IEA-Advanced Motor Fuels
ANNUAL REPORT 2024

Technology Collaboration Programme
by IEA

Chairpersons Message — AMF 2024

Jesper Schramm, Chair of the AMF TCP

The International Energy Agency's (IEA's) Technology Collaboration Programme (TCP) on Advanced Motor Fuels (AMF) aims to reduce greenhouse gas and local air pollutant emissions from the transport sector while ensuring the availability and affordability of transport fuels. The goal of the AMF TCP is to inform and advise by compiling 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.

The AMF TCP celebrated its 40th Anniversary in 2024, producing and issuing a special report to mark this important milestone. The anniversary provided a good opportunity to look back and evaluate both successes and opportunities for improvement. We should learn from the latter, and continue to focus on the things that we are good at.

AMF has been a well-organized platform for international collaboration. An internal survey revealed that the contracting parties are very satisfied with AMF and its activities and that they recognize its value. The evolving definition of the AMF acronym symbolizes the programme's ability to adapt to changing conditions: in 1984, AMF meant "Alcohol Motor Fuels," later changing to "Alternative Motor Fuels" and finally to today's "Advanced Motor Fuels." Recently, AMF has shifted its activities from focusing primarily on fuels for road vehicles to encompass non-road mobile machinery, shipping, and aviation, all of which are difficult to electrify.

IEA's Committee on Energy Research and Technology recently approved the 2025–2029 strategic plan for AMF, suggested by the AMF Executive Committee, and extended the AMF TCP contract for this 5-year period. The new period is very important for AMF because it provides us time to work toward a clear path forward based on input from the member countries, which will in turn be based on their response to our strategic plan. On the basis of the many discussions we have had so far, I feel confident that AMF will use its mandate to contribute to a zero-emission transportation future — a future in which electrification alone cannot "do the trick," but that will require innovations in aviation, marine transportation, and heavy-duty trucks for transportation.

Important fuels that we expect to contribute to this future are biofuels and e-fuels containing, for example, elementary fuels like hydrogen, methane, ammonia, methanol, ethanol. An overview of the status and applicability of a row of these fuels is provided in our recently completed Task 64 regarding e-fuels.

The applicability of the fuels depends on end-use perspectives (i.e., technical solutions available to apply these fuels in combustion engines), which is a key element in the traditional AMF work. I see many opportunities to progress here in collaboration with the Sustainable Combustion TCP and the Advanced Materials for Transportation TCP.

Another aspect of a zero-emissions transport sector is the production of fuels, which is not the key competence of AMF. However, it is crucial to consider such aspects as well, and I see good opportunities to collaborate with other TCPs in these fields. Obvious possibilities are the Hydrogen TCP and Biofuels TCP.

I am convinced that AMF will define a successful path forward in close collaboration with other IEA TCPs.

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 in 2024

Kim Winther, Subcommittee Strategy & Technology Chair

Geopolitical tensions and conflicts between Russia-Ukraine and Israel-Gaza resulted in supply chain challenges and increased liquefied natural gas (LNG) demand to offset the loss of pipeline supplies. The Nord Stream 1 and 2 pipelines remained non-operational throughout 2024. The Strait of Hormuz, a critical chokepoint through which 20% of global oil and LNG supplies flow, remained a high-risk zone.

After being re-elected in 2024, U.S. president Donald Trump commenced the nation's second withdrawal from the Paris climate agreement. His decision reversed the U.S. decision to rejoin the agreement during President Joe Biden's administration in 2021. The phrase "drill, baby, drill," widely associated with a push for increased oil and gas drilling, was prominently used by Trump during his 2024 presidential campaign.

In 2024, ammonia-powered engines continued to make significant progress, particularly in the maritime transportation sector. Several ship-to-ship ammonia bunkering trials were conducted, and the first ammonia-powered tugboats began operations. The MAN ME-LGI two-stroke ammonia engine was tested at full scale and is expected to become commercially available in 2025. Wärtsilä signed a letter of intent with Viridis Bulk Carriers, a Norwegian shipping company, to integrate the Wärtsilä 25 ammonia engine into a fleet of zero-emission bulk carriers. Finally, WinGD secured contracts for the installation of 6X52DF-A ammonia-fueled engines, built by Hyundai Heavy Industries, on seven liquefied petroleum gas (LPG)/ammonia carriers in China.

Hydrogen engines designed for off-highway applications, such as construction and agriculture, as well as small boats and automobiles, also continued to gain traction. Deutz finalized preparations for the TCG 7.8 H2 hydrogen combustion engine, which entered full production in 2024. Bosch Mobility debuted its first hydrogen combustion engine at the Consumer Electronics Show (CES) 2024 event. Yanmar Power Technology successfully completed trials of its pilot-ignition hydrogen 4-stroke engine. Auto manufacturers Toyota, BMW, Daimler, and Rolls Royce announced smaller hydrogen engines, (e.g., the HySE-X1 hydrogen engine showcased during the Dakar 2024 Mission 1000 Challenge).

The Haru Oni plant in Chile scaled up its production of e-fuels to 55 million liters annually in 2024. Marine fuels and sustainable fuels for the aviation industry remain high on the AMF agenda — priorities that are reflected in the new strategic work plan, which was approved in late 2024.

AMF continued its string of physical meetings at a reduced pace of one per year with a virtual meeting in between. The physical meeting in 2024 was held in Seattle, USA, kindly hosted by Pacific Northwest National Laboratory. The meeting provided valuable insights into activities on advanced motor fuels in the United States, U.S. automakers' interest in hybrid electric vehicles, and U.S. biofuel producers' activities in sustainable aviation fuel (SAF) production from ethanol. Marquis Energy and the United States Council for Automotive Research (USCAR) generously sponsored the arrangement.

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

Annual Report 2024 Production Notes

This Annual Report was produced by Kevin A. Brown (project coordination/management), Mary Fitzpatrick and Kathryn Jandeska (editing), Lorenza Salinas (document production), and Mike Holik (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 Innovation, Mobility, and Infrastructure (BMIMI)
Brazil	Energy Research Office
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 61	Remote Emission Sensing	Åke Sjödin
Task 62	Wear in Engines Using Alternative Fuels	Jesper Schramm
Task 64	E-Fuels and End-Use Perspectives	Zoe Stadler
Task 65	Powertrain Options for Non-Road Mobile Machinery	Rasmus Pettinen
Task 66	Recent Progress in Sustainable Aviation Fuels (SAF) Research	Doris Matschegg

Currency values in the Country and Task reports rely on the exchange rate at the time of 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,	BEST (Bioenergy and Sustainable	Secretary
Kerstin Brunbauer	Technologies GmbH)	Assistant to the Secretary

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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:

- Can reduce greenhouse gas (GHG) emissions and criteria air pollutant emissions,
- Have been or can be sustainably and (cost-) efficiently produced, and
- Are efficient to use in engines.

Fuels are needed in the on-road, long-haul, and heavy-duty transport sector and in non-road applications (e.g., forestry, agriculture, mining, and construction); in the marine and aviation transportation sectors; and in regions that continue to rely on fuels. Such fuels will enable clean, low-carbon, and efficient passenger and freight transport, economic development, and energy security for countries around the globe.

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

- Address the technical, environmental, economic, and social effects of advanced motor fuels, while considering the impact of various policies in the transport sector.
- Explore varied combustion technologies and the best use of advanced motor fuels.
- Encourage advanced motor fuels research activities in all modes of transport and assess the optimal allocation of different fuels in different transport subsectors.
- Promote cooperation among countries and TCPs in all aspects of motor fuels throughout the value chain — from fuel production to end-use.
- Provide support in overcoming barriers for the deployment of advanced motor fuels.

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 Innovation, Mobility, and Infrastructure (BMIMI) (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 among 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 **Subcommittees** 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 goals for the meetings of the Executive Committee, the Strategy Subcommittee, and the Technology Subcommittee are 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 evolution of AMF's scope, and efficient reaction to identified technology gaps or market barriers.

Current Work Program
Six projects were ongoing in 2024; three have since been closed:
- Task 28: Information Service and AMF Website
- Task 61: Remote Emission Sensing
- Task 62: Wear in Engines Using Alternative Fuels
- Task 64: E-Fuels and End-Use Perspectives
- Task 65: Powertrain Options for Non-Road Mobile Machinery
- Task 66: Recent Progress in Sustainable Aviation Fuels (SAF) Research

Cooperation with Other TCPs

The following transport-related TCPs comprise 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 2024

Task Number	Title	Task Manager
28	Information Service and AMF Website	Dina Bacovsky
61	Remote Emission Sensing	Åke Sjödin
62	Wear in Engines Using Alternative Fuels	Jesper Schramm
64	E-Fuels and End-Use Perspectives	Zoe Stadler
65	Powertrain Options for Non-Road Mobile Machinery	Rasmus Pettinen
66	Recent Progress in Sustainable Aviation Fuels (SAF) Research	Doris Matschegg

Tasks 61, 62, and 64 concluded in 2024. 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 2025.

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 48,000 (USD 52,100)
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 March 2024
    - Issue No. 2 July 2024
    - Issue No. 3 December 2024
- 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.

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 or by identifying a relevant Task in Figure 1 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 LinkedIn. Items focus on statements from AMF Task reports and Task key messages, and they also promote the AMF newsletter.

Publications

In 2024, the AMF TCP published three 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 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 227,938)
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 2024. 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 (https://cares-public-app.azurewebsites.net/) developed in 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 2024, we reported activities and progress in Executive Committee meeting 67. Four Task 61 work meetings were arranged in 2024, focusing on preparation of the final Task 61 report and a final dissemination webinar arranged in early June.

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.

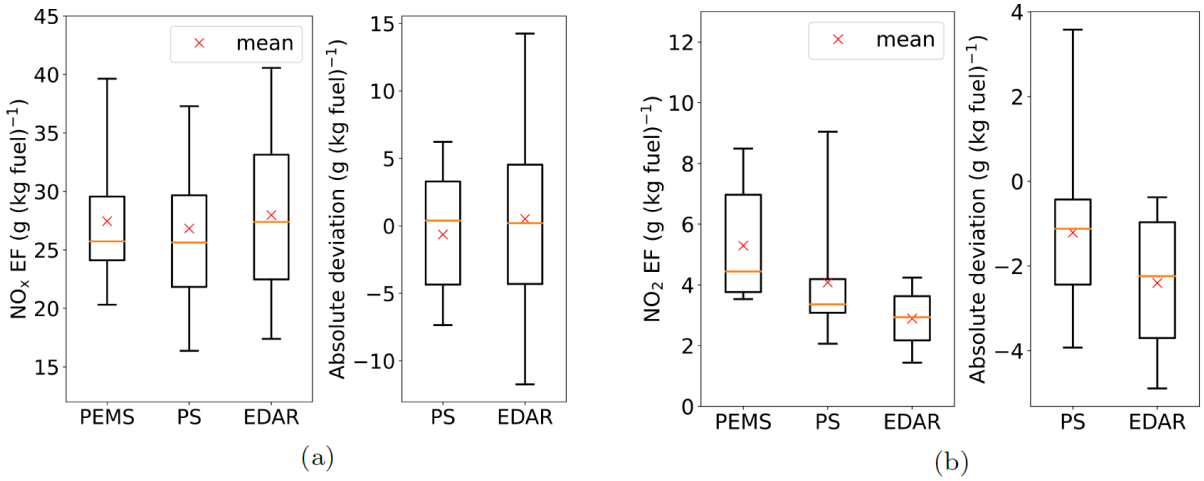


Figure 1. (a) Comparison of NO_x-fuel-based emission factors (EFs) measured with PEMS, RES Type 2 (point sampling [PS]) and RES Type 1 (emissions detection and reporting [EDAR]). Left: Boxplots of the EFs. Right: Deviation of PS and EDAR measurements compared to PEMS. (b) Comparison of fuel-based NO_2 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 on partner cities' measurements campaigns. https://cares-project.eu/city-measurement-summary/.
2. Knoll, M., M. Penz, C. Schmidt, D. Pöhler, T. Rossi, S. Casadei, Y. Bernard, Y., Å. Hallquist, Å. Sjödin, and A. Bergmann (2024) Evaluation of the point sampling method and inter-comparison of remote emission sensing systems for screening real-world car emissions (2024) *Sci. Tot. Env.*, **932**, 171710. https://doi.org/10.1016/j.scitotenv.2024.171710.
3. Knoll, M., Penz, M., Juchem, H., Schmidt, C., Pöhler, D., and Bergmann, A. (2024) Large-scale automated emission measurement of individual vehicles with point sampling *Atmos. Meas. Tech.*, **17**, 2481–2505. https://doi.org/10.5194/amt-17-2481-2024.
4. Schmidt, C., Carslaw, C. D., Farren, J. N., Gijlswijk, N. R., Knoll, M., Ligterink, E. N., Lollinga, J. P., Pechout, M., Schmitt, S., Vojtíšek, M., Vroom, Q., & Pöhler, D. (2025) Optimisation and validation of Plume Chasing for robust and automated NOx and particle vehicle emission measurements *Atm. Env.: X*, **25**, Article 100317. https://doi.org/10.1016/j.aeaoa.2025.100317.
5. Borken-Kleefeld, et al. (2023) CARES deliverable D4.8 — Final Report on High-emitter & clean vehicle identification. https://cares-project.eu/high-emitter-profiles/.
6. Sjödin, Å., et al. (2023) New knowledge on high-emitters and on-road emissions from the H2020 CARES project. Presentation at the Task Force on Emission Inventories and Projections Annual Meeting, Oxford, April 2023. https://www.tfeip-secretariat.org/oxford-2023.
7. Bernard, Y., et al. (2023) CARES deliverable D4.5 — Report on real-world emission factors and impact of low-emission zones. https://cares-project.eu/emission-factors-lez-impact/.

