incentives and regulations that promote the production and use of e-fuels.
- Life-cycle assessment (LCA): Exploration of the methods for LCA in the different countries/regions (e.g., Renewable Energy Directive II [REDII] in the European Union [EU]), including typical and expected net greenhouse gas (GHG) effects, as well as other environmental impacts (e.g., water consumption) associated with e-fuel production and use.
- Techno-economic assessment (TEA): Summary of the costs of different e-fuel production value chains in various countries, and methodology for economic calculation, including costs on the application side of the switch to e-fuels.
- Stakeholders: Identification of actors from research, industry, and administration along the value chain (e.g., raw material supply, conversion technologies, e-fuel suppliers, e-fuel consumers), as well as bioenergy research centres and academic institutions.

Activities

We organized workshops around each of these topics, during which participants formulated key messages and joint conclusions that served as the basis for the final report. The report provides an overview of ongoing activities worldwide, as well as past and current technical, economic, and regulatory challenges. In addition to the exchange of information, the report is intended to help raise awareness of the importance of global activities in the field of e-fuels.

At the end of the task, the main findings will be presented at a web seminar. The duration of the task is two years.

Key Findings

We identified the following commonalities among the strategies of different countries concerning e-fuels:

- Renewable Energy Focus: Many countries are aiming to increase the share of renewable energy sources in their energy matrices. These efforts include the development and utilization of bio- and e-fuels.
- Technological Development: There is a strong emphasis on research and development to improve technologies related to the production, distribution, and utilization of e-fuels. Such research includes advancements in catalyst systems, fuel synthesis processes (such as Fischer-Tropsch), and the development of new routes for producing advanced fuels.
- Decarbonization Goals: All countries are motivated by goals related to decarbonization and reducing carbon emissions. E-fuels are seen as a potential pathway to achieve these goals, particularly in sectors like aviation and shipping where electrification may not be immediately feasible.
- Diversification of Fuel Sources: There is a recognition of the need to diversify fuel sources to enhance energy security and resilience, including exploration of multiple types of e-fuels such as methanol, methane, and ammonia.

We identified the following differences among the strategies of different countries:

- Prioritization of Specific e-Fuels: Different countries prioritize different e-fuels based on their domestic resources, technological capabilities, and the specific needs of their industries.
- Target Sectors: The sectors targeted for use of e-fuels vary among countries. Some countries focus primarily on transportation — including aviation, shipping, and heavy-duty transport — while others also consider industrial applications and chemical manufacturing.
- Policy Emphasis: Each country has its own policy framework and incentives to promote the development and adoption of e-fuels. These may include subsidies, regulations, and government-led initiatives to support research, development, and commercialization efforts.
- International Collaboration and Trade: Some countries, particularly those with limited domestic resources or land area, may rely on international collaboration and trade to access e-fuels. Such collaboration might involve considering overseas production sites and partnerships for sourcing and distribution.
- Production Costs for E-Fuels: Because the production costs are largely influenced by the electricity costs for water electrolysis, the production of e-fuels is more economical in regions with lower electricity prices.

Because e-fuel production facilities have not yet been scaled up, workshop participants could share few experiences in the application of e-fuels. The different e-fuels have advantages and disadvantages in application, depending also if they can be used as drop-in fuels or need a separate distribution infrastructure and end-use equipment. In the transport sector, e-fuels like kerosene, diesel, and gasoline are compatible with existing infrastructure and can mostly be blended with their bio- or petroleum-based counterparts. Methanol and ammonia, on the other hand, need new infrastructure and application technologies for the transport sector.

Main Conclusions

E-fuels, together with biofuels, will play an important role in reaching a net-zero target in the energy and mobility sectors. Both types of renewable fuels have their advantages and challenges, and both are needed for a successful energy transition. E-fuels are an important complement to biofuels, and countries could combine the synergies and benefits of both. The opportunities that arise with the energy transition will lead to an increase in global technology diversity. Several new technologies are being developed and there is a global technological race, with several routes and alternatives capable of assuming a relevant role in the energy transition. In the future, emerging industries will coexist and eventually replace traditional technologies. Energy systems will follow a process of carbon intensity reduction in an energy transition branded by strong competition (among different technological alternatives). The climate agenda will increasingly influence international trade and international relations.

- **Technology Readiness Level:** In general, biofuels production technologies have a higher technology readiness level (TRL) than e-fuels. Some electro-fuels, such as FT fuels or methanol, can be produced via high TRL or mature technologies. However, although some single technologies might have a high TRL, the overall TRL for the combination of several technologies in an overall plant can be lower.

- **Political Strategies**: In many political strategies, e-fuels are considered important for various future applications. The expected demand for e-fuels is impressive, and questions arose as to whether these demands can be met. In terms of electrolyser production capacity, the production potential appears to meet current demand, and expansion is ongoing. If the numbers of produced electrolysers will meet the projected demand for low-carbon emission hydrogen, and therewith for e-fuel production, is still unclear.
- **Incentives and Regulations:** To support technology development and to increase e-fuel production, strategic programmes in several countries were implemented. Depending on the country, they consist of incentives for e-fuel production, support for research projects, or regulations that make a certain-percentage use of e-fuel mandatory, or a combination of these three. In addition to political programmes, companies are enforcing the use of sustainable fuels to reduce their carbon footprint.
- **Application of E-fuels:** The production of e-fuels is very energy-intensive if based on water electrolysis, which is why many discussions about their implementation center on whether these processes should be used primarily for applications that are difficult to electrify. These so-called "hard-to-abate" sectors are the aviation industry, maritime applications, and industrial processes. For aviation, ASTM certification is a key element. Currently, the one path to produce jet fuels is via FT synthesis. Using this production path, 70–80% of products can be used directly for aviation; the rest are by-products that can be used in the chemical and shipping industries. In the shipping industry, e-methanol, e-ammonia, e-methane, and hydrogen are considered interesting options for application. Regulations for onboard use of methanol and liquefied methane exist today, giving these fuels an advantage over ammonia or hydrogen for broad implementation.
- **Life-Cycle Assessments:** Water electrolysis for hydrogen production is a key technology in the production of e-fuels. There are other ways to produce hydrogen, but these are not considered here. While water electrolysis is necessary for all e-fuel production pathways, it has the largest impact on e-fuel production cost, as well as the carbon intensity of the product. LCA results show that using renewable electricity and hydrogen is key to low-carbon e-fuels. Usually, using an electricity grid mix to produce e-fuels does not provide GHG emission reduction benefits compared with fossil baseline fuels. It is therefore crucial to use renewable electricity sources to obtain an ecological benefit. The analysis shows that e-FT fuels and e-methanol offer significant GHG reduction benefits when coupled with renewable electricity and/or H_2 compared with their fossil counterparts. Regional distribution of CO_2 sources and the availability of fresh water must be considered further. Because a significant amount of fresh water is needed as a renewable source of hydrogen for e-fuel production, regional and seasonal variations in water availability and scarcity should be considered when siting carbon capture and utilisation (CCU) facilities to avoid water-scarce areas.
- **Techno-Economic Assessments:** The key cost driver of e-fuel production is hydrogen, and production cost depends primarily on electricity prices and capital cost, if the hydrogen is produced via water electrolysis (there are also other ways to produce hydrogen, but these are not considered here). Because electricity costs depend on the geographical area, the location of a production facility has a major influence. To obtain low-cost hydrogen for economical e-fuels production, both electricity cost and electrolyser capital cost need to decrease greatly. Ambitious learning curves are assumed, and high operating capacities are needed, which pose challenges. The costs of e-fuel production can be lowered by increasing the efficiencies of e-fuel production technologies, increasing the sizes of the production plants, and reducing costs for other resources like CO_2 and nitrogen. The price for CO_2 is mainly defined by post-combustion technologies like capture, purification, compression, and cooling. Point sources are more economical because capture costs increase with decreasing concentrations. However, e-fuels are generally more expensive than biofuels. Appropriate carbon pricing and low renewable power costs are critical to enhancing the economic competitiveness of e-fuels.

Despite economic challenges, projects for the production of e-fuels are announced frequently around the world. Political programmes and customer demand are the main drivers of these development projects, and a major expansion of production facilities is expected.

Task 65: Powertrain Options for Non-Road Mobile Machinery

Project Duration	November 2023–November 2025
Participants **Task sharing** **Cost sharing**	 Canada, Denmark, Finland, Sweden, and USA Possibly Sweden to Canada, will be decided later
Total Budget	EUR 1,327,000 (USD 1,438,724)
Task Manager	Rasmus Pettinen VTT Oy, Technical Research Centre of Finland LTD Email: rasmus.pettinen@vtt.fi
Website	https://iea-amf.org/content/projects/map_projects/65/

Purpose, Objectives, and Key Question

This Task will explore the potential of energy and powertrain options and the feasibility for non-road mobile machinery (NRMM) applications in different use cases. NRMM comprises a wide selection of different kinds of machinery operating in different environments. We will explore questions about what kind of powertrain and energy options offer the best fit for each application without adversely affecting the productivity, usability, and security of supply.

The Task will address the following main topics:

- Energy and powertrain options for NRMM.
- Implications for the use of new carbon-neutral and low-carbon powertrains on the security of supply and on productivity.
- End-use perspective of alternative powertrains (fuels and other energy carriers).
- Local air pollutant emissions associated with NRMM, especially NRMM operating in urban areas.
- Perspectives for CO_2 regulation in different countries.

Activities

Canada's task-sharing contribution

- Regulation of NRMM around the globe, including air pollutants and CO_2.
- National inventory of existing machinery.
- Real-driving emissions testing of all-terrain vehicles (ATVs) and snowmobiles and comparison to certification testing results.

Denmark's task-sharing contribution

- Report from an ongoing project on construction machinery, including the following:
  - Emission measurement during actual work by NRMM fueled by biofuel (hydrotreated or hydrogenated vegetable oil (HVO) and battery electric vehicles (BEVs).
  - Development of digital twin models using measurement data.
- Report from an ongoing project for airport ground-handling machinery.
- Report from portable emissions measurement sampling (PEMS) testing results from agriculture tractor.
- Project on greener fuel options for generator sets.
- Facilitation of snowmobile and ATV real driving emissions testing at Sisimiut municipality.

Finland's task-sharing contribution

- NRMM heavy-duty (HD) engine testing data covering different fuel options for spark-ignition (SI) combustion. Engines are tested on a non-road steady cycle (NRSC) and other steady-state operation points covering full-load and partial-load conditions.
- Testing data for an NRMM HD SI engine run with neat ethanol and methane, as well as with RE85 and a mixture of ethanol and methane.

- Testing data for a direct-injected SI-hydrogen (H_2) engine.
- Contribution through Government-funded project related to NRMM energy options and powertrains that includes information about and analyses of the potential of different energy and powertrain options in mining and forestry applications; analyses include both simulation and experimental methodologies.
- Development of a simulation model for analyzing energy and powertrain options for NRMM applications, including H_2 fuel-cell power production and ethanol and methane internal combustion engine (ICE) power production in generator and hybrid powertrain concepts.
- Development of a tool to evaluate machinery-level power generation options depending on use case and available energy options.

Sweden's task-sharing contribution:

- National inventory of existing machinery (described in the previous NRMM annex in AMF and AMF Task 50).
- Availability of zero-emission construction equipment.
- Identification of the need for advanced motor fuel technologies within the construction equipment sector.
- Strategies and visions for zero emissions in different counties (with focus on road and rail authorities).

In addition, Sweden and Canada are interested in emission testing of snowmobiles and possibly ATVs. If testing arrangements are possible, this task would be a joint task with Canada. Sweden is also willing to cost-share emission measurements for different technology pathways for snowmobiles (and possibly ATVs).

USA task-sharing contribution:

- Assessment of the following NRMM applications in the United States with their associated energy use and greenhouse gas (GHG) emission contributions: agriculture, mining, construction, locomotive, and marine applications.
- Assessment of the applicability of different low-carbon fuels and powertrains (including ICEs, hybrid configurations, battery EVs, and hydrogen fuel cells).
- Results of life-cycle analysis (LCA) and techno-economic analysis (TEA) of different fuel/powertrain combinations.
- Exploration of the impacts of GHG reductions, air pollutant reductions, and energy use reductions.

The U.S. contribution will be leveraged with a study by the U.S. Department of Energy in multiple national labs. If needed, the U.S. will assemble its industry stakeholders to present their visions and activities to decarbonize the NRMM sector in the U.S. and globally.

Possible other participants

Other participants are welcome to join the activity. Austria has indicated an interest in joining the Task. However, discussions regarding the country's possible contributions are still ongoing and cannot be confirmed yet.

Expected Results / Deliverables

The task will provide a synthesis of the potential of different energy/fuel options and powertrains for NRMM applications and an investigation of the emissions performance of current technologies compared with possible future regulatory frameworks.

The Task will result in a written Final Report that includes the following:

- Engine dynamometer and in-use NRMM test data: regulated emissions, energy consumption, CO_2 emissions, and alternative energy/fuel options assessed using the well-to-wheel approach.
- Discussion of the feasibility of different energy and powertrain options in NRMM depending on use case, location, available energy sources, and regulation.
- Review of regulatory environment in selected countries.
- National inventories of NRMM and strategies for adapting zero- and low-carbon NRMM in use.

The Global Situation for Advanced Motor Fuels

Country Reports

Countries participating in the AMF TCP have prepared reports to highlight the production and use of advanced motor fuels in their respective countries, as well as the existing policies associated with those fuels.

Austria

Drivers and Policies

Transport GHG Emissions Share and Increase

The decarbonization of road transport presents the greatest challenge in Austria compared with other sectors: the greenhouse gas (GHG) emissions associated with road transport have increased steadily since 1990 (+59%), mainly as a result of greater road use (in terms of kilometres driven) in passenger and freight transport. In addition, the amount of fuel sold in Austria but used abroad increased because of higher fuel prices in neighbouring countries. GHG emissions reached their peak in 2005, followed by a period between 2005 and 2012 when GHG emissions decreased due to lower amounts of fuel sold, increased use of biofuels for blending, and an improved fleet with lower specific fuel consumption. Since then, GHG emissions from transport have been gradually increasing again, except for a sharp decrease in the pandemic year (2020).

According to the Environmental Agency Austria, in 2021, the transport sector in Austria generated GHG emissions of approximately 21.6 million tonnes of carbon dioxide (CO_2) equivalent. Compared with 2020, emissions increased by 4.2% as a consequence of the higher mileage after the 2020 pandemic year. In 2021, 55% of the road transport GHG emissions were caused by passenger cars, 8% by light-duty vehicles, 36% by heavy-duty vehicles and buses, and around 1% by mopeds and motorcycles.

In 2021, biofuels (all types) replaced around 5.84% of fossil fuels sold. This share exceeds the substitution target of 5.75% of fossil fuel on the market, as stipulated in the Fuel Ordinance; again, however, it represents a decline compared with previous years. The relatively low sales volume of pure biofuels is due to its relatively lower competitiveness compared with fossil fuels. In 2021, the use of biofuels resulted in a reduction of approximately 1.37 million tonnes of CO_2 emissions in the transport sector.

Politics: Recent Activities and Developments

Austria is committed to carbon neutrality by 2040 — a goal that requires substantially increased decarbonization efforts across all energy sectors. Especially in the transport sector, a radical turnaround is needed to achieve this political target. For this reason, Austria has adopted a number of measures, such as a newly designed taxation system that imposes a price penalty on ecologically destructive activities. This system, enacted in 2021, introduces a CO_2 pricing system with a continuously increasing price penalty, from EUR 30 (USD 32. 4) per ton CO_2 (2022) up to EUR 55 (USD 59.4) per ton CO_2 (2025). Beginning in 2026, a European Union (EU)-wide CO_2 emissions trading system will replace national fixed-price rates. In addition, a mandatory procurement of zero-emission vehicles by the public sector is taking effect. Other measures already in place are an increased Normverbrauchsabgabe (NoVA) tax and the “Right to Plug,” which alleviates previous approval hurdles for the installation of charging stations in multi-apartment buildings.

Austria has also developed a number of national strategies in the area of transport, such as the Mobility Master Plan and the corresponding R&I Mobility Strategy. Complementary strategic plans for freight transport (the Master Plan for Freight Transport) and for hydrogen (the Hydrogen Strategy for Austria) have also been published recently. Despite significant efforts, a consistent, overarching activity document listing a full set of measures, their expected contributions, and corresponding key performance indicators (KPIs) (fully describing the path to climate neutrality in 2040) has not been developed. An updated Austrian National Energy and Climate Plan reflecting the ambitious European Green Deal targets in the *Fit for 55* package (a 55% reduction in GHG emissions by 2030) might serve as the nucleus for an aggregated report of all planned measures and an alignment of their expected impact contributions.

Austrian Integrated National Energy and Climate Plan

The integrated National Energy and Climate Plan (NECP) is a planning and monitoring instrument of the EU and its member states. It is intended to contribute to improved coordination of European energy and climate policy and serves as the central instrument for implementing the EU’s renewable energy and energy efficiency targets for 2030. For Austria, the current NECP includes measures to support an increase in the share of renewable energy sources in the transport sector. In Austria, the biogenic share

in relation to the energy content of diesel is about 6.3%; for petrol, it is currently about 3.4%. Taxes such as the NoVA tax — in which a bonus/penalty system for CO_2 emissions is levied when passenger cars are first placed on the domestic market (new car purchase or private import) — provide incentives to purchase vehicles with low CO_2 emissions. Despite being obligated to provide an updated version of the NECP in 2023, no national commonly shared vision on the measures and timelines necessary has been reached to date, thus putting at risk the achievement of the national climate targets.

Taxes and Incentives

In July 2008, Austria introduced the NoVA tax for new vehicles. New cars that emit less than 87g of CO_2/km are exempt from NoVA. Further reductions of 5g of CO_2/km per year are planned until 2024. Each additional g results in a financial penalty of EUR 80 (USD 86.4) on the purchase price of a passenger vehicle. Pure biofuels are exempt from the mineral oil tax. Compressed natural gas (CNG) is exempt from the mineral oil tax as well, but it is subject to the lower natural gas tax.

Advanced Motor Fuels Statistics

Fleet Distribution and Number of Vehicles in Austria

2023 marked the fourth time in history that the total number of motor vehicles registered in Austria exceeded 7 million, with 7.34 million registered motor vehicles — an increase of 1.0% or 70,736 vehicles compared with 2022. Passenger vehicles dominate the fleet with 5.19 (compared with 5.15 in 2022) million vehicles (Table 1), representing the largest share (70.6%) of vehicles in Austria.

Fleet numbers demonstrate a continuous trend toward advanced, alternative propulsion systems, especially toward battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs) (Figure 1). For instance, 155,491 BEVs and 158,867 HEVs were registered in 2023, illustrating a positive trend continuing from previous years and following an exponential trajectory. The number of vehicles powered by CNG and liquefied petroleum gas (LPG), including bivalent ones, remained relatively stable, representing a moderate fleet level of 5,114 vehicles (compared with 5,512 in 2022). The number of bivalent vehicles decreased from 2,947 in 2022 to 2,771 in 2023, and the CNG vehicle fleet also decreased marginally from 2,564 in 2022 to 2,342 in 2023. With only 67 vehicles (up slightly from 62 in 2022), the fuel cell electric vehicle (FCEV) fleet is still negligible.

Table 1. Austrian Fleet Distribution of Passenger Vehicles (M1) by Drivetrain, 2017–2023

Drivetrain	2017	2018	2019	2020	2021	2022	2023
Gasoline	2,074,442	2,133,473	2,173,772	2,190,388	2,192,128	2,189,530	2,184,042
Diesel	2,770,470	2,776,333	2,772,854	2,762,273	2,717,475	2,651,280	2,584,985
Electric	14,618	20,831	29,523	44,507	76,539	110,225	155,490
LPG	2	2	2	2	1	1	1
CNG	2,433	2,365	2,602	2,753	2,654	2,564	2,342
H_2	19	24	41	45	55	62	67
Bivalent gasoline/ ethanol (E85)	5,992	5,769	5,770	5,190	4,878	4,595	4,326
Bivalent gasoline/LPG	335	333	330	330	331	331	334
Bivalent gasoline/ CNG	2,773	3,177	3,143	2,978	2,801	2,616	2,437
Hybrid gasoline/ electric	26,039	34,086	45,645	68,983	108,978	148,284	195,439
Hybrid diesel/ electric	1,455	2,463	6,172	14,378	27,996	41,402	55,543
Total	4,898,578	4,978,856	5,039,854	5,091,827	5,133,836	5,150,890	5,185,006

Source: Statistik Austria.

New Registrations

In 2023, 239,150 (compared with 215,050 in 2022) new passenger cars were registered. After a Covid-related decline of 10.3% in 2022, registrations again show an upward trend with +11.2% (+24,100 vehicles). Despite the higher overall registration numbers, new registrations of petrol- and diesel-powered vehicles continued to fall by 1.5% to 77,354 (versus 78,567 in 2022) and by 3.2% to 46,568 (versus 48,155 in 2022), respectively.

With 47,621 new registrations, all-electric passenger cars showed an increase of 39.4%. The number of vehicles with hybrid drivetrains also increased (petrol-hybrid: +30.1%, diesel-hybrid: +8.9%) . Overall, in 2023, the share of all-electric passenger cars was 19.9%, the share of hybrid passenger cars was 28.3%.

Overall, the share of all alternatively powered passenger cars increased to 48.2% (compared with 41.1% in 2022), confirming the transition toward alternative drivetrains.

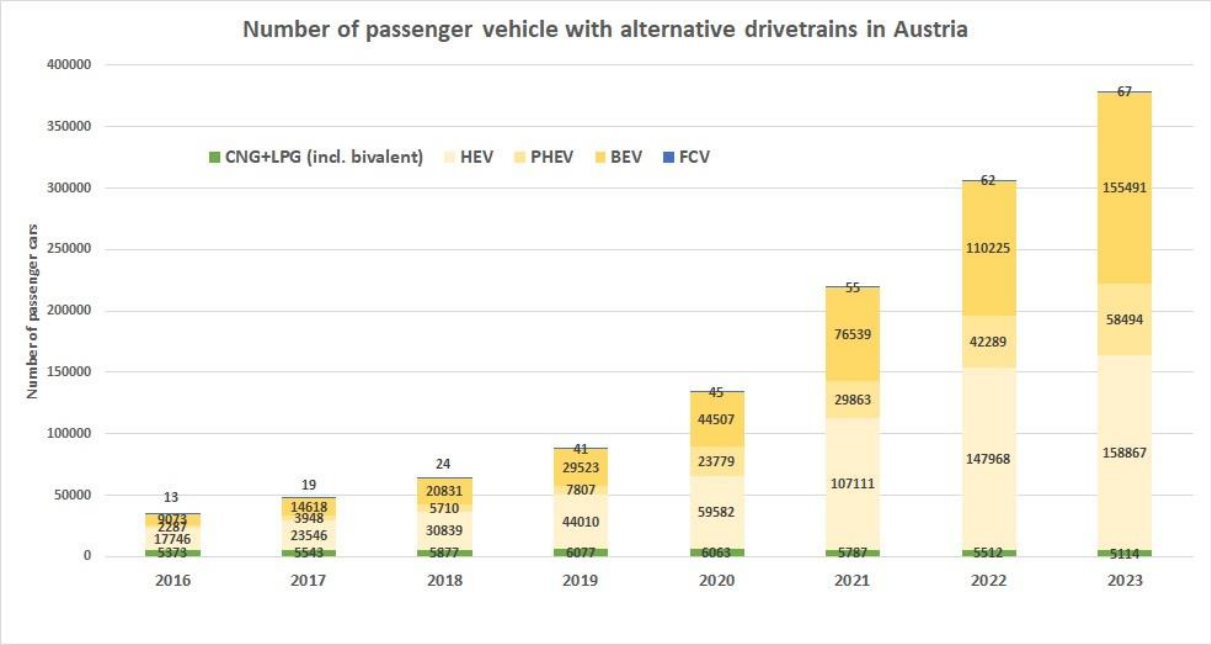


Figure 1. Trends for vehicles with alternative drivetrains in Austria, 2016–2023 (Source: Statistik Austria)

Average CO_2 Emissions of Passenger Cars

In 2023, the CO_2 emissions of newly registered passenger cars measured, on average, 130 g/km (compared with 134 g/km in 2022), based on the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) and excluding electric and hydrogen vehicles. The number drops to 104 g/km (compared with 112 g/km in 2022) if electric and hydrogen vehicles are included. The average emissions for petrol-powered M1 vehicles is 138 g/km (compared with 138 g/km in 2022); diesel-powered passenger vehicles generate an average of 146 g/km (compared with 149 g/km in 2022).

Development of Filling Stations

By the end of 2022, Austria had 2,759 publicly accessible filling stations (compared with 2,748 in 2021). As an annual average for 2023, the price of gasoline for private use at a filling station was EUR 1.599 (USD 1.727) per liter; the price of diesel was EUR 1.643 (USD 1.774) per liter. In 2023, 170 public CNG stations are available; 41 LPG filling stations are available (same as in 2022). In addition, four public liquified natural gas (LNG) filling stations are in operation: in Ennshafen and St. Marienkirchen (both Upper Austria), Feldkirchen (Styria), and Vienna.

Austria has seven hydrogen fueling stations (HFSs); five are publicly accessible. Of the other two, access in one is limited to companies, commercial enterprises, and municipalities, and the other is dedicated to hydrogen research. Except for the latter, all HFSs support a pressure of 70 MPa.

Research and Demonstration Focus

Energy Model Region

As part of the "Energy Model Region" initiative, made-in-Austria energy technologies are developed and demonstrated in large-scale, real-world applications with international visibility. The Austrian Climate and Energy Fund (KLIEN) invests up to EU 120 million (USD 130 million) in three Energy Model Regions. One of the regions — WIVA P&G — demonstrates the transition of the Austrian economy and energy production to an energy system based heavily on green hydrogen. Particular emphasis is focused on the development of hydrogen transport applications. A project database is available online. The WIVA P&G Energy Model Region forms part of the Mission Innovation Hydrogen Valley family.

klimaaktiv mobil Program

Austria's national action program for mobility management, klimaaktiv mobil, supports the development and implementation of mobility projects and transport initiatives that aim to reduce CO_2 emissions. Since 2004, 21,000 climate-friendly mobility projects have been funded. The klimaaktiv mobil website offers a map with details of each project. Total financial support until 2021 amounted to EUR 168 million (USD 181 million).

IEA Technology Cooperation Programmes Funding

Austria has been actively involved in the IEA Technology Collaboration Programmes (TCPs) since joining the IEA in 1975. The TCPs are seen as an important complement to Austrian national energy research and innovation (R&I) activities and contribute via Task outcomes and recommendations to national priorities. This funding programme fosters Austrian participation in the collaborative work within the IEA, disseminates results, and facilitates networking activities. On a national level, a yearly network event connects the expert networks active in the different IEA TCPs.

R&I Mobility Strategy 2030

The R&I Mobility Strategy 2030 provides financial support for R&I projects and activities for sustainable passenger and freight transport. The R&I Mobility Strategy 2030 focuses on four mission areas: Cities, Regions, Digitalization, and Technology. The annual budget ranges from EUR 15 million to 20 million (USD 16.2 million to USD 21.6 million). A project database is available online.

ERA-NET Bioenergy

In the European Research Area (ERA-NET) Bioenergy, Austria cooperates with Germany, Poland, and Switzerland in funding transnational bioenergy research and innovation projects.

Outlook

Austria is committed to reaching carbon neutrality by 2040, ten years earlier than the EU. The supporting Government Program identifies alternative fuels as indispensable for reaching this ambitious goal. Advanced motor fuels play a crucial role in the Austrian Climate and Energy Strategy and are considered an essential element for a successful Austrian transition toward sustainable mobility.

The areas of deployment, though, depend on the use case. Electrification is the preferred option for use cases with limited energy requirements, such as passenger cars or light-duty vehicles with limited mileage. Here, R&I funding schemes are no longer directed at improving internal combustion engine (ICE) drivetrains. Funding programs, including for ICE applications, therefore focus on hydrogen, biofuel, and synthetic fuel topics for use cases with high-energy-density demands, such as aviation, waterborne, or non-road mobile machinery applications.

Since 13 April 2024, the Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure is in force. The regulation outlines a framework for the deployment of charging and refueling infrastructure for road vehicles across the EU. It includes mandatory targets for member states instead of previous indicative targets, thus aiming to solve the uneven distribution of publicly accessible recharging infrastructure — a prerequisite for an EU-wide transition toward alternative drivetrains.

Additional Information Sources

- Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, http://www.bmk.gv.at/

Brazil

Drivers and Policies

Brazil has a long history with bioethanol dating back to the 1970s. Initial bioethanol efforts were associated with energy security issues related to the first oil crisis. As a result, the country has stimulated the production of ethanol and, since 2003, the use of hydrous ethanol in dedicated or fuel-flexible vehicles (FFVs). Today, the allowed blend level of ethanol is 27% in regular gasoline (MAPA 2015), and blend limits range between 18% and 27.5% (Brazil 2014). Since 2005, Brazil has also imposed minimum levels of biodiesel in diesel fuel, according to the Brazilian Program of Production and Use of Biodiesel (PNPB). The environmental agenda has supported the agricultural sector[1] and, in particular, the biofuels value chain, especially ethanol and biodiesel and, now, biogas. Note that Brazilian federal states apply differentiated consumption tax rates for gasoline (in general, higher rates) and hydrous ethanol (in a majority of the states, lower rates). Two recent public policies promote the production and consumption of biofuels: (1) the National Biofuel Policy, named RenovaBio (Brazil 2017), operational since March 2020; and (2) the Fuels of the Future Program (Civil House 2021), created in 2021. The Brazilian Parliament is reviewing a proposal to increase these limits up to E35% when market feasibility can be verified and also considering biodiesel mix up to B20 by 2030 (Brazil 2024a).

The official document driving Brazil's national policy framework for renewable energy is its Nationally Determined Contribution (NDC) (UNFCCC 2022) toward achieving the objective of the United Nations framework convention on climate change.

Under the third revision of its NDC concerning the Paris Agreement, Brazil committed to reducing its domestic greenhouse gas (GHG) emissions to 48.4% by 2025 and has declared its intention to reduce 53.1% of its emissions by 2030, both based on 2005 levels (MMA 2023). Brazil is also committing to the long-term objective of becoming carbon neutral by 2050. Such measures continue to include all sectors of the economy, such as agriculture and energy, with transport in the latter sector. Brazil also intends to adopt further measures consistent and aligned with the 1.5°C temperature goal, especially in the energy sector (IEA 2023).[2]

Brazilian Policy Framework

The main policy instruments behind the evolutions that will subsidize the future growth of biofuels in Brazil include the following:

- The *Brazilian Alcohol Program (PROALCOOL)*, created during the 1970s by the Brazilian government to increase the ethanol blending level to 25% in gasoline (E25) and introduce hydrous ethanol (E100 — approximately 95% ethanol and 5% water) for use in dedicated vehicles.
- The *Brazilian Program for Production and Use of Biodiesel (PNPB)*, created in 2005 to further stimulate energy, economic, and social objectives, and foster feedstock production among small farmers.
- *Flex fuel technology*, established in 2003 to enable consumers to choose between E27 and E100.
- *Biofuel addition on petroleum products.* Since 2015, all automotive gasoline sold at retail contains, by mandate, a blend of 27% anhydrous ethanol, or E27.[3] The government also mandated that biodiesel be added to fossil diesel: a final blend of roughly 11% in 2021 and, since April 2023, 12%.[4]

[1] The agriculture sector represents 23.8% of Brazil's gross domestic product (GDP) in 2023 (CEPEA 2024)

[2] Additional measures include the following:
- Expanding the use of renewable energy sources other than hydropower in the total energy mix.
- Expanding the use of non-fossil fuel energy sources domestically.
- Achieving 10% efficiency gains in the electricity sector by 2030.

In addition, in the transportation sector, Brazil intends to further promote efficiency measures and improve infrastructure for transport and public transportation in urban areas.

[3] Gasoline premium contains 25% anhydrous ethanol, according to MAPA Ordinance N. 75 (MAPA 2015). However, it accounts for a very small fraction of fuel sales.

[4] Blend definition in accordance with CNPE Resolutions (MME 2023a).

- *National Biofuel Policy (RenovaBio)* (Law 13,576/2017) (Brazil 2017), a state policy recognizing the strategic role of all types of biofuels in the national energy matrix, both for energy security and for the mitigation of GHG emissions. The policy includes the additional objective of reducing dependence on mineral diesel.
- *Fuels of the Future Program*, created in 2021, aims to further increase the use of sustainable and low-carbon fuels to decarbonize the national transport energy matrix.
- *Project of Law 4,516/2023* (Brazil 2024b), approved in the Brazilian Chamber of Deputies on 13 March 2024, this project of law, based on the discussions under the Fuels of the Future Program, proposes the increase of ethanol mixed in the gasoline from the current 27.5% to 35% and the increase of biodiesel mixed in diesel from the current 14% to 20% by 2030.
- *Federal and state tax differentiation* between renewables and fossil fuels,[5] establishing credit lines to support rural sugarcane producers and their cooperatives to select business plans and promote projects that consider the development, production, and commercialization of new industrial technologies for sugarcane biomass (E2G [second-generation ethanol], gasification, and more).[6]
- *Consolidation of the National Hydrogen Program (PNH2).* The Brazilian government organized and published a strategy for developing the country's hydrogen economy (Brazil 2023b), which would harmonize with other sources of its energy matrix.[7]
- *Brazil's membership* in the International Maritime Organization (IMO) and International Civil Aviation (ICAO)/Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).[8]
- *A pledged commitment to efficiency programs* such as INOVAR-Auto, INNOVA-E, and other governmental initiatives dedicated to improving motor fuel efficiency.
- *Federal government approval* of the framework of the Rota 2030 program (Law 13,755/2018) in December 2018 to foster efficiency and safety in vehicles produced in Brazil (Brazil 2018).
- Provisional Measure 1,205 (30 December 2023) to Institutionalize the *Green Mobility and Innovation Program (MOVER)*, which offers a broader approach for mobility than Rota 2030. MOVER's goals include a well-to-wheel perspective, which will measure energetic efficiency and an objective for car manufacturers to use at least 50% recyclable components to achieve tax differentiation. After 2027, vehicles commercialized in Brazil will be evaluated using a "cradle to grave" life-cycle model. MOVER also includes a financial bonus for automakers who take into account some sustainable indicators.
- *Decree number 11,902* (30 January 2024), which restructures the Social Biofuel Seal and creates significant investments. Starting in 2024 with Brazilian real (BRL) 740 million, in 2026, BRL 1.6 billion will be allocated to strengthen biodiesel production and support family farming. This policy aims to strengthen family farming, especially in the North, Northeast, and semi-arid regions of Brazil. It also encourages the production of new crops, such as macaúba, and palm tree that is abundant in the Northeast of the country (Brazil 2024a).
- *Brazilian Sustainable Taxonomy*. At the end of 2023, the Brazilian government launched a public consultation about the Brazilian Sustainable Taxonomy, a document that consists of a classification system that defines — in a clear, objective and scientifically based manner — activities, assets and/or project categories that contribute to climate, environmental, and/or social objectives through specific criteria (Brazil 2023a).

[5] Regarding federal taxes, Contribution for Intervention in the Economic Domain (CIDE) has been zeroed for ethanol since 2004, while for gasoline, the incident value is R$100.00/m³. Between 2017 and the second half of 2022, the Program of Social Integration (PIS)/Contribution for the Financing of Social Security (COFINS) on ethanol imports and commercialization was R$241.81/$m^3$, and for gasoline, R$ 792.5/m^3. From the second half of 2022, tax changes were made that zeroed PIS/Pasep, COFINS, and CIDE and limited the ICMS (sales and service tax) for gasoline to between 17% and 18% in 21 states of the federation (Fecombustíveis 2022). At the state level, ICMS has different rates in each Brazilian state (EPE 2023d)

[6] CPNE did all of this through CNPE Resolution number 07, 20 April 2021.

[7] The Triennial Plan for H_2 2024–2026 was approved in December 2023 by the Executive Committee of the PNH2 (Brazil's National Hydrogen Program).

[8] CORSIA is a global market-based measure designed to offset international aviation CO_2 emissions in order to stabilize the levels of such emissions (ICAO 2023).

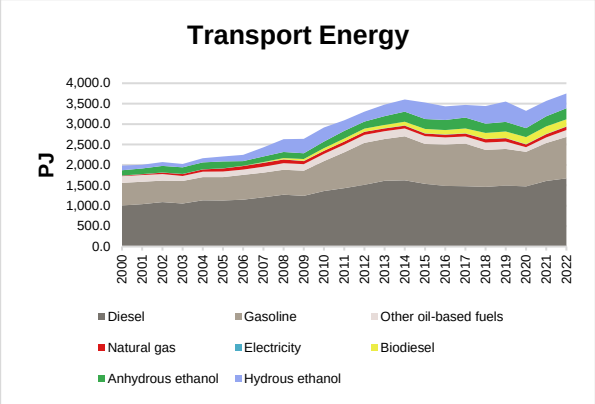
Advanced Motor Fuels Statistics

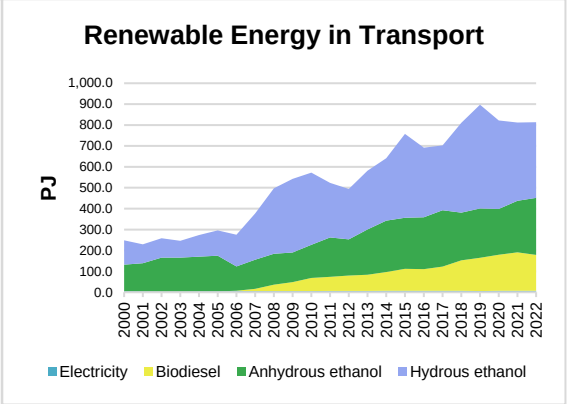
Transport

Figures 1 and 2 provide an overview of the energy used for transport in Brazil, categorized by different fuels/energy carriers. Note that Brazilian statistics define biogasoline (E27) as anhydrous bioethanol blended with gasoline and that hydrous ethanol is used in dedicated or FFVs. Bioethanol represented 38% by energy of combined gasoline and ethanol use in 2022 in Otto cycle engines.

Transport fuel consumption in Brazil has stabilized over the past five years, and the use of biofuels has grown steadily over the past 20 years. In particular, the use of hydrous ethanol in FFVs has substantially increased. The consumption of anhydrous ethanol has grown with gasoline consumption, as evidenced in Figure 1. Biodiesel was introduced in 2005 and has also steadily grown as a substitute for fossil diesel consumption, mainly for heavy-duty transport. On average, biodiesel represented 9.3%[9] (by energy) of diesel consumption in 2022, as Figure 2 shows.

Also as shown in Figure 1, electricity represents a share of 0.2% of total transport energy use in 2022, maintaining the share of previous years. This is mostly in rail — Brazil has no reporting of electricity used in road vehicles.





Figures 1 and 2. Evolution of Transport Fuels in Brazil, 2000–2022 (Source: EPE 2023a).

Table 1 displays the growth of the Brazilian fleet from 2013 to 2022.

Table 1. Growth of the Brazilian Fleet, 2013–2022

Vehicle Stock	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Motor spirit cars	10^6	11,7	11,0	10,3	9,6	8,9	8,2	7,6	7,1	6,5	6,0
Diesel oil cars	10^6	1,7	1,8	1,9	2,0	2,1	2,2	2,3	2,3	2,4	2,5
Electricity cars	10^6	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,001	0,004	0,012
Other type of cars (hybrid)	10^6	0,001	0,002	0,003	0,004	0,007	0,010	0,021	0,038	0,057	0,085
Flex fuel cars	10^6	20,7	23,2	24,9	26,0	27,1	28,4	29,7	30,2	30,7	31,0

Source: EPE 2023e.

[9] In 2021 the Brazilian Energy Policy Council (CNPE) decided to reduce from 12% to 10% the mandatory blend of biodiesel for the entire year of 2022, in response to societal interest and diesel B price conditions. The 12% requirement was reinstituted on 01 March 2023. The raise in demand and the blend reduction explains the share contraction from 10.3% in 2021 to 9.3% in 2022. Also note that from 2007 to 2021, biodiesel commercialization was accomplished though public auctions organized by ANP (Regulatory Agency for Oil, Natural Gas, and Biofuels). Since 01 January 2022, such commercialization occurs directly between productors and distributors (EPE 2023d).

Research and Demonstration Focus

Brazil has several government-backed mechanisms providing support for biofuels research, development, and demonstration (RD&D) plants. Public and publicly oriented support totaled more than BRL 250 million (USD 50 million) in 2022,[10] which includes support in the form of loans, equity participation, and grants and is also available via the PAISS programme for ethanol and other biofuel production (including cellulosic ethanol) and drop-in biofuels (including aviation fuels). Note that, within the scope of the Fuels of the Future (Civil House 2021) Technical Chamber (CT-CF), the government created and launched lines of financing for biofuels. Figure 3 illustrates the annual distribution of public investments in renewable energy, including research, development, and innovation (RD&I), by source.

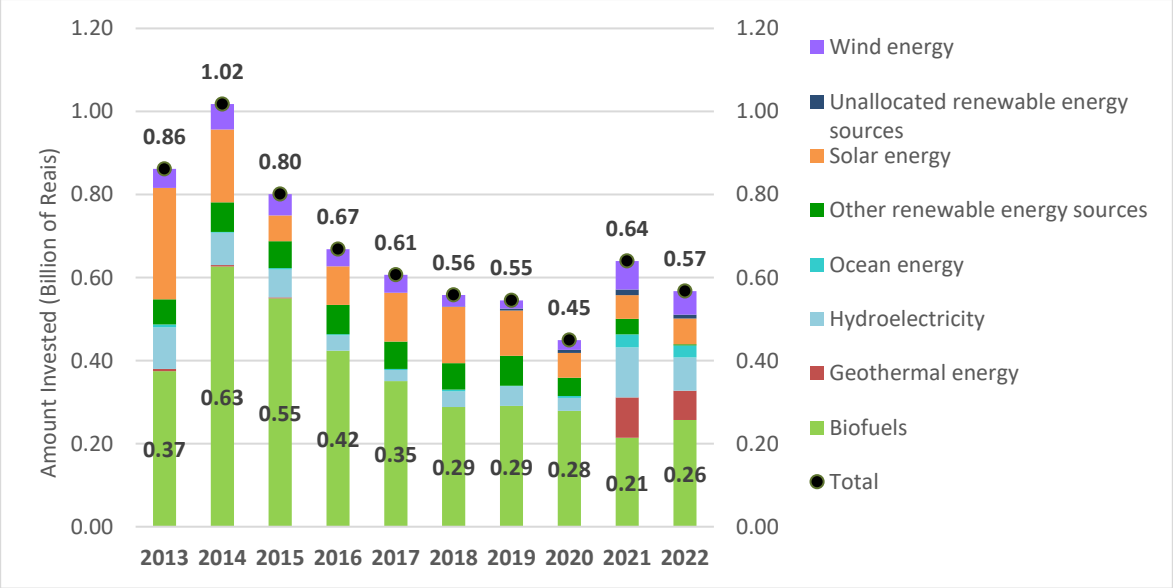


Figure 3. Public Investments in Renewable Energy RD&I, 2013–2022 (Source: EPE 2024).

Figure 4 displays the total amount of public financing specific to the sugar-energy sector. In 2022, total disbursements of the Brazilian Bank for Economic and Social Development (BNDES) in the agricultural area for the cultivation of sugarcane totaled USD 77.5 million (or roughly BRL 400 million) (BNDES 2023).[11]

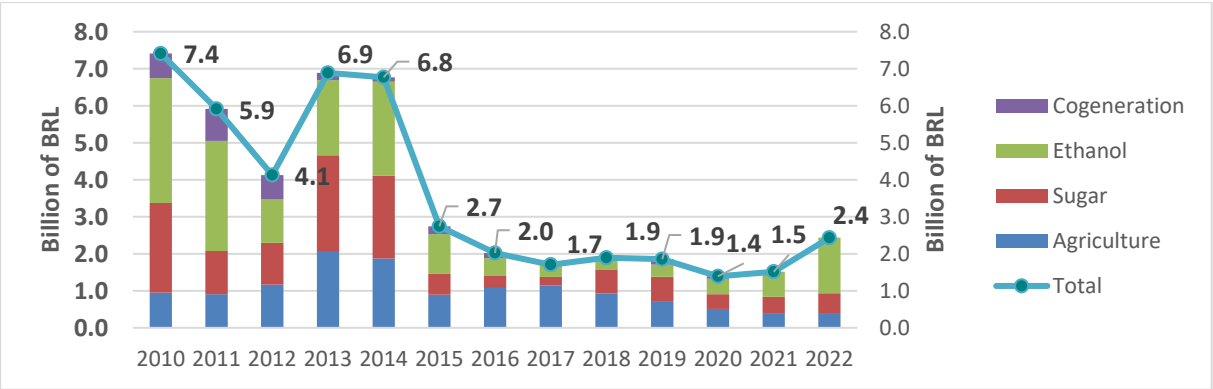


Figure 4. Public Funding for Sugar-energy Sector (Source: Constructed by EPE from data provided by BNDES [2023].

[10] The average 2022 USD to BRL exchange rate was 5.16 (BCB 2024).
[11] At the average 2022 USD to BRL exchange rate (BCB 2024).

Outlook

Figure 5 consolidates the demand for fuel ethanol and other (non-energy) uses, which grows at an annual rate of 3.3%, reaching 43.7 billion liters in 2033, with the major increase coming from the demand for hydrous ethanol fuel. When added to exports, 2.7 billion liters, the total value of ethanol amounts to 46.5 billion liters.

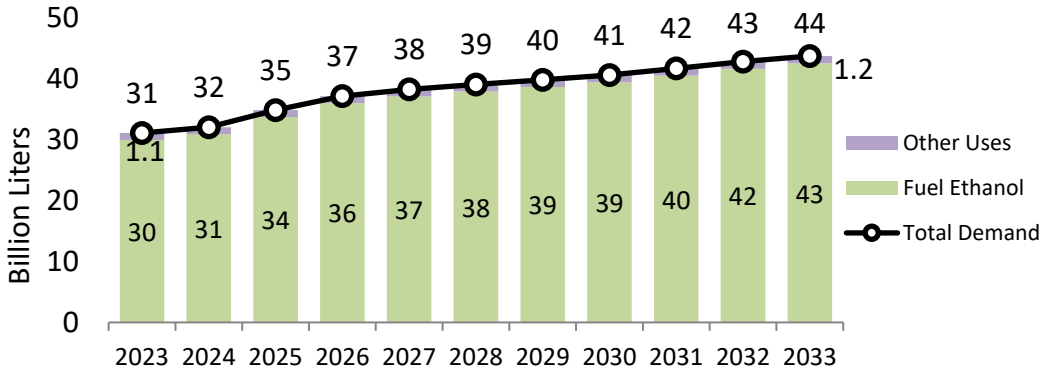


Figure 5. Forecast of Total Ethanol Demand, 2023–2033 (Source: EPE 2023b).

The biodiesel demand projections of this study were obtained based on the forecast of the regional consumption of oil diesel type-B (EPE 2023e) and the evolution of biodiesel blend (Figure 6).[12]

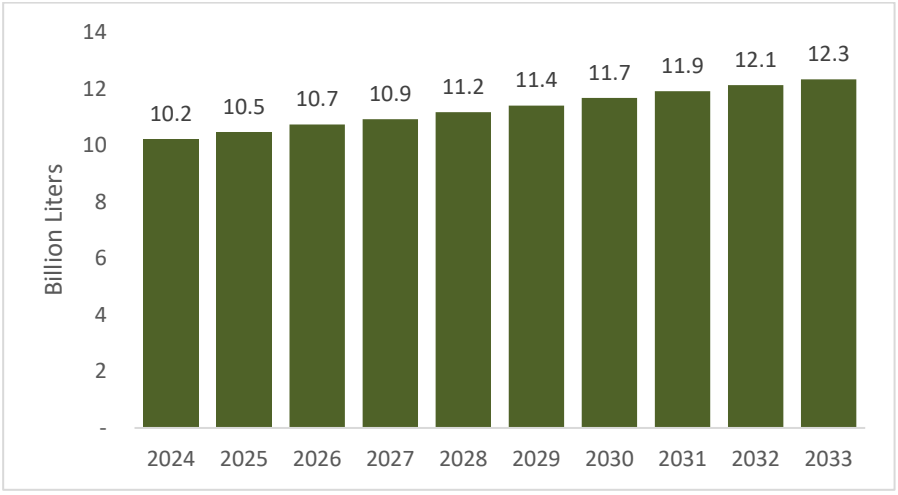


Figure 6. Forecast of Total Biodiesel Demand with Regional Distribution, 2024–2033 (Source: Based on EPE 2023e)

Projections for ethanol and sugar production presented in this study indicate a high amount of residues from this sector that can be used for biogas production. The methodology applied to this item considered both the vinasse and filter cake as part of the straw and tips to produce biogas, which will be destined for biodigestion. In this case, the technical potential of biogas from residual sugarcane biomass through monodigestion reaches 32.5 billion Nm³ in 2033, representing 17.9 billion Nm³ of biomethane.

[12] According to the CNPE definition on March 17, 2023 (MME 2023a), the biodiesel blend changed from 10% between January and March 2023 to 12% in April 2023, and following recent CNPE Resolution number 8, as of December 19, 2023 (MAPA 2023a; MAPA 2023b, Brasil 2024b), it will change from 13% to 14% in March 2024 and to 15% in March 2025.

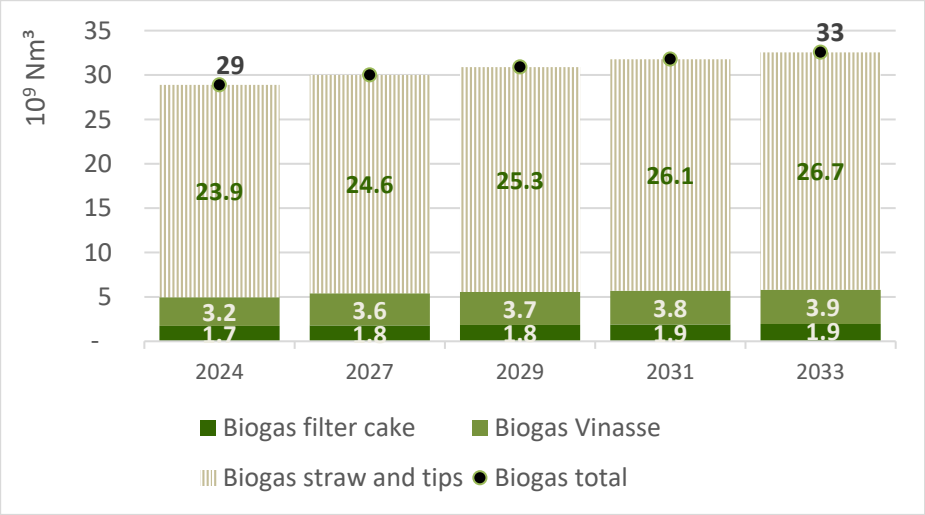


Figure 7. Biogas Potential with Sugarcane Residual Biomass, 2024–2033 (Note: Although identified as high potential, the different pattern on biogas from straw and tips indicates lower possibilities due logistic costs and conditions [Source: EPE 2023b]).

By 2033, the Brazilian fleet should achieve 50.4 million vehicles, according to the EPE (EPE 2023b).

Recent Developments

Brazil has two commercial E2G plants: GranBio's Bioflex-I commercial plants in São Miguel dos Campos (AL), with a nominal capacity of 30 million liters/year, and Raízen's, in Piracicaba (SP), with a capacity of 42 million liters /year (GranBio 2023a; Raízen 2024).

Bioflex-I has been in operation since 2017, and the company announced plans to expand its production capacity to 60 million liters by 2025. In 2022, this plant did not produce lignocellulosic ethanol and prioritized electricity generation (GranBio, 2023b). The validation of the production patent by European countries was also announced, allowing Brazilian companies to license the technology and the development and design of plants (NovaCana 2022a).

Currently, Raízen has five new E2G projects under construction, all with a capacity of 82 million liters per year at each facility. The company has three more projects with no announced location for implementation in 2026 and 2027. Raízen intends to sell lignocellulose ethanol to the foreign market, where it already has long-term contracts of 460 million liters over 9 years sold. The company managed to finance some of its new E2G plants using these already-sold long-term contracts as a guarantee (Globorural 2024; NovaCana, 2022b; UDOP 2023).

With regard to biogas, its participation in the internal supply of energy is still timid (0.14%), but it has shown accelerated growth: 18% per year over the last five years (EPE 2023a).

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Canada

Drivers and Policies

Clean Fuel Regulations

Registered on June 21, 2022, the Clean Fuel Regulations (CFR) require producers and importers of gasoline or diesel to reduce the carbon intensity of the fuels they produce in, and import into, Canada for use in Canada. The regulations establish a credit market in which the annual requirement to reduce carbon intensity can be met through three main categories of credit-creating actions:

1. Undertaking projects that reduce the lifecycle carbon intensity of liquid fossil fuels
2. Supplying low-carbon-intensity fuels, and
3. Supplying fuel or energy to advanced vehicle technology.

The annual carbon intensity reduction requirements for gasoline and diesel came into force on July 1, 2023, starting at 3.5 grams of CO_2e per unit of energy and increasing to 14 grams in 2030. Once fully implemented, the CFR will help cut up to 26.6 million tonnes (Mt) of greenhouse gas (GHG) pollution in 2030. In combination with the Government of Canada's $1.5 billion Clean Fuels Fund, the CFR creates incentives for the increased domestic production of low-carbon-intensity fuels. Along with the federal policy, Canada has provincial renewable fuel and low-carbon fuel requirement regulations that prescribe specific renewable fuels volumes and carbon intensity.

Renewable-fuels-related Standards

The Canadian General Standards Board (CGSB) is responsible for developing fuel and renewable fuel quality standards through consensus with the public and private sectors (see Table 1).

Table 1. CGSB Renewable Fuel-Quality-Related Standards

Fuel Standard	Number
Oxygenated automotive gasoline containing ethanol (E1-E10 and E11-E15)	CAN/CGSB 3.511
Automotive ethanol fuel (E50–E85 and E20–E25)	CAN/CGSB 3.512
Denatured fuel ethanol for use in automotive spark-ignition fuels	CAN/CGSB 3.516
Diesel fuel containing low levels of biodiesel (B1–B5)	CAN/CGSB 3.520
Diesel fuel containing biodiesel (B6–B20)	CAN/CGSB 3.522
Biodiesel (B100) for blending in middle distillate fuels	CAN/CGSB 3.524

Greenhouse Gas Emission Regulations

In 2021, Canada completed a mid-term evaluation of the appropriateness of its standards for model years 2022 to 2025 under the *Passenger Car and Light Truck GHG Emission Regulations*. Further, Canada is working with both the United States and the State of California to develop future light-duty vehicle (LDV) GHG regulations that align with the most stringent LDV GHG tailpipe regulations in the United States, whether at the federal or state level. In March 2022, Canada published the 2030 Emissions Reduction Plan with a commitment to develop regulations to achieve 100% of new LDVs as zero-emissions vehicles (ZEVs) by 2035, with interim targets of at least 20% in 2026 and at least 60% in 2030.

Canada published the Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations on December 20, 2023. These amendments require auto manufacturers and importers to meet increasingly stringent annual ZEVs targets, including the targets specified in the Emissions Reduction Plan (20% for the 2026 model year, 60% by 2030, and 100% for 2035). The next phase of Canadian emission standards will be informed by the release of the U.S. Environmental Protection Agency's (U.S. EPA's) final rulemaking entitled "Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles."

Canada's 2030 Emissions Reduction Plan also includes a commitment to further improve the efficiency of heavy-duty vehicle standards beyond 2025 by aligning with the most stringent standards in North America, whether at the U.S. federal or state level. Further, the Government of Canada committed to develop a medium- and heavy-duty vehicle (MHDV) ZEV regulation requiring 100% of MHDV sales to be ZEVs by 2040 for a subset of vehicle types — with interim 2030 regulated sales requirements that would vary by vehicle category based on feasibility — and explore interim targets for the mid-2020s.

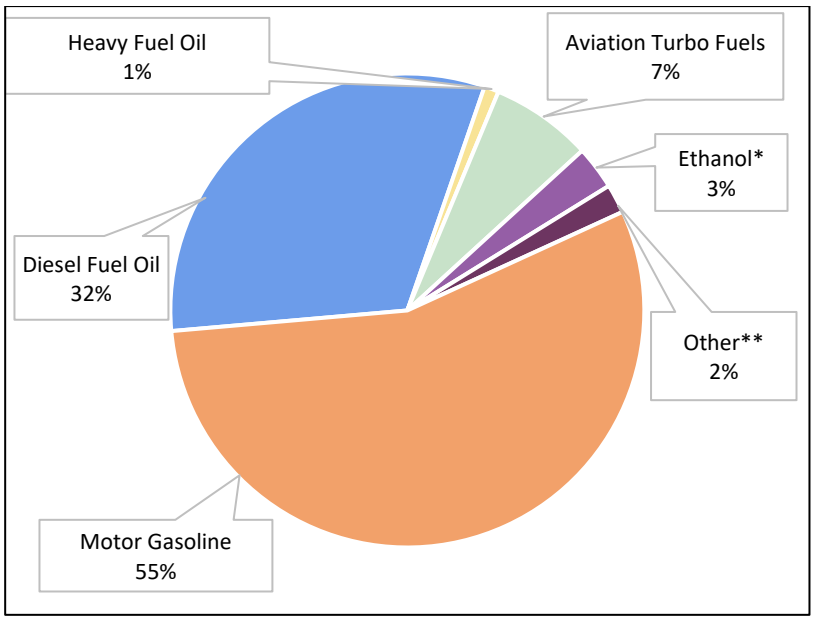
In 2023, Canada developed a regulatory framework for the transition of the MHDV sector to ZEVs to reduce emissions. The framework included a technical readiness assessment and consultations with industry. Canada maintained awareness of strategies undertaken in other jurisdictions, including individual provinces and the United States. Canada is also examining several proposed U.S. EPA rulemakings — the "Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles – Phase 3" and "Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles" — in accordance with its commitment to align with the most stringent emission standards in North America.

Pan-Canadian Framework on Clean Growth and Climate Change (PCF)
The Pan-Canadian Framework is the federal, provincial, and territorial plan to grow the economy, reduce GHG emissions, and build resilience in the face of a changing climate. The PCF includes more than 50 concrete actions that cover all sectors of the Canadian economy and puts Canada on a path to meeting its Paris Agreement GHG-emissions-reduction target of 31% below 2005 levels by 2030.

Hydrogen Strategy for Canada
Natural Resources Canada (NRCan) has been engaging with stakeholders, government, and Indigenous partners to create the Hydrogen Strategy for Canada, which seeks to leverage Canada's hydrogen through various pathways, including fuel for transportation. The strategy includes hydrogen end-use opportunities for LDVs, buses, trucks and equipment, rail, marine, and aviation.

Advanced Motor Fuels Statistics

Figure 1 shows energy use by fuel type in 2020 for transportation in Canada. Table 2 lists supply and demand for ethanol and biodiesel.



*Ethanol proportion is estimated on the basis of production data.
**Includes electricity, natural gas, biodiesel fuel oil, light fuel oil, aviation gasoline, and propane.

Figure 1. Fuel Mix of the Canadian Transportation Sector, 2020

Table 2. Canadian Supply and Demand of Biofuels, 2022 (in millions of liters)

Parameter	Ethanol	Biodiesel
Canadian production	1,692	369
Imports	1,752	846
Exports	82	379
Domestic use	3,343	1,052

Transportation GHG emissions (from passenger, freight, and other forms of transport) increased 5% from 2020 to 2021, reflecting a rebound since the first year of the pandemic. Despite the increase, transportation emissions were 12% below their pre-pandemic level in 2019.

Research and Demonstration Focus

ecoTECHNOLOGY for Vehicles (eTV) Program
The eTV Program, conducted through Transport Canada's Innovation Centre, conducts in-depth safety and environmental performance testing on a range of new and emerging advanced passenger car and truck technologies. The program investigates the performance of alternative-fueled vehicles, including renewable fuels, hybrid and electric, compressed natural gas (CNG), and hydrogen fuel cell vehicles.

Program of Energy Research and Development (PERD)
NRCan's PERD supports energy R&D conducted by the federal government and is designed to ensure a sustainable energy future for Canada. Key research areas focus on knowledge and technologies that will help reduce the carbon footprint of fuels, improve the efficiency of vehicles, electrify transport, and reduce emissions from transportation sources.

Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI)
Through NRCan's EVAFIDI program, $260 million was invested into public infrastructure to encourage the switch to low- or zero-emission vehicles. As of 2023, a total of 1,051 electric, hydrogen, and natural gas stations have been opened.

Zero Emissions Vehicle Infrastructure Program (ZEVIP)
NRCan's ZEVIP is a $680 million initiative to address the lack of charging and refueling stations in Canada by increasing the availability of localized charging and hydrogen refueling opportunities. The program provides opportunities for owners/operators of ZEV infrastructure, delivery organizations, and Indigenous organizations.

Electric Vehicle Infrastructure Demonstration Program (EVID)
NRCan's $76 million EVID program supports the demonstration of next-generation and innovative EV charging and hydrogen refuelling infrastructure. Projects address technical and non-technical barriers and gaps associated with installing, operating, and managing ZEV infrastructure.

Energy Innovation Program: On-Road Transportation Decarbonization
In May 2023, NRCan launched a $48 million On-Road Transportation Decarbonization Call for proposals to conduct research, development, and demonstration (RD&D) projects that address barriers to the uptake of zero-emission medium- and heavy-duty trucks, innovative infrastructure solutions to support ZEVs, and transportation system efficiency.

Strategic Innovation Fund (SIF)
The SIF, managed by Innovation, Science and Economic Development Canada, provides support to Canadian businesses investing in innovation and to industry efforts to accelerate the production of low- and zero-emission vehicles and the battery supply chain.

Incentives for Zero Emissions Vehicles Program (iZEV)
To encourage Canadians' adoption of ZEVs, the Government of Canada, led by Transport Canada, launched this program to provide incentives for consumers to buy ZEVs. In terms of total ZEVs on the road, steady annual progress toward the target of 100% ZEV sales by 2035 would translate to

approximately 1.4 million ZEVs on the road by 2026 (about 5% of total LDVs on the road); 4.6 million by 2030 (about 16%); and 12.4 million by 2035 (about 40%).

Clean Transportation System-Research and Development Program (CTS-RD)
Transport Canada established the CTS-RD to support projects that help improve the environmental performance of Canada's transportation system, specifically in the rail, marine, and aviation sectors. The program looks to advance new clean-technology innovations, practices, or research.

Canada's Aviation Climate Action Plan
Canada's Action Plan to Reduce GHG Emissions from Aviation includes R&D to support Canada's commitments to achieve net-zero emissions by 2050. In 2022, more than 60 airlines operating in Canada created the Canadian Council for Sustainable Aviation Fuels, which brings together industry and government to develop a competitive roadmap for Canadian-made sustainable aviation fuels (SAF).

Green Freight Program (GFP)
The GFP will help fleets reduce their fuel consumption and GHG emissions through fleet energy assessments, fleet retrofits, engine repowers, logistical best-practice implementation, and the purchase of low-carbon vehicles. To be considered for funding under the Repower activity, the applicant must submit a list of technologies/equipment, and the repower of eligible technologies must involve permanent modifications, demonstrate the capacity to reduce diesel consumption of MHDVs, and reduce GHG emissions by switching the fuel used to a lower-carbon alternative. Dual-fuel options are also eligible, including projects that involve replacing the engine and/or drivetrain.

Outlook

As depicted in Table 3, the Canadian transportation sector comprises several distinct subsectors, each exhibiting different trends during the projected period. GHG emissions from cars, trucks, and motorcycles are projected to decrease by 14 Mt between 2005 and 2030, while those for heavy-duty trucks and rail are projected to increase by 11 Mt.

Table 3. Transportation: GHG Emissions (Mt CO_2e)

Transportation Subsector	2005	2020	2030	Δ 2005 to 2030
Passenger Transport	**90**	**80**	**78**	**-12**
Cars, light trucks, and motorcycles	82	73	68	-14
Bus, rail, and domestic aviation	8	6	10	1
Freight Transport	**60**	**70**	**70**	**11**
Heavy-duty trucks, rail	54	66	66	11
Domestic aviation and marine	5	5	5	-1
Other: recreational, commercial, and residential off-road transportation	**10**	**9**	**9**	**-1**
Total	**160**	**159**	**158**	**-2**

This table includes projections with additional measures using Environment and Climate Change Canada's Energy, Emissions and Economy Model for Canada.

China

Drivers and Policies

In order to achieve China's peak carbon dioxide emissions goal before 2030 and carbon neutrality goal before 2060, China issued a series of related policies to promote both carbon reduction and green development. The automotive industry is an important area for green and low-carbon development, and advanced motor fuels will contribute significantly to reducing pollutant emissions in the transportation sector and promoting carbon neutrality.

Notice on Organizing and Carrying out the Pilot Work of the Comprehensive Electrification of Vehicles in the Public Domain

To further accelerate the pace of comprehensive electrification of vehicles in the public domain, eight ministries, such as the Ministry of Industry and Information Technology and the Ministry of Transport, jointly issued the "Notice on Organizing and Carrying Out the Pilot Work of the Comprehensive Electrification of Vehicles in the Public Domain" on February 3, 2023. The objectives of the Notice are to promote the electrification of vehicles in the public sector, accelerate the construction of a green and low-carbon transportation system, and implement China's national peak carbon and carbon neutrality strategies. The main goal is to significantly increase the proportion (by 80%) of clean energy vehicles in the nation's fleet of newly added and updated vehicles, including urban public buses, taxis, sanitation vehicles, postal express vehicles, and urban logistics and distribution vehicles. The Notice encourages local governments to improve (1) the comprehensive electrification support system for vehicles in the public domain, (2) promotion of new energy vehicles, (3) construction of charging and swapping infrastructure, (4) application of new technologies and new models, and (5) green policies, standards, and regulations.

Announcement on Matters Concerning the Implementation of China 6 Emission Standards for Automobiles

On May 9, 2023, five ministries, such as the Ministry of Ecology and Environment, the Ministry of Industry and Information Technology, and the Ministry of Commerce, jointly issued the "Announcement on Matters Concerning the Implementation of the China 6 Emission Standards for Automobiles." The China 6b emission standard, implemented nationwide on July 1, 2023, prohibits the production, import, and sale of vehicles that do not meet the China 6b emission standard. In accordance with the "Law of the People's Republic of China on the Prevention and Control of Air Pollution" and other relevant provisions, automobile production and import enterprises — the organizations primarily responsible for the consistency management of environment protection production — must disclose vehicle emission inspection information and pollution control technical information before a vehicle leaves the factory or enters the country to ensure that vehicles produced in or imported into China meet the requirements.

Announcement on the Extension and Optimization of the Vehicle Purchase Tax Reduction and Exemption Policy for New Energy Vehicles

On June 21, 2023, the Ministry of Finance, the State Administration of Taxation, and the Ministry of Industry and Information Technology jointly issued the "Announcement on the Extension and Optimization of the Vehicle Purchase Tax Reduction and Exemption Policy for New Energy Vehicles." New energy vehicles with a purchase date between January 1, 2024, and December 31, 2025, are exempt from vehicle purchase tax; the tax exemption for each new energy passenger vehicle shall not exceed RMB30,000 yuan. The vehicle purchase tax will be halved for new energy vehicles purchased between January 1, 2026, and December 31, 2027; the tax reduction for each new energy passenger vehicle shall not exceed RMB15,000 yuan. Preferential tax is provided to battery swapping vehicle models.

Opinions of the National Development and Reform Commission and Other Ministries on Accelerating the Establishment of a Product Carbon Footprint Management System

On November 24, 2023, the National Development and Reform Commission and other ministries issued their opinions on accelerating the establishment of a product carbon footprint management system. The goals of such a system are to improve the rules and standards for carbon footprint accounting methods for key products, establish a product carbon footprint background database, promote the construction of a product carbon label certification system, expand and enrich application scenarios, and expand the role of the product carbon footprint management system in promoting a

green and low-carbon production and lifestyle, thereby helping China achieve its peak carbon and carbon neutrality objectives. The main goal is that by 2025, carbon footprint accounting rules and standards for about 50 key products will be issued at the national level. New energy vehicles (including power batteries) are one of the key products, and the construction and improvement of their carbon footprint management system will be further accelerated under the guidance contained in the Opinions.

Existing National Standards on Alternative Motor Fuels

- GB/T 42416-2023, "M100 methanol fuel for motor vehicles," was released on May 23, 2023, and implemented on September 1, 2023.
- GB/T 42436-2023, "Additives for vehicular M100 methanol fuel," was released on May 23, 2023, and implemented on September 1, 2023.
- GB/T 23510-2009, "Fuel methanol for motor vehicles," was released on April 8, 2009, and implemented on November 1, 2009.
- GB/T 23799-2021, "Methanol gasoline (M85)," for motor vehicles was released on October 11, 2021, and implemented on May 1, 2022.
- GB/T 34548-2017, "The additive of methanol gasoline for vehicles," was released on October 14, 2017, and implemented on May 1, 2018.
- GB/T 31776-2015, "Determination method of methanol content in methanol gasoline for motor vehicles," was released on July 3, 2015, and implemented on October 1, 2015.
- GB/T 26127-2010, "Compressed coalbed methane as vehicle fuel," was released on January 14, 2011, and implemented on June 1, 2011.
- GB/T 26605-2011, "Dimethyl ether for motor vehicle fuel," was released on June 16, 2011, and implemented on November 1, 2011.
- GB 19159-2012, "Automotive liquefied petroleum gases," was released on November 5, 2012, and implemented on April 1, 2013.
- GB 25199-2017, "B5 diesel fuels," was released and implemented on September 7, 2017.
- GB 18351-2017, "Ethanol gasoline for motor vehicles (E10)," was released and implemented on September 7, 2017.
- GB/T 22030-2017, "Blendstocks of ethanol gasoline for motor vehicles," was released and implemented on September 7, 2017.
- GB 35793-2018, "Ethanol gasoline for motor vehicles E85," was released on February 6, 2018, and implemented on September 1, 2018.
- GB 18047-2017, "Compressed natural gas as vehicle fuel," was released on September 7, 2017, and implemented on April 1, 2018.
- GB/T 40510-2021, "Bio-natural gas as vehicle fuel," was released on August 20, 2021, and implemented on March 1, 2022.
- GB/T 34537-2017, "Hydrogen and compressed natural gas (HCNG) blended as vehicle fuel," was released on October 14, 2017, and implemented on May 1, 2018.
- GB/T 37178-2018, "Coal-based synthetic natural gas for vehicle," was released on December 28, 2018, and implemented on July 1, 2019.
- GB/T 37244-2018, "Fuel specification for proton exchange membrane fuel cell vehicles – Hydrogen," was released on December 28, 2018, and implemented on July 1, 2019.
- GB/T 40045-2021, "Fuel specification for hydrogen powered vehicles – Liquid hydrogen (LH_2)," was released on April 30, 2021, and implemented on November 1, 2021.