The Final Task 61 Report and associated Key Messages can be downloaded from: https://www.iea-amf.org/content/projects/map_projects/61.

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 162,000)
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 was to identify and present an overview of potential wear issues to prevent major surprises in the future.

The Task evaluated excess wear in internal combustion engines caused by the use of alternative fuels. The objectives were to review ongoing related projects in the member countries and conduct a general literature review to evaluate engine wear problems that can be foreseen with future application of alternative fuels.

The key questions to be addressed were 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

The Task involved 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, the Task members compiled the available information and reported 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 have been communicated through presentations from the responsible “activity” persons (or other designated people) at frequent seminars. The results from the seminars provided a background for the literature review report.

Key Findings

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

Main Conclusions

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

Publications

Task 62: Wear in Engines Using Alternative Fuels. Main report edited by Jesper Schramm

Task 62: Wear in Engines Using Alternative Fuels. Wear associated with application of methanol in combustion engines - Chinese experiences edited by Wei Anli

Task 62: Wear in Engines Using Alternative Fuels. The influence of fuel H/C ratio on engine wear Denmark: Rune WK Christensen, Jesper Schramm Germany: Fanny Langschwager, Ulrike Schuemann, Bert Buchholz

Task 64: E-fuels and End-Use Perspectives

Project Duration	May 2022–November 2024
Participants **Task sharing** **Cost sharing**	 Brazil, China, Denmark, Finland, Germany, Japan, Switzerland, USA None
Total Budget	EUR 200,000 (USD 216,900)
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 net-zero policy of most countries requires actions to reduce and replace the use of fossil fuels. These fuels are energy carriers that are currently used for mobility, industry, heating, and other purposes. There are some applications, such as aviation or international shipping and other "hard-to-abate" sectors, which cannot easily be electrified for long distances and involve difficulty to obtain low emission fuels. Therefore, demand for fuels will remain and these fuels will need to be produced from renewable energy or lower carbon intensity sources in the coming decades. The energy transition means that new technologies are tested and deployed to replace the fossil fuels. One option for fuels with low-carbon emissions could be e-fuels.

The technologies for e-fuel production and application are being developed around the world. Task 64 on e-fuels and end-use perspectives was set up in the AMF TCP to assess their significance at the international level. The aim was to gain an overview of the status of e-fuels in the various countries involved. The application of these fuels, some of which are new, is relevant for AMF TCP as they can be used for motorized processes. At the same time, there is still little experience in the use of these new fuels, as their production is still in infancy.

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

- Demo sites/pilot programmes
- Carbon dioxide (CO_2) and hydrogen (H_2) resources
- Application side
- Regulations and standards
- Life-cycle assessment (LCA)
- Techno-economic assessment (TEA)
- Stakeholders

Activities

The collaborating countries were Brazil, China, Denmark, Finland, Germany, Japan, Switzerland, and the USA (see list of participants). Furthermore, collaboration and exchanges with IEA Bioenergy TCP, IEA Hydrogen TCP, IEA HEV TCP, IEAGHG, and the International Transport Forum took place. The task was managed by Zoe Stadler, OST Eastern Switzerland University of Applied Sciences.

In the task, workshops around different e-fuel specific topics were organized, during which the task participants formulated key messages and joint conclusions that served as the basis for the final report. Various specific e-fuel topics were included: demo sites and pilot programmes, resources, application, regulations, life-cycle assessments, techno-economic assessments, and stakeholders.

The final task report provides an overview of ongoing activities in the participant countries, 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.

The duration of the task was two years with the main findings presented at a webinar.

Key Findings

Several countries have launched strategic programs to increase the production of e-fuels. These initiatives provide incentives, support research, or enact regulations that mandate a certain percentage of e-fuel use.

Key findings of task 64 are:

- E-fuels and biofuels must be considered together in the energy strategy, as both will play a crucial role in hard-to-electrify sectors (aviation, shipping, heavy-duty road transport, and industry).
- Some e-fuels can be produced with mature technologies, but the combination of several technologies in an e-fuel production plant can have a low overall technology maturity level.
- Strategic programs to support e-fuel production have been implemented in several countries. They consist of incentives for e-fuel production, support for research projects, and/or regulations that make the proportionate use of e-fuels mandatory.
- The energy-intensive production of e-fuels leads to the discussion as to whether they should primarily be used for applications that are difficult to electrify. These hard-to-abate sectors are the aviation industry, maritime applications, and industrial processes.
- Hydrogen production via water electrolysis has the largest impact on the carbon intensity of the product. Life-cycle assessments results show that using renewable electricity is key to having low-carbon e-fuels.
- The most important cost driver in the production of e-fuels is hydrogen production by water electrolysis, and production costs depend primarily on electricity prices, which depend on the geographical location, and capital costs.

Main Conclusions

To reach a net zero target in the energy and mobility system, e-fuels will play an important role together with biofuels. 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 can combine the synergies and benefits of e-fuels and biofuels. The opportunities that arise with the energy transition will lead to an increase in the 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 near future, there will be several emerging industries coexisting and eventually replacing the traditional technologies. Energy systems will follow a process of carbon intensity reduction, as the climate agenda will increasingly influence international trade and international relations.

In general, biofuels production technologies have a higher technology readiness level (TRL) than e-fuels. Some e-fuels, such as FT fuels or methanol, can be produced as well from high TRL or mature technologies. However, it needs to be pointed out that although some single technologies might have a high TRL, the overall TRL in the combination of several technologies in an overall plant can be lower.

In the strategies of most countries, e-fuels are regarded as important for different applications in the future. 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, of support for research projects or of regulations that make a certain percentage of the use of e-fuel mandatory, or a combination of these three. Next to political programmes, companies are also enforcing the use of sustainable fuels in order to reduce their carbon footprint.

The production of e-fuels is very energy-intensive if based on water electrolysis, which is why it is being discussed 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 international aviation, fuels need to be ASTM certified. According to ASTM D7566, the following routes are suitable for SAF production: hydroprocessed esters and fatty acids (HEFA), hydroprocessed HEFA (HC-HEFA), catalytic hydrothermolysis jet (CHJ), synthetic isoparaffins (SIP), alcohol to jet (ATJ), synthetic paraffinic kerosene (SPK-A), and synthetic paraffinic kerosene – Fischer-Tropsch (SPK-FT). In the shipping industry, e-methanol, e-ammonia, e-methane, and hydrogen are considered interesting for the use. Regulations for onboard use of methanol and liquefied methane exist today and thus gives their implementation an advantage over the implementation of ammonia or hydrogen.

When producing e-fuels, water electrolysis is a key technology. It is necessary for all e-fuel production pathways and 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 having low-carbon e-fuels. Usually, using electricity grid mix for producing e-fuels does not provide greenhouse gas (GHG) emission reduction benefits compared to the fossil baseline fuels. It is therefore crucial to use low-emission electricity sources to obtain an ecological benefit. The analysis shows that e-FT fuels and e-methanol present significant GHG reduction benefit coupled with renewable electricity and/or H_2 compared to their fossil counterparts. Regional distribution of CO_2 sources and the available freshwater need to be considered further. As the amount of freshwater needed as a renewable source of hydrogen for e-fuel production is significant, 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.

The key cost driver of e-fuel production is hydrogen, of which the production cost mainly depends on electricity prices and capital cost. Since electricity costs depend on the geographical area, the location of a production facility has a major influence. To achieve low-cost hydrogen for economical e-fuels production, both electricity cost and electrolyser capital cost needs to decrease greatly. There are ambitious learning curves assumed, and high operating capacities are needed (and a challenge). The costs of e-fuel production can additionally be lowered by increasing the efficiencies of e-fuel production technologies, increasing the size of production plants, and lowering costs for other resources like CO_2 and nitrogen. The price for the CO_2 is mainly defined by post-combustion technologies like capture, purification, compression, and cooling. Point sources are more economical, as capture costs increase with decreasing concentrations. However, e-fuels are generally more expensive than biofuels. Appropriate carbon pricing and low renewable power cost are critical to enhance the economic competitiveness of e-fuels.

Despite economic challenges, projects aimed at production of e-fuels are announced frequently and across the globe. Political programmes and customer demand are the main drivers of this development, and a major expansion of production facilities is expected. It remains to be seen which technologies will prevail and which countries will be the main producers and exporters.

Task 65: Powertrain Options for Non-Road Mobile Machinery

Project Duration	November 2023–November 2025
Participants **Task sharing** **Cost sharing**	 Austria, Canada, Denmark, Finland, Germany, 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 United States will assemble its industry stakeholders to present their visions and activities to decarbonize the NRMM sector in the United States and globally.

New task members
During 2024, Task 65 welcomed two new countries onboard, Austria and Germany. The Task contribution for these countries is stated as follows.

Austria's Task-sharing contribution:
- To generate a comparison of requirements considering Pressure Regulation Directive (PRD for NRMM), UN ECE R 134 (Automotive) and other proper hydrogen ISO standards.
- To establish and strengthen an argumentation for an interim compliance solution without adoptions in the PRD:
    - With reference to the knowledge of step 1, lining out in position papers (policy documents) that relevant requirements of the R 134 are sufficient also for NRMM where the wheel loader is just the reference machine.
    - Outlining in these position papers that out of the technical point of view the R 134 requirements are more practical for hydrogen machinery components than the PRD requirements.

Germany's Task-sharing contribution:
- Import national data from NRMM of the agricultural sector.
- Assess the availability of alternative drive technologies for agricultural machinery, incl. biofuel approval, series produced NRMM, retrofitting technology and battery electric drives.

- Contribute with a strategy/vision for decarbonisation of agricultural NRMM according to KTBL working group “Antriebssysteme für landwirtschaftliche Maschinen.”
- Distribute relevant information about the national regulatory framework (regarding targets, approvals, taxes, incentives).
- Report real driving emission and fuel consumption data for different agricultural tractors (exhaust stage IV and V) operated with various biofuels (e.g. HVO 100, FAME 100, Pure Rapeseed Oil 100) of already finished and ongoing PEMS measurement projects.
- Report PTO test stand data (limited exhaust emissions, fuel and urea consumption, efficiency) for different agricultural tractors (exhaust stage IV and V) operated with various biofuels (e.g. HVO 100, FAME 100, Pure Rapeseed Oil 100) of already finished and ongoing measurement projects.

Task status

During 2024, Task 65 held three joint task progress meetings. The task progress meetings focused on aligning and planning the content and work within given work packages. Additionally, methodologies and options on how to efficiently manage and merge the data that would be collected from relevant sources/partners by country were discussed. The collected data will be merged based on work package deliverable and data type during 2025. Task 65 work packages are defined as follows:

WP1: Task management
WP2: Review of alternative powertrains deployment and regulatory framework
WP3: Testing
WP4: Modelling and simulation
WP5: Cooperation with other IEA TCPs

Furthermore, a workshop related to decarbonization options and implementation of sustainable, alternative powertrain options is planned for 2025.

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.

Task 66: Recent progress in SAF research

Project Duration	October 2024–September 2027
Participants **Task sharing** **Cost sharing**	Austria, Brazil, China, Denmark, Germany, Spain, Switzerland, USA
Total Budget	290,000€ (314,542$)
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/66

Purpose, Objectives and Key Question

Sustainable aviation fuels (SAF) are being promoted as an important way to reduce greenhouse gas (GHG) emissions from the aviation sector, which is responsible for about 2% of global GHG emissions, 14.4% of EU transport emissions, and 11% of US transport emissions. However, there is a gap between supply and demand of SAF as such fuels currently represent only about 0.1% of global aviation fuel consumption (about 0.27 million t in 2022). IEA´s 2023 update to the Net Zero by 2050 Roadmap shows the need for a significant ramp-up of biofuels, hydrogen, and hydrogen-based fuels in the aviation sector to almost 15% of energy consumed in 2030 and 80% in 2050. In October 2022, member states of the International Civil Aviation Organization (ICAO) agreed to a long-term aspirational goal (LTAG) of net-zero carbon dioxide (CO_2) emissions from aviation by 2050, with a simultaneous increase in traffic volume of about 3% per year. To achieve this ambitious target and to fill the gap between supply and demand, further research on SAF production as well as on end-use aspects of SAF utilization needs to be conducted. Task 66 will organize information exchange on recent research on sustainable aviation fuels between researchers and other stakeholders in the field of aviation.