Advanced Motor Fuels Statistics

In 2023, non-fossil energy accounted for more than 40% of China's total new energy production, and the energy production and supply system is developing toward low carbon. China has continuously improved the level of greening and modernization of the energy industry chain and accelerated the formation of a diversified supply and consumption system. China 6b standard motor gasoline is supplied nationwide, and about 8.6 million charging pillar units had been built around the country.

In 2023, China's auto production and sales volume were 30.261 million units and 30.094 million units, with a year-on-year increase of 11.6% for production and 12% for sales. The volumes of new energy vehicles were 9.587 million units (production) and 9.495 million units (sales), accounting for 31.6% of market share. The volumes of battery electric vehicles were 6.704 million units (production) and

6.685 million units (sales); the volumes of plug-in hybrid electric vehicles were 2.877 million units (production) and 2.804 million units (sales); and the production and sales volume of hydrogen fuel cell electric vehicles were both 6,000 units. The sales volume of natural-gas-powered heavy-duty vehicles was 151,900 units. The top five provinces of natural-gas-powered heavy-duty vehicles by sales were Shanxi, Hebei, Ningxia, Henan, and Xinjiang.

Research and Demonstration Focus

Promotion of Methanol Gasoline Vehicles Pilot Project

In 2019, the Ministry of Industry and Information Technology and other relevant ministries jointly issued the "Guiding Opinions on the Application of Methanol Vehicles in Some Areas", supporting areas (such as Shanxi, Shaanxi, Guizhou, and Gansu provinces) with resources and experiences in operating methanol vehicles, to accelerate the application of M100 methanol vehicles.

In May 2023, Shanxi Province issued "Several Measures on Accelerating the Promotion and Application of Methanol Vehicles in the Province," which was officially implemented on June 18, 2023, and is valid for 5 years. Shanxi Province will accelerate the construction of a green transportation system for methanol vehicles based on heavy truck freight to help achieve China's peak carbon and carbon neutrality goals. Shanxi Province encourages provincial state-owned enterprises and municipal and county state-owned enterprises, especially large energy enterprises, to accelerate the construction of methanol heavy-truck application scenarios and take the lead in promoting the application of methanol heavy trucks. Shanxi Province promotes the green and clean replacement of vehicles in the public sector by encouraging organizations in the province to update existing gasoline and diesel-powered urban logistics vehicles, urban construction muck trucks, cement mixer trucks, and garbage removal trucks to methanol-powered vehicle models. Shanxi Province provides purchase subsidies and right-of-way preferential policies for methanol vehicles and is improving the construction of methanol refueling system for vehicles.

Guizhou Province has a large number of methanol vehicles, including commercial vehicles, taxis, special vehicles, etc. By the end of 2023, Guizhou had more than 18,000 methanol vehicles and operated more than 80 methanol refueling stations.

Promotion of Hydrogen Fuel Cell Electric Vehicles Pilot Project

In September 2020, the Ministry of Finance, Ministry of Industry and Information Technology, Ministry of Science and Technology, National Development and Reform Commission, and the National Energy Administration jointly issued the "Notice on Developing Demonstrative Application of Hydrogen Fuel Cell Electric Vehicles," supporting the key technology breakthrough and application of hydrogen fuel cell electric vehicles in China.

Up to now, five fuel cell vehicle demonstration city groups have been approved: the Beijing-Tianjin-Hebei city group, led by Beijing together with 12 cities or districts; the Shanghai city group, led by Shanghai together with 7 cities or districts; the Guangdong city group, led by Foshan together with 12 cities; the Hebei city group, led by Zhangjiakou together with 13 cities or districts; and the Henan city group, led by Zhengzhou together with 11 cities or districts.
During a four-year demonstration period, more than 30,000 units of hydrogen fuel cell electric vehicles would be promoted.

By the end of 2023, the population of hydrogen fuel cell electric vehicles in China had exceeded 18,000 units, and 407 hydrogen refueling stations were built. Most of the fuel cell electric vehicles on road are commercial vehicles. The demonstration covers multiple scenarios such as urban buses, logistics vehicles, trucks, engineering vehicles, and vehicles operated in ports and industrial parks.

Outlook

China actively develops clean energy, accelerates the introduction of green and low-carbon policies, promotes the “carbon peaking and carbon neutrality” work in an orderly manner, and promotes industry transformation and development toward green and low-carbon solutions.

China will build a carbon footprint management system for automotive products. Meanwhile, the industry will increase investment in green manufacturing, low-carbon product research and development (R&D) and supply, green materials and energy applications, and a circular economy to drive the green and low-carbon development of the whole industry chain. New energy vehicles will accelerate the replacement of fossil fuel vehicles.

Additional Information Sources

- National Development and Reform Commission (NDRC)
- Ministry of Industry and Information Technology (MIIT)
- Ministry of Ecology and Environment (MEE)
- China Association of Automobile Manufacturers (CAAM)
- CV World

Denmark

Drivers and Policies

In December 2019, Denmark approved a new Climate Act included a legally binding target to reduce greenhouse gas (GHG) emissions by 70% by 2030 (relative to 1990 level), to reach net-zero emissions by 2050 at the latest and to set milestone targets based on a 5-year cycle. Denmark's political understanding "A fair direction for Denmark," states that a 70% reduction target by 2030 is a very ambitious goal, and it will be particularly difficult to realize the last part of the goal (i.e., from 65% to 70%). Meeting the target will require currently unknown methods and, therefore, a close collaboration with the Danish Council on Climate Change and other experts. The Climate Act was followed by climate action plans, which will contribute to ensuring that national reduction targets are met. The Climate Action Plan in 2020 will include sector strategies and indicators (at a minimum) for central sectors such as agriculture, transport, energy, construction, and industry. Denmark has already taken the first steps toward establishing a professional and efficient energy sector as the basis for the transition to a sustainable green society. In June 2018, all parties of the Danish Parliament reached a political Energy Agreement to further build Denmark's international positions of strength with a focus on renewable energy, energy efficiency improvements, research and development (R&D), and energy regulation. The measures and policies decided in the agreement are now being implemented.

Advanced Motor Fuels Statistics

General Energy Data

Gross energy consumption has been relatively constant since 1990, with falling consumption of coal and increasing consumption of renewable energy (see Figure 1). Gross energy consumption peaked in 2007 at 873 petajoule (PJ) and has since followed a downward trend. Gross energy consumption is expected to drop annually by 1.2% until 2020, after which it will rise slightly to 778 PJ in 2030, corresponding to consumption in 2017. Coal consumption will fall considerably (by 14% annually) until 2030, due in particular to the expected stop in the use of coal in large-scale combined heat and power (CHP) production. In 2030, only the Fynsværket power station and the cement industry will consume large amounts of coal. However, some plants will retain the option for coal operation, although actual use is assumed to be limited.

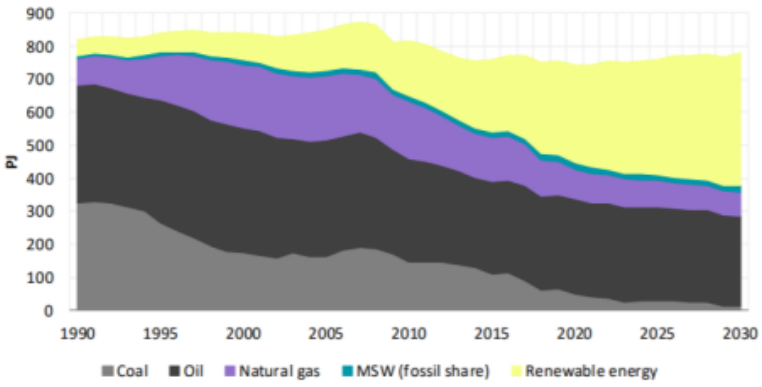


Figure 1. Gross energy consumption by type of energy 1990–2030 (in PJ). The calculation for 1990–2017 has been adjusted for outdoor temperature/degree days relative to normal years (climate-adjusted) and electricity trade with other countries.

Figure 2 shows the total share of renewables (RES) as well as renewables shares for transport (RES-T), electricity consumption (RES-E), heating and cooling (RES-H&C), and district heating (RES-DH), respectively, calculated on the basis of the method described in the EU Renewable Energy (RE) Directive (EU 2009; Eurostat 2018).

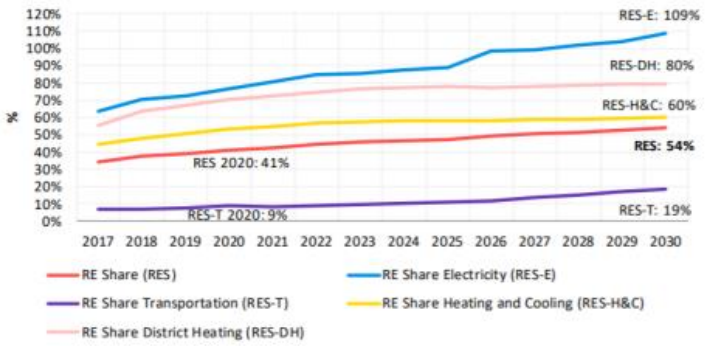


Figure 2. Renewables shares 2017–2030 [%]. The renewables shares are calculated as defined in the RE Directive (Eurostat 2018).

The RES and RES-T are subject to binding national European Union (EU) targets established in 2020. The EU RE Directive also sets out a 2030 target for 27% renewables for EU countries together, but this target has not been implemented as national obligations. Instead, EU Member States are obligated to account for their contributions to reaching the common EU target in their National Energy and Climate Plans.

The projections (from Danish Energy Agency 2019, 2023 and Energistyrelsen) show that the RES is expected to be 41% in 2020, in which case Denmark will have met, and exceeded, its EU obligation for a 30% renewables share by 2020. The RES-T will reach 9% in 2020, revealing a shortfall of 1 percentage point compared with the RE Directive obligation of 10% in 2020. The overall RES will increase to 54% in 2030. The projection depends on the deployment of offshore wind, onshore wind, and solar photovoltaic (PV) and on the conversion of CHP plants to biomass; energy-efficiency improvements in transport, industry, services, and households will contribute to a lesser extent.

The rate of renewables deployment in electricity supply is expected to exceed the rate of increase in electricity consumption, and Denmark's production of electricity from renewables is expected to exceed its electricity consumption from 2028. The country's RES-E is expected to increase to 109% in 2030, but the increase is particularly contingent on the offshore wind farms included in the 2018 Energy Agreement being commissioned by 2030.

There are also updated expectations regarding deployment of commercial solar PV (ground-mounted solar farms) and replacement of older onshore wind turbines with fewer, more efficient turbines. The projection of onshore wind and solar PV deployment depends on developments in electricity prices: maintenance of the level for tender prices achieved in the 2018 technology-neutral tendering round, voluntary renewable energy targets from large consumers, and the market for power purchase agreements (PPAs)/guarantees of origin. A high percentage of RES-E affects calculation of the RES-T because the RE Directive uses a multiplication factor of four for the renewables share of electric road transport and a multiplication factor of 1.5 for the renewables share of electric rail transport. Considering this background, RES-T increases to 19% in 2030, contingent on the number of electrified passenger cars and vans increasing to around 9% of the total number in 2030, and an increased use of electricity in rail transport.

Greater use of bio-natural gas in transport will contribute only to a very limited extent. The blending ratio of biofuels in petrol and diesel is expected to be maintained at the current level in the absence of new measures. Fuel consumption for domestic air traffic is included in the calculation of the renewables share. The aviation sector has announced ambitious plans for biofuel blending, but as these announcements are neither binding nor reflect a profitable development pathway for companies in the absence of new measures, the plans have not been included in a renewables contribution from this sector. Measured in relation to final energy consumption, the share of fossil fuels in the transport sector will fall from 95% in 2017 to 92% in 2030. This decrease is due to a combination of electrification of the rail and road transport sectors, as well as improved energy efficiency for conventional vehicles. Fossil fuel consumption in road transport is expected to amount to 73% of total fossil fuel consumption by the transport sector in the absence of any new measures.

Details on Advanced Motor Fuels

Renewables share increasingly consists of electricity produced from renewable energy sources (see Figure 3). In 2030, the RES-E by the transport sector will correspond to the consumption of first-generation biofuels; consumption of second-generation biofuels will constitute a smaller share.

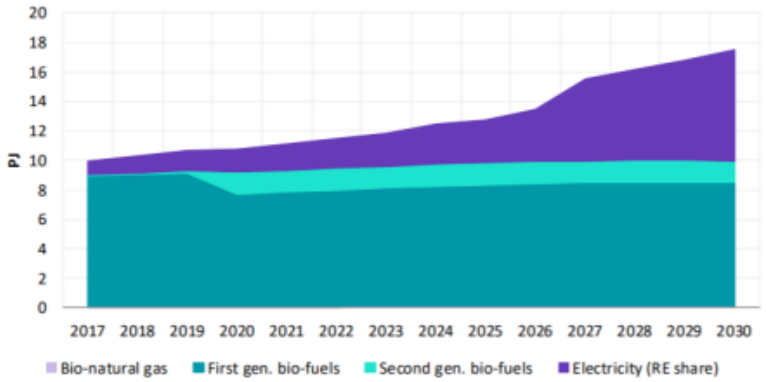


Figure 3. Renewable energy consumption by the transport sector 2017–2030 (in PJ).

Sales of electric cars in particular are therefore likely to increase considerably, and by 2030, electric and plug-in hybrid cars are expected to amount to about 48% of all new car registrations. This trend is expected to increase the percentage of zero- and lower-emission cars on the road to about 22% in 2030, corresponding to around 730,000 electric and plug-in hybrid cars, of which purely electric vehicles will amount to about 75%, as shown in Figure 4. A beginning transition is also expected for vans, so that the number of electric cars and vans in 2030 will total around 800,000.

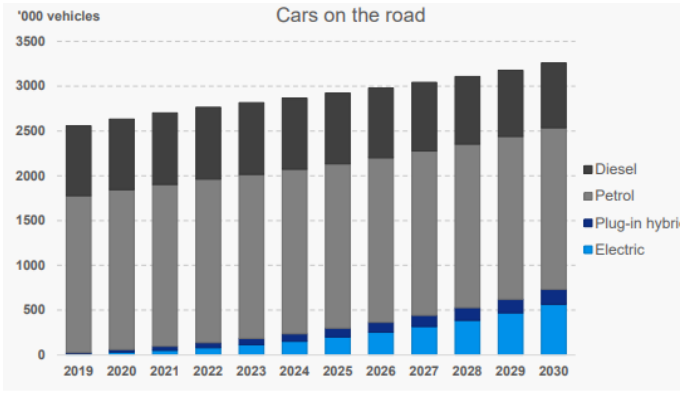


Figure 4. Number of cars by technology, 2019–2030

Emissions from road transport

Although sales of electric and plug-in hybrid cars are expected to increase, petrol and diesel cars are still expected to amount to around 78% of cars on the road in 2030, due to inertia in the transition because of the relatively long lifetime of vehicles.

Road transport is responsible for, by far, the majority of emissions from the transport sector. In 2019, road transport emitted 12.4 million tonnes CO_2e, corresponding to 92% of total emissions by the transport sector. Emissions fell during the Covid-19 pandemic to 11.4 million tonnes CO_2e in 2020 and 11.6 million tonnes CO_2e in 2021. The projection show an increase in emissions in the wake of the pandemic, but after this, emissions are projected to decrease significantly in spite of continuous growth in demand for road transport. By 2025, emissions will have fallen to 11.2 million tonnes CO_2e, and by 2030 and 2035, they will have fallen to 9.6 million tonnes CO_2e and 7.3 million tonnes CO_2e, respectively.

Cars account for the largest share of emissions from road transport, at 57% in 2021, followed by vans and lorries. Figure 5 shows GHG emissions from road transport, broken down by type of vehicle and cross-border trade. Cars are also the category for which the projected decrease in emissions is greatest in absolute figures. Despite a continued increase in traffic, the projection shows a reduction in emissions of GHGs from all vehicle types. This decrease is attributable to vehicle electrification, higher blending ratios for renewable fuels, and continued energy-efficiency improvements in conventional vehicles.

Emissions from rail transport

In 2019, rail transport emitted 0.2 million tonnes of CO_2e, corresponding to around 2% of emissions by the transport sector. Despite an expected expansion in train operations, a considerable reduction in emissions is projected after 2025, corresponding to the electrification of inter-city and regional trains, which are responsible for most emissions. In 2030, emissions from rail transport are projected to be 0.02 million tonnes CO_2e — a mere tenth of today's emissions — and in 2035, there will be no emissions at all. The last diesel trains are expected to be phased out just after 2030.

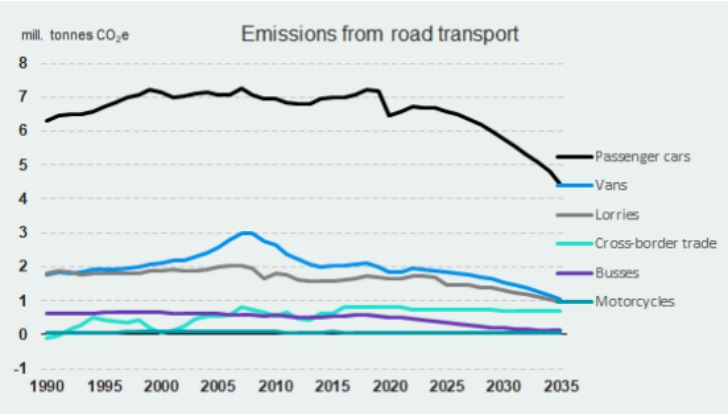


Figure 5. Emissions from road transport by vehicle

Emissions from domestic aviation

Emissions from domestic aviation were 0.15 million tonnes CO_2e in 2019, corresponding to around 1% of total transport sector emissions. As a result of the Covid-19 pandemic, emissions from domestic aviation were 0.08 million tonnes CO_2e in 2020 and 0.09 million tonnes CO_2e in 2021. The projection that activity in the sector will increase gradually as a result of increased demand for domestic flights includes a caveat that it may not return to the pre-pandemic level until 2025.

The projection includes an expectation that the incrementally increasing CO_2 tax on fuels for domestic aviation under the 2022 Green Tax Reform for Industry Etc. agreement, which will take effect in 2025, will put a damper on developments in aviation activity. The projection also assumes general energy efficiency improvements.

Emissions from domestic aviation are expected to increase to 0.13 million tonnes CO_2e in 2025 and 0.14 million tonnes CO_2e in 2030, after which emissions will remain unchanged. Renewable fuels blending is not assessed to be financially feasible without further regulation of the sector, and use of renewable fuels in domestic aviation has therefore not been included in the projection.

Emissions from domestic shipping

Emissions from domestic shipping accounted for 3.9% of total emissions by the transport sector in 2019. The projection shows that emissions will remain more or less constant at around 0.5 million tonnes CO_2e in the period up to 2035. However, the projection predicts a slight reduction in emissions as a result of electrification of a number of short ferry services, partly resulting from deployment of the pool to promote green transition of domestic ferries in 2021 (11 ferries received commitment of funding) and in 2022 (three ferries received commitment of funding); the program replaced 15 existing ferries with 14 green electric-powered ferries, either through refurbishment or new purchase.

Further, the introduction of a CO_2 tax as part of the 2022 Green Tax Reform for Industry Etc. agreement is assessed to increase the incentive to opt for electric ferries when buying new ferries. The projection does not include use of renewable fuels, such as ammonia or methanol in domestic shipping, because such fuels are not financially feasible without further regulation of the sector. Even with the introduction of the agreed CO_2 tax, renewable fuels are associated with a considerable additional cost, including the cost of having to invest in infrastructure, etc.

Outlook

In Denmark, the transportation sector is still almost entirely dependent on oil. By 2050, the government aims to meet all Danish energy demand with renewable energy, including that required by the transportation sector. In 2012, a broad majority in Parliament reached an energy agreement defining initiatives covering crucial energy policy areas for the period 2012–2020, and agreed to discuss additional initiatives for the period after 2020. The analysis from 2012 indicates that by 2020 and beyond, electricity, biogas, and natural gas could become especially attractive as alternatives to petrol and diesel in the transportation sector. Electricity is the most energy-efficient alternative because of high efficiency in the engine and an increase in the share of wind-generated electricity supply.

Energy islands

The world's first energy islands will be constructed in Denmark, exploiting our immense wind resources in the North and Baltic seas. The energy islands will serve as hubs that can create better connections between energy generated from offshore wind and the energy systems in the region around the two seas.

In the North Sea, an artificial island will be constructed, which will be a hub for 3-GW offshore wind farms, with the possibility of 10 GW in the long term — enough to power 10 million households. The wind turbines that will supply power to the island are expected to be larger than they are today, and they will extend further out to sea than before. The technical equipment for energy distribution will be located on the island; it will not be possible to see the turbines from land. The energy islands are part of the development of the energy systems of the future. Political agreements state that electricity from the energy islands should be converted into new forms of energy (e.g., Power-to-X), creating green power that will contribute to the phasing out of fossil fuels in both Denmark and Europe.

In the Baltic Sea, the technical equipment for energy distribution will be located on Bornholm, where electricity from offshore wind farms will be transported to the electricity grid on Zealand and neighboring countries. The offshore wind farms will stand approximately 20 km south-southwest of the coast and will be visible but not dominant on the horizon.

The parks at Bornholm must have a capacity of 2 GW, corresponding to the electricity consumption of two million households. Like the island in the North Sea, the ambition is for electricity from the offshore wind farms to be converted into other forms of energy (Power-to-X).

Additional Information Sources

- Danish Energy Agency, 2019, *Danish Energy and Climate Outlook 2019*, https://ens.dk/sites/ens.dk/files/Analyser/deco19.pdf.
- Energistyrelsen, www.ens.dk.
- Danish Energy Agency, 2023, Denmark's Climate Status and Outlook 2023. https://ens.dk/sites/ens.dk/files/Basisfremskrivning/kf23_hovedrapport_v3_eng.pdf.

Finland

Drivers and Policies

Finland's 2016 energy and climate strategy calls for a 50% reduction in carbon dioxide (CO_2) emissions from transport by 2030 (from reference year 2005).[13] The 2019 Government Programme sets a new upper level: Finland will achieve carbon neutrality by 2035 and aims to be the world's first fossil-free welfare society.

In May 2021, the Ministry of Transport and Communications of Finland published a roadmap for fossil-free transport with the goal of halving greenhouse gas (GHG) emissions from transport by 2030, (using 2005 as the base year) and achieving zero emissions by 2045. Roadmap measures include actions to support the procurement of electric and gas-powered vehicles, the distribution infrastructure, pedestrian and bicycle traffic, and public transport. In addition, roadmap cover the impacts of a stricter obligation to distribute renewable fuels, as well as the impacts of remote work, new transport services, and combined transports in freight traffic.[14]

In spring 2019, the biofuels obligation was revised and Finland's pathway toward 2030 was set. The biofuel target for 2029 and beyond was set at 30%, and this time, the target reflects actual energy contributions without double counting, which explains the lower obligation for 2021 compared with 2020 (20%). A separate sub target for advanced biofuels also exists, following the European Union (EU) Renewable Energy Directive (RED II): 2% between 2021 and 2023. In 2021, Finland passed a law amending gaseous and liquefied biogas in the transport biofuels obligation beginning January 1, 2022, and passed a law amending electro-fuels in the biofuels obligation beginning January 1, 2023.[15,16] In September 2022, the government proposed that Parliament increase the renewable fuels blending obligation to 34% in 2030 and onward.[17] The original biofuels obligation (liquid biofuels) calls for 19.5% biofuels for on-road transportation in 2022. However, due to a sudden increase in fuel prices during the spring of 2022, the government decided to reduce the blending obligation by 7.5%, to 12% for 2022. In October 2023, the government of Finland proposed that Parliament reduce the biofuels obligation from 28% to 13.5% for 2024,[18] which was the approved. The reason for reduction was an estimated 17-cent increase in diesel and 15-cent increase in gasoline prices that would result from a 28% biofuels obligation.

In addition, a separate renewable fuels obligation was established for non-road machinery diesel fuels. With the current level at 6%, the original law called for an annual increase of up to 10% in 2030. In November 2022, the government proposed that Parliament increase the renewable fuels blending obligation in non-road machinery use to 30% in 2030 and onward.[19]

As of 2011, the fuel tax system consists of an energy component, a CO_2 component, and a bonus for reduced local emissions. The system favours the best biofuels, but it is still transparent and technology-neutral and can be used in combination with the obligation for liquid biofuels. Passenger car taxation (purchase tax and annual tax) has been CO_2-based (tailpipe) since 2008, providing substantial incentives for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).[20] In addition, since 2020, Finland has offered a reduced-tax benefit for citizens who drive a company-

[13] Ministry of Economic Affairs and Employment of Finland, "Energy and Climate Strategy," https://tem.fi/en/energy-and-climate-strategy-2016

[14] Ministry of Transport and Communications, "Transport emissions can be halved by 2030 through national and EU measures," https://www.lvm.fi/en/-/transport-emissions-can-be-halved-by-2030-through-national-and-eu-measures-1641099.

[15] EdiLex, "Obligation to distribute biofuels,"https://www.edilex.fi/verohallinnon_ohjeet/2020_1116.html

[16] Ministry of Economic Affairs and Employment of Finland, "Working Life Barometer 2023: More support for continuous learning needed at workplaces," https://tem.fi/-/biopolttoaineet-jakeluvelvoitteeseen.

[17] Parliament of Finland, "Government proposal HE 174 /2022 vp," https://www.eduskunta.fi/FI/vaski/HallituksenEsitys/Sivut/HE_174+2022.aspx.

[18] Ministry of Economic Affairs and Employment of Finland, "Bill: Transportation fuel distribution obligation 13.5% also next year," https://tem.fi/-/lakiesitys-liikennepolttoaineiden-jakeluvelvoite-13-5-myos-ensi-vuonna-.

[19] Parliament of Finland, "Government proposal HE 297 /2022 vp," https://www.eduskunta.fi/FI/vaski/HallituksenEsitys/Sivut/HE_297+2022.aspx

[20] Parkkonen, L., 2013, "Taxation of petroleum products and vehicles in Finland," CEN/TC 19 Conference. Helsinki, May 27, 2013.

owned car. The value has been 170€/a for BEVs and 85€/a for cars with CO_2 emissions in the range of 1–100g/km. The benefit will end at the end of 2025.

The current government programme promotes the use of renewable fuels via fuel conversion kits. The government has also proposed national legislation modifications for promoting flexi-fuel (E85) and biomethane passenger car conversion kit installations.[21] However, the proposal leaves open the details regarding how motorists with converted cars can demonstrate compliance with safety and emissions requirements.

Advanced Motor Fuels Statistics

In 2022, the energy consumption in domestic transport (all modes together) was 164 petajoules (PJ), and energy consumption in road transport was 151 PJ, or 3600 kilo tonnes of oil equivalent (toe) (Table 1). Relative to Finland's total energy consumption of 1,275 PJ in 2022, the transport consumption figures were 12.9% (total) and 11.8% (road), respectively.[22]

Table 1. Energy in Road Transport, 2022

	PJ	ktoe	Share of fuels (%)	Share of biofuels (%)
Petrol (fossil)	44.1	1052	27.98	
Biocompatible petrol	4.8	114	3.0	9.8 of petrol
Diesel (fossil)	81.7	1951	54,7	
Biocompatible diesel	17.7	423	17.8	22.2 of diesel
Natural gas	0.25	0.6	0.02	
Biomethane	1.16	27.7	0.78	99.8 of gas
∑ fuels	149.4	3569		15.8 of fuels
	PJ	**ktoe**	**Share of total (%)**	
Electricity	1.44	34.5	0.97	
Total	**150.9**	**3,604**		

Source: pxnet2.stat.fi/PXWeb/pxweb/fi/StatFin/StatFin__ene__ehk/statfin_ehk_pxt_12sz.px/

In terms of energy, the contribution of biofuels relative to the total fuel consumption in road transport is 15.8%, varying from 9.8% in petrol (mostly ethanol and some ethyl tertiary-butyl ether [ETBE], but also bio-naphtha; the statistics do not give details on this) to 99.8% in methane. The actual amount was 565 ktoe, or 15.8% of the fuels.

The four major Finnish players in biofuels are Neste (the world's biggest producer of hydrotreated vegetable oil [HVO]), UPM, St1, and Gasum.

Table 2 presents the vehicle fleet in use at the end of 2022 (without two- and three-wheelers and light four-wheelers). Table 3 presents the sales figures for new passenger cars in 2015–2022 (revised).

[21] Finlex, "The government's proposal to parliament as a law on amending the Vehicle Act and related laws," https://www.finlex.fi/fi/esitykset/he/2022/20220291

[22] StatFin, "12sz — Energy consumption in transport, 1990–2022," https://pxdata.stat.fi/PxWeb/pxweb/fi/StatFin/StatFin__ehk/statfin_ehk_pxt_12sz.px/

Table 2. Vehicle Fleet in Use at the End of 2023 (without two- and three-wheelers and light four-wheelers)[23]

Fuel	Cars	Vans	Trucks	Buses	Special vehicles
Petrol	1,820,926	8,920	2,354	20	260
FFV/ethanol	4,496	16	131	0	0
Diesel	695,233	330,367	86,896	10,250	1,227
Methane	7,766	849	331	67	0
Methane bi-fuel	8,620	323	96	0	0
BEV	83,762	3,181	65	653	0
PHEV petrol	128,564	212	0	0	0
PHEV diesel	6,541	82	5	2	0
Other	59	17	194	5	0
Total	2,756,015	343,976	90,086	11,000	1,487
Fuel	**Cars (%)**	**Vans (%)**	**Trucks (%)**	**Buses (%)**	**Special vehicles (%)**
Petrol	66.1	2.6	2.6	0.2	17.5
FFV/ethanol	0.2	0.0	0.1	0.0	0.0
Diesel	26.1	96.4	99.6	95.2	88.0
Methane	0.3	0.2	0.4	0.6	0.0
Methane bi-fuel	0.3	0.1	0.1	0.0	0.0
BEV	3.0	0.9	0.1	5.9	0.0
PHEV petrol	4.7	0.1	0.0	0.0	0.0
PHEV diesel	0.2	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.2	0.0	0.0

Table 3. Sales of New Passenger Cars, 2015–2023[24]

Year	Petrol (P)	FFV	CNG	Diesel (D)	HEV P	HEV D	PHEV P	PHEV D	BEV
2015	66,248	105	158	38,797	2,817	29	400	15	243
2016	7,3251	14	165	39,451	4,668	11	1115	93	223
2017	70,520	1	433	36,060	8,512	2	2,401	152	502
2018	73,065	0	1,161	28,710	11,631	224	4,797	135	776
2019	67,751	0	2,142	20,871	14,582	990	5,807	159	1,897
2020	45,589	0	1,841	14,133	17,371	1,354	12,797	435	4,245
2021	30,757	12	909	8,397	25,871	2,235	19,519	620	10,152
2022	19,244	27	595	5,418	24,084	1,626	15,770	401	14,530
2023	12,910	17	453	4,124	21,444	932	17,897	220	29,535

In 2023, 87,502 new cars were sold – approximately 7% more than in 2022. Diesel shares of new sales continue to decline and in 2023 represented only 4.7%, compared to 35.7% in 2015. Sales of PHEVs increased slightly to around 20.7% of total new sales. BEVs are becoming more popular, and sales have increased year over year. In 2023, BEVs represented about 34% of total new sales.

[23] Tieto.Traficom, "Vehicle fleet statistics," https://tieto.traficom.fi/fi/tilastot/ajoneuvokannan-tilastot?toggle=K%C3%A4ytt%C3%B6voimat

[24] Finnish Information Centre of Automobile Sector, "Motive power statistics of first registered passenger cars," https://www.aut.fi/tilastot/ensirekisteroinnit/ensirekisteroinnit_kayttovoimittain/henkiloautojen_kayttovoimatilastot.

Finland has an estimated 558 alternative-fueled trucks, including FFVs and bi-fuel vehicles. Methane-fueled trucks represent the greatest share. The numbers for these two categories are explained by the fact that some heavy pickup trucks and vans are registered as trucks. With the development of liquefied natural gas (LNG) refueling infrastructure and increased offerings of heavy gas trucks, trucks fueled by LNG now operate on Finnish roads. The number of trucks fueled by compressed natural gas (CNG) and LNG has grown to 331 in 2023. In the case of buses, the number of battery electric buses has surpassed the number of CNG buses. The increase of electric (city) buses has been rapid. In 2020, Finland has a total of 87 electric buses and in 2023, already 656.

Research and Demonstration Focus

The following paragraphs describe some major national R&D projects in which the VTT Technical Research Centre of Finland (VTT) is taking part, as well as a number of additional projects.

In 2020, Business Finland funded a new project on liquid electrofuels. The E-Fuel project (2021–2024) aims to integrate hydrogen production through high-temperature electrolysis with CO_2 sequestration and Fischer-Tropsch fuel synthesis; the project also includes research on end use. Electrofuel developed from green hydrogen and CO_2 was demonstrated in an agricultural tractor in November 2023.[25].

The BIOFLEX project (2020–2024) explores how suitable fuel oils made from biomass and waste plastics are for power plants and ship diesel engines. The project studied the development of production processes and measurements of the emissions when using new biofuels in marine engines.

The Clean Propulsion Project (2021–2024), funded by Business Finland, focuses on developing maritime and non-road engine technologies for better efficiency and renewable fuels. The project has four focus areas:

1. Developing a roadmap for sustainable shipping.
2. Investigating and developing multiple power source propulsion systems, including hybrid technology demonstration.
3. Formulating novel combustion concepts and exhaust gas after-treatment technologies that achieve close to zero emissions. Different fuel options are investigated, including hydrogen in non-road applications.
4. Developing a virtual sensor and control algorithm for increased powertrain efficiency and full deployment of renewable fuels.

The NoDamageTruck project (2022–2024), funded by Business Finland, focuses on developing an electrically assisted trailer axle for heavy-duty vehicles to improve the energy efficiency of internal combustion engine (ICE)-powered vehicles and improve work productivity. The focus is on typical Nordic countries' vehicle applications (i.e., vehicles with a gross weight up to 76 tonnes). The project includes formulating a flexible and rapid design methodology for combining model-based development with experimental testing activities to accelerate the overall development process. The project also includes a simulation-based evaluation of the potential of e-axles in different heavy-duty vehicle (HDV) applications, such as timber, long-haul, and rock transport. The e-axle concept will be demonstrated on an experimental basis.

The DeCARBO project (2022–2024), funded by Business Finland, investigates the most suitable technologies for decarbonization of non-road mobile machinery (NRMM) in mining, harbour, and forestry use cases. The project consists of four focus areas.

1. Foresight and scenario investigation that allows researchers to offer guidance on possible future development paths.

[25] VTT, "Electrofuel developed from green hydrogen and carbon dioxide to be tested in practice for the first time," https://www.vttresearch.com/en/news-and-ideas/electrofuel-developed-green-hydrogen-and-carbon-dioxide-be-tested-practice-first.

2. Research on the most promising potential technological solutions for decarbonization of NRMM in different use cases and operational environments. In particular, the study looks at different options for off-grid-environment NRMM applications.
3. Hydrogen fuel-cell and renewable fuel ICE power generation options for off-grid power generation needs.
4. Techno-economic analyses to evaluate not only technical attributes but also economic feasibility.

Outlook

Finland must reduce its CO_2 in the non-ETS (not part of the EU emissions trading scheme) sector by 39% by 2030, putting pressure on emission reductions in transport. Biofuels — or, in more general terms, renewable fuels—— are seen as a very important element of emission reductions in transport. With its new liquid biofuels mandate written into law in spring 2019, Finland is one of the few countries with a fixed biofuels policy articulated through 2030. In parallel with increasing the amount of biofuels, Finland is promoting energy efficiency and electrification in transport as well.

In the newest government program, much attention is given to the circular economy and biogas, so the country has the political will to promote the use of biomethane in transport. Opening the gas market (gas transmission and sales separated) as of 2020, a new pipeline connector to Estonia, and terminals for LNG offer important new possibilities for methane in stationary, as well as mobile, applications on land and at sea.[26] Currently, the Finnish LNG vessel fleet encompasses 10 LNG-fueled ships, including passenger and cargo ships, one icebreaker, and one border patrol vessel. At the end of 2020, a biogas obligation for transport and heating gas was proposed. The new law requires that biogas be mixed in the national gas grid.

Finnish energy companies have a record of being active in the field of biofuels. New capacity is to be expected within the borders of Finland and abroad.

During 2022, green hydrogen and e-fuels production advanced as many new investment plans were published. In total, currently planned capacity will be more than 1 GW for green hydrogen and more than 500 MW for green methane production. In addition, there are investment plans for green ammonia production. Green methane is targeted to support green fuels use in HDVs.

To support e-fuels production, more than 3,680 MW of new wind power capacity was installed during 2022 and 2023. At the end of 2023, the total peak power capacity of wind was around 6,949 MW in comparison to around 12,000 MW capacity of traditional sources (combined heat and power [CHP], condensing power, hydro, and nuclear). Wind power capacity is expected to increase to around 9,000 MW by 2025.[27]

Major changes
Finland's energy and climate strategy calls for a 50% reduction in CO_2 emissions from transport by 2030, and a new upper-level target for the country to be CO_2-neutral by 2035. A renewable fuel (including liquids and biomethane) law for road transport calls for an actual energy share of 34% renewable fuels by 2030. A separate sub-target of 10% is set for advanced biofuels. In addition, the law for non-road machinery fuels calls for a 30% share of renewable fuels beginning in 2030. This legislation signals that Finland is implementing one of the world's most progressive biofuels policies. In addition, the government emphasizes a circular economy and the development of biogas.

[26] GASGRID, 2020, "This Is How The Gas Market Opened in Finland," https://gasgrid.fi/en/2020/06/30/this-is-how-the-gas-market-opened-in-finland/.
[27] Investment decision made before 01 April 2023.

Germany

Drivers and Policies

Germany has set significant targets to reduce greenhouse gas (GHG) emissions on both the European Union (EU) and national levels (e.g., European Green Deal and Federal Climate Change Act). The transition toward decarbonization progressed in 2023 despite a year marked by the ongoing Russian invasion of Ukraine. Overall, energy security and climate change mitigation remain the key priorities of the German government.[28] The government aims to accelerate the energy transition by ending reliance on Russian oil and gas, encouraging energy savings and costs reductions, building liquefied natural gas (LNG) terminals, creating a bridge to hydrogen utilization, and phasing out nuclear power.[29] Importantly, massive budget cuts for climate protection measures are expected for the upcoming years, due to a decision by the Federal Constitutional Court.[30]

In the Climate Change Act, Germany set binding targets of at least a 65% decrease in GHG emissions by 2030 (compared to 1990 levels) and aims to reach the ambitious goal of becoming carbon neutral by 2045.[31] For the first time, Germany managed to reach its GHG emissions goals in 2023; the government is optimistic that the nation can also reach its goals for 2030.[32] Notably, achievement of the 2023 goal was partially due to a slow-down in the economy.[33] The permissible emission budget for the transport sector is 85 million tonnes (Mt) carbon dioxide equivalent (CO_2-eq) in 2030. Moreover, the federal government forecasts a cumulative compliance gap of 180 Mt CO_2-eq for the transport sector by 2030.[34]

While national and sector-wide GHG emissions reduction targets for 2030 are in line with the German long-term strategy, they are not always reflected in sector-specific national contributions (i.e., EU energy efficiency target) and policies and measures (e.g., in the transport sector). These measures, specified in the Climate Action Programme 2030, target a GHG emissions reduction in the transport sector of only 41–42% by 2030,[35] which translates to 98 to 95 Mt CO_2-eq GHG emissions in the transport sector by 2030.[36]

Although Germany has already taken comprehensive climate measures, further efforts are required to achieve the CO_2 savings goal formulated in the Climate Change Act.[37] Figure 1 illustrates the massive gap between trends and targets in the transport sector, highlighting that significant action must be taken quickly to reach the GHG emissions target of 85 Mt CO_2-eq by 2030.

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[28] The Federal Government, 2023, “Energy supply in Germany: Climate-friendly and crisis-proof,” https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/energieversorgung-sicherheit-2040098, last accessed: 04.03.2024.

[29] Ibid.

[30] The Federal Government, 2023, “The Climate and Transformation Fund 2024: Create relief, secure future investments, shape transformation,” https://www.bundesregierung.de/breg-de/aktuelles/der-klima-und-transformationsfonds-2024-2250738, last accessed: 02.04.2024.

[31] The Federal Government, 2021, “Climate Change Act 2021: Intergenerational contract for the climate,” https://www.bundesregierung.de/breg-de/themen/klimaschutz/climate-change-act-2021-1936846, last accessed: 04.03.2024.

[32] Federal Ministry for Economic Affairs and Climate Action, 2024, “Germany is on track for the first time with its 2030 climate goals,” https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2024/03/20240315-deutschland-bei-klimazielen-2030-erstmals-auf-kurs.html, last accessed: 20.03.2024.

[33] Daily News, 2024,“Germany can achieve its climate target for 2030,” https://www.tagesschau.de/inland/innenpolitik/deutschland-klimaziele-erreichbar-100.html, last visited: 20.03.2024.

[34] Federal Ministry for Economic Affairs and Climate Action, 2024, ”Germany is on track for the first time with its 2030 climate goals,” https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2024/03/20240315-deutschland-bei-klimazielen-2030-erstmals-auf-kurs.html, last accessed: 02.04.2024.

[35] The Federal Government, 2024, ”Climate Action Programme 2030,” https://www.bundesregierung.de/breg-en/issues/climate-action/klimaschutzprogramm-2030-1674080, last accessed: 04.03.2024.

[36] The Federal Government, “Climate protection program 2030 to implement the climate protection plan 2050,” https://www.bundesregierung.de/resource/blob/974430/1679914/e01d6bd855f09bf05cf7498e06d0a3ff/2019-10-09-klima-massnahmen-data.pdf?download=1, last accessed: 04.03.2024.

[37] DBFZ (German Biomass Research Center), 2023, ”Monitoring of renewable energies in transport,” https://www.dbfz.de/pressemediathek/publikationsreihen-des-dbfz/dbfz-reports/dbfz-report-nr-44, last accessed: 04.03.2024.

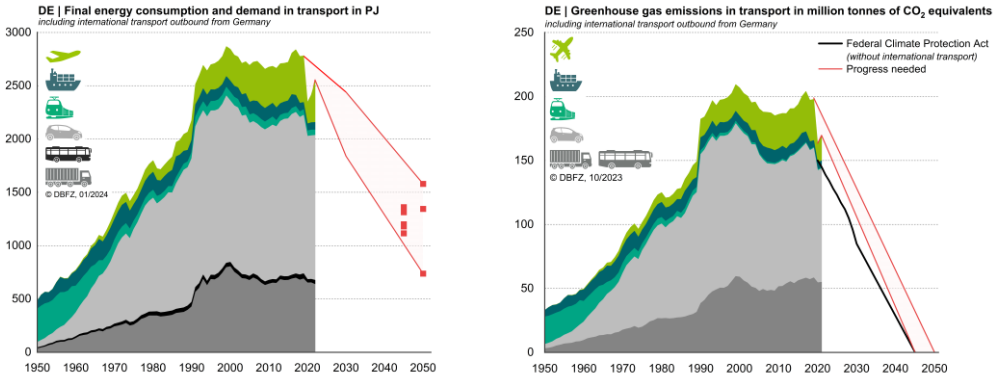

Figure 1. The massive gap between trends, targets, and scenarios in transport, 1990–2050[38] (Source: DBFZ).

The main public drivers regarding policy in the transport sector remain the revised EU Renewable Energy Directive (RED II) and the Fuel Quality Directive (FQD), which are implemented by the Federal Emissions Control Act (BImSchG §37) and the GHG mitigation quota. The FQD is defined by EU Member States to implement GHG reduction targets for fuels on the market. By 2020, the target reduction was set for a 6% reduction, achieved through renewable fuels and including crediting of up to 1.2% upstream emission reductions (UER 2018). Fuel suppliers are obligated to report GHG emissions for the fuels they have introduced into the market.[39] RED II formally became national law in September 2021, continuing the GHG mitigation quota and increasing this quota incrementally from 7% in 2022 to 25% by 2030[40] (Table 1 provides a summary).

The requirements outlined in the RED on sustainability and balancing GHG emissions are codified into national law by the biofuel sustainability ordinance (Biokraft-NachV)). The RED was revised in 2023, and took effect on 20 November 2023.[41] The revised RED sets an overall binding *renewable energy target* of at least 42.5% at the EU level by 2030 — but aiming for 45%, requiring Germany to codify most of the directive's provisions into national law within an 18-month period.[42]

Importantly, the German government does not consider nuclear power a viable option; the last nuclear power plants were closed on 15 April 2023.[43] Germany's position on nuclear power is unlike that of many European countries, where nuclear power is considered an essential energy source.[44] Similarly the National Energy and Climate Plan (NECP) is an instrument of the EU to ensure that all EU Member States jointly work toward reaching EU climate goals. The national plans are monitored closely to ensure that every Member State is on the right track.[45] Germany submitted a first draft of the updated NECP to the Commission in November 2023.[46]

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38 DBFZ Report No.44, "Monitoring renewable energies in transport," https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_44_EN.pdf, last accessed: 04.03.2024.

39 DBFZ, 2021, "Further development of the German greenhouse gas reduction quota," https://www.dbfz.de/fileadmin/user_upload/Referenzen/Statements/Hintergrundpapier_Weiterentwicklung_THG-Quote.pdf, last accessed: 04.03.2024.

40 Federal Ministry of Justice, "Law to protect against harmful environmental effects caused by air pollution, noise, vibrations and similar processes." https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&start=//*[@attr_id=%27bgbl121s4458.pdf%27]#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl121s4458.pdf%27%5D__1646058705951, last accessed: 04.03.2024.

41 European Commission, Renewable Energy Directive," https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en, last accessed: 04.03.2024.

42 Ibid.

43 The Federal Government, 2022, "Energy supply security is key," https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/ausstieg-aus-der-kernkraft-2135796, last accessed: 04.03.2024.

44 EuroNews, 2023, "Nuclear energy in Europe: Who is for and against it and why?" https://www.euronews.com/business/2023/12/23/nuclear-energy-in-europe-who-is-for-and-against-it-and-why, last accessed: 04.03.2024.

45 Federal Ministry for Economic Affairs and Climate Action, "National Energy and Climate Plan," https://www.bmwk.de/Redaktion/DE/Textsammlungen/Energie/necp.html, last accessed: 20.03.2024.

46 Federal Ministry for Economic Affairs and Climate Action, https://www.bmwk.de/Redaktion/DE/Downloads/M-O/necp-entwurf-2023.pdf?__blob=publicationFile&v=2, last accessed: 20.03.2024.

Table 1. Summary GHG Mitigation Quota until 2030 and Compliance Options in Germany

	Explanation
Quota	
GHG mitigation quota	Minimum share of GHG mitigation (yearly increase): 7% in 2022, up to 25% in 2030
Advanced biofuels in road transport (RED II Annex IX A)	Minimum share of energy (yearly increase): 0.2% in 2022, up to 2.6% in 2030
PtL jet fuel in aviation	Minimum share of jet fuel energy: 0.5% by 2026, 1% by 2028, and 2% by 2030
Compliance Options	
Advanced biofuels (RED II Annex IX A)	Amounts above minimum share with twofold counting for amount above minimum share
Biofuels from used cooking oil (UCO) and animal fats (RED II Annex IX B)	Maximum share of energy: 1.9%
Conventional biofuels from resources also relevant for food and feed	Maximum share of energy: 4.4% and from 2023 onward; opt out of palm oil
Green hydrogen and resulting products (Power-to-X [PTX]/e-fuels, renewable fuels of non-biological origin [RFNBO])	Use in refineries and as fuel with twofold counting
Electricity	Threefold counting, adjustment mechanism factor 0.5 to 1.5
Upstream Emission Reduction (UER)	GHG mitigation through UER with maximum 1.2% until 2026

To decarbonize the transport sector, high priority has recently been given to the enforcement of hydrogen and LNG infrastructure along the most important middle- and long-distance road networks and the expansion of the charging infrastructure for electric vehicles. The Federal Ministry for Economic Affairs and Climate Action (BMWK) invested EUR 62 million in the construction of three bunker vessels (refueling ships) for LNG, which will later be used to refuel ammonia.[47] The project's aim is to build a modern and sustainable infrastructure for maritime vessels. Likewise, the first German LNG terminal was inaugurated on 17 December 2022 in Wilhelmshaven. Overall, three LNG terminals are currently in use, while three LNG terminals are still under construction.[48] The capacities of these three terminals will initially enable import of around 13.5 billion cubic meters of LNG to Germany in 2023.[49] Overall, the federal government is sowing the seeds for a transition in the maritime sector.

The application of hydrogen as a transport fuel is one of Germany's main strategies to reach GHG quotas, as outlined in the National Hydrogen Strategy dated June 2020. By 2030, the EU expects to have capacity to meet a total hydrogen demand of 90 to 110 terawatt hours (TWh) (approximately 2.7 to 3.3 million metric tons), of which about 14 TWh (0.4 million metric tons) will be produced in Germany.[50] The strategy includes a strong focus on green hydrogen from electrolysis based on renewable electricity; biomass-based hydrogen is only considered on biotechnological routes or even as an advanced biofuel in line with the RED II. In this respect, Germany's strategy differs from the EU

[47] Federal Ministry for Economic Affairs and Climate Action, "Habeck hands over funding notices: €62 million for the construction of three innovative LNG bunker vessels," https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221223-habeck-hands-over-funding-notices-eur62-million-for-the-construction-of-three-innovative-lng-bunker-vessels.html, last accessed: 04.03.2024.

[48] Federal Ministry for Economic Affairs and Climate Action, "The Federal Ministry for Economic Affairs and Climate Action presents a report on the plans for floating and fixed LNG terminals and their capacities", https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2023/03/20230303the-federal-ministry-for-economic-affairs-and-climate-action-presents-a-report-on-the-plans-for-floating-and-fixed-lng-terminals-and-their-capacities.html, last accessed:08.05.2024

[49] Ibid.

[50] DBFZ, 2022, "Hydrogen from biomass," https://www.dbfz.de/pressemediathek/publikationsreihen-des-dbfz/dbfz-reports/dbfz-report-nr-46, last accessed: 04.03.2024.

hydrogen strategy, which includes biomass as a renewable hydrogen source.[51] The strategy highlights the overall critical stance of the federal government toward using biomass for renewable fuel production. The strategy was revised in July 2023 and takes into account the increased level of ambition on the path to climate neutrality and the changing demands and challenges that have resulted from the Russian war of aggression.[52] The main points of the strategy include accelerating the market ramp-up of hydrogen, ensuring sufficient availability of hydrogen and its derivatives, development of an efficient hydrogen infrastructure, and establishment of hydrogen applications in the sectors.[53] In addition, the federal government aims to become the leading supplier of hydrogen technologies by 2023 and to create the right conditions to support the introduction of hydrogen.[54]

The power-to-liquid (PtL) Roadmap, published in May 2021, outlines Germany's efforts to expand the production of sustainable aviation fuel (SAF) from renewable energy sources.[55] The federal government, federal states, and industry representatives agreed in particular that electricity-based PtL kerosene from renewable energy sources will play a key role in making the aviation sector carbon-neutral and sustainable. Germany has set a goal of a minimum of 200,000 tonnes of PtL kerosene used in German aviation by 2030; this target is linked to the National Hydrogen Strategy.[56] The country intends to achieve the target through technological development, establishing uniform sustainability criteria, and supporting the market ramp-up.

When it comes to on-road vehicles, on the other hand, all eyes are on electrification. The Trilogue's October 2022 agreement to ban the sale of new combustion engine cars after 2035 illustrates a strong commitment to electric vehicles.[57] The federal government supports the agreement and believes that it will provide German industry the necessary planning security.[58] The number of electric vehicles and plug-ins has significantly increased since 2017: today, 25% of newly purchased vehicles are either electric or plug-in,[59] although the restructuring of the transport sector continues to be slow. This trend was particularly apparent when electric vehicle purchases increased by only 11.4% compared with the previous year.[60] Experts predict that 40 million vehicles with combustion engines will still be in use in 2030, and that 2045 will continue to see vehicles with combustion engines, due to the difficulty of electrifying certain areas of transport.[61]

As of the end of 2023, 99 electric car series are available on the German market.[62] Interestingly, there is a wide selection of different electric models in the luxury segment,[63] indicating that car manufacturers are mostly aiming at consumers from a high socioeconomic class. As of October 2023, there are 87.155 "normal" and 21.111 high-speed publicly accessible charging points in Germany.[64] To

[51] Ibid.
[52] DENA, 2023, "Update of the National Hydrogen Strategy: What's in it?,"https://www.dena.de/newsroom/fortschreibung-der-nationalen-wasserstoffstrategie/, last accessed: 04.03.2024.
[53] Federal Ministry for Economic Affairs and Climate Action, 2023, "Update of the National Hydrogen strategy" https://www.bmwk.de/Redaktion/DE/Wasserstoff/Downloads/Fortschreibung.pdf?__blob=publicationFile&v=4 , last accessed: 04.03.2024.
[54] Ibid.
[55] The Federal Government, "PtL roadmap: Sustainable aviation fuel from renewable energy sources for aviation in Germany," https://bmdv.bund.de/SharedDocs/DE/Anlage/G/ptl-roadmap-englisch.pdf?__blob=publicationFile, last accessed: 04.03.2024.
[56] Ibid.
[57] News of the European Parliament, 2022, "Deal confirms zero-emissions target for new cars and vans in 2035," https://www.europarl.europa.eu/news/en/press-room/20221024IPR45734/deal-confirms-zero-emissions-target-for-new-cars-and-vans-in-2035, last accessed: 04.03.2024.
[58] German Parliament, "Answer of the federal government to the small question from the CDU/CSU faction," https://dserver.bundestag.de/btd/20/050/2005047.pdf, last accessed: 04.03.2024.
[59] DBFZ, "Monitoring of renewable fuels in the transport sector," https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_44_DE.pdf, last accessed: 04.03.2024.
[60] Tagesschau, 2024, "The number of electric cars in Germany is increasing more slowly," https://www.tagesschau.de/wirtschaft/verbraucher/autos-zulassungszahlen-100.html, last accessed: 04.03.2024
[61] Ibid.
[62] ADAC, 2024, "Overview: Which electric cars are currently available to buy?" https://www.adac.de/rund-ums-fahrzeug/elektromobilitaet/kaufen/elektroautos-uebersicht/, last accessed 27.02.2024.
[63] Ibid.
[64] Federal Network Agency, "Electromobility: Public charging infrastructure," https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/E-Mobilitaet/start.html, last accessed 27.02.2024.

make electric vehicles more attractive, the federal government introduced additional impetus for e-mobility. The overall package consisted of temporary purchase incentives until the end of 2025, additional funds for the expansion of the charging infrastructure, and additional efforts in the public procurement of electric vehicles and tax measures, which ended in December 2023 — earlier than planned, due to shortages in the Climate Transformation Fund (KTF).[65]

While the political direction is clear, consumers offer various reasons for being hesitant to invest in non-combustion engine vehicles. Vehicle range and prices for refueling are the most important factors when purchasing a vehicle, thus limiting consumers' willingness to purchase a vehicle that runs on renewable fuels.[66] Interestingly, in a study conducted by German Aerospace Center (DLR), the majority of respondents stated that every second service station in their region would need to offer renewable fuels for them to consider these fuels; in reality, 69% of respondents refuel at only 2–3 gas stations, revealing a discrepancy between their expectations and actual mobility behavior.

With regard to public transport, the federal government implemented measures including the introduction of a €49 monthly public transport ticket on 1 May 2023 ("Deutschlandticket" or "Germany Ticket"), on buses, tramways, and metro and regional trains throughout Germany.[67] The ticket is a follow-up to the popular €9 ticket, which was available from June to August 2022, but is now only available through a subscription. After heavy debates about financing the ticket, it was decided that the ticket would be kept at the same price for 2024.[68] Of the 11 million subscribers, 8% are new subscribers who have never used public transport before.[69] Thus, the ticket has not led to a major change in mobility behavior, but rewards those who already use public transport by making the monthly ticket a significantly less expensive.

Advanced Motor Fuels Statistics

The consumption of biofuels in Germany — primarily low-level blends of biodiesel, hydrotreated vegetable oil (HVO), bioethanol, and biomethane — totaled 52.2 Mt in 2022 (Figure 2).[70] To a minor extent, biomethane is used for compressed natural gas (CNG). The absence of incentives results in no market demand for E85 and pure biodiesel. Overall, energy crops and their use as fuel are limited, and need to be expanded in order to meet the climate goals.

[65] Federal Office of Economics and Export Control, https://www.bafa.de/DE/Energie/Energieeffizienz/Elektromobilitaet/Neuen_Antrag_stellen/neuen_antrag_stellen.html, last accessed: 20.03.2024.
[66] Dr. Jipp, DLR, Presentation at "Fuels of the Future Conference" in Berlin on 23 January 2023.
[67] The Federal Government, "One ticket for all of Germany," https://www.bundesregierung.de/breg-de/aktuelles/deutschlandticket-2134074, last accessed: 04.03.2024.
[68] Ibid.
[69] VDV, "Deutschland Ticket: the biggest fare revolution in public transport," https://www.vdv.de/deutschlandticket.aspx#:~:text=Mehr%20als%2011%20Millionen%20verkaufte%20Deutschland%2DTicket%2DAbos&text=In%20den%20Sommerferienmonaten%20Juli%20und,Nutzerinnen%20und%20Nutzer)%20weiter%20gestiegen, last accessed: 04.03.2024.
[70] FNR, "Fuel consumption in Germany," https://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/biokraftstoffe/kraftstoffverbrauch-in-deutschland.html, last accessed: 04.03.2024.

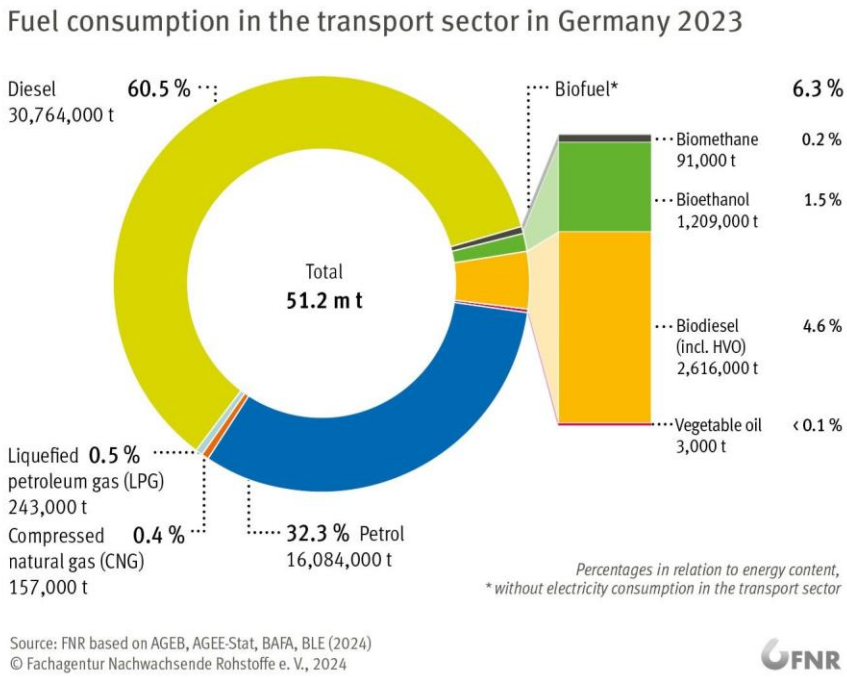

Figure 2. Fuel Consumption in the Transport Sector in Germany in 2022[71]

Tables 2 and 3 show the 2013–2023 sales trends for biofuels and biofuel blends. The overall savings in GHG emissions resulting from the use of all biofuels (pure) was 83% compared with fossil fuels; experts predict that number will remain at this high level.[72]

Table 2. Trends in German Biodiesel Sales (FAME, HVO, FT-BtL), 2013–2022 (in Mt)[73]

Sale	2015	2016	2017	2018	2019	2020	2021	2022	2023
Blend	1.978	1.987	2.183	2.296	2.301	3.025	2.559	2.301	2.380
Pure biodiesel	0.003	0.001	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total	1.981	1.988	2.183	2.296	2.301	3.025	2.559	2.301	2.380

Table 3. Trends in German Bioethanol Sales, 2013–2022 (in Mt)[74]

Sale	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
E85	0.010	0.007	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ethanol	1.082	1.049	1.047	1.045	1.077	1.055	0.972	0.995	0.966	1.000
ETBE	0.139	0.119	0.129	0.111	0.110	0.088	0.126	0.157	0.120	0.124
Total	1.231	1.177	1.176	1.156	1.187	1.177	1.098	1.152	1.086	1.124

[71] Federal Office for Economic Affairs and Export Control; BAFA et al. (Federal Statistics Office [Destatis], DVFG [German LPG Association], the Federal Ministry of Finance [or BMF], Agency for Renewable Resources [Fachagentur Nachwachsende Rohstoffe e.V., or FNR]), 2021.

[72] Federal Agency for Agriculture and Food "2019 Evaluation and Experience Report," https://www.ble.de/SharedDocs/Downloads/DE/Klima-Energie/Nachhaltige-Biomasseherstellung/Evaluationsbericht_2019.pdf?__blob=publicationFile&v=4, last accessed: 04.03.2024.

[73] Bafa Official Mineral Oil Data, 2023 Data from November 2023, https://www.bafa.de/SiteGlobals/Forms/Suche/Infothek/Infothek_Formular.html?nn=8064038&submit=Senden&resultsPerPage=100&documentType_=type_statistic&templateQueryString=Amtliche+Daten+Mineral%C3%B6ldaten&sortOrder=dateOfIssue_dt+desc, last accessed 27.02.2024.

[74] Ibid.

A total of 60.1 million vehicles were registered in Germany as of January 1, 2023 (+1% compared with 2022), including 48.8 million passenger cars, 3.6 million trucks, 2.4 million towing vehicles, and 3.6 million buses.[75] Table 4 shows the number of passenger cars in Germany by fuel type for 2016–2023. The number of electric vehicles increased by 63.8% compared to 1 January of the previous year.[76] Interestingly, bigger and heavier cars are becoming more popular, with an 11.22% increase in sport utility vehicles (SUVs). On average, Germany has 722 cars per 1,000 inhabitants.[77] For comparison, Austria has 566 cars per 1,000 inhabitants.[78]

Table 4. Number of Passenger Cars in Germany by Fuel Type on January 1, 2016–2023

Year	Gasoline	Diesel	LPG	CNG	EV	Hybrid	Plug-in
2016	29,825,223	14,532,426	475,711	80,300	25,502	130,365	X
2017	29,978,635	15,089,392	448,025	77,187	34,022	165,405	20,975
2018	30,451,268	15,225,296	421,283	75,459	53,861	236,710	44,419
2019	31,031,021	15,153,364	395,592	80,776	83,175	341,411	66,997
2020	31,464,680	15,111,382	371,472	82,198	136,617	539,383	102,175
2021	31,435,340	15,060,124	346,765	83,067	309,083	1,004,089	279,861
2022	31,005,134	14,824,262	331,481	82,309	618,460	1,669,051	565,956
2023	30,556,538	14,437,489	326,853	80.630	1,013,009	2,337,897	864,712

LPG = liquefied petroleum gas, according to European fuel quality standard EN 589
CNG = compressed natural gas, according to German fuel quality standard DIN 51624
EV = electric vehicle X = values not comparable *Source: KBA 2023.*[79]

Research and Demonstration Focus

Public funding for alternative motor fuels on the national scale is supported by the Federal Ministry for Digital and Transport (BMDV) in the areas of National Innovation Programme Hydrogen and Fuel Cell Technology (NIPII), infrastructure, e-mobility, LNG, CNG, and jet fuel. Likewise, the Federal Ministry of Education and Research (BMBF) funds research through the "Kopernikus Projects" (P2X and SynErgie).[80] In 2022, the BMBF funded three lighthouse projects with a total funding of EUR 700 million (USD 764 million): H2Giga, H2Mare, and TransHyDE.[81] The H2Giga flagship project aims to mass-produce electrolysers for the production and scaleup of hydrogen, while the H2Mare flagship project intends to produce hydrogen on the high seas, and the TransHyDE flagship project aims to develop a hydrogen transport infrastructure. The CARE-O-SENE project, funded with EUR 40 million, develops catalysts for green kerosene.[82]

[75] https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/fz_b_jahresbilanz_node.html, last accessed: 04.03.2024.
[76] KBA (Federal Motor Transport authority), "Annual balance 2024," https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/fz_b_jahresbilanz_node.html, last accessed: 04.03.2024.
[77] KBA, "Duration," https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html, last accessed: 04.03.2024.
[78] https://www.statistik.at/statistiken/tourismus-und-verkehr/fahrzeuge/kfz-bestand, December 2023, last accessed: 04.03.2024.
[79] KBA, 2023, "Passenger cars on January 1, 2023 according to selected characteristics," https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/2023/2023_b_jahresbilanz_tabellen.html?nn=3532350&fromStatistic=3532350&yearFilter=2023&fromStatistic=3532350&yearFilter=2023, last accessed: 04.03.2024.
[80] Federal Institute for Education and Research, 2021, "Karliczek: Research shows concrete paths to climate neutrality in Germany for the first time," https://www.bmbf.de/bmbf/shareddocs/pressemitteilungen/de/2021/10/111021-Ariadne.html, last accessed: 04.03.2024.
[81] Federal Institute for Education and Research, "Welcome to Hydrogen Flagship Projects," https://www.wasserstoff-leitprojekte.de/home, last accessed: 04.03.2024.
[82] CARE-O-SENE, "Research for a green future: CARE-O-SENE – Catalyst Research for Sustainable Kerosene," https://care-o-sene.com/en/, last accessed: 04.03.2024.

The BMDV funds research on renewable fuels, with EUR 1.54 billion (USD 1.68 billion) available for 2021–2024, consisting of resources from the KTF and the National Hydrogen Strategy.[83] EUR 640 million (USD 698 million) will be used for research and development (R&D) projects.[84] This funding program scope also includes advanced biofuels. The InnoFuels project intends to promote networking, further development of framework conditions for the ramp-up of electricity-based fuels, and advanced biofuels. In 2022, a call on renewable fuels for the maritime sector (electric and bio-based) was published and closed in April 2023.[85] Funding is also available at the state level; for example, Baden-Württemberg funds various R&D projects through its renewable fuels strategy.[86] For 2024, budget cuts in the KTF will be in place, resulting in less funding for R&D projects.[87] For example, R&D for electromobility will no longer be funded — a move that has been heavily criticized by universities and research institutes.[88]

Outlook

With the revision of the RED, Germany now has to codify the provisions of the directive into national law. Nevertheless, no major adaptation is expected as ambitious targets are already in place. The ongoing debate on biofuels ("food vs. fuel") has been reignited by the Green party with a proposal by the Ministry of Environment in January 2023 to phase out crop-based biofuels by 2030.[89] Similarly, the intention of the federal government to cut subsidies for diesel used for agriculture and forestry caused major protests by farmers throughout the country.[90] Biofuels account for 4% of German transport fuel consumption. To meet the 2030 climate target, GHG emissions from the transport sector will have to be reduced by 43% in 2030, relative to 2022 levels.[91] It seems inevitable that all types of fuels will be needed.[92]

The incentives to purchase electric vehicles decreased in late 2023 compared with previous years. Following this trend, the market share of battery electric vehicles (BEVs) is expected to be only 15% in 2024.[93] Importantly, the federal government had to revise its national budget based on a decision by the Federal Constitutional Court in November 2023 that resulted in budget cuts for R&D funding and subsidies for the transport sector in the upcoming year.[94] This ultimately makes accelerating the energy transition increasingly difficult. Finally, the Russian invasion of Ukraine was a wake-up call for the

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83 Federal Agency for Digital Affairs and Transport, "Climate protection in transport – alternative fuels," https://bmdv.bund.de/DE/Themen/Mobilitaet/Klimaschutz-im-Verkehr/Alternative-Kraftstoffe/alternative-kraftstoffe.html, last accessed: 04.03.2024.

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federal government, not just with regard to territorial security but also energy security. Ensuring energy security while continuing to meet ambitious climate targets remains a mammoth task.

Additional Information Sources

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- Fachagentur Nachwachsende Rohstoffe e.V.
- Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie
- Deutsches Biomasseforschungszentrum gemeinnützige GmbH[95]
- eFuel Alliance

Major changes

- Revision of the National Hydrogen Strategy, illustrating the emphasis of the federal government on hydrogen as an energy carrier.
- End of subsidies for purchasing electric vehicles.
- Introduction of new subscription for public transport ("Deutschlandticket").
- Revision of the RED, leading to the need for Germany to codify the directive's provisions into national law.

Benefits of participation in AMF

Access to global information and expertise with regard to advanced transport fuels; exchange of experience on implementation of solutions in AMF member countries.

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India

Drivers & Policies

India is the third-largest consumer of oil in the world. However, its per-capita energy consumption is among the lowest in the world at 0.6 tons of oil equivalent (toe)— a third of the average in other countries (1.79toe). India ranks as the world's second-largest net crude importer and sixth-largest petroleum product exporter, and the country is forecast to be the single largest source of global oil demand growth from 2023 to 2030, narrowly ahead of China. Underpinned by strong economic and demographic growth, India is on track to post an increase in oil demand of almost 1.2 million barrels per day (mb/d) over the forecast period, accounting for more than one-third of the projected 3.2 mb/d global gains.