The purpose of the SAF follow-up Task is to facilitate information exchange between the participating countries on recent SAF research through a series of online workshops. Topics for the online workshops will be jointly defined during scoping meeting(s) and will reflect the R&D interests and ongoing projects of the participants. Conducting these workshops will also serve to enlarge the existing AMF network of SAF stakeholders by including further stakeholders, to be identified during the initial stage of the proposed Task. This is important to ensure that the voice of stakeholders (industry, academia, policy makers, working groups, and initiatives) will be heard, hereby increasing the relevance of the workshop topics within this Task for stakeholders.

Three key areas of interest have been identified: SAF production, SAF utilization, and policy recommendations. A number of key workshop topics within these areas of interest have already been identified in Task 63 and during the preparation of the Task description. Prioritization, sequence, and details of the workshops will be further elaborated upon during scoping meetings during the Task implementation. For each topic at least one partner takes the lead for the workshop supported by the Task Manager.

Activities

The activities of the SAF follow-up Task will be a series of in-depth discussion in form of thematic workshops about recent research work on sustainable aviation fuels to realize the potential of SAF and their emission reduction contribution to the net-zero target. Stakeholders in the field of aviation (industry, academia, policy makers, international organizations, finance sector), which have been identified during Task 63 (as well as additional stakeholders), will be invited to participate in this information exchange.

Planned activities within this Task are listed below:

- Identification of additional stakeholders in the field of aviation (industry, academia, policy makers, international organizations, finance sector). All Task participants will contribute.
- Organization of scoping meetings with Task participants to further process already identified main barriers for market uptake and discussion on additional barriers and research needs as input for the online workshops. The topics for the online workshops will be agreed on during annual scoping meetings. The Task Manager will organize the first scoping meeting as part of the kick-off meeting. During the scoping meeting the Task participants fix the workshop topics and their sequence for the first year. The Task Manager will propose a guideline for the workshop structure and a documentation template in the first scoping meeting.
- Definition and publication of the outline of the workshop series on the Task website, based on input from Task participants and stakeholders during the scoping meetings. In order to facilitate communication and ensure that all interested parties are kept informed of upcoming events, an option will be made available on the website to subscribe to an email list. This will allow users to receive notifications of workshop announcements. The Task Manager will be in charge of the Task website.
- Organization of 10 online workshops (2 hours each). Central communication will be performed by the Task Manager based on information from Task participants. Workshop topics will be distributed among Task participants and they will act as Workshop Leaders.
    - Invitation of relevant stakeholders regarding the topic of discussion (Task participants)
    - Provision of information material to the respective topic prior to the online workshops (prepared by Workshop Leader, publication on website by Task Manager)
    - In-depth discussion on the respective topic during the workshop. If necessary, the same topic can be discussed in more than one workshop (Task participants and stakeholders)
    - Summary Information Sheets will be provided on the Task Website after the workshops, creating a central point of knowledge, on main findings, key messages, policy recommendations (if applicable), and further research needs for upcoming workshops (topics of stakeholders can be integrated in the workshop outline) (Prepared jointly by the Task Manager and the Workshop leader)
- Development of national recommendations (Task participants for their own countries, not obligatory)
- Documentation of the information gathered during the discussions at each online workshop in brief information sheets (Workshop Leader together with Task Manager)
- Compilation of a final report composed of elements of the information and summary sheets of each workshop, highlighting the most relevant findings, and creation of a key messages document (Task Manager, input from all)

Key Findings

Due to the early stage of Task 66, no key findings have yet been identified. However, the Task Participants agreed on the topics for the first online workshops during the Scoping Meeting.

- Q1 2025: Enable the use of drop-in unblended SAF and SAF blends up to 100%
- Q2 2025: Identification of production process parameters and desirable end-use properties, relevant to mixture preparation, combustion, stability and emission formation through experiments and simulations (take off, cruise etc.)
- Q3 2025: Monitoring of SAF R&D, demonstration projects and production deployment
- Q4 2025: Status and developments of engine technology in aircrafts using SAF
- Q1 2026: Recommendations of new policy measures to further promote SAF production and utilization

Main Conclusions

Not yet applicable

Publications

Not yet applicable

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 by +38% since 1990 mainly because 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 because of lower amounts of fuel sold, increased use of biofuels for blending, and an improved fleet with lower specific fuel consumption. Until 2022, GHG emissions from transport had gradually increased again, except for a sharp decrease during the pandemic (2020). Since 2022, GHG emissions have again decreased, leading in 2024 to the lowest value since 2000.

According to Environmental Agency Austria, in 2024, the transport sector in Austria generated GHG emissions of approximately 19.1 million tonnes of carbon dioxide equivalent (CO_2e) (compared with 19.8 million tonnes of CO_2e in 2023). In 2023, emissions decreased by 3.8% (compared with a decrease of 4.6% in 2022, or 21.6 million tonnes of CO_2e) as a consequence of the reduced fuel exports in the heavy commercial vehicle sector. In 2022, 58% of the road transport GHG emissions were caused by passenger cars, 8% by light-duty vehicles, 32% by heavy-duty vehicles and buses, and around 1% by mopeds and motorcycles. Railway, air traffic, shipping, and military accounted for 1% of GHG emissions.

In 2022, biofuels (all types) replaced around 5.75% of fossil fuels sold. This share meets the substitution target of 5.75% of fossil fuel on the market, as stipulated in the Fuel Ordinance, and represents a decline compared with previous years. The relatively low sales volume of pure biofuels is due to its relatively lower commercial competitiveness compared with fossil fuels. In 2022, the use of biofuels resulted in a reduction of approximately 1.32 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, including a taxation system that imposes a price penalty on ecologically destructive activities. Enacted in 2021 and described in the National Emissions Trading Act of 2022 (NEHG 2022), the system introduced continuously increasing price penalties for CO_2e, ranging from EUR 30 (USD 32.4) per ton in 2022 to EUR 55 (USD 59.4) per ton in 2025. In 2022, the CO_2 pricing scheme resulted in a price increase of 8.17 cents (including value added tax [VAT]) per litre of petrol (with blending) and 9.0 cents (including VAT) per litre of diesel (with blending).

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 2030 Mobility Master Plan and the corresponding research and innovation (R&I) Mobility Strategy. Complementary strategic plans for freight transport (the Freight Transport Master Plan 2030) and for hydrogen (the Hydrogen Strategy for Austria) have also been developed. 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.

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. The NECP 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 energy share, in relation to the energy content of diesel, is about 6.3%; for petrol, it is currently about 3.4%. The NECP contains the national plan with a commonly shared vision, national targets and objectives, and policies and measures to ensure the achievement of the national climate targets.

Incentives and Pricing

In July 2008, Austria introduced the NoVA tax for new vehicles. Such taxes — 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. 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 2025. Each additional gram/km per year 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 also exempt from the mineral oil tax, but it is subject to the lower natural gas tax.

Advanced Motor Fuels Statistics

Fleet Distribution and Number of Vehicles in Austria

2024 marked the fifth time in Austria's history that the total number of motor vehicles registered in the country exceeded 7 million, with 7.43 million registered motor vehicles — an increase of 1.2% or 84,790 vehicles compared with 2023. Passenger vehicles dominate the fleet with 5.23 (compared with 5.19 in 2023) million vehicles (Table 1), representing the largest share (70.5%) of vehicles in Austria.

Fleet numbers demonstrate a slight but continuous trend toward advanced, alternative propulsion systems, especially toward battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs) (Figure 1). For instance, 200,603 BEVs and 242,094 HEVs were registered in 2024, illustrating a positive trend continuing from previous years. The number of vehicles powered by CNG and liquefied petroleum gas (LPG), including bivalent vehicles, decreased in 2024 by 8.2% (420 vehicles), representing a moderate fleet level of 4,694 vehicles (compared with 5,114 in 2023). The number of bivalent vehicles decreased from 2,771 in 2023 to 2,521 in 2024, and the CNG vehicle fleet decreased marginally from 2,342 in 2023 to 2,172 in 2024. With only 62 vehicles (67 in 2023), the fuel cell electric vehicle (FCEV) fleet in Austria is still negligible.

Table 1. Austrian Fleet Distribution of Passenger Vehicles (M1) by Drivetrain, 2018–2024

Drivetrain	2018	2019	2020	2021	2022	2023	2024
Gasoline	2,133,473	2,173,772	2,190,388	2,192,128	2,189,530	2,184,042	2,183,076
Diesel	2,776,333	2,772,854	2,762,273	2,717,475	2,651,280	2,584,985	2,510,099
Electric	20,831	29,523	44,507	76,539	110,225	155,490	200,603
LPG	2	2	2	1	1	1	1
CNG	2,365	2,602	2,753	2,654	2,564	2,342	2,172
Hydrogen (H_2)	24	41	45	55	62	67	62
Bivalent gasoline/ ethanol (E85)	5,769	5,770	5,190	4,878	4,595	4,326	3,424
Bivalent gasoline/LPG	333	330	330	331	331	334	297
Bivalent gasoline/ CNG	3,177	3,143	2,978	2,801	2,616	2,437	2,224
Hybrid gasoline/ electric	34,086	45,645	68,983	108,978	148,284	195,439	257,588
Hybrid diesel/ electric	2,463	6,172	14,378	27,996	41,402	55,543	72,347
Total	4,978,856	5,039,854	5,091,827	5,133,836	5,150,890	5,185,006	5,231,893

Source: Statistik Austria.

New Registrations

In 2024, 253,789 (compared with 239,150 in 2023) new passenger cars were registered. After 2023 with +11.2% (+24,100 vehicles) registrations, 2024 again showed an upward trend of 6.1% (+14,639 vehicles). In 2024, new registrations of petrol-powered vehicles increased by 8.6% (+14,639 units). Registrations of diesel-powered vehicles continued to fall, by 5.2% to 44,132 (versus 46,568 in 2023).

With 44,622 new registrations, all-electric passenger cars showed a decrease of 6.3%. The number of vehicles with hybrid drivetrains also increased (petrol-hybrid: +25.9%, diesel-hybrid: -1.9%). In 2024, the share of all-electric passenger cars was 17.6%; the share of hybrid passenger cars was 31.9%.

Overall, the share of all alternatively powered passenger cars increased to 49.5% (compared with 48.2% in 2023), confirming the transition toward alternative drivetrains.

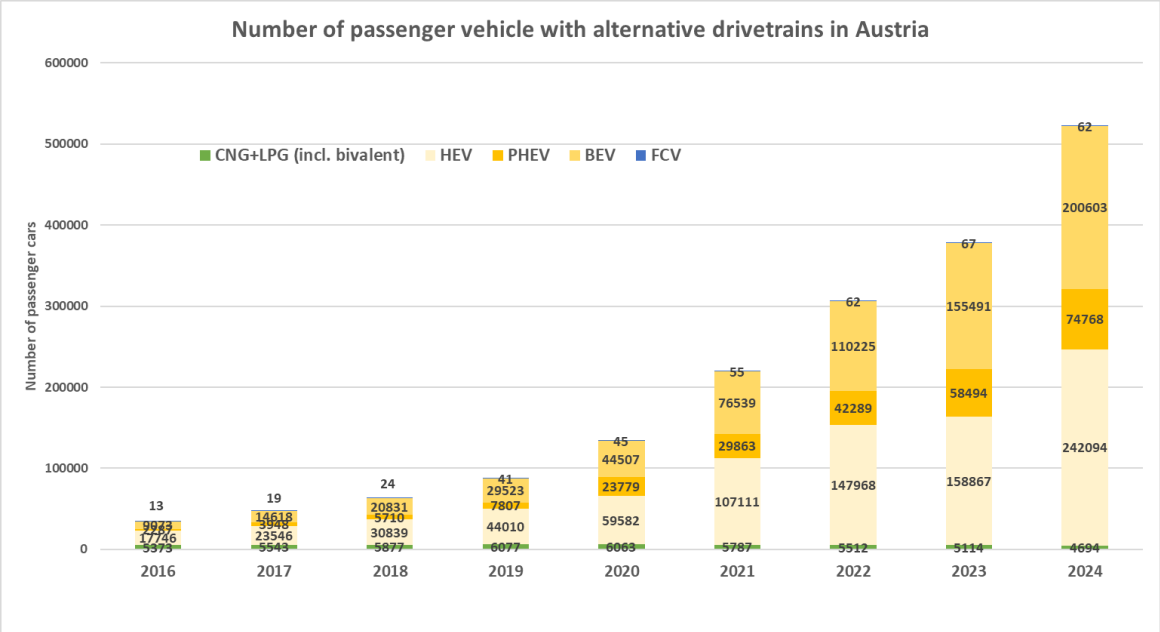


Figure 1. Trends for vehicles with alternative drivetrains in Austria, 2016–2024 (Source: Statistik Austria)

Average CO_2 Emissions of Passenger Cars

In 2024, the CO_2 emissions of newly registered passenger cars measured, on average, 129 g/km (compared with 130 g/km in 2023), based on the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) and excluding electric and hydrogen vehicles. The number drops to 106 g/km (compared with 104 g/km in 2023) if electric and hydrogen vehicles are included in the calculation. The average emissions for petrol-powered M1 vehicles in 2024 is 134 g/km (compared with 138 g/km in 2023); diesel-powered passenger vehicles generate an average of 149 g/km (compared with 146 g/km in 2023).

Development of Filling Stations

By the end of 2023, Austria had 2,751 publicly accessible filling stations (compared with 2,759 in 2022). As an annual average for 2024, the price of gasoline for private use at a filling station was EUR 1.573 (USD 1.699) per liter; the price of diesel was EUR 1.597 (USD 1.725) per liter. In 2024, 79 public CNG stations are available, and 40 LPG filling stations are available (41 in 2023). In addition, six public liquified natural gas (LNG) filling stations are in Ennshafen, St. Marienkirchen, Reichersberg (Upper Austria), Feldkirchen (Styria), Himberg (Lower Austria), and Wals/Salzburg.

Austria has five publicly accessible hydrogen fueling stations (HFSs) all operated by OMV (an Austrian integrated crude oil, natural gas, and petrochemicals group). There are two more H_2 fueling stations, but access for 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 about each project. In 2024, the klimaaktiv website had a complete relaunch to enhance design, content, and usability. Total financial support until 2024 amounted to EUR 180 million (USD 194 million).

IEA Technology Cooperation Programmes Funding

Austria has been actively involved in the International Energy Agency (IEA) Technology Collaboration Programmes (TCPs) since joining the IEA in 1975. The TCPs are an important complement to Austrian national energy 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 experts who are 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 strategy focuses on four mission areas: cities, regions, digitalization, and technology. The annual budget ranges from EUR 15 million to EUR 20 million (USD 16.2 million to USD 21.6 million). A project database is available online.

CETP (Clean Energy Transition Partnership)

The Clean Energy Transition Partnership (CET Partnership) is a transnational initiative on joint research, technological development, and Innovation (RTDI) programming to boost and accelerate the energy transition, building upon regional and national RTDI funding programs. It brings together more than 70 partners from 32 countries. An Austrian national requirement for applicants is a clear focus on mobility. The yearly funding sum is around 1.5 to 2.0 Mio. EUR (USD 1.62 million to 2.16 million) for Austrian participants.

SET-Plan IWG (Implementation Working Group) on hydrogen

The Implementation Working Group (IWG) on hydrogen established in 2023 aims to implement part of the Strategic Research and Innovation Agenda (SRIA) of the European Research Area (ERA) pilot on green hydrogen and coordinate the work on hydrogen previously split between different IWGs of the SET Plan.

Outlook

In its government programme, the new Austrian government confirms the goal of reaching carbon neutrality by 2040 — 10 years earlier than the EU. Alternative fuels are indispensable for reaching this ambitious goal. The governmental programme reflects a continuation of measures defined in the Austrian Climate and Energy Strategy to reach this 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, as acknowledged in the new governmental programme.

The areas of deployment 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.

Use cases with high-energy-density demands, such as aviation, waterborne, or non-road mobile machinery applications focus on hydrogen, biofuel, and synthetic and advanced fuels. Although R&I funding schemes and programs are no longer directed at improving internal combustion engine (ICE) drivetrains, they aim to support the improvement and uptake of ICE applications, such as hydrogen, biofuel, and synthetic and advanced fuels for use cases with high-energy-density demands.

Since April 13, 2024, Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure has been 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 charging infrastructure — a prerequisite for an EU-wide transition toward alternative drivetrains. The new governmental programme states that the new EU Renewable Energy Directive III (RED III) regulation will be implemented as quickly and completely as possible (e.g., through acceleration of authorization procedures).

Additional Information Sources

- Federal Ministry for Innovation, Mobility and Infrastructure, https://www.bmimi.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). The Fuels of the Future Law (14993/2024), enacted by Brazilian President Luís Inácio Lula da Silva on October 9, 2024, allows for new biofuels mandatory blends for ethanol and biodiesel only after CNPE (Brazilian Energy Policy Council) approval. 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 and advanced fuels, including sustainable aviation fuels (SAF) and hydrotreated vegetable oil (HVO). 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). Another public policy that promotes the production and consumption of biofuels is the National Biofuel Policy, known as RenovaBio (Brazil 2017), which has been operational since March 2020.

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 fourth revision of its NDC concerning the Paris Agreement, Brazil committed to reducing its domestic greenhouse gas (GHG) emissions to between 59% and 67% below 2005 levels by 2035, which is consistent with an emission level of 1.05 to 0.85 gigatons CO_2 equivalent ($GtCO_2e$). The new commitment increases the emission reduction target set in the first NDC, consolidating a trajectory of increased ambition, as determined by the Paris Agreement. Between 2025 and 2030, the absolute emission reduction was 9% and, for the period from 2030 to 2035, the new NDC increases its goal to a reduction ranging from 13% to 29% (MMA 2024). 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, aimed to increase the level of ethanol blending in gasoline to 25% (E25) and introduce hydrous ethanol (E100 [approximately 95% ethanol and 5% water]) for use in dedicated vehicles. The program was successful until the 1990s, when falling oil prices reduced ethanol's competitiveness. However, in 2003, a new oil crisis boosted the manufacture of flex-fuel cars, which can use both alcohol and gasoline (EPE 2023). Since then, Proálcool has contributed significantly to Brazil's economy and sustainability, generating energy savings equivalent to more than 2.5 billion barrels of oil and resulting in savings of about $205 billion in gasoline imports (Brasil 2024d; Fapesp 2016).

[1] The agriculture sector represents 22.0% of Brazil's gross domestic product (GDP) in 2024 preliminary results until Sept. 2024 (CEPEA 2025)

[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.

- The *Brazilian Program for Production and Use of Biodiesel (PNPB)* was created by Law No. 11,097/2005, on January 13, 2005 (Brazil 2005), to further stimulate energy, economic, and social objectives and foster feedstock production among small farmers.
- *Flex fuel technology* was 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. According to the chronogram stipulated by CNPE, there was a gradual increase in the mandatory blend of biodiesel in diesel fuel. In April 2023, the established mix was set at 12% and, since March 2024, 14%.[4]
- *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.
- *Law 14,993/2024* (Brazil 2024b), sanctioned by Brazilian President Luís Inácio Lula da Silva on October 9, 2024 — This law, based on discussions under the Fuels of the Future Program, aims to further increase the use of sustainable and low-carbon fuels to decarbonize the Brazilian transport energy matrix. Allows the increase of ethanol mixed in gasoline from the current 27.5% to 35% and the increase of biodiesel mixed in diesel from the current 14% to 25%.
- *Federal and state tax differentiation* between renewables and fossil fuels[5] establishes 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]
- *Law 14,948/2024* (Brazil 2024c) establishes the regulatory framework for the production of low-carbon hydrogen. The law also creates incentive mechanisms for the sector, provides for the National Policy for Low Carbon Hydrogen; creates the Low Carbon Emission Hydrogen Development Program (PHBC), and establishes a voluntary certification.
- *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, INOVA-E, and other governmental initiatives dedicated to improving efficiency and innovation.
- *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 (December 30, 2023) enacted June 27, 2024, the *Green Mobility and Innovation Program (MOVER)*, offer 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

[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).

[5] Regarding federal taxes, gasoline and ethanol are subject to the following levies: the Contribution to the Social Integration Program and the Civil Service Asset Formation Program (PIS/Pasep), the Contribution to Social Security Financing (Cofins), and the Contribution for Intervention in the Economic Domain (Cide). The current PIS/Pasep and Cofins rates are R$ 792.50/m³ for gasoline A (pure gasoline, without ethanol), R$ 241.81/m³ for hydrous ethanol, and R$ 130.90/m³ for anhydrous ethanol. The current Cide rate is R$ 100/m³ for gasoline, while for both anhydrous and hydrous ethanol, it has been set at zero since 2004. As for the state tax, the ICMS follows a single-phase taxation system for gasoline and anhydrous ethanol sales, applying fixed and uniform rates nationwide. The current rate for these two products is R$ 1.47/l. For hydrous ethanol, however, the ICMS is applied under a different system, with ad valorem rates that vary by state. At present, the lowest ICMS rate is 11.33% in the state of Mato Grosso do Sul, while the highest rate is 22% in the state of Maranhão. (EPE 2025)

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

grave" life-cycle model. MOVER also includes a financial bonus for automakers that take into account some sustainable indicators.

- *Decree number 11,902* (January 30, 2024), which restructures the Social Biofuel Seal (Brazil 2024a) 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. Compared to year 2022, the number of registered families is estimated to grow by 120% this year. The Social Biofuel Seal is a fundamental instrument that has already guaranteed the participation of more than 54,000 family farmers in the biodiesel production chain (Brazil 2024e). 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, which is abundant in northeastern Brazil (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).
- PPI Program — Created by Law No. 13,334 of 2016, the Investment Partnerships Program (PPI) aims to modernize and increase the logistical efficiency of Brazil, covering all modes of transport (air, road, rail, waterway, and pipeline).
- Energy Efficiency Programs (PEE) (Programas de Eficiência Energética [PEE], linked to Law No. 9,991/2000) — These programs require public electricity distribution concessionaires and permit holders to annually invest in R&D of the electricity sector and in energy efficiency programs for end use.
- Brazilian Emissions Trading System **(**Sistema Brasileiro de Comércio de Emissões [SBCE], instituted by Law No. 15,042, December 11, 2024) — The SBCE regulates the carbon market in Brazil, establishing an emissions trading system to reduce greenhouse gases and stimulate low-carbon technological innovations.
- Energy Transition Acceleration Program (Paten [Programa de Aceleração da Transição Energética], instituted by Law No. 15,103, January 22, 2025) — Paten facilitates access to credit for sustainable projects, promoting clean technologies and expanding Brazil's renewable energy matrix.
- PLANTE National Energy Transition Plan (Plano Nacional de Transição Energética) — Part of the PLANTE is a long-term action plan to achieve the goals of the National Energy Transition Policy, aiming for a more sustainable energy matrix and neutrality in greenhouse gas emissions.
- National Integrated Plan for Natural Gas and Biomethane Infrastructure (Plano Nacional Integrado das Infraestruturas de Gás Natural e Biometano), instituted by Decree 12,153/2024. This plan aims to integrate and develop natural gas and biomethane infrastructure in Brazil, promoting a more sustainable energy matrix.

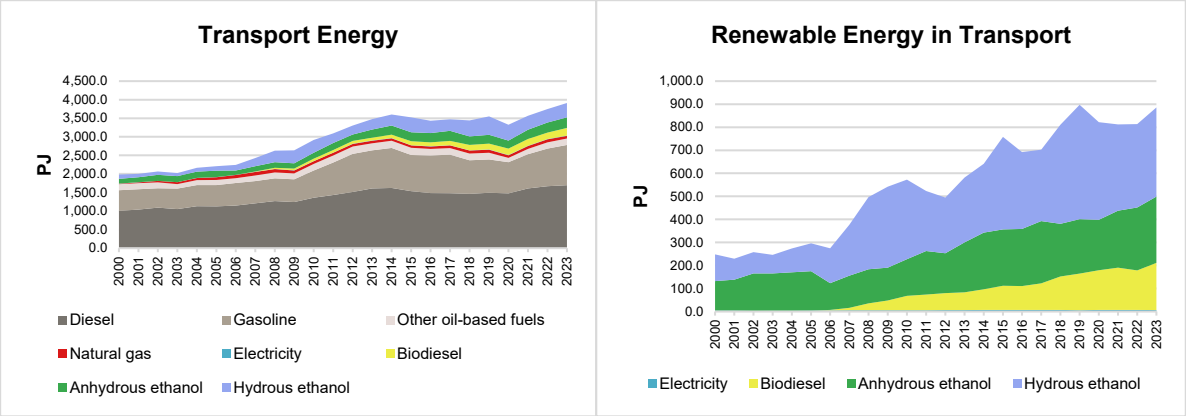
Advanced Motor Fuels Statistics

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 2023 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 10.8% (by energy) of diesel consumption in 2023, as Figure 2 shows.