Primary energy demand will increase significantly under all three scenarios (Accelerated, Net Zero, and New Momentum), more than doubling between 2019–2050.As result of strong growth, India will account for around 14% of global primary energy consumption in 2050across all scenarios, up from around7% in 2019.The share of coal in India's total primary energy mix has been remarkably stable, consistently in line with 2019 levels (45%) over the past 40years. However, the coal share is projected to decline under all scenarios, reaching between 6%and 34% by 2050. Renewable energy growth is strong, averaging4%–6% per year, and is expected to represent between 31% and 66% of total primary energy in 2050.Electricity generation in 2050 is around four times that in 2019 in the New Momentum and Accelerated scenarios, and five times the2019 level in the Net Zero scenario, with solar and wind power accounting for 57% to 95% of that growth. Hydrogen demand grows by a factor of four in the New Momentum scenario, and by a factor of twelve in the Net Zero scenario.

Currently, India imports approximately 88% of its crude oil and 46% of its natural gas requirements. Growing concern about the nation's dependence on imported fuel in tandem with environmental pollution issues has driven India's need for alternative fuels. India plans to reduce import dependency in the oil and gas sectors by adopting a five-pronged strategy: increasing domestic production, adopting biofuels and renewables, establishing energy-efficiency norms, improving refinery processes, and implementing demand substitution.

Since 2014, the Indian government has undertaken multiple interventions to promote biofuels through structured programs such as the Ethanol Blended Petrol (EBP) program, Biodiesel Blending in Diesel, and SATAT (Sustainable Alternative Towards Affordable Transportation) — an initiative for promotion of compressed biogas (CBG). India introduced a National Policy on Biofuels in 2018 (subsequently amended in June 2022) that aims to achieve 20% blending of ethanol in petrol by ethanol supply year (ESY) 2025–26 and 5% blending of biodiesel in diesel by 2030. To enhance use and adoption of CBG, phased mandatory blending of CBG in compressed natural gas (CNG) (for transport) and piped natural gas (PNG) (for domestic use) in the city gas distribution (CGD) sector would begin in financial year (FY) 2025–26. The CBG Blending Obligation (CBO) will be 1%, 3%, and 4% of total CNG/PNG consumption for FYs 2025–26, 2026–27, and 2027–28, respectively. Beginning in 2028–2029, the CBO will be 5%.The government has also set targets of 1%, 2%, and 5% blending of sustainable aviation fuel (SAF) in aviation turbine fuel (ATF) with effect from 2027, 2028, and 2030 respectively, initially for international flights.

The major feature of India's biofuels policy is the categorization of such fuels as either "basic biofuels" (e.g., first-generation "1G" ethanol, biodiesel) and "advanced biofuels" (e.g., 2G ethanol, drop-in fuels) to expand the scope of raw material for ethanol production.To promote a hydrogen economy, the Indian government launched the National Green Hydrogen Mission on January 4, 2023.

Advanced Motor Fuels Statistics

The Indian government has been promoting and encouraging the use of advanced motor fuels in the transport sector, including the blending of biofuels— which are sustainable and have lower emissions than fossil fuels — in petrol, diesel, and natural gas. Loans for the construction of oil extraction/ processing units for production of biofuels and of storage and distribution infrastructure and loans to entrepreneurs to develop CBG plants were classified under priority sector lending by India's Central Bank on September 4, 2020.

With a view to decarbonizing the transport sector, the Indian government developed the "Roadmap for Ethanol Blending in India 2020–25," providing guidance to meet the target of 20% blending of ethanol in petrol (E20) by 2025–26. In line with its Ethanol Blending Roadmap, India launched E20 fuel in February 2023 and by January 2024, more than 10,000 retail outlets across the country were selling E20 fuel.

Ethanol Blended Petrol Programme

Under the EBP programme, the PSUOMCs (Public Sector Undertaking Oil Marketing Companies) achieved the highest-ever blending of ethanol in petrol (12.06%)in ESY 2022–23. Further, the government has already notified and allowed the oil marketing companies (OMCs) to sell E20, in accordance with the Bureau of Indian Standards (BIS) specification effective from December 15, 2022.

The Government of India has taken steps to increase the production and use of ethanol, including permitting procurement of ethanol produced from non-food feedstocks besides molasses (e.g., cellulosic) and lignocelluloses materials (e.g., cotton stalk, wheat straw, rice straw, bagasse, bamboo), and via petrochemical routes, subject to their meeting the relevant BIS standards. The government has also allowed the conversion of sugarcane and food grains (maize and surplus stocks of rice with the Food Corporation of India) to ethanol; administered a price mechanism for procuring ethanol under the EBP Programme, including an enhanced ex-mill price; lowered the goods and services tax (GST) rate to 5% on ethanol for the EBP Programme; amended the Industries (Development & Regulation) Act for free movement of ethanol across states for blending; and instituted a special incentive for maize-based ethanol, among other actions. These steps facilitated an increase in the blending of ethanol in petrol from 154 million liters during ESY 2012–13 to around 5,085 million litres during ESY 2022–23, achieving an average blending rate of 12.06% in petrol (see Table 1).During ESY 2022–23, ethanol distillation capacity increased from 9.47 billion litres to 14.44 billion litres per year (52% increase).

Table 1. Trends in Ethanol Procurement/Blending under EBP Program

Trend	Ethanol Supply Year (Dec. to Nov.)						
	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
Ethanol procured/blended by PSU OMCs[a] (in million litres)	665	1505	1886	1730	3023	4336	5085
National average blending (percentage)	2.0	4.2	5.0	5.0	8.1	10.02	12.06

[a] Public Sector OMCs (i.e., Indian Oil Corporation Ltd. (IOCL), Bharat Petroleum Corporation Ltd. (BPCL), and Hindustan Petroleum Corporation Ltd. (HPCL).

To promote the establishment of distilleries, dedicated ethanol plants (DEPs) are being set up in states where ethanol production is low to avoid the need to transport ethanol over long distances and mitigate supply fluctuations that might impact achievement of blending requirements. DEPs have been commissioned with a design capacity of 257 crore litres per year. In addition, from July 2018 to April 2022, the government notified various ethanol interest subvention schemes for sugar mills and molasses- and grain-based stand-alone distilleries to arrange for entrepreneurs to set up new distilleries or expand existing ones in all states, including those that have a shortage of ethanol. Major developments in 2023 include constitution of a maize development task force and funding of special projects on maize research, upscaling of the maize-based silage value chain, and enhancement of maize production in the catchment area of the ethanol industry.

2G Ethanol Program

The Government of India instituted the "Pradhan Mantri JI-VAN (JaivIndhan-Vatavaran Anukoolfasalawashesh Nivaran) Yojana," to provide financial assistance of approximately $300 million USD from 2018–19 to 2023–24 to support commercial, as well as demonstration, projects for 2G ethanol. India's government has allowed the procurement of ethanol produced from other non-food feedstocks besides molasses, like cellulosic and lignocellulosic materials. The 2G feedstocks include agri-residues such as rice and wheat straw, cane trash, corn cobs and stover, cotton stalk, bagasse, and empty fruit bunches (EFB). In accordance with this decision, PSU OMCs are setting up 2G ethanol bio-refineries in various parts of the country. A 2G ethanol plant in Panipat was dedicated to the nation on World Biofuel Day (August 10, 2022).Projects at Bhatinda (Punjab), Bargarh (Odisha), and Numaligarh (Assam) are in advanced stages of construction and are likely to become operational in

2024. Financial assistance of more than 110 million USD has been approved to public and private sector companies. The government has allowed export of 2G ethanol, which will help valorization of 2G ethanol by project proponents.

Biodiesel and Sustainable Aviation Fuel

In June 2017, the government allowed the direct sale of biodiesel (B-100) for blending with high-speed diesel to all consumers, in accordance with specified blending limits and BIS standards. The government issued "Guidelines for Sale of Biodiesel for Blending with High-Speed Diesel for Transportation Purposes 2019" on May 1, 2019.Biodiesel procurement increased from 0.6 million litres in FY2021–22 to 439.9 million litres in FY 2023–24 (April 2023–March 2024).

In June 2021, the government assembled a committee to advance the SAF/bio-aviation turbine fuel (Bio-ATF) program. The committee examined various aspects of the Bio-ATF program and recently submitted a report that is currently under examination by the Ministry. To promote SAF, OMCs are setting up plants across the country that are likely to be operational between 2025 and 2027. The government has set targets of 1%, 2%, and 5% blending of SAF in ATF to take effect in 2027, 2028, and 2030, respectively, for international flights.

Compressed Biogas

As part of an initiative under the National Policy on Biofuels2018, the SATAT initiative was launched in October 2018 to promote the use of CBG along with natural gas. Under this initiative, oil and gas marketing companies (OGMCs) are inviting expressions of interest from potential investors and entrepreneurs to procure CBG for sale to automotive and commercial customers.

As of December 2023, 55 CBG plants with a total production capacity of around 340 metric tons (MT) per day have been commissioned;57 CBG plants are at various stages of construction.Sales of CBG have been initiated from more than 150 retail outlets. CBG is also being supplied to industrial customers, and CBG injection in the CGD network has started.

India's Ministry of Petroleum and Natural Gas (MoP&NG) has issued guidelines for synchronization of CBG with City Gas Distribution (CGD) network. Under the CBG-CGD synchronization scheme, CBG sales have been initiated in 22 geographical areas of the CGD network.

Under this initiative, various measures have been taken to increase the production of CBG, including establishing an assured price for off-take of CBG, central financial assistance to CBG/biogas plants under the Umbrella Scheme of the National Bio Energy Programme (of the Ministry of New and Renewable Energy), and additional central assistance to states and union territories for establishing municipal solid waste (MSW)-based CBG projects through Swachh Bharat Mission Urban 2.0 of the Ministry of Housing and Urban Affairs.

Earlier developments involve the inclusion of bio-manure produced from CBG plants as fermented organic manure (FOM) and liquid fermented organic manure (LFOM) under the Fertilizer Control Order of 1985; the inclusion of CBG projects under the "White Category" by the Central Pollution Control Board on a case-by-case basis; the inclusion of CBG projects under priority sector lending by the Reserve Bank of India (RBI); and loan products from various banks to finance CBG projects.

Major developments in 2023 include an exemption in the excise duty on the biogas or CBG portion of blended CNG; an exemption from the requirement to obtain authorization for sale of FOM/LFOM for three years; implementation of India's Policy on Promotion of Organic Fertilizer which, among other things, provides market development assistance and crop residue management guidelines (CRM-23-24),including financial assistance to facilitate establishment of a crop residue/paddy straw supply chain. In addition, the government has approved ascheme to provide financial assistance to CBG producers for 4 years to allow them to purchase aggregation machinery to collect biomass.

To promote the production and consumption of CBG in the country, the government implemented a phased blending of CBG in CNG (for transport) and PNG (for domestic use) in the CGD sector. The CBO will be voluntary until FY 2024–2025; mandatory blending will begin in FY 2025–26 at 1%, in 2026–27 at 3%, and in 2027–28 at4% of total CNG/PNG consumption. Beginning in 2028–29, the CBO will be 5%.

Green Hydrogen

The Indian Government approved the National Green Hydrogen Mission on January 4, 2023, with a total financial investment of approximately 2.5 billion USD (₹ 19,744 crore), including an outlay of about 2.2 billion USD (₹ 17,490 crore)in incentives for green hydrogen production and eletrolyser manufacturing; the remainder will be used for pilot projects, research and development (R&D), and other mission components. India's green hydrogen production capacity is likely to reach 5 million metric tons (MMT) per year by 2030, with the goals of reducing its fossil fuel imports of approximately 12 billion USD (₹ 1 lakh crore), achieving over 100 billion USD ((₹ 8 lakh crore) in total investments, creating more than 600,000 jobs, and eliminating nearly 50 MMT per year of greenhouse gas emissions.

Various government-owned entities are taking steps to aid the ambitious National Green Hydrogen Mission by establishing hydrogen projects. GAIL Ltd. has started India's maiden project of blending hydrogen in the CGD grid —2% (by volume) of hydrogen is being blended into the CNG network and 8% (by volume) is being blended into the PNG network on a pilot basis.

MoP&NG has further directed the OGMCs to setup green hydrogen projects across the country. In 2023, OGMCs identified their short-term (by 2027) and long-term (by 2030) commercial project targets. A few pilot/small-scale plants are anticipated to commence production in 2024 as a part of these initiatives.

Global Biofuel Alliance

The Global Biofuels Alliance (GBA) is a unique multi-stakeholder alliance, launched during India's G20 presidency in September 2023 in the presence of the leaders from nine countries, as chair's initiative. GBA aims to enhance global development and deployment of sustainable biofuels by bringing together the biggest consumers and producers.

Since its inception, GBA has received tremendous enthusiasm. Initially supported by 19 countries and 12 international organizations at launch, the alliance has since expanded its membership to include 24 countries and 12 international organizations, with a trajectory of ongoing growth and membership interest from more countries. In addition, the alliance has been receiving tremendous support from industry, both in India and abroad.

The alliance intends to expedite the global uptake of biofuels across a wide spectrum of stakeholders by facilitating capacity-building exercises across the value chain; providing technical support for national programs; and promoting policy lessons sharing and technology advances. GBA will also facilitate development, adoption, and implementation of internationally recognized standards, codes, sustainability principles, and regulations to incentivize biofuels adoption and trade. Finally, the alliance will act as a central repository of knowledge and an expert hub. GBA aims to serve as a catalytic platform, fostering global collaboration for the advancement and widespread adoption of biofuels.

Research and Demonstration Focus

The Centre for High Technology (CHT) — PSU OMC's research and development unit under the MoP&NG, the Department of Biotechnology (DBT), and the Council of Scientific and Industrial Research – Indian Institute of Petroleum (CSIR-IIP), Dehradun — is working on a program to support R&D pertaining to energy biosciences in India through various schemes with major emphasis on advanced biofuels. The DBT-ICT center based in Mumbai has developed lignocelluloses technology at a demonstration scale that is now being used to establish commercial plants.

India has undertaken several initiatives to increase the use of hydrogen in its energy mix. Indian Oil Corporation Ltd. has undertaken an ambitious R&D project under the aegis of MoPNG at a cost of $35.8 million USD (₹ 297 crore). It is the first scientific project in India to address all aspects of the value chain of hydrogen-based mobility. Four demonstration-scale hydrogen production units producing 1 ton per day will be set up. Of the four units, three will employ renewable sources (biomass gasification, reforming CBG, and solar photovoltaic [PV]-based electrolysis) to produce green hydrogen. To utilize green hydrogen produced from the demonstration plant, 15 fuel cell buses are being developed jointly with India's leading heavy-duty vehicle manufacturer. Initial testing of the buses is underway by original equipment manufacturers (OEMs).Seven buses have been developed and

deployed at the Indian Oil Corporation Ltd. (IOCL) R&D center; IOCL will use these 15 indigenously manufactured/integrated hydrogen fuel cell buses to conduct a 20,000-km field trial in Delhi's National Capital Region.

Studies are in advanced stages at the IOCL R&D center to install the world's first pilot plant with a capacity of 10 kgCO_2per day using gas fermentation technology. Anaerobic gas fermentation technology will convert CO_2 into acetic acid, and aerobic fermentation technology will convert acetic acid into highly valuable omega-3fatty acids (docosahexaenoic acid, or DHA) and biodiesel. This value chain makes the overall process economically feasible.

IOCL is also setting up a third generation (3G) ethanol production plant to produce around 128 KL per day of ethanol using gas fermentation technology from off gases at Panipat Refinery.

In a significant development for decarbonizing of the aviation sector, India's first commercial passenger flight using an indigenously produced SAF blend was successfully flown on May 19, 2023.

In January 2024, Praj Industries Ltd.'s R&D unit established the first pilot project for producing aviation turbine fuel from alcohol near Pune in Pirangut, which was inaugurated by the Union Minister of India.

Hindustan Petroleum Corporation, Ltd. (HPCL), in collaboration with a renowned institute, completed the assembly of an electrolyser for producing green hydrogen at a 5 Nm^3/h capacity based on indigenously developed technology (alkaline). HPCL is planning to setup CBG plants with HP-RAMP (rapid acidification for methane production) technology and utilize the CBG in a steam methane reformer to produce about 21 KTPA green hydrogen. Bharat Petroleum Corporation Ltd. (BPCL) R&D is also working on long-term solutions for hydrogen storage and indigenous fuel cell systems, along with various academic institutes. A study of the impact on the CGD network/NG pipeline resulting from various levels of hydrogen is in progress.

Current efforts are focused on the development of cost-effective and -efficient enzymes for 2G bioethanol refineries; the development of value-added products by lignin valorization; commercial production of biojet fuel; compressed biogas from biomass, food waste, and municipal solid waste; cost-effective biofuels from industrial waste gases; and green hydrogen.

Outlook

The outlook for biofuels in India remains promising, considering the government's promotion of biofuels and advanced biofuels as "environment friendly" fuels.

Ethanol blended by PSU OMCs reached 5,085 million liters in ESY 2022–23. OMCs achieved the highest-ever average blending percentage of (12.06%) during ESY2022–23. With the rollout of the roadmap for E20 in India and the commitment shown by all stakeholders, the projected annual demand for ethanol is targeted at over 10 billion liters by 2025–26.Since the government's announcement on E20 fuel in February2023, E20 availability has increased to more than10,000 outlets in less than a year.E100 fuels have been launched at 183 retail outlets across the country. Biodiesel procurement surged to its highest-ever level of 439.9 million litres during FY 2023–24 (April 2023–March 2024) with expectations of further growth, reaching a new peak in FY 2024–25.

The SATAT initiative will help India to reduce its dependence on fossil fuels, increase the share of gas in primary energy consumption, and integrate the vast retail network of companies with upcoming CBG projects. The government's phased program to blend CBG with NGin the CGD sector will increase the use of CBG to 5% by 2028–29.Public and private sector companies have undertaken initiatives to adopt green hydrogen and announced commercial projects plans, with expectations that a few pilot/small-scale green hydrogen plants will start production in 2024.

These highlighted initiatives have already begun to impact India's biofuel industry. Major developments in the advanced biofuel sector — in terms of deployment in the transport sector, investments, project establishment, and enhanced R&D — are expected in the coming years.

Additional Information Sources

- www.ppac.org.in for data on fossil fuels production, consumption, import, and export
- www.mopng.gov.in for data related to the petroleum sector
- Ministry of New and Renewable Energy for data on R&D projects
- https://www.siamindia.com for data on the automotive industry
- www.dbtindia.nic.in
- IndianOil, the Energy of India for data on R&D projects
- 1-BP Outlook 2023 Edition, India
- Roadmap for Ethanol Blending in India 2020–25
- IEA Indian Oil Market Outlook to 2030

Japan

Drivers and Policies

On October 22, 2021, the Cabinet approved the *Sixth Strategic Energy Plan* for submission to the Diet.[96] The Plan includes two key themes:

1. An energy policy approach to achieving carbon neutrality by 2050, as announced in October 2020. The proposed approach has a greenhouse gas (GHG) emission reduction target of 46% in fiscal year (FY) 2030 (from baseline FY 2013 levels) and continues Japan's strenuous efforts to meet its lofty goal of cutting its emission by 50%, as announced in April 2021.
2. Initiatives to ensure a stable energy supply and reduce energy costs based on the major premise of ensuring safety, in order to solve challenges facing Japan's energy supply and demand structure while acting against climate change.

In accordance with the *Sixth Strategic Energy Plan*, the Diet passed the "Bill for the Act of Partial Revision of the Act on the Rationalization etc. of Energy Use and Other Acts in Order to Establish Stable Energy Supply and Demand Structure" on May 13, 2022. In addition, the Act on the Rationalization of Energy Use (e.g., improving energy consumption per unit) was expanded to include non-fossil energy, calling for specific operators to develop medium- to long-term plans to transition to non-fossil fuel energy.[97]

In June 2021, the Ministry of Economy, Trade, and Industry (METI), in collaboration with other ministries and agencies, formulated the "Green Growth Strategy through Achieving Carbon Neutrality in 2050."[98] The strategy specifies 14 promising fields that are expected to grow and provides representatives of these fields with action plans from the viewpoints of both industrial and energy policies. Japan upholds an ambitious goal while demonstrating realistic pathways to meet that goal wherever possible. A 2-trillion-yen Green Innovation Fund has been established to encourage companies to take on ambitious challenges.[99] In December 2023, to simultaneously achieve the three goals of decarbonization, economic growth, and a stable energy supply through GX (green transformation), the Government of Japan compiled "Sector-specific Investment Strategies" for 10 years in the prioritized fields as an effort to improve companies' predictability and strongly encourage companies to invest in GX. [100]

To decarbonize the transportation sector, Japan will promote the reduction of CO_2 emissions through the production, use, and disposal of automobiles; the improvement of energy efficiency in the logistics sector; and the decarbonization of fuel itself.[101, 102]

For passenger cars, comprehensive measures such as expanding the introduction of electrified vehicles and infrastructures and reinforcing technologies related to electrified vehicles (e.g., batteries, supply chain, and value chain) will be taken to achieve 100% electrified vehicle sales by 2035.

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96 Agency for Natural Resources and Energy, "Cabinet Decision on the Sixth Strategic Energy Plan," https://www.meti.go.jp/english/press/2021/1022_002.html.

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98 METI, June 12, 2022, "Green Growth Strategy through Achieving Carbon Neutrality in 2050," https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/index.html.

99 METI, August 31, 2021, "Budget (Green Innovation Fund)," https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/1_budget.pdf.

100 METI, December 22, 2023, "Sector-specific Investment Strategies" Compiled as Effort for Specifying Investment Promotion Measures for the Realization of GX," https://www.meti.go.jp/english/press/2023/1222_002.html.

101 Agency for Natural Resources and Energy, October 2021, "Outline of Strategic Energy Plan," https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/6th_outline.pdf.

102 Agency for Natural Resources and Energy, October 2021 (in Japanese), "Strategic Energy Plan," https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/20211022_01.pdf.

For commercial vehicles, the following electrification targets were set:[103]

- Electrified vehicles account for 20–30% of new light vehicle sales by 2030, with electrified vehicles and decarbonized fuel vehicles to account for 100% by 2040.
- An advanced introduction of 5,000 heavy vehicles in the 2020s and a target by 2030 for 2040 electrified vehicle penetration.

Advanced Motor Fuels Statistics

Figure 1 shows the energy sources used in the transportation sector in Japan.[104] Oil-related energy accounts for 97.8% of total usage. The market for alternative fuels is very small in Japan, as is the number of alternative fuel vehicles owned (Table 1). Methanol vehicles, compressed natural gas (CNG) vehicles, hybrid and plug-in hybrid vehicles (HEVs and PHVs), electric vehicles (EVs), and fuel cell vehicles (FCVs) currently constitute the environmentally friendly vehicle options in Japan.

The number of hybrid vehicles is rather large, owing to the number of passenger hybrid vehicles. CNG and hybrid vehicles currently account for the largest number of vehicles in the low-emission truck category. The penetration of FCVs in the market has expanded: Japan has 7,473 FCVs.

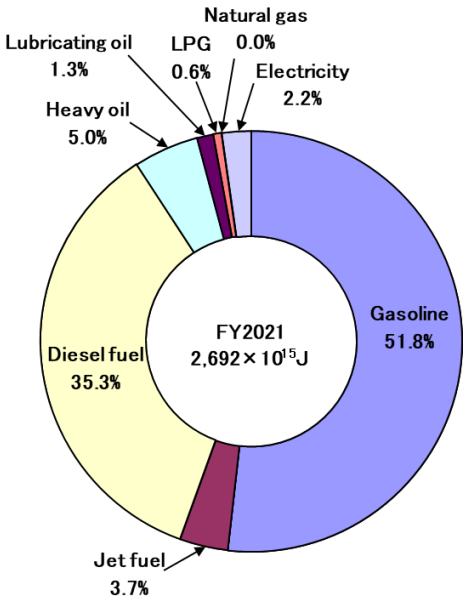


Figure 1. Energy Sources Used in the Transportation Sector in Japan, 2021

Table 1. Penetration of Environmentally Friendly Vehicles Owned in Japan, March 2023

Vehicle Type	Methanol[14,15]	CNG[14,15]	Hybrid[14]	PHV[14]	EV[14]	FCV[14]	Vehicle Registration[16]
Passenger vehicles	2	7	11,447,604	207,578	162,389	7,310	38,882,417
Light, mid, and heavy-duty trucks	1	3,478	86,021	3	2,070	11	5,956,671
Buses	0	92	1,399	1	252	133	212,180
Special vehicles	1	1,064	13,733	281	342	19	1,647,775
Small vehicles	1	1,186	1	2	30	NA	31,308,530
Total	5	5,827	11,548,758	207,865	165,083	7,473	78,007,573

[103] METI, "Automobile/battery industries," https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/05_automobile.pdf .

[104] Agency for Natural Resources and Energy, June 6, 2023, "Cabinet Decision Made on the FY2022 Annual Report on Energy (Japan's Energy White Paper 2023)," https://www.meti.go.jp/english/press/2023/0606_003.html.

Research and Demonstration Focus

Hydrogen

In 2017, Japan formulated the world's first national hydrogen strategy, the Basic Hydrogen Strategy. Under this strategy, Japan achieved several accomplishments: commercialization of the world's first FCVs, increased utilization of fuel cells by households, and a world-class number of related patents. In this context, Japan's efforts to transition into a hydrogen-based society are moving from the technology development phase to the commercial phase.

In June 2023, the Basic Hydrogen Strategy was revised[105] to include two new basic pillars: the "Hydrogen Industry Strategy" — a policy for strengthening the industrial competitiveness of hydrogen — and the "Hydrogen Safety Strategy" — a policy for the safe use of hydrogen. This revised strategy will be reviewed within a 5-year period.

With regard to the use of hydrogen in mobility, Japan is providing support for the spread of fuel cell vehicles and the development of hydrogen stations. Commercial vehicles such as trucks are one of the areas where hydrogen utilization is expected in the transportation field; trucks need to transport goods daily over long distances, which is difficult for EVs given their range limitations. In the future, the spread of FCVs and the systematic development of hydrogen refueling stations will be accelerated. In particular, the cumulative number of fuel cell trucks on the road is expected to be up to 15 million by 2050, at a value of approximately USD 2.7 trillion. In terms of refueling infrastructure, approximately 1,000 hydrogen stations will be installed in optimal locations by 2030, in anticipation of the widespread use of FCVs including fuel cell buses and trucks. Nationwide as of December 2023, hydrogen stations for FCVs operated in 161 locations.[106]

In response to Japan's hydrogen strategy, the New Energy and Industrial Technology Development (NEDO) CO_2-free Hydrogen Energy Supply-chain Technology Research Association (HySTRA) pilot project (the marine transportation and unloading of liquid hydrogen produced in Australia and delivered to Japan) was initiated in May 2021.[107] The world's first liquefied hydrogen carrier, the Suiso Frontier, departed Victoria, Australia, on January 28, 2022, marking a significant milestone for the pilot project. Built by Kawasaki Heavy Industries Ltd., the Suiso Frontier enables the safe transport of liquefied hydrogen in large quantities from the Port of Hastings, Victoria, to Kobe, Japan.

To establish a safer and more efficient cargo-handling operation, on March 4, 2023, HySTRA successfully conducted a handling demonstration test using the world's first rigid-type loading arm system (LAS) for ship-to-shore transfer of liquefied hydrogen. The new rigid-type LAS, installed at the "Hy touch Kobe," offers a more compact design compared with existing hose-type LASs, which is advantageous to increase the size of the system in the near future.

Because hydrogen engines can leverage well-established internal combustion engine (ICE) technologies, they have a high potential for commercialization at lower cost. Toyota has installed the hydrogen engine in a commercial light-duty vehicle (HiAce) to conduct on-road feasibility testing by fleet operators on public roads in Australia.[108]

Natural Gas

Approximately 80% of the natural gas vehicles (NGVs) in Japan are commercial vehicles, such as trucks, buses, or special vehicles (mainly garbage trucks). Of the trucks, the majority are light- to medium-duty vehicles designed for short- or medium-distance transportation. In this context, Isuzu Motors Limited released a CNG heavy-duty truck in December 2015[109] and a heavy-duty LNG truck in October 2021.[110] Mitsubishi Corporation and Air Water Inc. have jointly developed Japan's first

[105] The Ministerial Council on Renewable Energy, Hydrogen and Related Issues, June 6, 2023, "Basic Hydrogen Strategy," https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/20230606_5.pdf.
[106] Next Generation Vehicle Promotion Center (in Japanese), http://www.cev-pc.or.jp/suiso_station/index.html
[107] HySTRA (CO_2-free Hydrogen Energy Supply-chain Technology Research Association), "Hydrogen Supply Chain: Hydrogen Energy Supply Chain Pilot Project between Australia and Japan," https://www.hystra.or.jp/en/project/.
[108] Toyota, November 11, 2023, "Evolution of Hydrogen Technology and Taking on New Challenges in Australia," https://global.toyota/en/newsroom/corporate/40081554.html
[109] Isuzu Motors Limited (in Japanese), https://www.isuzu.co.jp/product/cng/giga.html.
[110] Isuzu Motors Limited (in Japanese), https://www.isuzu.co.jp/newsroom/details/20211028_01.html.

compact LNG filling facility for LNG-powered trucks. They launched trial operations of the facility and LNG trucks in Hokkaido under the Ministry of the Environment's Low Carbon Technology R&D Program on November18, 2022.[111] This project uses LNG mixed with liquified bio methane (LBM) refined from livestock manure-based biogas, which is expected to be a carbon-negative fuel.

Biofuel

With respect to initiatives aiming to encourage the use of biofuels in Japan, sales of gasoline blended with ethyl tert-butyl ether (ETBE) in FY 2022 again achieved the target defined in the Act on Sophisticated Methods of Energy Supply Structures (500,000 kL [crude oil equivalent] of bioethanol and 1.94 million kL of bio-ETBE each year).[112] According to trade statistics, approximately 57,825 kL of ethanol were imported (mainly from Brazil) in FY 2022 as raw material for ETBE (equivalent to roughly 127,900 kL of ETBE).[113]

E-fuel

In order to achieve a cost lower than the price of gasoline for synthetic fuels in 2050, Japan will work on commercialization of synthetic fuels. In addition to improving the efficiency of existing technologies (reverse shift reaction plus Fischer Tropsch [FT] synthesis process) and designing and developing production facilities, innovative new technologies and processes (e.g., co-electrolysis, direct-FT) will be developed as part of an integrated production process for synthetic fuels. The Green Growth Strategy aims to establish high-efficiency and large-scale production technology by 2030, expand the introduction and reduce costs during the 2030s, and achieve independent commercialization by 2040 by intensively developing and demonstrating technologies for such synthetic fuels over the next 10 years.[114]

METI launched the "Public-private sector council to promote the introduction of synthetic fuels (e-fuel)" on September 16, 2022, and the "Public-private sector council for methanation promotion" on June 28, 2021, to address issues such as technology and price to enable commercialization of synthetic fuels through public-private partnership.[115]

On March 2, 2022, 16 companies — including airlines and plant construction companies — announced the launch of "Act for Sky," an organization that will transcend industry boundaries with the aim of domestically producing sustainable aviation fuel (SAF), an alternative fuel for aircraft. The organization will research stable procurement of used cooking oil and other raw materials and methods to produce it at reduced cost.[116]

Outlook

In a "Green Growth Strategy towards 2050 Carbon Neutrality," Japan will promote the electrification of automobiles and take comprehensive measures to achieve 100% electrified vehicles (EVs, FCVs, HEVs and PHVs) in new passenger car sales by the mid-2030s at the latest. Furthermore, through efforts to neutralize energy such as e-fuel, Japan aims to achieve net zero emissions through the production, use, and disposal of automobiles in 2050.

Additional Information Sources

- METI, "Overview of Japan's Green Growth Strategy Through Achieving Carbon Neutrality in 2050," January 2021.

[111] Mitsubishi Corporation, "Introduction of Trial Operations of Compact LNG Filling Facilities for LNG Trucks in Hokkaido," https://www.mitsubishicorp.com/jp/en/bg/natural-gas-group/topics/lng-filling-facilities/.
[112] Japan Biofuels Supply LLP, https://www.jbsl.jp/english/objective/
[113] Japan Alcohol Association (in Japanese), http://www.alcohol.jp/statis/import.pdf
[114] The Ministry of Economy, Trade, and Industry, "Green Growth Strategy Through Achieving Carbon Neutrality in 2050," Formulated, June 2021 https://www.meti.go.jp/english/press/2021/0618_002.html
[115] METI, "Public-private sector council to promote the introduction of synthetic fuels (e-fuel)," https://www.meti.go.jp/shingikai/energy_environment/e_fuel/001.html
[116] https://actforsky.jp/

Benefits of Participation in the AMF TCP
Participation in the AMF TCP makes it possible to obtain the latest information on advanced motor fuels for stakeholders, policy makers, and industries. AMF TCP activities facilitate an international network on advanced motor fuels.

Republic of Korea

Drivers and Policies

Renewable Fuel Standards

Korea introduced and distributed transportation biofuels in 2022 to improve the atmosphere quality and began 0.5% mixing for the first time in 2007. As of 2023, biofuels that have been commercialized and distributed in Korea include biodiesel for transportation (diesel fuel replacement) and bio-heavy oil (B-C) for power generation. Bioethanol for transportation, which is used in major overseas countries, has not yet been commercialized in Korea.

The Korean government is implementing the Renewable Fuel Standards (RFS), a system that requires transportation fuel suppliers to mix biofuels with existing fossil fuels at a certain ratio. The RFS is based on Article 23(2) of the Renewable Energy Act, revised in 2013, and has been in effect since July 31, 2015, following a 2-year grace period after the revision of the law.

Currently, transportation fossil fuels and renewable energy fuels subject to mandatory mixing are limited to 'automobile diesel' and 'biodiesel,' respectively. The mandatory mixing amount is determined by multiplying the domestic sales of transportation fuel by the annual mixing obligation ratio.

The mandatory mixing ratio was 2.5% from the beginning of the RFS in 2015 until 2017 and was revised to 3.0% in January 1, 2018, and 3.5% in 2023; it will be raised to 5.0% by 2030. In addition, the Korean government plans to expand the mandatory mixing ratio from 5% to 8% through the introduction of next-generation biodiesel[117] in order to revitalize biofuels, as described in the "Eco-Friendly Biofuel Expansion Plan" dated October 2022 (Table 1).

Table 1. Ratio of New and Renewable Energy Fuel Blending to Transportation Fuel[a]

Year	Blending Ratio
2015	0.025
2016	0.025
2017	0.025
2018	0.03
2019	0.03
2020	0.03
January 2021–June 2021	0.03
July 2021–December 2021	0.035
2022	0.035
2023	0.035
2024	0.04
2025	0.04
2026	0.04
2027	0.045
2028	0.045
2029	0.045
After 2030	0.05

[a] To determine the compulsory blending amount by year, multiply the compulsory blending ratio by year by the domestic sales volume of transportation fuel, including mixed renewable energy fuels.

[117] Next-generation biodiesel = a biodiesel with the same chemical properties as ordinary diesel that will be introduced in 2026.

Advanced Motor Fuels Statistics

Table 2 lists the number and ratio of vehicles registered in Korea by year and fuel type from 2016 to 2023.