Also as shown in Figure 1, electricity represents a share of 0.2% of total transport energy use in 2023, maintaining the share of previous years. This is mostly in rail — Brazil has no report of electricity used in road vehicles.



Figures 1 and 2. Evolution of Transport Fuels in Brazil, 2000–2023 (Source: EPE 2024a).

Table 1 displays the growth of the Brazilian fleet from 2013 to 2023.

Table 1. Growth of the Brazilian Fleet, 2013–2023

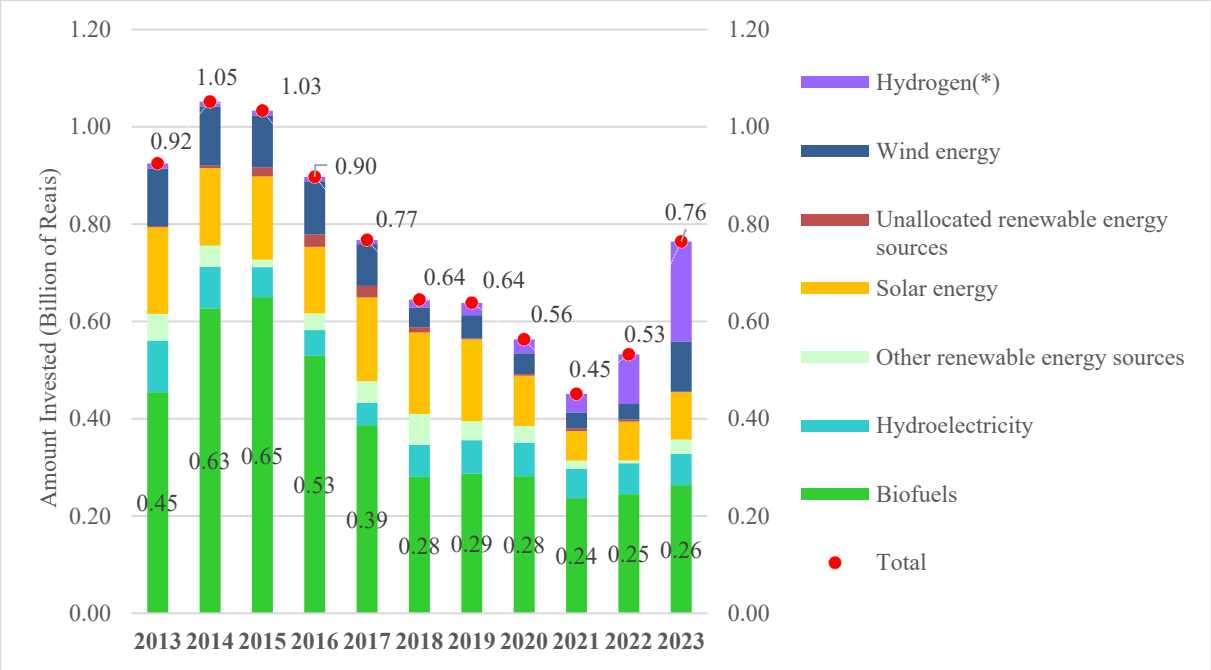
Stock of Vehicles	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Motor spirit cars	10^6	11,7	11,0	10,3	9,6	8,9	8,2	7,6	7,1	6,5	6,0	5,5
Diesel oil cars	10^6	1,7	1,8	1,9	2,0	2,1	2,2	2,3	2,3	2,4	2,5	2,7
Electricity cars	10^6	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,001	0,004	0,012	0,0
Other 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	0,1
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	30,9

Source: EPE 2024e.

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 2023,[9] 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 (Law 14,993/2024, Brazil 2024b), the government created and launched lines of financing and incentive mechanisms for biofuels. Furthermore, Law 14,948/2024, (Brazil 2024c) established the National Low Carbon Hydrogen Policy, having as one of its principles the promotion of R&D for the use of low carbon hydrogen. Figure 3 illustrates the annual distribution of public investments in renewable energy, including research, development, and innovation (RD&I), by source.

[9] The average 2023 USD to BRL exchange rate was 4.99 (BCB 2025).



*Hydrogen investments may include non-renewable hydrogen research.

Figure 3. Public Investments in Renewable Energy RD&I, 2013–2023 (Source: EPE 2024f).

Figure 4 displays the total amount of public financing specific to the sugar-energy sector. In 2023, total disbursements of the Brazilian Bank for Economic and Social Development (BNDES) in the agricultural area for the cultivation of sugarcane totaled USD 180 million (or roughly BRL 900 million) (BNDES 2024).[10]

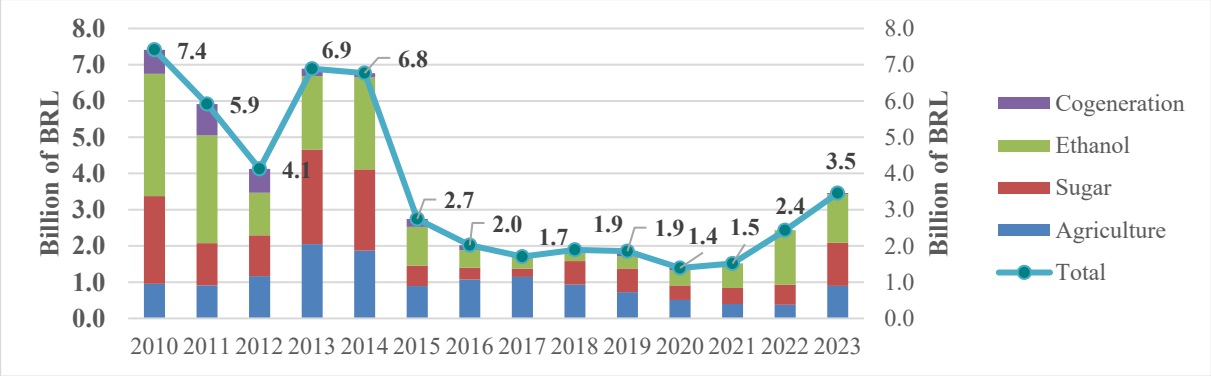


Figure 4. Public Funding for Sugar-energy Sector (Source: Constructed by EPE from data provided by BNDES [2025].

Outlook

Figure 5 consolidates the demand for fuel ethanol and other (non-energy) uses, which grows at an annual rate of 3.8%, in a ten-year period, reaching an estimated 45.7 billion liters in 2034, with the major increase coming from the demand for hydrous ethanol fuel. By 2034, the Brazilian fleet should achieve 45.4 million vehicles, according to the EPE (EPE 2024b).

[10] At the average 2023 USD to BRL exchange rate (BCB 2025).

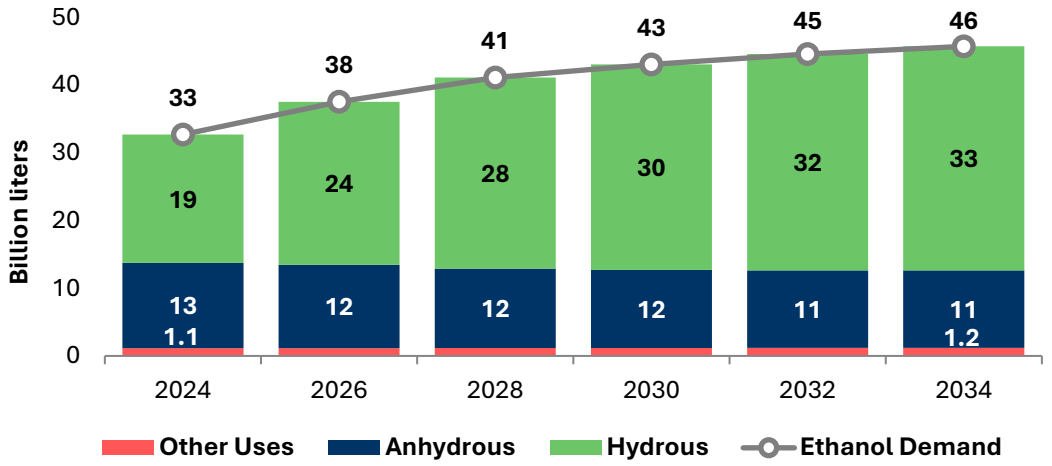


Figure 5. Forecast of Total Ethanol Demand, 2024–2034 (Source: EPE 2024b).

When added to imports, 0.5 billion liters, the total value of ethanol amounts (split into sugarcane and corn) to 48.0 billion liters. Figure 6 shows the forecast for total ethanol supply.

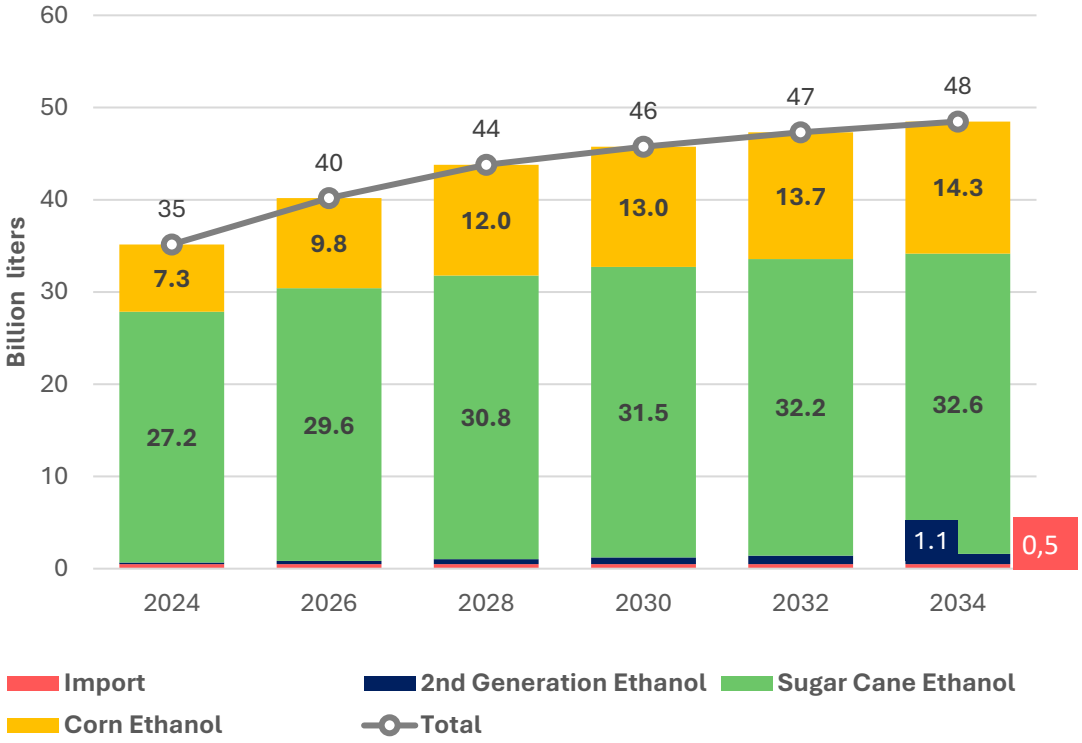


Figure 6. Forecast of Total Ethanol Supply, 2024–2034 (Source: EPE 2024b).

The biodiesel demand projections of this study were obtained based on the forecast of the regional consumption of oil diesel type-B (EPE 2024e) and the evolution of biodiesel blend, which follows CNPE stipulated chronogram according to Law No. 13,263/2016, will maintain 15% levels from 2025 onwards (Figure 7). Although there is no blend obligation for the maritime sector, voluntary tests with 24% blend on maritime fuels have been made.

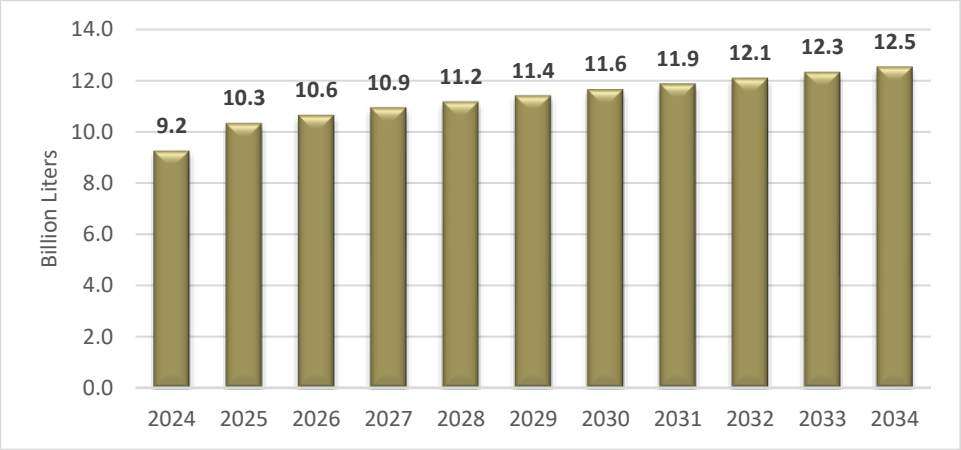


Figure 7. Forecast of Total Biodiesel Demand, 2024–2034 (Source: Based on EPE 2024e)

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 biogas production, which will be destined for biodigestion. In this case, the technical potential of biogas from residual sugarcane biomass through monodigestion reaches 6.4 billion Nm³ in 2034, representing 3.6 billion Nm³ of biomethane (Figure 8).

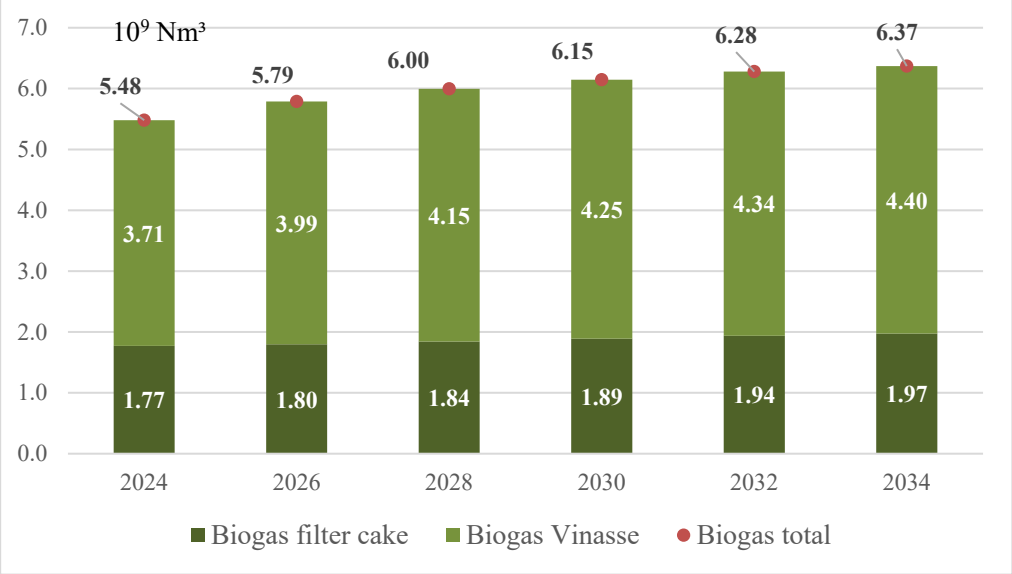


Figure 8. Biogas Potential with Sugarcane Residual Biomass, 2024–2034. Source: EPE 2024b.

Recent Developments

Currently, Raízen has one operational E2G plant in Guariba (SP), two plants in commissioning phases, and two more under construction (Raízen 2024). The company plans to complete these projects by the 2025/2026 harvest, increasing its total production capacity to 440 million liters per year (Forbes 2024). Raízen has shifted its strategy and will no longer produce E2G at its Piracicaba plant, which will now be dedicated to tests and future developments (Globo 2025). Additionally, Raízen secured a R$ 1 billion financing from BNDES for the construction of a new E2G plant in Andradina (SP), with a capacity of 82 million liters per year (BNDES 2025).

With regard to biogas, its participation in the internal supply of energy is still timid (0.15%), but it has shown accelerated growth: 17.7% per year over the last five years (EPE 2024a). Recently, the Louis Dreyfus Company (LDC) began constructing the world's largest biogas plant using citrus residues in Bebedouro (SP), which will contribute to biogas production in Brazil (LDC 2025).

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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 (CI) 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 life-cycle carbon intensity of liquid fossil fuels,
2. Supplying low-carbon-intensity fuels, and
3. Supplying fuel or energy to advanced vehicle technology.

The annual CI reduction requirements for gasoline and diesel came into force on July 1, 2023, starting at 3.5 grams of carbon dioxide equivalent (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.

Last June, ECCC released its first CFR Credit Market Report, which presented data on the compliance credit market. Credit creation data, number of credit transfers, and average price of credit transfers are provided for the 2022 and 2023 compliance periods (June 21, 2022, to December 31, 2023), and credit transfer data are presented for transactions completed from June 30, 2023, to May 31, 2024. The report first highlights key aspects of the credit market, such as credit prices and number of transfers, and then presents more details on credit creation by compliance category.

In combination with the Government of Canada's $1.5 billion Clean Fuels Fund, the CFR creates incentives for increased domestic production of low-carbon-intensity fuels. Budget 2024 announced the retooling of the Clean Fuels Fund and its extension to March 31, 2030. Support will be available to de-risk capital investments and studies that expand Canada's clean fuel production capacity, and to address gaps and alignment in codes, standards, and regulations.

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.[11] For example, Ontario[12] and Quebec[13] require 10% renewable content in gasoline, which will be increased to 15% in 2030. British Columbia's Low Carbon Fuel Standard mandates a minimum 5% annual average renewable fuel content in gasoline and 8% renewable fuel content in diesel. The Standard also requires fuel suppliers to reduce the average CI of their fuels annually to achieve a 30% reduction by 2030.[14] British Columbia has also implemented a minimum blending requirement in jet fuel, starting at 1% vol in 2028 and increasing to 3% vol by 2030.[15]

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).

[11] Navius Research, 2024, Biofuels in Canada 2024 Annual Report, work sponsored by Advanced Biofuels Canada.
[12] Ontario, Canada, Cleaner transportation fuels.
[13] Gouvernement du Québec, Ethanol and biodiesel.
[14] Province of British Columbia, Renewable and Low Carbon Fuels.
[15] Victoria, British Columbia, Low Carbon Fuels (General) Regulation.

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

Canada's Climate Plans and Targets

The 2016 Pan-Canadian Framework on Clean Growth and Climate Change (PCF) is Canada's first-ever national climate plan. The PCF was developed with provinces and territories, and in consultation with Indigenous peoples. The objective is to meet Canada's emission reduction targets, grow the economy, and build resilience to a changing climate. The plan includes a pan-Canadian approach to pricing carbon pollution and measures to achieve reductions across all sectors of the economy.

In March 2022, the Government of Canada introduced Canada's 2030 Emissions Reduction Plan, which builds on the efforts of the PCF. The plan provides a sector-by-sector roadmap for Canada to reach its emissions reduction target of 40% below 2005 levels by 2030 and net-zero emissions by 2050.

The Canadian Net-Zero Emissions Accountability Act, which became law in June 2021, formalizes Canada's commitment to achieve net-zero emissions by 2050. The Net-Zero Advisory Body (NZAB) engages Canadians and provides independent advice to the Minister of Environment and Climate Change with respect to achieving Canada's net-zero emissions goal.

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 Automobile 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. The 2030 Emissions Reduction Plan makes a commitment to develop regulations to make 100% of new LDVs 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 ZEV targets, including the targets specified in the Emissions Reduction Plan (20% for the 2026 model year, 60% by 2030, and 100% by 2035). The next phase of Canadian emission standards will be informed by the release of the U.S. Environmental Protection Agency'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 (1) develop a medium- and heavy-duty vehicle (MHDV) ZEV regulation requiring 100% of MHDVs sold 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 (2) explore interim targets for the mid-2020s.

Canada also 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 EPA rulemakings — the "Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles — Phase 3" and

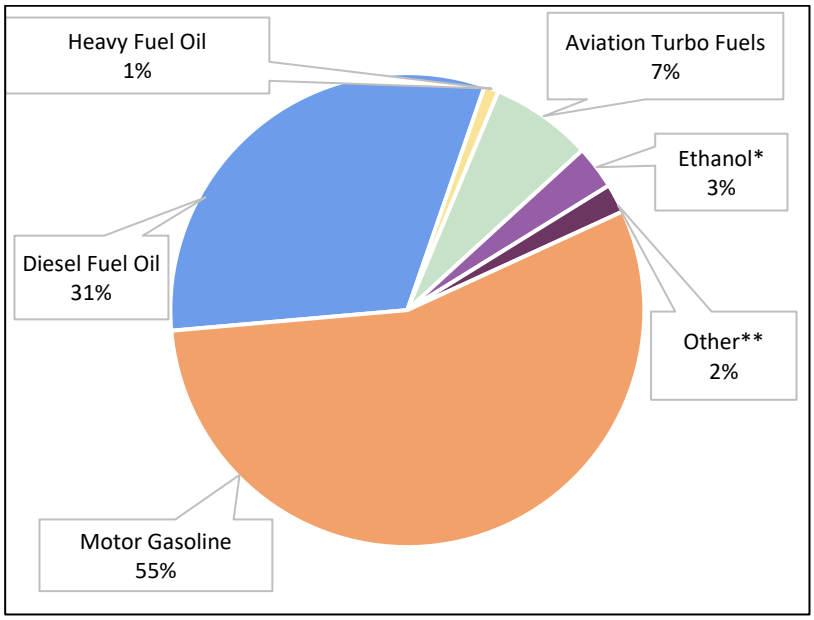
"Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles" — in accordance with its commitment to align with the most stringent emission standards in North America.

Hydrogen Strategy for Canada

Since 2020, Natural Resources Canada (NRCan) has engaged 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. In May 2024, after 3 years of engagement, the Hydrogen Strategy for Canada: Progress Report was released as a strategic directional document. One key finding in the Progress Report indicated that hydrogen used in transport could range from 12% to 35% of the transport sector's energy use in 2050 and up to 18% of energy consumption in the transportation industry.

Advanced Motor Fuels Statistics

Figure 1 shows energy use by fuel type in 2021 for transportation in Canada. Table 2 lists supply and demand for ethanol and biodiesel in 2023.



*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, 2021

Table 2. Canadian Supply and Demand of Biofuels, 2023 (in millions of liters)

Parameter	Ethanol	Biodiesel
Canadian production	1,717	481
Imports	2,389	1,222
Exports	72	518
Domestic use	3,950	1,133

Transportation GHG emissions (from passenger, freight, and other forms of transport) increased 4% from 2020 to 2022, reflecting a rebound from the pandemic. Despite the increase, transportation emissions were 8% below their pre-pandemic (2019) level.

Research and Demonstration Focus

ecoTECHNOLOGY for Vehicles (eTV) Program
The eTV Program, conducted through Transport Canada's Innovation Centre, tests the safety, environmental impact, and driving performance of new technologies for passenger cars and heavy-duty trucks. The program investigates the performance of new technologies for advanced engines and transmissions, renewable fuels, hybrid and electric vehicles, hydrogen and fuel cell vehicles, and connected and automated 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 include 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, funds are invested into public infrastructure to encourage the transition to low- or zero-emission vehicles. As of 2024, a total of 1,072 electric, 6 hydrogen, and 14 natural gas stations have opened in Canada.

Zero Emissions Vehicle Infrastructure Program (ZEVIP)
NRCan's ZEVIP is an 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.

Energy Innovation Program (EIP): On-Road Transportation Decarbonization
NRCan's On-Road Transportation Decarbonization program conducts research, development, and demonstration (RD&D) projects that address barriers to the uptake of zero-emission MHDVs, innovative infrastructure solutions to support ZEVs, and transportation system efficiency. Projects funded under the EIP focus on influencing the pace and direction of energy system transformation and targeting the most impactful technologies to maximize environmental and economic outcomes.

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 improve the battery supply chain.

Canada's Aviation Climate Action Plan
Canada's Aviation Climate Action Plan includes R&D to support Canada's commitments to achieve net-zero emissions by 2050. More than 60 airlines operating in Canada participate in the Canadian Council for Sustainable Aviation Fuels, which brings together industry and government to develop a competitive roadmap for Canadian-made sustainable aviation fuels.

Green Freight Program (GFP)
The GFP, funded through NRCan, 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. Fleet modernization is a component of the program and includes vehicle repowering, purchases of low-carbon alternative-fuel vehicles, and implementation of logistical best practices.

The Green Shipping Corridor Program (GSCP)
Transport Canada's GSCP provides funding for projects that contribute to the establishment of green shipping corridors and the decarbonization of Canada's marine sector. One area of focus is building the capacity of Canadian vessel owners/operators to identify, plan, and incorporate next-generation low-carbon and zero-emission ship technology and marine fuels into their vessel operations.

Low-carbon Fuel Procurement Program (LCFPP)
Within the Greening Government Fund, the LCFPP will provide funding to federal air and marine fleet departments for the purchase of low-carbon fuels. This program supports the purchase of approximately 200 million litres of low-carbon fuels by the end of fiscal year 2030–31.