Table 2. Vehicles Registered in Korea, 2016–2023

Fuel	2016	2017	2018	2019	2020	2021	2022	2023
Total	21,803,351	22,528,295	23,202,555	23,677,366	24,365,979	24,911,101	25,657,123	25,949,201
Gasoline	10,092,399	10,369,752	10,629,296	10,960,779	11,410,484	11,759,565	12,069,043	12,314,186
	(46.29%)	(46.03%)	(45.81%)	(46.29%)	(46.83%)	(47.21%)	(47.04%)	(47.45%)
Diesel	9,170,456	9,576,395	9,929,537	9,957,543	9,992,124	9,871,951	9,758,173	9,500,164
	(42.06%)	(42.52%)	(42.80%)	(42.06%)	(41.01%)	(39.63%)	(38.03%)	(36.61%)
LPG	2,167,094	2,104,675	2,035,403	2,004,730	1,979,407	1,945,674	1,904,860	1,832,535
	(9.94%)	(9.34%)	(8.77%)	(8.77%)	(8.12%)	(7.81%)	(7.42%)	(7.06%)
HEV	233,216	313,856	405,084	506,047	674,461	908,240	1,170,507	30,352
	(1.07%)	(1.39%)	(1.75%)	(2.14%)	(2.77%)	(3.65%)	(4.56%)	(0.12%)
CNG	38,880	38.918	38,934	38,147	36,940	35,208	32,780	1,542,132
	(0.18%)	(0.17%)	(0.17%)	(0.16%)	(0.15%)	(0.14%)	(0.13%)	(5.94%)
EV	10,855	25.108	55,756	89,918	134,962	231,443	389,855	543,900
	(0.05%)	(0.11%)	(0.24%)	(0.38%)	(0.55%)	(0.93%)	(1.53%)	(2.10%)
H_2	87	170	893	5,083	10,906	19,404	29,623	34,258
	(0.00%)	(0.00%)	(0.00%)	(0.02%)	(0.04%)	(0.08%)	(0.12%)	(0.13%)
Other[a]	90,364	99,421	107,652	115,119	126,695	139,616	148,237	151,674
	(0.41%)	(0.44%)	(0.46%)	(0.49%)	(0.52%)	(0.56%)	(0.58%)	(0.58%)

[a] Other fuels (kerosene, alcohol, solar, liquefied natural gas [LNG]) and towed vehicles (trailers, etc.)

As of the end of 2023, the cumulative number of registered automobiles in Korea was 25,949,000 — up 1.7% (446,000 vehicles) from the end of the previous year. At the end of December 2023, the number of new registrations was 1,759,000: 831,000 gasoline cars, 294,000 diesel cars, 67,000 liquefied petroleum gas (LPG) cars, 391,000 hybrid vehicles, 163,000 electric vehicles (EVs), and 5,000 hydrogen (H_2) cars.

The cumulative number of registered vehicles using fossil fuels decreased for the first time compared to the previous year, and eco-friendly (electric, hydrogen, hybrid) vehicles are steadily increasing. In 2023, the cumulative number of EVs increased by 39.5% compared to the previous year (to 543,900). Korea aims to increase the proportion of eco-friendly, domestically produced vehicles to 33% by 2030. H_2-fueled vehicles increased by 15.6% compared to the previous year (to 34,258). Through the next-generation H_2 fuel system development project, the government is pushing to increase the fuel efficiency of H_2 vehicles by more than 30% by investing USD 24 million by 2024.

Research and Demonstration Focus

Biodiesel

Biodiesel is mainly made using waste cooking oil, animal oil, palm oil, and by-products (palm fat acid distillate [PFAD]) of refined palm oil. Biodiesel, which has been in use since 2006, is distributed by mixing 3.5% (2023) in diesel for automobiles. Based on the total domestic sales and fuel mixing of the mixed obligators by year, the mixing performance ratios from 2015 to 2018 were 2.58%, 2.52%, 2.53%, and 3.03%, respectively, indicating that the target obligation ratio stipulated in the law has been achieved each year (Table 2).

Table 3. Year-over-year performance of RFS obligations

Business year	Domestic sales volume (A, kℓ)	New/Renewable energy fuel mixing volume (B, kℓ)	Mixing ratio (C=B÷AX100, %)
2015	8,693,516	224,145	2.58
2016	23,032,087	580,953	2.52
2017	24,727,402	624,534	2.52
2018	25,083,294	759,475	3.03

Source: Ministry of Trade, Industry and Energy/Korea Energy Agency (2019.04.11)

Looking at the supply status of biodiesel in Korea by year, the actual production of biodiesel increased every year until 2019. On the other hand, in the case of 'Supply capacity,' which means the maximum production capacity of biodiesel each year, the degree of increase was not significant compared to the trend of increase in production (Table 4).

Table 4. Domestic biodiesel supply performance by year

Year	Production (kℓ)	Supply capacity (kℓ/year)
2006	58,945	333,000
2007	105,705	507,700
2008	196,289	743,204
2009	280,872	1,142,900
2010	394,278	1,104,400
2011	372,979	1,204,400
2012	399,463	1,204,400
2013	409,635	1,177,468
2014	430,298	887,087
2015	489,839	854,687
2016	491,519	854,687
2017	475,087	1,008,630
2018	697,177	2,283,370
2019	713,992	1,441,330
2020	704,037	1,237,630
2021	609,253	1,259,230
2022	696,958	1,325,880

Source: Ministry of Trade, Industry and Energy/Korea Energy Agency, "2022 New/Renewable Energy Supply Statistics."

Bioethanol

In 2016, Korea began an empirical study of bioethanol supply, with the results for manufacturing, supply, infrastructure, and applicability of fuel verified in 2019.

One gas station was selected, and equipment and storage problems were checked for 365 days by season. The study examined the exhaust gas and vehicle conditions of four demonstration vehicles after endurance driving up to about 45,000 km.

In addition, from 2019 to 2020, Korea conducted a 9-month feasibility review study aimed at expanding the introduction of biofuels in the domestic transportation field. The study determined that more careful review is necessary for the future introduction of bioethanol.

Hydrogen and Electricity

Since 2021, hydrogen engines (vehicle and power generation) have been reflected in policies aimed at carbon neutrality, fostering the hydrogen industry, and developing the automotive industry.

Government

- The *1st Basic Plan for the Implementation of the Hydrogen Economy* (2021.11, Ministry of Trade, Industry and Energy): The plan presents development of hydrogen engines for vehicles, LPG convergence charging stations, and smart power supply and demand plans using pipelines and hydrogen engines.
- The 5th Hydrogen Economy Committee (2022.11, joint session of relevant ministries presided over by the Prime Minister): The committee's goal is to diversify distributed power sources by creating large-scale demand for hydrogen and developing hydrogen engines. The government intends to establish standards and operation plans for clean hydrogen and introduce the "Korean clean hydrogen certification system" that can be used internationally by 2024. The committee also proposed a vision of Korea as a hydrogen-leading country.

Industry

- HD Hyundai Infracore announced the commercialization of hydrogen engines during 2025. The company is mass-producing HD Hyundai Infracore hydrogen engines (11 liters, 200–300 kW class) by 2024, and is pursuing additional technology development and lineup expansion. In early 2024, the hydrogen engine will be installed on a low-floor bus, and after that, it will gradually expand to equipment such as trucks and excavators.
- In 2024, Korea East-West Power will start developing a hydrogen power plant engine for power generation. HD Hyundai Heavy Industries Group announced the success of the LNG-hydrogen mixed combustion engine development in December 2022 and is pushing for it to be used as a ship engine and a land power generation engine.

Outlook

The Korean government announced a plan to expand eco-friendly biofuels in October 2022, including expanding the supply of existing biofuels and promoting the introduction of new biofuels.

Biodiesel

The Korean government is pushing to raise the current mandatory mixing ratio for diesel cars to 8% in 2030 by expanding the introduction of renewable diesel. The plan addresses the composition of renewable diesel task force, quality and performance evaluation criteria after empirical analysis, and establishment of a plan to increase the mandatory mixing ratio of RFS by year (2024~2025)

Bioethanol

Safety, eco-friendliness, and economic feasibility will be reviewed through private-led pilot projects beginning in 2024 that address vehicles of public institutions, test gas stations.

Sustainable Aviation Fuel

The sustainable aviation fuel (SAF) production-demand industry is participating in a demonstration project (2023–2024) to promote the introduction of SAFs in Korea by 2026. The project includes the following elements:

- Establishment of quality standards in time for domestic production (currently under investment plan for refiners) and inclusion of new targets for RFS application.
- Public-private consultative body[118] to prepare and promote supply plans, such as applying RFS to bio-airline oil, establishing infrastructure, and preparing incentives (around November 2022).

In January 2024, the Oil Business Act was revised by the National Assembly plenary session, securing a legal basis for SAF production.

Additional Information Sources

- K-Petro
- Korea Register
- Ministry of Trade, Industry and Energy
- Korea Automobile Manufacturers Association

[118] Participation of the Ministry of Trade, Industry and Energy (MOTIE), the Ministry of Land, Infrastructure and Transport (MOLIT), the Petroleum Association, the Aviation Association, and oil refiners and airlines.

Spain

Drivers and Policies

The main policy instrument aimed at fostering the consumption of advanced motor fuels in Spain is the biofuel quota obligation. Wholesale and retail fuel operators, as well as consumers not supplied by wholesale or retail operators, are obliged to sell/consume a minimum quota of biofuels. Each obligated subject must prove compliance by presenting a number of certificates to a national certification entity, the Ministry for Ecological Transition and Demographic Challenge. Certificates have a value of 1 tonne of oil equivalent (TOE), can be carried over to the following year (up to 30% of the annual obligation), and can be traded. If the biofuel quota obligation is not met, a penalty fee applies (in 2021, the fee was updated to EUR 1,623 per certificate). In case of over-compliance (parties selling or consuming more than they are obliged to), the amounts collected from the penalty fees are redistributed by the certification entity proportionally to the subjects that sold/consumed biofuels at quantities exceeding their quota obligation.

Royal Decree 1085/2015, on the promotion of biofuels, established these mandatory targets for sale or consumption. The 2023 target (in energy content) was 10.5%. In 2019, the double-counting of some biofuels came into play, and in 2020 the National Markets and Competition Commission (CNMC) published a list of feedstocks that, converted to biofuels, qualify as meeting the biofuels quota obligation. The list also specifies whether a feedstock will be single- or double-counted, as well as information requirements regarding the mandatory sustainability criteria that operators must meet.

Royal Decree 1085/2015 was modified in 2021 to introduce new requirements for obligated parties. For 2023, it established a mandatory target of 0.3% for advanced biofuels (according to the definition included in the Directive [EU] 2018/2001 on promotion of the use of energy from renewable sources). The decree also limited the contribution of biofuels produced from used cooking oil and animal fats (categories 1 and 2) to 1.7%.

Ministerial Order ITC/1342/2022 was issued in 2022 to establish the maximum limit for biofuels produced from food and feed crops. For 2023, this limit was set at 3.5%.

In March 2022, the Spanish Government approved the Biogas Roadmap, which identifies the challenges and opportunities for the development of this renewable gas. The Roadmap includes 45 specific measures categorized into five lines of action: regulatory instruments, sectoral instruments, economic instruments, transversal instruments, and promotion of research, development, and innovation (RD&I). For transport, the quota system will be updated to enable biomethane to be counted toward the obligation; the use of biomethane in heavy-duty vehicles will be prioritised by promoting its use in, among others, municipal fleets of buses and trucks.

Also published in 2022 was a call for proposals to allocate 150 million euros from the Recovery, Transformation and Resilience Plan to biogas projects, including plants intended to produce biomethane used for transport.

In 2020, the Spanish Government approved the “Hydrogen Roadmap: a Commitment to Renewable Hydrogen.” The Roadmap is intended to identify the challenges and opportunities associated with full development of renewable hydrogen in Spain. The document provides a series of measures aimed at boosting investment action to take advantage of the European consensus on the role that this energy source should play in the context of green recovery. The Roadmap provides a Vision 2030 and 2050, establishing ambitious country targets in 2030. In particular, regarding transport, the following milestones are projected by 2030:

- A fleet of at least 150 to 200 buses with renewable hydrogen fuel cells.
- At least 5,000 to 7,500 light and heavy hydrogen fuel cell vehicles (FCVs) for the transport of goods.
- A network of at least 100 to 150 hydrogen stations distributed across the country, located no more than 250 km apart.
- Use of hydrogen-powered trains on a continuous basis on at least two commercial medium- and long-distance routes on lines not currently electrified.

- Introduction of handling machinery that uses renewable hydrogen fuel cells and supply points at the top five ports and airports (by volume of goods and passengers).

Advanced Motor Fuels Statistics

Biofuels account for the largest part of alternative transportation fuel in Spain. The largest biofuel contribution is from biodiesel (fatty acid methyl ester [FAME]), the second from hydrotreated vegetable oil (HVO), and the third from bioethanol. Other alternative fuels consumed in Spain are natural gas and liquefied petroleum gas (LPG). Figure 1 shows the share (in terms of energy content) of fuels consumed for road transport and alternative fuels consumption in 2023.

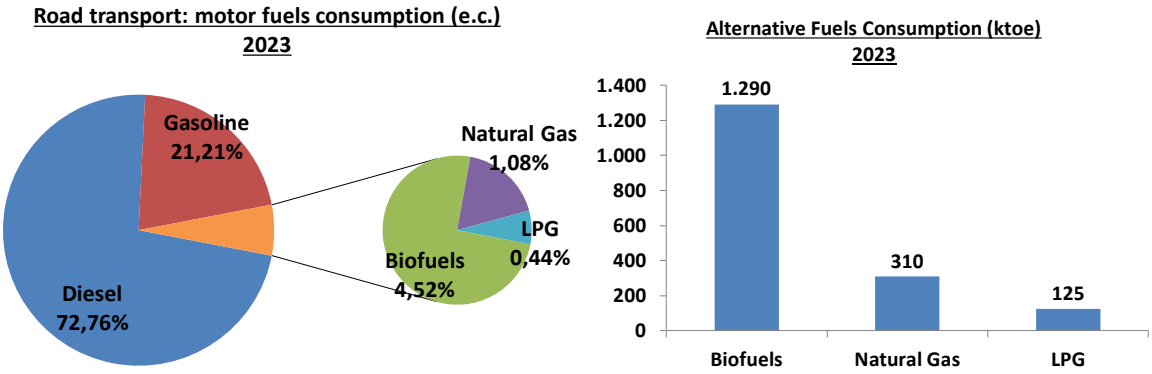


Figure 1. Fuel consumption (share in energy content) in Spain in 2023 (Sources: CORES, Enagás).

In 2023, the Ministry for Ecological Transition and Demographic Challenge published data on biofuels consumption, feedstocks, and greenhouse gas (GHG) emissions reductions until 2022 (information for 2023 was not yet available). Figure 2 shows biofuels consumption from 2011 to 2022, as well as the biofuels share in liquid fuels for road transport.

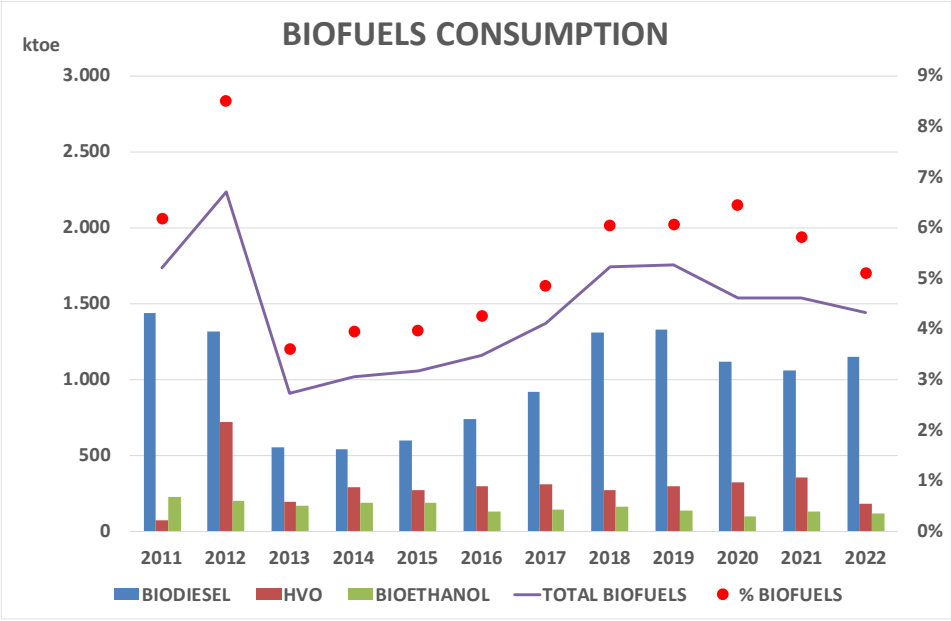


Figure 2. Biofuels consumption (ktoe and share in liquid fuels for road transport) in Spain, 2011–2022 (Source: Ministry for Ecological Transition and Demographic Challenge).

Figure 3 displays GHG emissions reductions attributable to the use of biofuels.

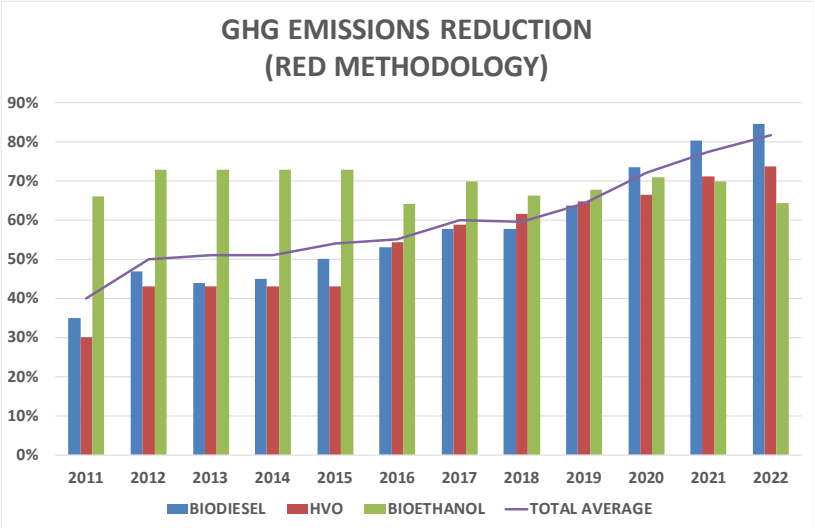
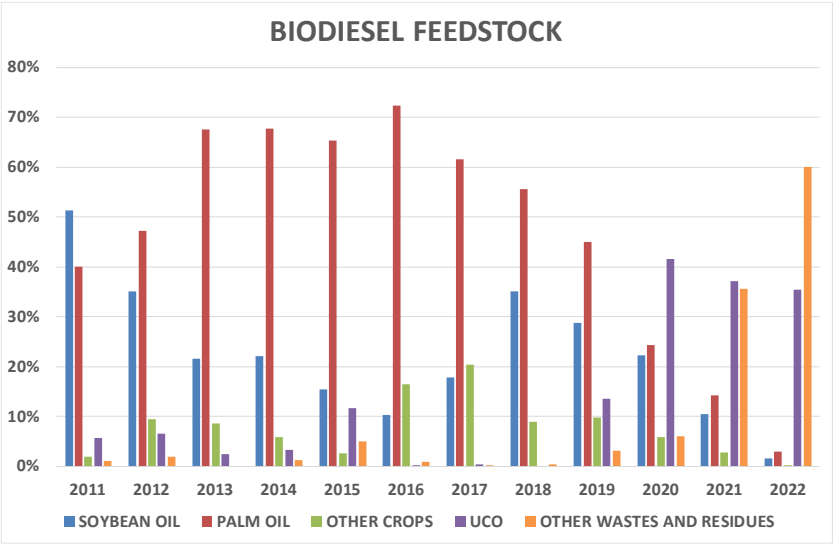
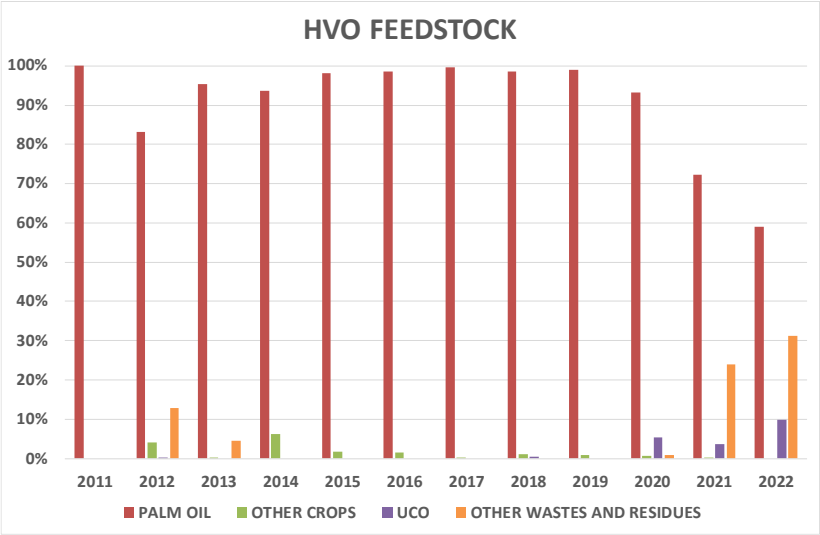


Figure 3. GHG emissions reductions attributable to the use of biofuels in Spain, 2011–2022 (Source: Ministry for Ecological Transition and Demographic Challenge).

Figure 4 shows feedstocks used for biodiesel, HVO, and bioethanol consumed.





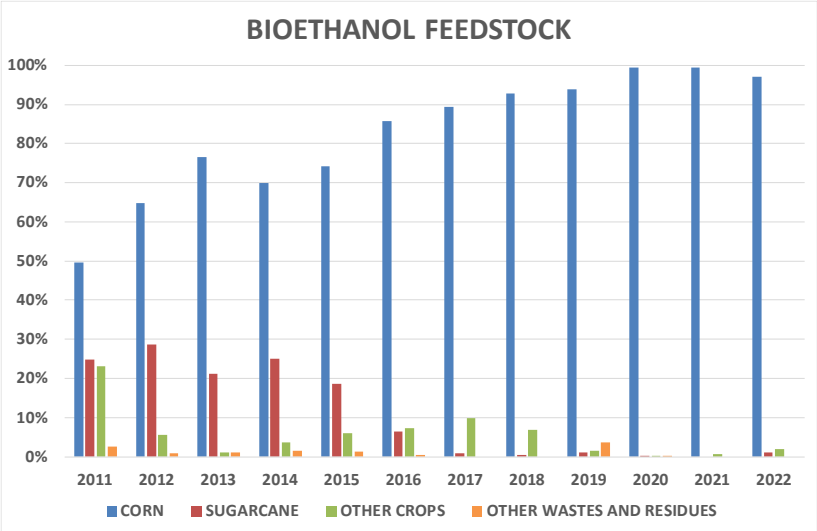


Figure 4. Feedstocks used for biodiesel, HVO, and bioethanol consumed in Spain, 2011–2022 (Source: Ministry for Ecological Transition and Demographic Challenge).

Research and Demonstration Focus

The Spanish Science, Technology and Innovation Strategy is the basic instrument for consolidating and strengthening the nation's science, technology, and innovation system. The strategy, which will be developed via two state plans (2021–2023 and 2024–2027), prioritises strategic national sectors in specific areas, including climate, energy, and mobility. The *2021–2023 State Plan for Scientific and Technical Research and Innovation* defines targets and actions for strategic areas identified in the Strategy. It addresses decarbonization and sustainable transport by means of measures intended to foster the development of renewable fuels, as well as more efficient fuels and vehicles.

The National Action Framework for Alternative Energies in Transport supports RDI by means of specific programs related to creation of clusters for innovation, incentives, cooperation through technology platforms, and support to research centers.

The updated draft integrated *National Energy and Climate Plan 2023–2030* (NECP), submitted in June 2023 to the European Commission, addresses general RDI areas, the development of advanced biofuels among them.

Two National Technology Platforms deal with topics related to advanced motor fuels. Bioplat, the Spanish Biomass Technology Platform, brings together companies, research entities, universities, and other organizations in Spain to encourage and promote sustainable commercial development of biomass technology. Bioplat addresses tasks related to biomass resources, production processes, and final uses (including biofuels for transport). The Spanish Hydrogen Technology Platform (PTE-HPC) is aimed primarily at facilitating and accelerating the development and use in Spain of systems based on hydrogen and fuel cells for different applications, transport among them.

Outlook

Directive (EU) 2018/2011, on the promotion of energy from renewable sources, was amended in 2023. The amended version sets a specific renewable fuels target for the transport sector. Member States must establish an obligation for fuel suppliers to ensure that the amount of renewable fuels/renewable electricity supplied to the transport sector results in a final consumption share of at least 29% renewable energy in the transport sector by 2030 or, alternatively, to a GHG intensity reduction of at least 14.5 % by 2030. The contribution of biofuels produced from food and feed crops is limited to a maximum of 7%. Within that 29%, there is a dedicated combined sub-target for advanced biofuels and biogas (which are produced from feedstocks listed in Part A of Annex IX to the directive) and for renewable fuels of non-biological origin (RFNBO). These fuels must be supplied at a minimum of 5.5% of transport energy in 2030, of which a share of at least 1% must be from RFNBO. A specific methodology for the calculation of such shares (including different multipliers for some technologies) is provided in the directive.

EU regulations on ensuring a level playing field for sustainable air transport (ReFuelEU aviation) and on the use of renewable and low-carbon fuels in maritime transport (FuelEU maritime) were approved in 2023. These regulations aim to increase the use of sustainable fuels by aircraft and ships and, consequently, reduce the GHG emissions from these transport sectors. The ReFuelEU aviation regulation will require aircraft fuel suppliers at EU airports to gradually increase the share of sustainable fuels that they distribute to reach 6% in 2030 and 70% in 2050. The FuelEU maritime regulation will require vessels above 5,000 gross tonnage that call at European ports to reduce the GHG emissions intensity of the energy used on board by means of biofuels, biogas, and RFNBO to reach a 6% GHG reduction in 2030 and an 80% reduction in 2050.

According to the updated draft integrated NECP, in 2030, the share of renewable energy in transport in Spain will be 25% with a GHG emissions reduction of 16.6%, well above the target established in the directive (14.5%). The contribution of biofuels from food and feed crops will be 2.6%, and advanced biofuels and biogas will reach 7.5%, while the combined share with RFNBO will be 11.1%.

The main trends included in the NECP for energy consumption in transport over the next decade are as follows:

- A relevant decrease in final energy consumption resulting from increased efficiency and modal shift policies.
- A very significant decrease in the consumption of oil products and natural gas, as well as a sharp growth in electricity use in vehicles.

The NECP includes specific measures to promote the use of biofuels in transport, the decarbonization of maritime transport, the decarbonization of Spain's aviation sector, and the development of biogas and biomethane. The measures consist of efforts aimed at supporting biofuels production and consumption, mandatory targets, and aid programs for sustainable aviation fuels facilities, among others.

Additional Information Sources

- Bioplat: Spanish Biomass Technology Platform
- CNMC: National Markets and Competition Commission (in Spanish)
- CORES: Corporación de Reservas Estratégicas (Oil Stockholding Agency) (in Spanish),
- Enagás: Transmission System Operator
- IDAE: Instituto para la Diversificación y Ahorro de la Energía (Institute for Energy Diversification and Saving) (in Spanish)
- Ministry for Ecological Transition and Demographic Challenge (in Spanish)
- PTE-HPC: Spanish Hydrogen Technology Platform (in Spanish)

Major changes

- Amendment of Directive (EU) 2018/2011 on the promotion of energy from renewable sources by Directive (EU) 2023/2413, which sets targets for the share of energy from renewable sources in the transport sector.
- Approval of Regulation (EU) 2023/1805 on the use of renewable and low-carbon fuels in maritime transport (FuelEU maritime), which sets targets for reducing GHG emissions from the energy used on board.
- Approval of Regulation (EU) 2023/2405 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation), which sets targets for sustainable fuels supplied at EU airports.
- Publication of the updated draft *National Energy and Climate Plan*, which includes shares of renewable energy in transport and GHG emissions reduction to be reached in 2030.

Benefits of participation in AMF
Membership in the AMF TCP provides wider and easier access to information on advanced motor fuels, as well as helpful analyses that can be used to guide national policies and programs.

Sweden

Drivers and Policies

The overall goal of Sweden's environmental policy is to be able to pass on to the next generation a society in which major environmental problems have been solved, without increasing environmental and health problems beyond the country's borders. Sweden aims to become one of the world's first fossil-free welfare countries. To achieve this goal, the transport industry must be freed of its dependence on fossil fuel by taking measures such as reducing the total energy demand of the transport sector and ensuring that the remaining energy is both renewable and sustainable.

In 2017, Sweden approved a new climate policy framework with a long-term climate goal of no net greenhouse gas (GHG) emissions by 2045, at the latest. What this means is that emissions from activities on Swedish territory will be cut by at least 85% compared with those generated in 1990. To achieve net-zero emissions, Sweden must include flexible measures in its climate strategy. For the transport sector, Sweden has also adopted an emissions reduction goal of at least 70% by 2030 compared with 2010 (not including domestic air travel).

In mid-2018, the Swedish government introduced what was known as a *bonus-malus system,* under which environmentally adapted vehicles with relatively low carbon dioxide (CO_2) emissions were awarded a bonus of up to SEK 70,000 (USD 6,699) at the time of purchase. Under the system, vehicles with relatively high CO_2 emissions (above 90 g/km as of April 1, 2021) were subject to a higher tax (malus) during the first three years. The system included cars, light buses, and light trucks. In November 2022, the newly appointed government canceled the bonus feature. However, from February 13, 2024, the bonus was reintroduced for light-duty vehicles with a bonus of up to SEK 50,000 (USD 4,769). Furthermore, a GHG reduction premium was also introduced for zero-emission heavy goods vehicles (HGVs). For HGVs, the premium may amount to a maximum of 25% of the purchase cost.

Another important measure introduced in mid-2018 is the reduction obligation — an obligation for fuel suppliers to reduce GHG emissions from sold volumes of petrol and diesel fuels by incorporating biofuels. In 2023, the reduction obligation was 7.8% for petrol and 30.5% for diesel. The biofuels included in the reduction obligation system are subject to the same energy and CO_2 taxation as fossil fuels. Biofuels outside the reduction obligation scheme have reduced taxes. As of July 1, 2021, aviation fuels were also subject to the reduction obligation which, in 2022, stood at 1.7%. In 2023, the Swedish government lowered the reduction obligation for both petrol and diesel to 6% for 2024–2026 and discarded the reduction obligations for 2027–2030.

Advanced Motor Fuels Statistics

Since 1990, the number of passenger cars in Sweden has increased from approximately 3.5 million to 5.0 million. At the same time, GHG emissions from passenger cars remained stable, at around 13 million tons from 1990 to 2007. However, since 2007, emissions have decreased significantly, measuring about 8.3 million tons in 2022. The main reason for the reduction is the increased energy efficiency of new vehicles and renewable motor fuels.

The fleet of alternative-fueled passenger cars totaled around 650,000 at the end of 2022 (see Figure 1). In addition, automakers have produced an increasing share of conventional diesel vehicles to be fueled with hydrotreated vegetable oil (HVO)100. However, no statistics are currently available on the size of this share.

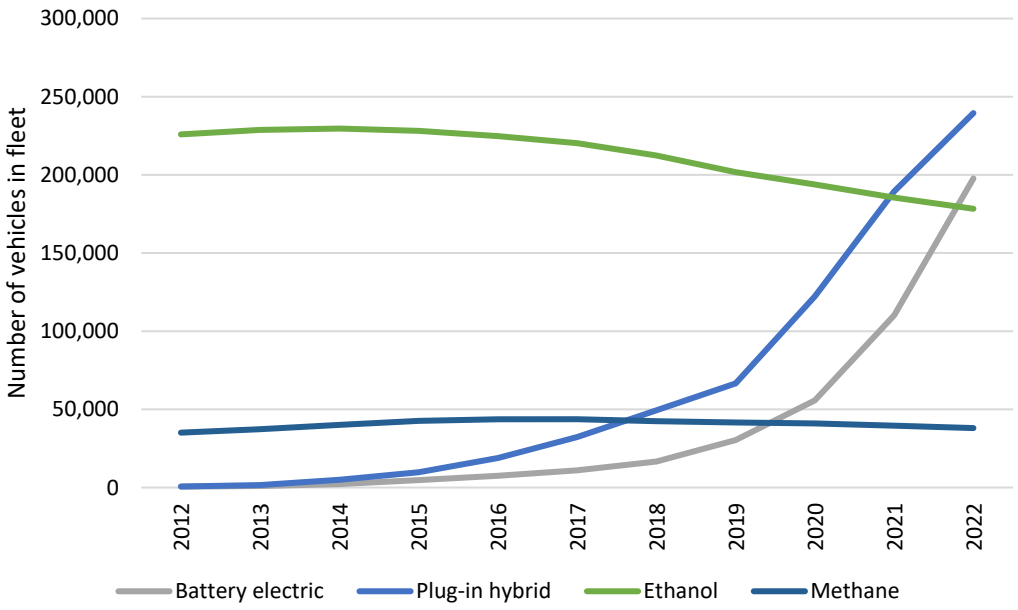


Figure 1. Number of Advanced Motor Fuel Passenger Cars in the Swedish Fleet, 2012–2022

Alternative-fueled vehicles correspond to 13% of the total fleet of passenger cars (excluding diesel cars that can be fueled with HVO100). Light commercial and heavy-duty vehicles make up 4% and 3% of the total fleet, respectively. However, vehicles registered as other than petrol- or diesel-fueled number around 27% of the bus fleet. Diesel-registered buses make extensive use of HVO100.

The use of renewable biofuels and electricity for transport in Sweden amounted to 21.8 terawatt hours (TWh), or 31% of the transportation fuels sold during 2023 (see Figure 2). Approximately 75% of the renewable fuel used in Sweden during 2023 was HVO and fatty acid methyl ester (FAME).

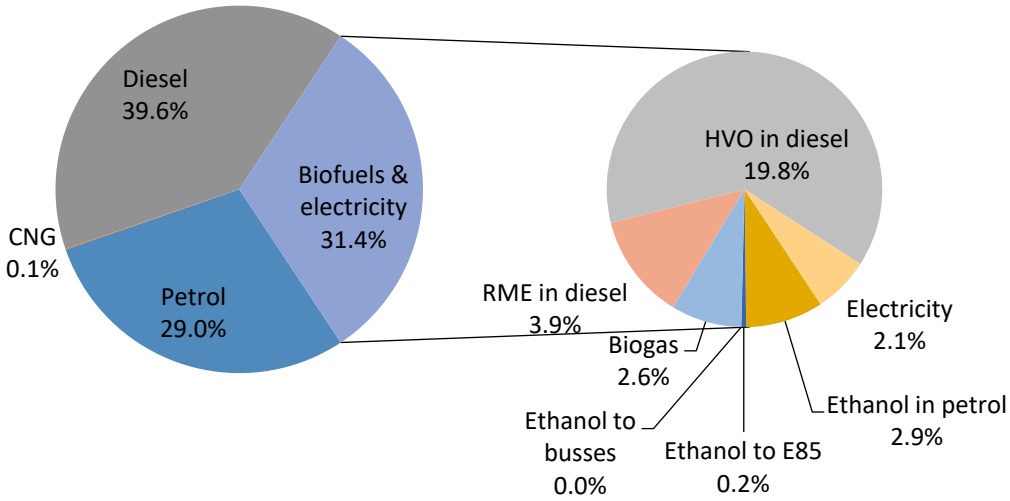


Figure 2. Fuel Consumption (in TWh) within the Road Transport Sector, Preliminary Statistics, 2023

When HVO was introduced in the Swedish market, it was produced from crude tall oil from Sweden, Finland, and the United States. As the demand for HVO grew, the number of feedstocks and countries of origin increased. In 2022, the raw materials were, to a large extent, animal waste (76%), with the remaining shares consisting of used cooking oil, crude tall oil, palm oil, rapeseed oil (RME), and palm fatty acid distillate. The majority of feedstocks for HVO are imported, as shown in Figure 3. The average GHG emissions from HVO use in Sweden during 2022 corresponded to around 7 g carbon dioxide equivalent (CO_2-eq) per megajoule (MJ).