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 10 Mt between 2005 and 2030, while those for heavy-duty trucks and rail are projected to increase by 14 Mt.

Table 3. Transportation: GHG Emissions (Mt CO_2e)

Transportation Subsector	2005	2020	2030	Δ 2005 to 2030
Passenger Transport	**90**	**80**	**82**	**-8**
Cars, light trucks, and motorcycles	82	73	72	-10
Bus, rail, and domestic aviation	8	6	10	2
Freight Transport	**60**	**70**	**71**	**11**
Heavy-duty trucks, rail	54	66	68	14
Domestic aviation and marine	5	5	5	0
Other: recreational, commercial, and residential off-road transportation	**10**	**9**	**10**	**0**
Total	**160**	**159**	**163**	**3**

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.

Implementation Plan for Establishing a Carbon Footprint Management System

To accelerate the establishment of a carbon footprint management system, foster green and low-carbon supply chains and lifestyles, drive the development of new quality productive forces, and support the achievement of carbon peaking and carbon neutrality goals, the Ministry of Ecology and Environment (MEE), in collaboration with 15 other ministries, released the Implementation Plan for Establishing a Carbon Footprint Management System on May 22, 2024.

By 2027, the carbon footprint management system will be preliminarily established. This includes formulating and releasing a national general standard for product carbon footprint accounting aligned with international norms as well as developing around 100 product-specific carbon footprint accounting standards for key products. By 2030, the system will be further refined, with expanded application scenarios. Approximately 200 product-specific carbon footprint standards will be issued, a comprehensive and internationally influential carbon footprint factor database will be established, and a carbon labeling certification and hierarchical management system will be fully implemented. The carbon footprint accounting rules, factor databases, and certification systems will gradually align with international standards, and China will actively participate in shaping global carbon footprint regulations. This policy will significantly impact the certification and development of low-carbon fuels in China.

Notice on Organizing Technological Breakthroughs and Industrialization Pilots for Green Liquid Fuels (Draft for Public Comment)

On August 21, 2024, China's National Energy Administration (NEA) released the "Notice on Organizing Technological Breakthroughs and Industrialization Pilots for Green Liquid Fuels (Draft for Public Comment)." The term "green liquid fuels" includes biodiesel; sustainable aviation fuel, or SAF (produced from biomass); renewable alcohol ethers (produced from biomass or captured carbon dioxide); and renewable ammonia (produced from green hydrogen). This policy will urge provincial authorities and energy enterprises across China to advance technological research and industrial pilot projects for green liquid fuels.

Guidelines on Vigorously Implementing Renewable Energy Substitution Actions

On October 18, 2024, China's National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology (MIIT), and four other ministries jointly released the "Guidelines on Vigorously Implementing Renewable Energy Substitution Actions." The policy sets two major targets:

1. During the 14th Five-Year Plan period (2021–2025), renewable energy substitution in key sectors will make active progress, with national renewable energy consumption reaching over 1.1 billion tons of standard coal equivalent (SCE) by 2025.
2. During the 15th Five-Year Plan period (2026–2030), a production and lifestyle prioritizing renewable energy will be basically established, with renewable energy consumption exceeding 1.5 billion tons of SCE by 2030, strongly supporting the achievement of China's 2030 carbon peaking target. Additionally, the policy emphasizes promoting the application of sustainable aviation fuels, orderly expanding pilot projects for green and clean liquid fuels in vehicles, and supporting regions with suitable conditions to conduct trials of biodiesel, bio-aviation fuel, biogas, and green hydrogen-ammonia-alcohols in shipping and aviation sectors.

2025 Energy Work Guidelines

On February 27, 2025, China's National Energy Administration (NEA) released the "2025 Energy Work Guidelines," emphasizing the following priorities:

1. Continuously improve the energy technology innovation system. Strengthen standardization in energy digitalization and intelligence, new-type power systems, new energy storage, hydrogen energy, and green liquid fuels, and establish technical committees for emerging fields.
2. Cultivate and expand new energy industries and business models. Explore integrated development models for large-scale wind and solar power bases with related industries, steadily develop renewable hydrogen production and sustainable fuel industries, promote pilot applications of fuel cell vehicles, advance the construction of a national hydrogen energy information platform, prudently explore pilot pipeline hydrogen transmission projects, and improve hydrogen management mechanisms nationwide. Additionally, accelerate technological breakthroughs and industrial pilot projects for green liquid fuels.

Existing National Standards on Alternative Motor Fuels

- GB/T 30366-2024, "Biomass vocabulary," was released on March 15, 2024, and implemented on October 1, 2024.
- GB/T 44723-2024, "Hydrogen internal combustion engines — General technical specification," was released on September 29, 2024, and will be implemented on April 1, 2025.
- 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.
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Advanced Motor Fuels Statistics

In 2024, non-fossil energy accounted for 58.2% of China's total installed power capacity, with renewable energy generation exceeding 3.4 trillion kWh and contributing nearly 40% of total electricity production. The energy system has accelerated its transition to a low-carbon structure, characterized by diversified supply and green consumption. China has achieved nationwide supply of China 6b standard gasoline, and charging infrastructure continued to expand; about 12.4 million charging pillar units have been built around the country.

In 2024, China's auto production and sales reached 31.282 million and 31.436 million units, respectively, maintaining steady growth. New energy vehicle (NEV) production and sales surged to 12.888 million and 12.866 million units, capturing 40.9% of the total automotive market. Battery electric vehicles (BEVs) dominated with 7.72 million units (60% of NEV sales), while plug-in hybrids (PHEVs) reached 5.14 million units (40% of NEV sales). Hydrogen fuel cell vehicle (FCV) sales grew to 7,075 units, primarily in commercial vehicles like trucks and buses. Natural-gas-powered heavy-duty truck sales hit a record 178,200 units, with top provinces being Shanxi (27,381 units), Hebei (27,345 units), Henan (15,187 units), Shandong (significant growth), and Guangdong (rapidly emerging).

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 2024, Chinese local governments continued to advance methanol vehicle deployment through region-specific policies and infrastructure expansion. Shanxi Province, a key hub for methanol production, introduced subsidies of up to 50,000 RMB per vehicle to accelerate the replacement of diesel-powered heavy-duty trucks, urban logistics vehicles, and construction machinery with methanol models. The province prioritized methanol refueling infrastructure upgrades, retrofitting 35 gas stations into methanol-compatible facilities along major freight corridors, and established a dedicated methanol heavy-truck logistics platform in Jinzhong City. Guizhou Province, building on its "Guiyang Model" centered on methanol taxis, expanded its fleet to over 21,000 methanol vehicles by 2024, supported by 92 methanol refueling stations, reducing regional gasoline dependence by 9% annually. Inner Mongolia's Hohhot City launched its first methanol vehicle manufacturing base with an annual capacity of 10,000 units, targeting coal transport routes and partnering with energy firms to deploy 4,000 methanol trucks by 2026. Northeastern regions like Shenyang granted methanol vehicles equal road rights to EVs, while Gansu and Shaanxi focused on intercity freight networks, collectively adding 12,000 methanol trucks to replace diesel equivalents in mining and logistics sectors. Nationwide, methanol vehicle reached 52,000 units by Q3 2024, with commercial vehicles (85%) dominating applications, and annual methanol fuel consumption exceeded 3 million tons, displacing 1.8 million tons of gasoline. These efforts were bolstered by Geely's 20 methanol vehicle models, which accumulated over 12 billion kilometers in total mileage, demonstrating the technology's scalability.

Promotion of Hydrogen Fuel Cell Electric Vehicles Pilot Project

In 2024, China's hydrogen fuel cell vehicle (FCV) demonstration programs achieved significant progress through expanded regional collaborations and policy innovations. Building on the 2020 national framework, the five approved city clusters — Beijing-Tianjin-Hebei, Shanghai, Guangdong, Hebei, and Henan — collectively deployed over 15,000 FCVs by mid-2024, with 500+ hydrogen refueling stations operational nationwide, a 23% increase from 2023. Commercial vehicles dominated applications, representing 85% of total FCV sales, particularly in heavy-duty logistics and port operations. For instance, Inner Mongolia deployed 300kW fuel cell systems in coal-hauling trucks, doubling the power output of earlier models.

Local governments introduced tailored incentives to accelerate adoption. Shandong and Guangdong provinces granted FCVs toll-free highway access to boost intercity logistics, while Chengdu launched a "demonstration alliance" model, linking hydrogen system manufacturers, vehicle operators, and refueling stations to deploy 500 FCVs in 2024. Cost reductions further spurred growth: fuel cell system prices dropped to 2,000–2,500 RMB/kW (down 80% from 2020 levels), driven by localized production of core components like membrane electrodes. Infrastructure expanded rapidly, with the Beijing-Tianjin-Hebei cluster adding 40 stations to support heavy trucks with 600-km ranges.

Notable breakthroughs included GAC's E9 hydrogen-electric sedan, which completed a 10,000-km demonstration run in Tianjin with a hydrogen consumption of 1.4 kg/100 km and 3.5-minute refueling time. Meanwhile, international collaboration advanced through events like the Seoul Hydrogen Industry Summit and the Shanghai FCV Expo, where China led the Global Hydrogen Initiative to harmonize standards. By year-end, China's FCV operational fleet exceeded 25,000 units, displacing over 170,000 tons of CO_2. Challenges persisted in passenger vehicle adoption and hydrogen pricing, but regional policies — such as Shanxi's mileage-based subsidies (up to 150,000 RMB annually per truck) — laid groundwork for post-2024 commercialization.

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

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- 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

The adoption of the Climate Act in 2020 set an ambitious direction for Danish climate policy and Denmark's diplomatic role in the world related to climate change. Central to the goal are reducing Danish greenhouse gas (GHG) emissions by 70% by 2030 compared with 1990 levels and achieving climate neutrality by 2050 at the latest. The new government — consisting of the Social Democrats, the Liberal Party, and the Moderates — has moved the climate neutrality goal up to 2045, and set a goal of a 110% reduction in GHG emissions by 2050 compared with 1990 levels. Since the Climate Act, more than 75 green agreements have been concluded, and more than 129 billion DKKR has been prioritized to meet major climate agreements. For example, agreements have been made on a high and more uniform carbon-dioxide-equivalent (CO_2e) tax for industry, a significant expansion of Denmark's renewable energy production, and a binding reduction target for the agricultural and forestry sector; all of these will contribute significantly to achievement of the 70% GHG emissions target.

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, as use of coal in large-scale combined heat and power (CHP) production is expected to stop. In 2030, only the Fynsværket power station and the cement industry will consume substantial amounts of coal. However, some plants will retain the option for coal operation, although actual use is assumed to be limited.

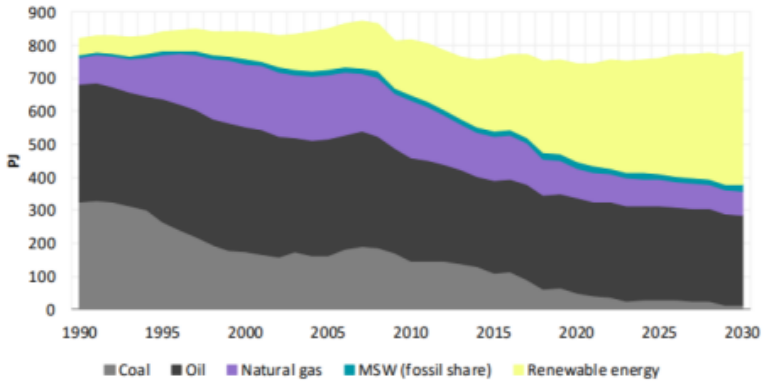

Figure 1. Gross energy consumption by type of energy 1990–2030 (in PJ). The calculation for 1990–2017 has been adjusted for outdoor temperature/degree days relative to normal years (climate-adjusted) and electricity trade with other countries.

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).

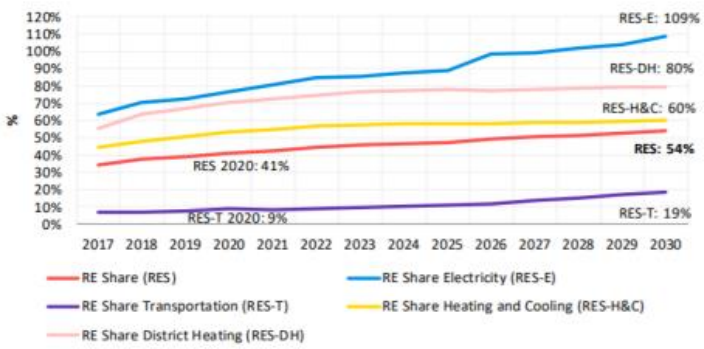

Figure 2. Renewables shares 2017–2030 [%]. The renewables shares are calculated as defined in the RE Directive (Eurostat 2018).