FAME is primarily produced from rapeseed oil. A preferred feedstock, rapeseed oil's cold climate properties (i.e., cloud point) are more suitable than are many other vegetable oils for the Nordic climate.

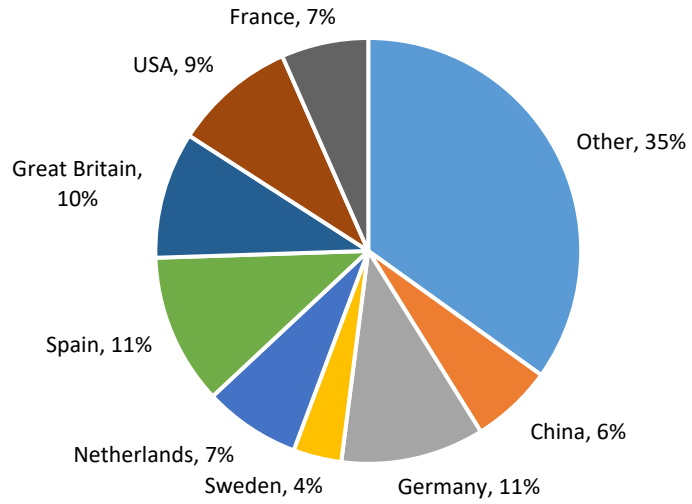


Figure 3. Country of Feedstock Origin for HVO Consumed in Sweden, 2021

Research and Demonstration Focus

The Swedish Energy Agency has several energy-related research, development, and demonstration programs:

- *Biogas Solutions Research Center*
- *TechForH2 (*TechForH2 bäddar för framtidens vätgasteknologi | Chalmers*)*
- CESTAP – Competence centre in sustainable turbine fuels for aviation and power
- Competence centre, Kompetenscentrum katalys (KCK)
- Hydrogen-related: *Ongoing Assignments and Investments*

Outlook

The goal is set high in Sweden, with a reduction in GHG emissions of 70% in 2030 compared with 2010, and no net CO_2 emissions by 2045. Considering the rate of turnover of the vehicle fleet, advanced motor fuels play an important role in reaching these targets.

Additional Information Sources

- Swedish Energy Agency
- The Swedish Knowledge Centre for Renewable Transportation Fuels

Major Changes

In 2017, the Swedish Parliament adopted a new climate law with the following targets:

- No later than 2045, Sweden shall have no net emissions of GHGs to the atmosphere.
- Emissions from domestic transport (excluding aviation) shall be reduced by at least 70% by 2030, compared with 2010.

Benefits of Participation in the AMF TCP

Sustainable and clean energy for transport is necessary to achieve national and international targets. The AMF TCP gives us an arena where we can cooperate with countries worldwide to develop unbiased reports on the effects of various advanced motor fuels.

Switzerland

Drivers and Policies

The key basis of Swiss energy policy is the article on energy enshrined in the Federal Constitution since 1990. The Energy Act, the CO_2 Act, the Climate and Innovation Act, and the Electricity Supply Act all build on this article and together form the body of legislation on which Switzerland's sustainable and modern energy policy is based.

In 2017, the Swiss public voted in favour of the revised Energy Act.[119] This was the first step in implementing the 2050 Energy Strategy, which contains the following objectives:

- Increase energy efficiency;
- Promote renewable energy in Switzerland; and
- Phase out nuclear power.

While existing nuclear power plants can remain in operation as long as they are safe, Switzerland has banned construction of new nuclear power plants.

At the end of 2020, the Federal Department of the Environment, Transport, Energy and Communications (DETEC) published its Energy Perspectives 2050+.[120] This document further develops the 2050 Energy Strategy by identifying technological paths in a series of scenarios, which outline the objectives of both energy policy (a secure and largely renewable energy supply by 2050) and climate policy (net zero emissions by 2050).

Laws are periodically adapted to address new boundary conditions or strengthened to reflect recent developments. New or revised acts are subject to an optional referendum and can be rejected by the public, as happened to the revised CO_2 Act,[121] which was rejected in June 2021.

Based on an initiative submitted in November 2019, the Federal Council adopted a Federal Act on Climate Protection Goals, Innovation and Strengthening Energy Security.[122] After passing the parliament in June 2022, opponents successfully filed a referendum against it. But in June 2023, the Swiss public voted in favour of this new Federal Act, which creates a framework for Swiss climate policy and sets interim targets for reducing greenhouse gas (GHG) emissions by 2050. The Act also includes incentives to encourage the replacement of fossil-fuel heating systems with climate-friendly ones and the replacement of electric heating systems that still consume a lot of power in winter. All these measures contribute to Switzerland's energy security. In addition, the Climate and Innovation Act supports businesses that invest in innovative, climate-friendly technologies within a given timeframe.

The draft Federal Act on a Secure Electricity Supply from Renewable Energy Sources[123] was approved by the Federal Council in June 2021. The draft Act is based on the conclusions of Energy Perspectives 2050+ and results from a revision of the Energy Act and Electricity Supply Act. The key aim is to strengthen Switzerland's security of supply, particularly in the winter months, by expanding domestic renewable electricity production and setting binding expansion targets and energy consumption reduction targets. The bill was passed by Parliament in September 2023. Because a referendum was successfully filed against it, a public vote will be held in June 2024.

CO_2 Emission Regulations for Cars

Carbon dioxide (CO_2) emissions regulations for new cars apply in Switzerland just as they do in the remainder of the European Union (EU). For the first time, in 2021, under the World Harmonised Light-Duty Vehicles Test Procedure (WLTP), the average level of emissions from cars registered in Switzerland could not exceed 118 g CO_2/km, while the maximum level of CO_2 emissions from delivery and light articulated vehicles (collectively referred to as *light commercial vehicles)* was 186 g CO_2/km.

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[119] Fedlex, Energy Law SR 730.0, https://www.fedlex.admin.ch/eli/cc/1999/27/de

[120] Swiss Federal Office of Energy, "Energy perspectives 2050+," https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html/.

[121] Fedlex, 641.71: Federal Act on the Reduction of CO_2 Emissions, https://www.fedlex.admin.ch/eli/cc/2012/855/en.

[122] Federal Law on Climate Protection Goals, Innovation and Strengthening Energy Security, 2022.

[123] SFOE (Swiss Federal Office of Energy), 2021, Federal Act on a Secure Electricity Supply from Renewable Energy Sources.

These targets correspond to those previously applied based on the New European Driving Cycle (NEDC) measurement procedure of 95 g CO_2/km for new cars and 147 g CO_2/km for new light commercial vehicles. Each importer's vehicle fleet must comply with an individual target based on these values. If the target is exceeded, the importer will pay a penalty. In 2022, the average CO_2 emissions from passenger cars were 120.9 gCO_2/km, exceeding the target value by only 2.9 g CO_2/km and decreasing by 8.9 gCO_2/km compared with 2021 levels (129.8 g CO_2/km) (Figure 1). This emissions reduction had a positive effect on the penalty, which dropped from EUR 26.0 million (USD 30.7 million) in 2021 to EUR 16.4 million (USD 17.2 million) in 2022.[124] The narrowing of the gap between the target maximum CO_2 emissions and the emissions of newly registered vehicles was influenced primarily by a significant decline in sales of gasoline and diesel vehicles and a marked increase in hybrid and electric vehicle sales.

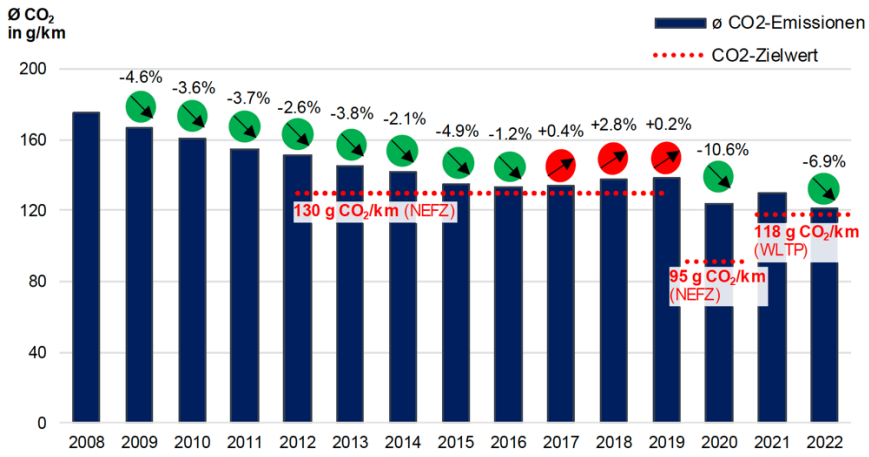

Figure 1. Average annual CO_2 emissions of passenger cars registered for the first time and reduction rates from 2008–2022. The arrows and percentages show the change compared with the previous year.

CO_2 Emissions Compensation: Motor Fuels

Importers of fossil motor fuels are required to compensate a certain amount of the CO_2 emissions (regulated by the CO_2 ordinance per year) caused by transport. They may conduct their own projects or acquire certificates. The compensation rate in 2021 was 12%, which will rise to 23% in 2024.[125] In 2022 and beyond, a minimum of 15% must be compensated by domestic measures. The Swiss Petroleum Association established the Foundation for Climate Protection and Carbon Offset (KliK), which launches and subsidizes projects to reduce CO_2 emissions in fields such as transportation, industry, buildings, and agriculture. Another measure to reduce CO_2 emissions is to blend fossil fuels with biofuels. Because Switzerland is under no legal obligation to blend fossil fuels, emissions compensation is the only driver for blends.

Mineral Oil Tax Reduction for Natural Gas and Biofuels

To support the target for CO_2 emissions, a reduction — or even an exemption — for environmentally friendly motor fuels was enacted in 2008. Biofuels that satisfy minimum environmental and social requirements are completely or partially exempt from the mineral oil tax. As a result, the tax reduction for biofuels is now EUR 0.69 (USD 0.82) per liter, compared with fossil fuels. The mineral oil tax reduction is valid until the end of 2024.[126] To offset the loss of tax revenue from this tax cut, the fossil fuel tax will be gradually increased until 2028. These measures will be continued with the revision of the CO_2 Act.

[124] SFOE, 2022, "Vollzug der CO_2-Emissionsvorschriften 2021."
[125] BAFU (Bundesamt für Umwelt) (Federal Office for the Environment), https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/compensation/motor-fuels.html.
[126] Mineralölsteuergesetz (MinöStG), Stand: January 1, 2022.

Advanced Motor Fuels Statistics

The following numbers and statements are based on 2022 statistics.

Energy and Fuels

Final total energy consumption in Switzerland in 2022 amounted to 765,070 terajoules, which represents a decrease of 3.9% compared with the previous year. Consumption was impacted by the Russian invasion of Ukraine on 24 February 2022, which led to major uncertainties in Switzerland's energy supply and government calls for savings. Warmer weather also played a role. Compared with the previous year, the heating degree day index (HDD index) was 18.4 % lower, which resulted in a correspondingly lower heating energy requirement: heating oil: -19.5%, natural gas: -17.0%.

Gasoline and diesel consumption decreased by a total of 1.4% (gasoline -2.9%, diesel -0.2%). Sales of aviation fuels increased markedly — by 76.1% — but were still 26.2% lower than in 2019 (i.e., before the coronavirus pandemic). Overall, fuel consumption was 9.9% higher than in 2021. Transport fuels account for 33.5% of total Swiss energy consumption; all fossil fuels were imported (Figure 2).

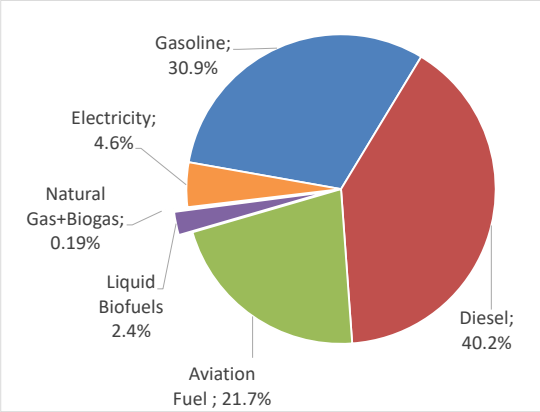

Figure 2. Shares of Energy Sources in Energy Consumption for the Transportation Sector in Switzerland, 2022[127]

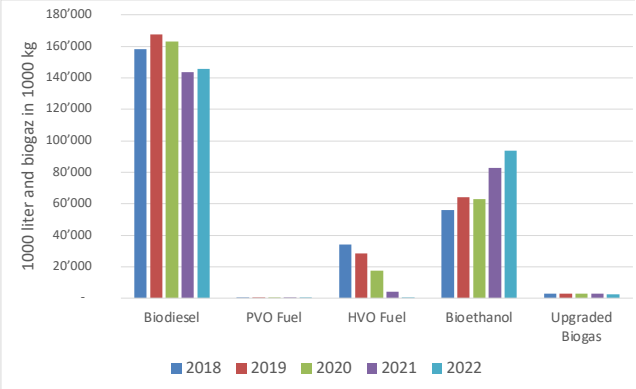

Figure 3. Use of Biofuels as Motor Fuels in Switzerland, 2016–2020

When importers of fossil motor fuels began blending fossil fuels with biofuels in 2014, the use of liquid biofuels rose — from 29.4 million liters in 2014 to 239.5 million in 2022.

In 2022, 145.6 million liters of biodiesel and 93.6 million liters of bioethanol were used (see Figure 3). Hydrotreated vegetable oil (HVO) has been used in Switzerland only since 2016, achieving a maximum in 2018 with 34.1 million liters and dropping to 5,000 liters in 2022. Pure vegetable oil fuel use is also almost negligible (39,000 liters). Upgraded biogas as a transport fuel remained at a low level (2.7 million kg).[128]

Only 14.1 million liters of biodiesel were produced in Switzerland; the remaining 131.5 million liters were imported (Germany, 71.8%; France, 14.6%; Austria, 7.9%; Japan, 3.9%; Greece, 1.1%; China, 0.7%;). All bioethanol is imported (Poland, 31.0%; The Netherlands, 18.5; Germany, 11.7%; Italy, 15.1%; Sweden, 12.0%; Norway, 4.8%; United States, 3.1%; Austria, 2.6%; Belgium, 1.2%).[129] The small amount of hydrotreated vegetable oil used in Switzerland is imported from Sweden.

The total amount of biogas produced and used in Switzerland in 2022 was 134.0 million kg. Only 33.3 million kg has been upgraded and fed into the natural gas grid. Of this, 2.7 million kg has been sold as biogas for cars, and the rest for heating. Almost all biogas used as motor fuel in cars is upgraded biogas fed into the natural gas grid. Figure 3 shows the development of the use of biogas and natural gas as motor fuels in cars. Despite an increasing amount of biogas fed into the natural gas grid, the demand for it as a motor fuel remains low: 91.9% of biogas is used for residential heating.[130]

[127] SFOE, 2022, "Gesamtenergiestatistik 2021."
[128] SFOE, 2022, "Schweizerische Statistik erneuerbarer Energien 2021."
[129] Swiss Custom Administration, 2022, "T2.8 Biogene Treibstoffe 2021."
[130] Association of the Swiss Gas Industry, 2022, "VSG-Jahresstatistik."

Motor Vehicles

In 2022, 322,387 motor vehicles were newly registered in Switzerland, representing a decrease of 7.8% over 2021 and 21.1% less than in 2019. New registrations of passenger cars decreased by 5.2%. The number of newly registered hybrid cars was almost the same (-0.5%) and electric cars (+26.5%) rose again. Sales of gasoline-fueled cars dropped by 14.4%, and sales of diesel-fueled cars dropped by 18.5%. Compared to 2019 totals, sales of those cars declined by 58.5% (Figure 4).

Despite the steep rise in sales of electric and hybrid passenger cars, their share of the total (4,721,280) is still very small. Figure 5 illustrates this fact, using passenger cars as an example. Hybrid vehicles have a share of 6.0% of the total passenger car fleet, whereas the share of electric vehicles amounts to 2.3%. Most of the electricity used in the transport sector is for railroad transportation.

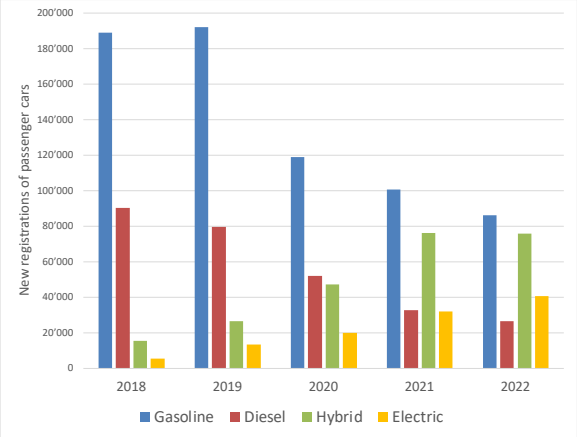

Figure 4. New Registrations of Passenger Cars by Fuel

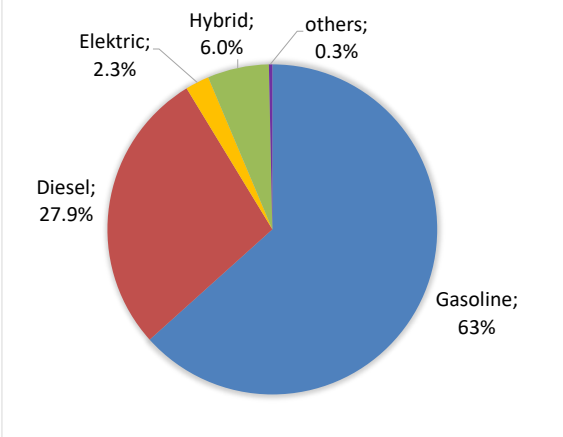

Figure 5. Passenger Car Share by Fuel, 2022. Total Number is 4,721,280

Research and Demonstration Focus

The Swiss Federal Office of Energy (SFOE) has three funding schemes for subsidiary support of energy-related projects.

- The main focus of the Energy Research Programme is on development and application.
- The Pilot and Demonstration Programme promotes the testing and implementation of new technologies, solutions, and concepts.
- The purpose of the SWEET ("**SW**iss **E**nergy research for the **E**nergy **T**ransition") programme is to accelerate innovations that are key to implementing Switzerland's Energy Strategy 2050 and achieving the country's climate targets.[131]

The overarching goals of all funded projects are to foster energy security, energy efficiency, decarbonization, and renewable energies.

According to Scenario ZERO Basis (of the Swiss Energy Perspectives 2050+), after 2050, the transport sector should be operated without fossil fuel. That means a reduction from 196.8 petajoules (PJ) gasoline, diesel, and natural gas plus 6.9 PJ biofuels and 12.8 PJ electricity in 2022 to 71.9 PJ renewable fuels and 60.7 PJ electricity in 2050 (data without fuels for aviation, which totaled 59.9 PJ in 2022). Figure 6 displays final energy demand.

[131] SFOE, "Energy Strategy 2050," https://www.bfe.admin.ch/bfe/de/home/politik/energiestrategie-2050.html.

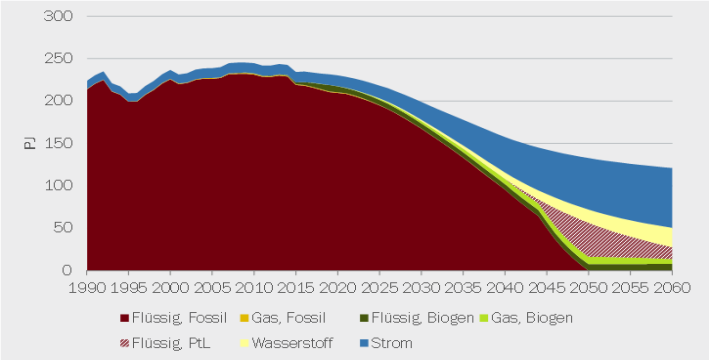

Figure 6. Final Energy Demand of Domestic Transport (Scenario ZERO Basis, Excluding International Aviation)[132]

Therefore, in the transport sector, the priority is electrification of passenger cars, public transport, the municipal sector, and freight transport and the use of non-fossil fuels for the rest. The projects mentioned below cover the production, storage, and distribution of the fuels, as well as their highly efficient use in internal combustion engines and exhaust gas after-treatment. The combustion and engine-relevant properties of biogas, hydrogen (H_2), methanol (MeOH), dimethyl ether (DME), and ammonia (NH_3) are investigated.

Sustainable Chemical Transport Fuels for Switzerland (2021–2024)[133]
This project investigates the role and perspectives of sustainable chemical transportation fuels within a net-zero Swiss energy system. It includes a techno-economic, environmental, and social life-cycle assessment of a comprehensive portfolio of chemical fuels — including hydrogen, biogenic, sun-to-liquid, and power-to-gas/liquid fuels. The results will be integrated into a scenario-driven energy system analysis. Because there are few sustainable primary energy resources for such fuel production in Switzerland, the analysis will be performed on a global level to identify plausible sources and locations for fuel production and import pathways.

E-Fuels: International Exchange of Research Findings and Activities (2021–2024)[134]
This project comprises an international exchange on the topic of e-fuels for transportation. Researchers will identify both the needs of the participating countries and their expertise. The exchange should enable individual countries to fill the knowledge gaps of other countries with their expertise and, conversely, benefit from the expertise of other countries. One goal of this project for Switzerland is to gain knowledge about e-fuels through the exchange at both the national and international level. This will enable Switzerland to get a picture of the state of development of e-fuels on a global level and identify research gaps. The products of this project are a compilation of previous findings from Switzerland and coordination of the international exchange of information. The project contributes to IEA AMF Task 64.

Recording and allocation of emission data in real road traffic using RES[135]
Remote emission sensing (RES) measures exhaust emissions by absorption spectroscopy in the wake of passing vehicles without interfering with traffic. This project focused on the numerical simulation of the distribution of exhaust gas components in the vehicle wake (Figure 7). Extensive numerical simulations have shown that the emission formation is contained in the 0.5- to 3-m downstream of the vehicle, independent of driving or environmental parameters. Further downstream, the dilution is too strong. This is an important requirement for the measurement frequency of the RES instruments. The project demonstrated the potential of hybrid large eddy simulation (LES)/Reynolds-averaged Navier–Stokes (RANS) simulations to improve the accuracy of exhaust cloud dispersion prediction. A direct correlation between the exhaust concentration measured by RES and the actual vehicle emission is

[132] SFOE, 2022, Energy Perspectives 2050+, Technical Report
[133] PSI Paul Scherrer Institute, “Sheltered – Sustainable chemical fuels for Switzerland,” https://www.aramis.admin.ch/Texte/?ProjectID=49507.
[134] OST Ostschweizer Fachhochschule, “E-Fuels: International Exchange of Research Findings and Activities,” https://www.aramis.admin.ch/Texte/?ProjectID=49314.
[135] Empa, “Collection and allocation of emission data in real road traffic using remote emission sensing,” https://www.aramis.admin.ch/Texte/?ProjectID=47374.

subject to larger uncertainties due to the instantaneous nature of the RES measurement and the measurement uncertainty of the instruments themselves. Experiments indicate a lack of coverage of truck exhaust clouds. The project contributes to IEA AMF Task 61.

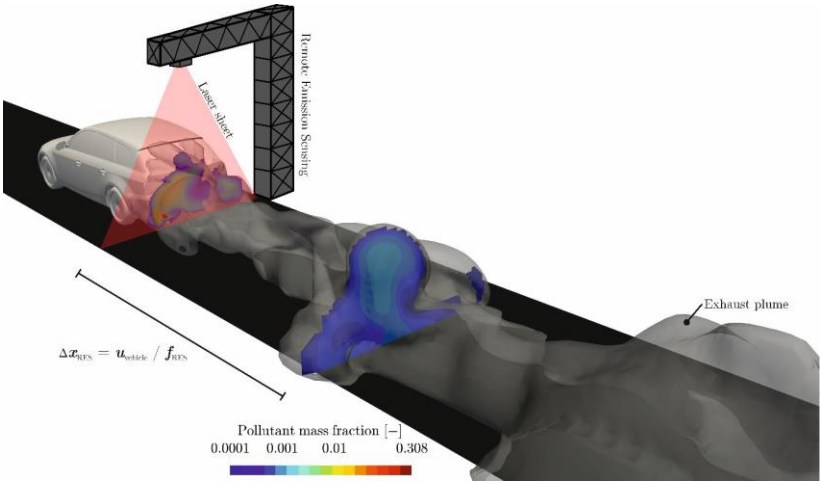

Figure 7. Measuring system and pollutant distribution behind the vehicle (J. Plogmann, Empa 2023)

SWEET refuel.ch: Renewable Fuels and Chemicals for Switzerland (2023-2030)[136]
To comply with the ambitious timeline of Swiss renewable energy and GHG emission targets, accelerated market development of sustainable fuels and platform chemicals is necessary. While first-generation technology is available to initiate a ramp-up, this is not the case for policies, laws, regulations, and markets (non-technical aspects). A first aim of the SWEET reFuel.ch (Renewable Fuels and Chemicals for Switzerland 23023–2030) project to investigate how investment security can be improved by closing this knowledge gap. reFuel.ch will develop robust and practical pathways for introducing sustainable fuels and platform chemicals to markets and the Swiss energy system using an inter- and transdisciplinary approach. This development will include inputs from social sciences (sociology, law, economics, and political science), natural sciences, and engineering, as well as dialogue with relevant stakeholders (i.e., policy makers, regulators, market actors, and end users). A second aim is to strengthen innovative technologies currently at low technology readiness levels (TRLs). This goal will be achieved by focusing on green methanol pathways and other technologies with breakthrough potential for sustainable fuel and platform chemical production.

Efficient part-load operation of heavy duty DME engines (2022–2023)[137]
This project complements the investigations carried out in a previous project,[138,139] in which mainly high load conditions — typical for the operation of heavy-duty vehicles — were investigated with excellent results. At lower loads, difficulties arise due to the low temperature dosing limit of the exhaust gas after-treatment system. To solve this problem, researchers investigated partially premixed charge and compression ignition (PCCI) operation with late start of injection (SOI) and high exhaust gas recirculation (EGR) rates. The chosen strategy clearly shows that a high EGR in combination with a late SOI enables significantly lower fuel consumption losses than conventional exhaust gas flap operation. Lower NO_x emissions at the engine outlet also mean lower tailpipe emissions during the warm-up phase until the selective catalytic reduction (SCR) system is activated. Finally, the higher outside temperatures of the engine enable the dosing of the reducing agent for the SCR (w/AdBlue), so that Euro 7 and Tier 5 regulations can be achieved using a Euro 6-like aftertreatment system.

[136] Swiss Federal Office of Energy, "SWEET: Sustainable Fuels," https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/funding-program-sweet/calls-for-proposals-overview/sweet-call-2-2022.html.
[137] Empa, "HDV-DME-Part Load Efficient part-load operation of heavy duty DME engines," https://www.aramis.admin.ch/Texte/?ProjectID=51282.
[138] FTP, "Efficient Diesel – Combustion chamber insulation for improved Diesel engine efficiency," https://www.aramis.admin.ch/Texte/?ProjectID=40682.
[139] FPT, "HDV-DME – Investigation of the suitability of DME as an alternative fuel in HDV," https://www.aramis.admin.ch/Texte/?ProjectID=41773.

NH_3 ICE ammonia combustion engine (2023-2027)
Ammonia is primarily considered for powering large marine engines. In this project, currently being conducted by Liebherr Machine Bulle SA, ammonia will be used for medium- to high-speed engines for mining machinery, smaller marine vessels, or cogeneration. A Liebherr prototype ammonia/hydrogen 4-stroke engine — fully equipped with sensors, fuel injection system, and open electronic control unit — is installed at the experimental facilities of the University of Nottingham. The research team will quantify ammonia slip and nitrous oxide (N_2O) emissions and perform emission measurements of secondary and particulate formations.

N_2O Exhaust Gas Treatment in Ammonia Engines (2022–2025)[140]
NH_3 is considered a promising fuel for large engines and, in particular, for international shipping applications because no CO_2 is produced from its combustion. However, high concentrations of the pollutants NO_x, NH_3, and N_2O can be released. This project aims to develop recommendations for exhaust after-treatment systems that reduce pollutant emissions from NH_3-fueled engines. Catalytic experiments will be performed in a wide range of pollutant concentrations and other feed components (e.g., O_2, H_2O) as well as temperatures in order to provide recommendations for after-treatment setups and catalyst compositions depending on these operating conditions. The project will include a general screening of suitable catalysts, but currently Fe-exchanged zeolites "seem most promising to remove N_2O and NO_x from exhaust gases with the help of NH_3".

E-Methanol Compression Ignition Combustion ("EMOCION") (2023-2027)[141]
Renewable methanol is a technically and economically promising solution for net-zero CO_2-free internal combustion engines for applications that cannot be electrified. The novelty, compared with existing methanol engines, is the use of a compression-ignition process (quasi "methanol diesel engine") to achieve the highest efficiency and power density. Feasibility and limitations need to be evaluated. An optically accessible test bench will be used to investigate the underlying mechanisms under relevant pressure, temperature, and flow conditions, as well as different injection strategies. In addition, researchers will evaluate possibly required ignition-promotion concepts.

Outlook

Sales of electric or plug-in hybrid cars are expected to account for at least 50% of new registrations as early as 2025. The demand for large electric vehicles for municipal use, local public transport, and freight transportation is also increasing. The demand for fuels will therefore decrease, and electricity consumption will increase. This poses an additional challenge for the renewable electricity supply in Switzerland, which will have to be greatly expanded anyway because of the planned gradual phase-out of nuclear energy. In addition, a large increase in the number of charging stations for electric vehicles is required.

For the remaining transport systems powered by combustion engines (still part of long-distance transport, maritime transport, various off-road applications, and combined heat and power), research institutes and industry are looking for the most suitable solutions using renewable fuels. The focus here is primarily on H_2, but also on NH_3, methanol, and DME. The challenge is that it is not clear which of these fuels is the most suitable and will prevail.

Cooperation between the research and development around renewable fuels and their use in combustion systems is therefore important. Just as for electromobility, the systems for supplying renewable fuels must also be set up in good time and, where possible, the existing ones must be converted. The production and procurement of non-fossil fuels are of great importance here.

[140] ETHZ ESC, "VADER – Value of sustainable fuels for the decarbonisation of Switzerland," https://www.aramis.admin.ch/Texte/?ProjectID=51133.
[141] AFHB, "Usage of LBG (Liquefied Biogas) for Heavy Duty Transport in Switzerland," https://www.aramis.admin.ch/Texte/?ProjectID=53959

Major changes
In June 2023, the Swiss public voted in favour of the new Act on Climate Protection Goals, Innovation and Strengthening Energy Security.

In 2022, sales of motor vehicles dropped by 7.9% compared with 2021. Sales of gasoline- and diesel-fueled passenger cars declined by 15.4%; hybrid remained the same; and 26.5% more electric passenger cars were sold. The share of gasoline and diesel vehicles sold in 2022 decreased to 49.2%, while hybrid vehicles accounted for 33.1%, and electric vehicles for 17.7%. These sales had a positive effect on the average CO_2 emissions from newly registered passenger cars, which exceeded the target value by 11.8 g CO_2/km and was 58.7% lower than in 2020 (28.6 g CO_2/km).

Sales of biofuels dropped slightly and remain at a very low level (3.3%) compared with the consumption of diesel and gasoline.

Benefits of participation in AMF
The future of internal combustion engines depends, among other things, on the successful market introduction of reduced-CO_2 fuels. The AMF TCP is a pioneer in researching and describing novel fuels and their application, benefits, and effects in terms of efficiency and emissions. AMF is a unique source of information and a platform for international exchange of experience and cooperation.

United States

Drivers and Policies

The Biden Administration seeks to reduce U.S. greenhouse gas (GHG) emissions to net zero on an economy-wide basis by 2050. Playing a critical role in achieving this goal is the transportation sector, the largest contributor to U.S. GHG emissions. At the same time, consumer utility and affordability must be maintained, especially as the administration focuses on the redress of historical inequities. This monumental effort is seen as a vital response to the climate crisis.

In 2021, the U.S. Congress enacted the Bipartisan Infrastructure Law (BIL). The law establishes aggressive goals for transportation electrification and decarbonization with significant federal government investments in battery electric vehicles (BEVs), charging stations, hydrogen fuel cell vehicles (FCVs), and hydrogen production deployment. Under the law, the federal government will develop partnerships and provide financial assistance through competitive grants to state governments and industry to meet these goals. The following year, Congress enacted the Inflation Reduction Act (IRA), the single largest investment in climate and energy in U.S. history. Included in the legislation are several tax credits supporting alternative fuel vehicles and infrastructure, support of fleet acquisition of clean and zero-emission vehicles, and support of domestic manufacturing of clean vehicles and their battery supply chain. The IRA also established incentives for the production and use of sustainable aviation fuels, clean hydrogen, and clean fuels. The incentive levels for these fuels are based on their life-cycle GHG emissions. Together, the BIL and IRA are projected to lower economy-wide emissions by more than 40% by 2030, relative to 2005 levels.

In 2022, the U.S. Department of Energy (DOE), Department of Transportation, Environmental Protection Agency (EPA), and Department of Housing and Urban Development signed a joint memorandum of understanding to formalize the Administration's commitment to collaboration and coordination on transportation decarbonization. The four agencies published a decarbonization strategy for the entire transportation sector to guide future policymaking and research, development, demonstration, and deployment (RDD&D) in the public and private sectors.[142] The blueprint's strategy is built on five guiding principles:

1. Implement bold actions to achieve measurable results.
2. Embrace creative solutions across the entire transportation system.
3. Ensure safety, equity, and access.
4. Increase collaboration.
5. Establish U.S. leadership.

The agencies also defined six categories of levers they can pursue to decarbonize the transportation sector: (1) policy and regulation; (2) infrastructure, industrial investments, and financing; (3) research and innovation; (4) data and analytic tools; (5) workforce education and training; and (6) stakeholder engagement and public-private partnerships.

The Energy Policy Act of 1992 requires certain centrally fueled fleets (federal, state, and alternative fuel provider fleets, such as those used by utility companies) to acquire light-duty alternative fuel vehicles (AFVs) as most of their new vehicle acquisitions. AFVs are promoted for their benefits for emission reductions, energy diversification, and low operating costs.

The DOE Technology Integration Program is a government-industry partnership that supports local decisions to reduce petroleum use and GHGs in the transportation sector through the use of alternative fuels, hybrid and electric-drive vehicles, idle reduction technologies, smarter driving practices, and improved fuel economy measures. Data from the Technology Integration Program for 2022 reveal that the program saved 1,066 million gasoline gallons equivalent (GGE), including 745 million GGE from alternative fuels/vehicles and 128 million GGE from electric and hybrid vehicles.

The transportation sector continues to use a large amount of renewable fuels. The primary driver of renewable fuel use in the United States is the Renewable Fuel Standard (RFS), adopted in 2005 and expanded in 2007 (RFS2). The Standard requires the use of increasing volumes of renewable fuels in

[142] DOE, 2023, *The U.S. National Blueprint for Transportation Decarbonization*, DOE/EE-2674, January 2023.

motor fuels. On June 1, 2022, the EPA finalized a slight increase of total renewable fuel volumes from 20.6 billion gallons in 2022 to 20.9 billion gallons in 2023.[143] In addition, the EPA set 2024 and 2025 volumes to 21.5 billion gallons and 22.3 billion gallons, respectively. The 2023 volume is significantly lower than the original target of 36 billion gallons in the RFS legislation, which envisioned much more robust growth in cellulosic fuel production than has materialized.

The cellulosic biofuel category in the RFS was created largely with cellulosic ethanol in mind. However, renewable natural gas from landfills and anaerobic digesters, treated as cellulosic biofuel by the EPA through rulemakings in 2013 and 2014, has dwarfed liquid fuels in that category. Biomass-based diesel is mainly traditional biodiesel derived from soy, corn oil, canola, and other vegetable and animal fats and oils. These categories are nested into the category of advanced biofuels, which also includes renewable diesel, biogas, renewable heating oil, and renewable fuels co-processed in petroleum refining. Finally, the broad category "renewable fuel" includes all of these categories combined with starch- and sugar-based ethanol.

The State of California developed the Low-Carbon Fuel Standard (LCFS) to reduce the average carbon intensity of its transportation fuels by 10% from 2010 to 2020. In 2019, California extended the LCFS to 2030 with reduced carbon intensities for transportation fuels by an additional 10%. Using life-cycle analysis, California developed carbon intensities for different fuels, including alternative fuels and biofuels. With both the RFS and LCFS, a significant volume of biofuels — about 3.1 billion GGE — was used in California in 2022, which was 20% higher than in 2021.

Advanced Motor Fuels Statistics

The U.S. Energy Information Administration (EIA) estimated that total U.S. transportation energy consumption for 2023 was 28,057 trillion British thermal units (Btu) — 2% higher than in 2022.[144] About 90% of this consumption is petroleum-based fuels (gasoline and diesel), with much of the remainder being ethanol blended into gasoline at 10%. Biomass accounted for 1,788 trillion Btu during 2023, natural gas for 1,322 trillion Btu, electricity for 57 trillion Btu, and propane for 10 trillion Btu.[145]

Biofuels

The best biofuel use data come from the EPA's recording of Renewable Identification Numbers (RINs) filed by refiner/marketers of liquid transportation fuels, as shown in Figure 1.[146] Each RIN is equivalent to 1 gallon of ethanol by Btu content; RINs are generated when a motor fuel refiner/blender blends or sells the renewable fuel or fuel blend. Renewable fuel volumes grew from 19.1 billion gallons in 2022 to 20.7 billion gallons in 2023, as fuel consumption continued to grow after the first year of the pandemic.

[143] EPA, 2023, Renewable Fuel Annual Standards, June 21, 2023.
[144] EIA, *EIA Monthly Energy Review*, March 2024.
[145] Ibid.
[146] EPA, 2024, *EPA Moderated Transaction System*, February 2024.

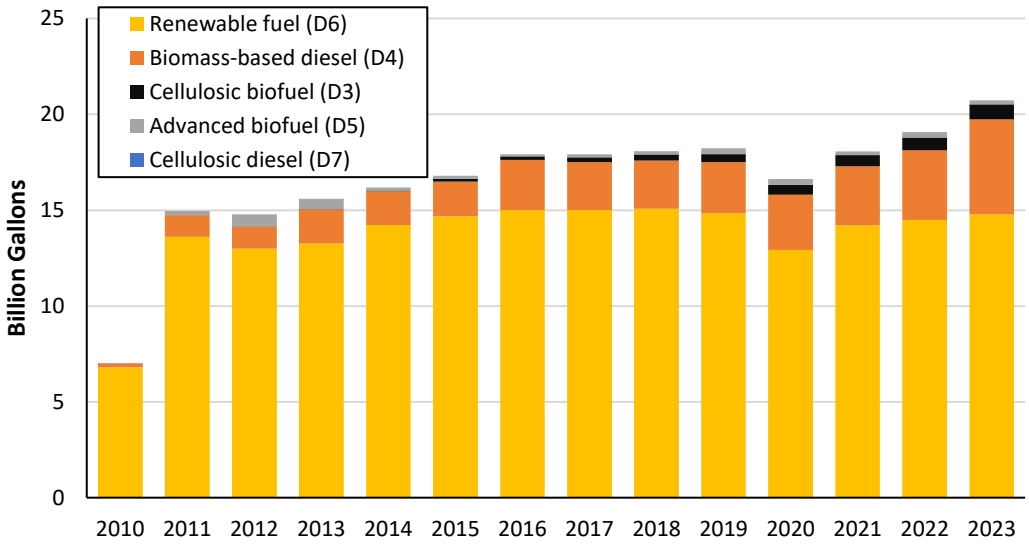

Figure 1. Renewable Fuel Volumes Resulting from U.S. Renewable Fuel Standard

Electric Vehicles

Sales of plug-in hybrid electric vehicles (PHEVs) and BEVs in 2023, totaling 1,432,657, resulted in the largest EV sales year in U.S. history.[147] In addition, sales of HEVs (non-plug-in) were up significantly in 2023, totaling 1,175,597.[148] As of March 2024, consumers could choose from 105 available plug-in models for model year 2024.[149]

Alternative Fuel Infrastructure

The DOE's Alternative Fuels Data Center provides the number of alternative fuel refueling stations in the United States.[150] As Table 1 shows, exclusive of electric recharging stations, the total number of alternative fueling stations in the United States increased by 57% between 2012 and 2023. However, the number of compressed natural gas (CNG) and liquefied natural gas (LNG) stations decreased slightly in 2023. The total number of public and private non-residential EV recharging outlets jumped by over 1200% over this period, with a 22% gain in 2023.

Table 1. U.S. Alternative Fuel Refueling Stations by Type, 2012–2022 (including public and private stations)

Year	BD	CNG	E85	Electric Outlets[a]	H_2	LNG	LPG	RD[b]	Total	Total Non-electric
2012	675	1,107	2,553	13,392	58	59	2,654	0	20,498	7,106
2013	757	1,263	2,639	19,410	53	81	2,956	0	27,159	7,749
2014	784	1,489	2,780	25,511	51	102	2,916	0	33,633	8,122
2015	721	1,563	2,990	30,945	39	111	3,594	0	39,963	9,018
2016	718	1,703	3,147	46,886	59	139	3,658	0	56,310	9,424
2017	704	1,671	3,399	53,141	63	136	3,478	0	62,592	9,451
2018	670	1,574	3,632	67,957	64	114	3,328	0	77,339	9,382
2019	614	1,583	3,837	87,457	64	116	3,118	0	96,789	9,332
2020	703	1,549	3,949	108,190	64	103	2,967	0	117,525	9,335
2021	1,102	1,506	4,378	130,241	67	103	2,804	0	140,201	9,960
2022	1,193	1,399	4,426	143,771	72	98	2,713	573	154,245	10,474
2023	1,700	1,392	4,495	176,032	76	94	2,813	606	187,208	11,176

[a] Total number of recharging outlets, not sites.

[b] Renewable diesel (RD) station data collection began in 2022.

[147] Argonne National Laboratory, 2024, "Light Duty Electric Drive Vehicles Monthly Sales Updates."
[148] Ibid.
[149] DOE, 2024, Alternative Fuels Data Center, "Availability of Hybrid and Plug-In Electric Vehicles."
[150] DOE, 2024, "Alternative Fueling Station Counts by State."

Research and Demonstration Focus

The DOE's Vehicle Technologies Office (VTO) sponsors RDD&D in a broad range of technologies for all levels of vehicles and transportation systems. Areas of active research include energy storage, electric drive, materials, powertrain and fuels for non-road applications, mobility systems, and technology deployment. VTO's current portfolio comprises the following: conducting research in fuels and advanced combustion engines to displace petroleum-derived fuels, better matching engines and fuel characteristics, and increasing engine and vehicle efficiencies. This research covers a very broad range of fuel, engine, and vehicle technologies. The summary provided here focuses on fuels and fuel effects and is based on a report summarizing the findings and impact of a multi-year project.[151]

The Co-Optimization of Fuels and Engines (Co-Optima) was a six-year initiative (2016 to 2021) led jointly by DOE's VTO and Bioenergy Technology Office (BETO). Co-Optima's goal was to identify and evaluate technology options leading to high-performance, sustainable, affordable, and scalable co-optimized fuels and engines. Breakthroughs from the initiative could improve cars' fuel economy by 10% for today's turbocharged engines and 14% more for advanced engines using multiple combustion modes, compared to a 2015 baseline. In addition, new bio-based fuel components identified in the project could produce at least 60% fewer GHGs than petroleum-based fuels. The research addressed in this initiative was documented in 250 peer-reviewed journal articles, conference papers, and technical reports.

As documented in the multi-agency decarbonization blueprint, VTO R&D in engines and fuels will now focus exclusively on off-road applications, including rail, marine, aviation, and off-road equipment for agriculture, mining, construction, and forestry. While we recognize that engines will continue to be used in on-road transportation for years, VTO powertrain research for such applications will focus on battery electrification and hydrogen FCVs.

In addition, BETO will continue to promote the development of new fuels from initial concepts, laboratory R&D, and pilot and demonstration plant phases. Research areas include feedstocks, algae, biochemical conversion, and thermochemical conversion for aviation and marine fuels and high-value chemicals.

The DOE has begun to make significant investments in sustainable aviation fuels (SAFs) to help decarbonize the U.S. aviation sector. The U.S. federal government has established an SAF Grand Challenge with a goal of 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050.[152] The DOE, the Department of Transportation, and the Department of Agriculture are leading the grand challenge to develop a comprehensive strategy for scaling up new technologies to produce SAF on a commercial scale.

Outlook

The EIA's *Annual Energy Outlook 2023* (AEO 2024 was not published due to model enhancements) projects decreasing on-road transportation energy use from 2021 through 2043 resulting from mandated increases in fuel efficiency and increased use of electric vehicles. However, growth in travel demand, largely attributable to the increase in use of light trucks in place of passenger cars, will outpace these benefits, and energy use will increase from 2044 to 2050.[153] The EPA's GHG emission standard for light-duty vehicles (LDVs) incentivizes the introduction of efficient vehicle technologies and electrified vehicles including PHEVs, BEVs, and FCEVs. The federal government and the auto industry anticipate electrification of the U.S. LDV fleet by 2050. Low-carbon fuels in internal combustion engines can help decarbonize long-haul trucks, the aviation sector, and the marine sector.

[151] DOE, 2022, *The Road Ahead Toward a Net-Zero-Carbon Transportation Future Findings and Impact*, DOE/EE-2359, June 2022.
[152] DOE BETO, 2021, "Sustainable Aviation Fuel Grand Challenge".
[153] Energy Information Administration, 2023, *Annual Energy Outlook 2023*.

Additional Information Sources

- Oak Ridge National Laboratory, "Transportation Energy Data Book"
- DOE, Federal and State Laws and Incentives
- EIA, *Monthly Energy Review*
- DOE, Technology Integration Program
- DOE, BETO program,

4 Further Information

4.a
About the International Energy Agency

Established in 1974, the International Energy Agency (IEA) carries out a comprehensive program of energy cooperation for its 30 members and eight association countries and beyond. The IEA examines the full spectrum of energy issues and advocates for policies that will enhance energy security, economic development, and environmental awareness and engagement worldwide. The IEA is governed by the IEA Governing Board, which is supported through a number of specialized standing groups and committees. For more information on the IEA, visit the IEA web site.

The IEA Energy Technology Network

The IEA Energy Technology Network (ETN) is composed of 6,000 experts participating in governing bodies and international groups that manage technology programs. The Committee on Energy Research and Technology (CERT), which consists of senior experts from IEA member governments, considers effective energy technology and policies to improve energy security, encourage environmental protection, and maintain economic growth.

Four specialized Working Parties support the CERT:

- Working Party on Energy End-use Technologies (EUWP): examines technologies and processes to improve efficiency in the building, electricity, industry, and transport sectors.
- Working Party on Fossil Fuels (WPFF): promotes cleaner use of coal, improvements in gas/oil exploration, and carbon capture and storage.
- Fusion Power Coordinating Committee (FPCC): explores fusion devices, technologies, materials, and physics phenomena.
- Working Party on Renewable Energy Technology (REWP): examines technologies, socioeconomic issues, and deployment policies.

Each Working Party coordinates the research activities of relevant IEA Technology Collaboration Programmes (TCPs). The CERT directly oversees TCPs of a cross-cutting nature.

IEA Technology Collaboration Programmes

The IEA TCPs consist of international groups of experts who enable governments and industries from around the world to lead programs and projects that address a wide range of energy technologies and related issues — from building pilot plants to providing policy guidance in support of energy security, economic growth, and environmental protection. Since the creation of the first TCP in 1975, participants have examined close to 2,000 topics. Today, TCP participants represent more than 300 public- and private-sector organizations from more than 50 countries. TCPs are governed by a flexible and effective framework and are organized through an Implementing Agreement. TCP activities and programs are managed and financed by the participants. To learn more about the TCPs, please consult the IEA website.

4.b
AMF TCP Contact Information

4.b.i
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[a] Alphabetical order by country name.

If you are interested in contributing to AMF's work and your country is already a member, please contact your respective Executive Committee representative.

4.b.ii
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If you have specific questions about a Task, please contact the Task Managers listed above.

4.b.iii
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The AMF Secretary serves as the main point of contact. However, you may also address one of the Executive Committee chairs or heads of subcommittees with more specific questions.

4.c
AMF TCP Publications in 2023

Task 60: The Progress of Advanced Marine Fuels

This report is the result of a multinational collaboration in which researchers from different countries each submitted their findings and technological highlights from both national and global perspectives. The report addresses every marine segment from the smallest fishing boats on the Yangtze River to the largest ocean-going container vessels.

The work process, coinciding with the Covid pandemic, has been carried out largely by remote meetings every two months. Each country has given both oral and written presentations of their work. The entire report has been collated by the task manager and posted for review on a shared server. The task was managed by Kim Winther, Technology Subcommittee Chair of the AMF TCP.

- Final Report, October 2023
- Key Messages, September 2023
- Website

Task 63: Sustainable Aviation Fuels

Sustainable aviation fuels (SAFs) have the potential to reduce greenhouse gas emissions from the aviation sector. However, this potential remains largely untapped because such fuels currently represent only 0.05% of total jet fuel consumption. The aim of the Task was to lay the foundation for collaborative research, development, and demonstration (RD&D) work on sustainable aviation fuels within the AMF TCP. Thus, the Task focused on identifying stakeholders and experts, assessing participants' national situation, and facilitating information exchange regarding the main challenges in taking up sustainable aviation fuels. The Task addressed both biofuels and e-fuels.

The final report includes an overview on the status of SAF production and consumption and related technologies, national assessments for six countries, and best practice examples of supply and operation, feedstock and conversion, and market and policy. The Task included three public workshops, the presentations of which can be assessed through the task website.

- Final Report, July 2023
- Key Messages, July 2023
- Website

4.d
How to Join the AMF TCP

Participation in the multilateral technology initiative AMF TCP is based on the mutual benefits it can bring to the TCP and the interested newcomer.

If you are interested in joining the AMF TCP, please contact the AMF Secretary, who will provide you with details about the AMF TCP and invite you to attend an Executive Committee meeting as an observer. By attending or even hosting an Executive Committee meeting, you will become familiar with the TCP.

Contracting parties to the AMF TCP are usually governments. Therefore, you need to seek support from your government to join the TCP. The government will later appoint a delegate and an alternate to represent the contracting party in the Executive Committee.

Financial obligations of membership include:

- An annual membership fee (currently EUR 10,250 [USD 11,173]).
- Funding for an Executive Committee delegate to attend two annual meetings.
- Cost-sharing contributions to Tasks in which you wish to participate (cost shares range from EUR 10,000 to EUR 100,000 [USD 10,900 to USD 109,000]).

Participation in Tasks can take place through cost sharing and/or task sharing. The institution participating in a Task does not necessarily need to be the institution of the Executive Committee delegate.

The AMF TCP Secretary and IEA Secretariat will guide you through the formalities of joining the AMF TCP.

4.e
Partnerships

Collaboration with the ITF of the OECD

The International Transport Forum (ITF) at the Organization for Economic Cooperation and Development (OECD) is an intergovernmental organization with 63 member countries that acts as a think tank for transport policy and organizes an annual summit of transport ministers. The ITF is the only global body that covers all transport modes. Administratively, the ITF is integrated with the OECD but it is politically autonomous.

The ITF works to establish transport policies that improve people's lives. Its mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability, and social inclusion, and to raise the public profile of transport policy.

The ITF organizes global dialogue for better transport, acting as a platform for discussion and pre-negotiation of policy issues across all transport modes and analyzing trends, sharing knowledge, and promoting exchange among transport decision makers and civil society. The ITF's Annual Summit is the world's largest gathering of transport ministers and the leading global platform for dialogue on transport policy.

The collaboration of the ITF with the AMF TCP brings constructive inputs to the activities of the TCP and also provides greater visibility to the outputs of the AMF TCP.

This close relationship facilitates inputs and contributions for the AMF TCP and its members to support the development of transport-related policy instruments that are at the core of the ITF's work, strengthening the impact of the work of the AMF TCP. The cooperation enables an exchange of best practices.

Glossary

Advanced Motor Fuels (AMF)

The Technology Collaboration Programme on Advanced Motor Fuels (AMF TCP) is one of the multilateral technology initiatives supported by the International Energy Agency (IEA). Formally, these are also known as Implementing Agreements. The AMF TCP promotes more advanced vehicle technologies, along with cleaner and more-efficient fuels. Transportation is responsible for approximately 20%–30% of all the energy consumed and is considered to be the main producer of harmful emissions. Although the transportation sector is still highly dependent upon crude oil, advances are being made to allow for domestically made biofuels and other forms of energy.

Biofuels

Liquid or gaseous fuels produced from biomass, or feedstocks, with the purpose of using them for the propulsion of vehicles (cars, trucks, buses, trains, ships, planes). Feedstocks include food and feed crops, energy crops, agricultural residues, forest and forest industry residues, industrial residues, and organic waste fractions.

Dimethyl Ether (DME)

Fuel created from natural gas, coal, or biomass that is noted for producing low levels of NO_x emissions and low smoke levels when compared to petroleum-derived diesel fuels. DME does not exhibit some of the transportation issues associated with other alternative fuels (such as ethanol, which causes corrosion in pipelines). Because DME is a gas at room temperature, unlike ethanol it must be placed under pressure in large tanks for transportation and storage.

Electrofuel

A class of fuel produced by storing electrical energy from renewable sources in the chemical bonds of liquid or gas fuels. Butanol, biodiesel, and hydrogen are the primary targets, but methane and butane are also options for this class of fuel.

E85

Fuel composed of 85% ethanol and 15% gasoline by volume. This type of fuel is used in flex-fuel vehicles, which can be powered by pump gasoline and available alternative fuels. Consequent fuels, such as E0, E5, and E20, contain a certain volume percentage of ethanol, denoted by the number in their name, with the rest of the mixture being gasoline.

Ethanol (C_2H_5OH)

An alcohol fuel derived from plant matter (commonly feed corn or sugar cane); ethanol is blended into pump gasoline as an oxygenate. Engine and exhaust systems must be altered in order to run a higher ethanol blend. Ethanol is a popular alternative fuel because of its propensity to increase an engine's thermal efficiency. Ethanol is also popular because it can be domestically produced, despite discussions of its impact on food supplies. By law, ethanol must be denatured by using gasoline to prevent human consumption.

Ethyl Tertiary-Butyl Ether (ETBE)

Additive introduced into gasoline during the production process. As an additive, ETBE can be used to create some of the emission benefits inherent in oxygenates. ETBE can be derived from ethanol, which allows it to be included as a biofuel.

Fatty Acid Methyl Ester (FAME)

A form of biodiesel derived from waste biomass, such as animal fats, recycled vegetable oils, and virgin oils. Pure biodiesel, B100 must meet standards before it can be blended into diesel fuels. In the United States, different blends of biodiesel can be found across the nation, ranging from 5% to 20% biodiesel. Manufacturers are now creating engines compatible with biodiesel blends up to B20. Under European standards, the terms *FAME* and *biodiesel* are used synonymously. B100 may be used as a pure fuel as well, with only minor adaptations to vehicles.

Flex-Fuel Vehicle (FFV)
A vehicle capable of safely handling various fuels, ranging from gasoline to high-ethanol-content blends. The fuel system in an FFV vehicle is designed to handle the flow of ethanol, which would harm a normal vehicle. General Motors is a major producer of FFVs. These vehicles do see a loss in fuel economy when running on alternative fuels, due to the lower energy content of ethanol.

Fuel Cell Vehicle (FCV)
A type of hybrid that uses a hydrogen-powered fuel cell to produce electrical energy, which then powers electric motors that drive the vehicle. FCVs have the potential to lower harmful emissions in comparison to internal combustion engines.

Green Hydrogen
Clean-burning fuel produced from renewable energy sources. The most discussed production pathway consists of splitting water by electrolysis, driven by electricity from renewable energy sources such as solar or wind. A number of other pathways, based on biomass, can also create green hydrogen.

Greenhouse Gas (GHG)
Emissions that increase the harmful greenhouse effect in the Earth's atmosphere. The emission of carbon dioxide, a common GHG, is a direct product of combustion. GHGs are responsible for trapping heat in the Earth's atmosphere. Methane, another powerful GHG, can remain in the atmosphere for longer than a decade and is at least 20 times more effective than carbon dioxide at trapping heat. GHGs have been a topic of great debate concerning global climate change in years past.

Hydrotreated Vegetable Oil (HVO)
Bio-based diesel fuel created by treating vegetable oil with a process using hydrogen. HVO can be used as a renewable diesel fuel and can be blended with regular diesel to create varying blends on a volume basis.

Internal Combustion Engine (ICE)
Device that uses stored chemical energy in a fuel to produce a mechanical work output. More than 600 million ICEs are in operation today, used for transportation and stationary purposes. Typical peak efficiencies for gasoline, diesel, and stationary engines are 37%, 42%, and 50%, respectively. Efficiencies of transportation gasoline and diesel engines are lower than their peak efficiencies because they do not operate in the peak range.

Liquefied Natural Gas (LNG)
Fuel produced by liquefying natural gas and used to power heavy-duty vehicles, such as transit buses. LNG is composed primarily of methane (CH_4), with impurities being removed during liquefaction.

Liquefied Petroleum Gas (LPG)
Clean-burning fossil fuel consisting of propane (C_3H_{10}) and butane (C_4H_{10}), with its exact composition varying by region. LPG can be used, with modification, to power current vehicles equipped with internal combustion engines, as an alternative to gasoline. LPG can be produced domestically.

Natural Gas
A fossil fuel consisting primarily of methane (CH_4), which can be used after a refining process. Natural gas is extracted from the ground and burns relatively clean. Not only is it less expensive than gasoline, but it also contributes to lower greenhouse gas emissions and smog-forming pollutants. Current gasoline and diesel vehicles can be converted to operate on natural gas.

Natural Gas Vehicle (NGV)

A vehicle that operates on compressed or liquid natural gas, both of which burn cleaner than traditional fuels. Current vehicles can be converted to operate on natural gas – a popular trend among fleet vehicles. The only new original equipment manufacturer (OEM) NGV available in the U.S. market is the Honda Civic GX compressed natural gas car; in years past, by comparison, multiple vehicles were available. Countries in Europe and Asia offer a much wider selection of OEM NGVs.

Nitrogen Oxide (NO_x)

A family of gases consisting of nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x is formed from the nitrogen and oxygen molecules in the air and is a product of high-combustion temperatures. NO_x is responsible for the formation of acid rain and smog. The three-way catalyst, which operates most efficiently at stoichiometric air-fuel ratios, has tremendously reduced NO_x emissions in spark-ignited engines. A lean-burn after-treatment system is needed for compression-ignition engines because they do not operate at stoichiometric conditions.

Particulate Matter (PM)

An emission produced during the combustion process. Particulate matter smaller than 10 micrometers in diameter can cause serious health issues because it can be inhaled and trapped in the lungs. With the advent of diesel particulate filters, PM emissions have been tremendously reduced.

Plug-in Hybrid Electric Vehicle (PHEV)

A type of hybrid electric vehicle equipped with an internal battery pack, which can be charged by plugging the vehicle into an outlet and drawing power from the electrical grid. PHEVs are becoming popular because the vehicle itself produces very low emission levels.

Scrubber

Device that filters particulates and liquid hydrocarbons from natural gas products, improving the purity of natural gas and reducing sulfur content and NO_x. Scrubbers use particle filters, coalescers, mesh pads, and other devices to remove pollutants from the gas stream.

Well-to-Wheel (WTW)

A concept that considers all of the emissions created from the initial energy source to the end system for the desired mode of transport. For instance, an electric vehicle will create lower greenhouse gas emissions than a gasoline-powered vehicle. If the electricity used to charge the electric vehicle came from a combustion power plant and if other transmissions of power were considered, the electric-vehicle-related emissions could, in fact, exceed the emissions of the gasoline counterpart.

Notation and Units of Measure

1G	first generation
2G	second generation
3G	third generation
AIST	National Institute of Advanced Industrial Science and Technology (Japan)
AFV	alternative fuel vehicle
ANP	Regulatory agency for oil, natural gas, and biofuels (Brazil)
ATF	aviation turbine fuel
ATJ	alcohol-to-jet
ATV	all-terrain vehicle
B20	biodiesel (20%)
B100	biodiesel (100%)
BCB	Banco Central De Brasil
BEST	Bioenergy and Sustainable Technologies GmbH
BETO	Bioenergy Technology Office (United States)
BEV	battery electric vehicle
BIS	Bureau of Indian Standards
BMVF	Federal Ministry of Education and Research (Germany)
BMDV	Federal Ministry for Digital and Transport (Germany)
BMF	Federal Ministry of Finance (Germany)
BMK	Austrian Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology
BMWK	Federal Ministry for Economic Affairs and Climate Action (Germany)
BMBF	Federal Ministry of Education and Research (Germany)
BMDV	Federal Ministry for Digital and Transport (Germany)
BMWK	Federal Ministry of Economic Affairs and Climate Action
BNDES	Brazilian Bank for Economic and Social Development
BPCL	Bharat Petroleum Corporation Ltd.
BRL	Brazilian real
CAAM	China Association of Automobile Manufacturers
CARES	City Air Remote Emission Sensing program
CATARC	China Automotive Technology and Research Center
CBG	compressed biogas
CBO	CBG Blending Obligation (India)
CCU	carbon capture and utilisation
CEP	core exhaust plume
CERT	Committee on Energy Research and Technology (IEA)
CEPEA	Center for Advanced Studies in Applied Economics (Brazil)
CFR	Clean Fuel Regulations (Canada)
CGSB	Canadian General Standards Board
CHP	combined heat and power
CHT	Centre for High Technology (India)
CI	compression ignition
CNG	compressed natural gas
CNMC	National Markets and Competition Commission (Spain)
CNPE	Brazilian Energy Policy Council
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
COFINS	Contribution for the Financing of Social Security (Brazil)
CORES	Corporación de Reservas Estratégicas (Spain)
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation

CSIR-IIP	Council of Scientific and Industrial Research – Indian Institute of Petroleum
CTS-RD	Clean Transportation System-Research and Development Program (Canada)
DBFZ	German Biomass Research Center
DBT	Department of Biotechnology (India)
DEP	dedicated ethanol plant
DETEC	Department of the Environment, Transport, Energy and Communications (Switzerland)
DHA	docosahexaenoic acid (India)
DLR	German Aerospace Center
DME	methanol/dimethyl ether
DOE	U.S. Department of Energy
DTI	Danish Technological Institute
DTU	Technical University of Denmark
E2G	second-generation ethanol
E25	25% ethanol in gasoline
E27	biogasoline
E85	85% ethanol in gasoline
E100	pure anhydrous ethanol
EBP	ethanol blended petrol
EDAR	emissions detection and reporting
EF	emission factor
EFB	empty fruit bunches (India)
EBP	ethanol blended petrol (India)
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPA	Energy Research Office (Brazil)
ERA-NET	European Research Area Bioenergy
ESY	ethanol supply year
ETBE	ethyl tertiary-butyl ether
ETN	Energy Technology Network (IEA)
ETS	Emissions Trading Scheme (EU)
eTV	ecoTechnology for Vehicles (Canada)
EU	European Union
EU-ETS	European Union Emissions Trading System
EV	electric vehicle
EVAFIDI	Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (Canada)
EVID	Electric Vehicle Infrastructure Demonstration Program (Canada)
FAME	fatty acid methyl ester
FCV	fuel cell vehicle
FCEV	fuel cell electric vehicle
FFV	flexible fuel vehicle
FOM	fermented organic manure
FNR	Agency for Renewable Resources (Germany)
FQD	Fuel Quality Directive (Germany)
FT	Fischer-Tropsch
FT-BtL	Fischer-Tropsch biomass-to-liquid
FY	fiscal year
GDP	gross domestic product
GFP	Green Freight Program (Canada)
GHG	Greenhouse gas
GST	goods and services tax (India)
GX	green transformation (Japan)
H_2	hydrogen
HCNG	hydrogen and compressed natural gas

HD	heavy duty
HDV	Heavy-duty vehicle
HEFA	hydroprocessed esters and fatty acids
HEV	hybrid electric vehicle
HFO	heavy fuel oil
HFS	hydrogen fueling station
HHI-EMD	Hyundai Heavy Industries Engines and Machinery Division
HGV	heavy goods vehicles (Sweden)
HPCL	Hindustan Petroleum Corporation, Ltd.
HVO	hydrogenated vegetable oil
HySTRA	CO_2-free Hydrogen Energy Supply-chain Technology Research Association (Japan)
ICAO	International Civil Aviation Organization
IC	internal combustion
ICE	internal combustion engine
IDAE	Institute for Diversification and Saving of Energy (Spain)
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IMO	International Maritime Organization
IOCL	Indian Oil Corporation Limited
iZEV	Incentives for Zero Emissions Vehicles Program (Canada)
KETEP	Korea Institute of Energy Technology Evaluation and Planning
KLIEN	Austrian Climate and Energy Fund
KliK	Foundation for Climate Protection and Carbon Offset (Switzerland)
KPI	key performance indicator
KTF	Climate and Transition Fund (Germany)
LBG	liquefied biogas
LBM	liquefied biomethane
LCA	life-cycle assessment
LCFS	Low-Carbon Fuel Standard (United States)
LDV	light-duty vehicle
LEVO	Organization for the Promotion of Low Emission Vehicles (Japan)
LFOM	liquid fermented organic manure
LH_2	liquid hydrogen
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MAPA	Ministry of Agriculture, Livestock and Supply (Brazil)
MEE	Ministry of Ecology and Environment (China)
METI	Ministry of Economy, Trade, and Industry (Japan)
MIIT	Ministry of Industry and Information Technology (China)
MMA	Ministry of Environmental and Climate Change (Brazil)
MME	Ministry of Mines and Energy (Brazil)
MoPNG	Ministry of Petroleum and Natural Gas (India)
MOVER	Green Mobility and Innovation Program (Brazil)
NDC	Nationally Determined Contribution (Brazil)
NECP	National Energy and Climate Plan (EU)
NEDC	New European Driving Cycle
NEDO	New Energy and Industrial Technology Development (Japan)
NGV	natural gas vehicle
NIPII	National Innovation Programme Hydrogen and Fuel Cell Technology (Germany)
NO_x	nitrogen oxide(s)
NoVA	Normverbrauchsabgabe (Austria)
NRCan	Natural Resources Canada
NRDC	National Development and Reform Commission (China)
NRMM	non-road mobile machinery

NRSC	non-road steady cycle
NTSEL	National Traffic Safety and Environment Laboratory (Japan)
OEM	original equipment manufacturer
OMC	oil marketing company
PCF	Pan-Canadian Framework on Clean Growth and Climate Change
PEMS	Portable emissions measurement sampling
PERD	Program of Energy Research and Development (Canada)
PFAD	palm fat acid distillate
PHEV	plug-in hybrid electric vehicle
PIS	Program of Social Integration (Brazil)
PM	particulate matter
PNBP	Program of Production and Use of Biodiesel (Brazil)
PNG	piped natural gas
PNH2	National Hydrogen Program (Brazil)
PPA	power purchase agreement
PS	point sampling
PSU	public sector units
PTE-HPC	Spanish Hydrogen Technology Platform
PTI	periodic technical inspection
PtL	power to liquid
PtX/P2X	power to X (Germany)
PV	photovoltaic (solar)
PVO	pure vegetable oil
R&D	research and development
RD&D	research, development, and demonstration
RD&I	research, development, and innovation
RED	Renewable Energy Directive
RED II	Renewable Energy Directive II
RES	remote emission sensing
RES	renewables, total share of (Denmark)
RES-E	renewables share for electricity consumption
RES-DH	renewables shares for district heating
RES-H&C	renewables share for heating and cooling
RES-T	renewables shares for transport
RFS	Renewable Fuel Standards (Korea)
RI	research and innovation
RIN	Renewable Identification Numbers
RFNBO	renewable fuels of non-biological origin
RFR	Renewable Fuels Regulations (Canada)
RFS	Renewable Fuel Standard
RME	rapeseed oil
SAF	sustainable aviation fuel
SATAT	Sustainable Alternative Towards Affordable Transportation (India)
SCR	selective catalytic reduction
SFOE	Swiss Federal Office of Energy
SI	spark injection
SIF	Strategic Innovation Fund (Canada)
STA	Swedish Transport Administration
SUV	sport utility vehicle
TCP	Technical Collaboration Program (IEA)
TEA	techno-economic assessment
TRL	technology readiness level

UCO	used cooking oil
UDOP	União Nacional da Bioenergia (Brazil)
UER	upstream emissions reduction
UNFCCC	United National Framework Convention on Climate Change
USD	U.S. dollars
VRDS	Residual Oil Desulfurization Facility (Korea)
VTO	Vehicle Technologies Office (United States)
VTT	The Technical Research Centre of Finland
WLTP	World Harmonised Light-Duty Vehicles Test Procedure
ZEV	zero-emission vehicle
ZEVIP	Zero Emissions Vehicle Infrastructure Program (Canada)

Units of Measure

Btu	British thermal unit(s)
g	gram(s)
GGE	gasoline gallon(s) equivalent
g/km	gram(s) per kilometer(s)
kg	kilogram(s)
kL	kiloliter(s)
km	kilometer(s)
mbd	million barrel(s) per day
MJ	megajoule (s)
MPa	megapascal(s)
Mt	million ton(s)
Mtoe	megaton(s) of oil equivalent
PJ	petajoule(s)
TJ	terajoule(s)
toe	ton(s) of oil equivalent
TWh	terawatt hour(s)