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 an extremely 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 because 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.

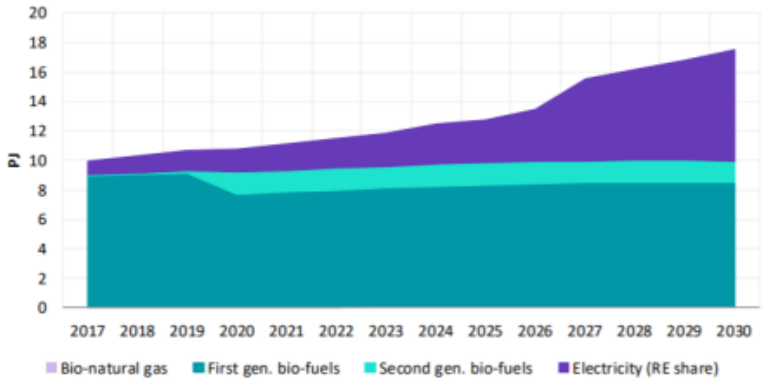

Figure 3. Renewable energy consumption by the transport sector 2017–2030 (in PJ).

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.

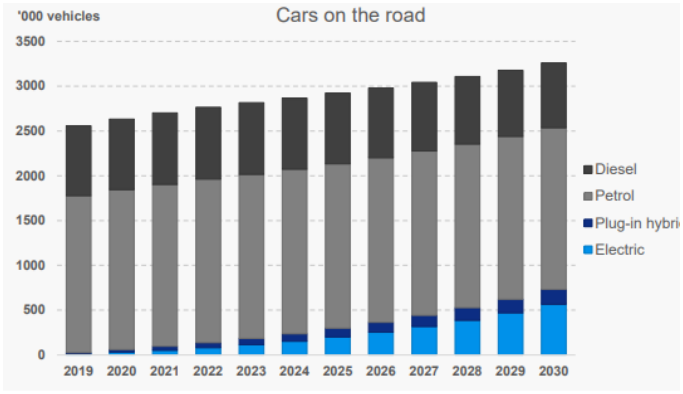

Figure 4. Number of cars by technology, 2019–2030

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 a lag 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 data 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.

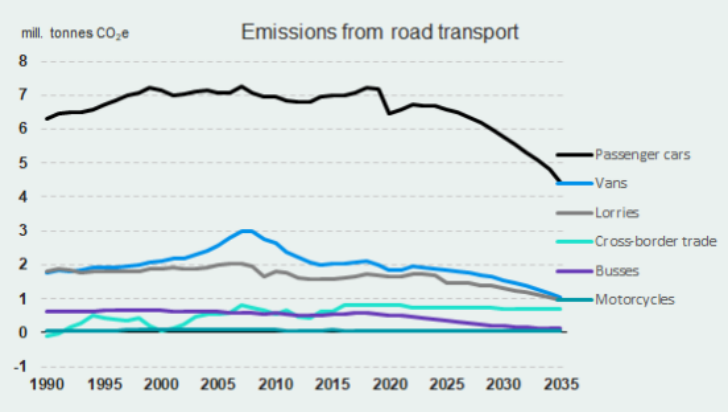

Figure 5. Emissions from road transport by vehicle

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.

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 (e.g., 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.

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).[16] 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. Currently, Finland is encountering huge challenges to meeting this target because the carbon sinks in the forests and soil have been included in the calculation. During the last few years, forests have turned from carbon sinks to net carbon sources. At the time that the Finnish climate law was established, forests were acting as carbon sinks, providing a favourable outlook for reducing GHG emissions.

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 and enhancements to distribution infrastructure, pedestrian and bicycle traffic, and public transport. In addition, the roadmap covers 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.[17]

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 was also established, 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 a law amending electro-fuels in the biofuels obligation beginning January 1, 2023.[18,19] In September 2022, the government proposed that Parliament increase the renewable fuels blending obligation to 34% in 2030 and onward.[20] 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 and to 13.5% for 2023. In October 2023, the government of Finland proposed that Parliament reduce the biofuels obligation from 28% to 13.5% also for 2024,[21] which was then approved. The reason for the reduction was an estimated 17-cent increase in diesel and 15-cent increase per liter in gasoline prices that would result from a 28% biofuels obligation. The current blending obligation[22] calls for 16.5% for 2025 and 19.5% for 2026. In 2030, the regulation still calls for a 34% biofuel share.

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.[23] However, this proposal was not accepted.

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

[17] 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.

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

[19] 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.

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

[21] 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-.

[22] Law for deployment of renewable fuels in road transport. https://www.finlex.fi/fi/lainsaadanto/2007/446

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

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).[24] In addition, since 2020, Finland has offered a reduced-tax benefit for citizens who drive a company-owned car. The value has been 170€ annually for BEVs and 85€ annually for cars with CO_2 emissions in the range of 1–100 g/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 (85% ethanol in gasoline [E85]) and biomethane passenger car conversion kit installations.[25] 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 2023, the energy consumption in domestic transport (all modes together) was 161 petajoules (PJ), and energy consumption in road transport was 148 PJ, or 3533 kilo tonnes of oil equivalent (toe) (Table 1). Relative to Finland's total energy consumption of 1,317 PJ in 2023, the transport consumption figures were 12.2% (total) and 11.2% (road), respectively.[26]

Table 1. Energy in Road Transport, 2023[27]

	PJ	ktoe	Share of fuels (%)	Share of biofuels (%)
Petrol (fossil)	44.2	1056	27.98	
Biocompatible petrol incl. E85 ethanol	5.5	132	3.8	11.1 of petrol
Diesel (fossil)	76.9	17617	52.8	
Biocompatible diesel	17.6	421	12.1	18.6 of diesel
Natural gas	0.003	0.1	0.00	
Biomethane	1.31	31.4	0.78	99.9 of gas
∑ fuels	145.6	3477		16.8 of fuels
	PJ	**ktoe**	**Share of total (%)**	
Electricity	2.4	57.4	1.6	
Total	**148.0**	**3,534**		

In terms of energy, the contribution of biofuels relative to the total fuel consumption in road transport is 16.8%, ranging from 11.1% in petrol (mostly ethanol and some ethyl tertiary-butyl ether [ETBE], but also bio-naphtha; the statistics do not include details on this) to 99.9% in methane. The actual amount was 565 ktoe, or 16.8% 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.

[24] Parkkonen, L., 2013, "Taxation of petroleum products and vehicles in Finland," CEN/TC 19 Conference. Helsinki, May 27, 2013.
[25] 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
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[27] Source: Tilastokeskus, "Energy supply and consumption – Energy consumption in transport, 1990–2023," https://pxdata.stat.fi/PxWeb/pxweb/fi/StatFin/StatFin__ehk/statfin_ehk_pxt_12sz.px/table/tableViewLayout1/

Table 2 presents the vehicle fleet in use at the end of 2024 (without two- and three-wheelers and light four-wheelers). Table 3 lists the sales figures for new passenger cars in 2015–2024 (revised).

Table 2. Vehicle Fleet in Use at the End of 2024 (without two- and three-wheelers and light four-wheelers)[28]

Fuel	Cars	Vans	Trucks	Buses	Special vehicles
Petrol	1,807,229	8,837	2,482	19	262
Ethanol in flexible fuel vehicles (FFVs)	4,643	16	131	0	0
Diesel	665,768	331,091	85,939	10,082	1,113
Methane	8,121	915	412	65	0
Methane bi-fuel	8,515	306	87	0	0
BEV	118,297	4,470	126	962	0
PHEV petrol	159,381	308	1	0	0
PHEV diesel	7,467	98	6	0	0
Other	59	17	194	5	0
Total	2,767,803	346,067	89,526	11,139	1,376
Fuel	**Cars (%)**	**Vans (%)**	**Trucks (%)**	**Buses (%)**	**Special vehicles (%)**
Petrol	64.9	2.6	2.8	0.2	19.1
Ethanol in FFVs	0.2	0.0	0.1	0.0	0.0
Diesel	24.1	95.7	96	90.5	80.9
Methane	0.3	0.3	0.5	0.6	0.0
Methane bi-fuel	0.3	0.1	0.1	0.0	0.0
BEV	4.3	1.3	0.1	8.6	0.0
PHEV petrol	5.8	0.1	0.0	0.0	0.0
PHEV diesel	0.3	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.2	0.0	0.0

Table 3. First Registration of New Passenger Cars, 2015–2024[29]

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
2024	11,256	46	114	3,413	22,109	396	14,667	196	21,868

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

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

In 2024, only 74,072 new cars were sold — approximately 15% less than in 2023. Fewer cars were sold only during 1992–1994. Diesel shares of new sales continue to decline and in 2024 represented only 4.6%, compared with 35.7% in 2015. Sales of PHEVs remained at around 20.1% of total new sales. BEVs are becoming more popular, and sales have increased year over year. In 2024, BEVs represented about 29.5% of total new sales.

Finland has an estimated 829 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 grew to 412 in 2024. The number of battery electric buses has surpassed the number of CNG buses. The increase in electric (city) buses has been rapid. In 2020, Finland had a total of 87 electric buses and in 2024, the nation had 962.

Research and Demonstration Focus

The following paragraphs describe some national Business Finland funded research and development (R&D) projects, in which the VTT Technical Research Centre of Finland (VTT) is taking part.

The E-Fuel project (2021–2024) focused on integration of hydrogen production through high-temperature electrolysis with CO_2 sequestration and Fischer-Tropsch fuel synthesis. Electrofuel developed from green hydrogen and CO_2 was demonstrated in an agricultural tractor in 2023.[30]

he **BIOFLEX project (2020–2024),** explored the suitability of fuel oils made from biomass and waste plastics for power plants and marine diesel engines. The project team studied the development of production processes and measured emissions when using new biofuels in marine engines.

The **Clean Propulsion Project (2021–2024)**, focused on developing maritime and non-road engine technologies that run efficiently on renewable fuels. The project had 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. This focus area includes investigation of different fuel options, 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 (2022–2025)**, 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.

[30] 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.

The **DeCARBO project (2022–2025)**, 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.
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.

The Clean Propulsion Project, completed between 2021–2024, followed by the **Flexible Clean Propulsion Project (2024-2027)**,[31] which continues to investigate new fuel and combustion alternatives for marine and off-road solutions. The project comprises topics such as

1. Multi-fuel combustion for medium-speed applications.
2. Multi-fuel combustion for high-speed applications.
3. Regulations and feasibility of multi-fuel combos.
4. Aftertreatment technologies for multi-fuel engines.

The **iHAPC (Integrated Hydrogen-Argon Power Cycle) project (2025–2027)**, funded by Business Finland, focuses on research to achieve full valorisation of green hydrogen (H2) with unprecedented power generation efficiency. The concept offers a step-change for well-established and robust combustion engine technology, by substituting air with a monoatomic gas, argon. The project aims to bring H-APC to technology readiness level 6 (TRL-6) by demonstrating sustainable operation with at least 65% efficiency on a 150-kW single-cylinder engine.

VTT participates in several EU-funded projects related to advanced motor fuels, such as **GREEN RAY** (2022-2027), which aims at minimizing methane slip from LNG vessels; **APOLLO** (2023-2025), which demonstrates the use of ammonia as fuel in an offshore supply vessel, **REFOLUTION** (2023-2026), which aims to demonstrate the cost-effective production of advanced biofuels for aviation and marine sector, and **PAREMPI** (2023-2025) on particle emission prevention and impact; covering pathway from real-world emissions of traffic to secondary PM of urban air.

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 particularly important element of emissions 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 2022, green hydrogen and e-fuels production advanced as many new investment plans were published. In total, the plans described capacity goals of more than 1 GW for green hydrogen and more than 500 MW for green methane production. In addition, there were investment plans for green ammonia production, and the nation plans to target green methane to support green fuels use in HDVs. During 2023, new investment plans were published. Thus far, implementation of only few of the plans introduced since 2022 has progressed to construction of the plants.

[31] Clean Propulsion, "Flexible Clean Propulsion Technologies Project," https://cleanpropulsion.org/

The very first industrial-scale hydrogen production plant will begin operation during the first half of 2025. The plant has a capacity of 20 MW of power for electrolyses.

DNV has projected in its report[32] that Finland could become an important hydrogen supplier in the Nordic region, estimating that Finland has export potential up to 70 TWh of hydrogen annually in 2050. In the report, low cost and high production of renewable electricity were mentioned as the main contributors for the outlook.

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 2024, the total peak power capacity of wind was around 8,358 MW, in comparison to around 13,000 MW capacity of traditional sources (combined heat and power [CHP], condensing power, hydro, and nuclear).

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% was set for advanced biofuels. In addition, the law for non-road machinery fuels calls for a 10% 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. Despite the significant increase in wind electricity production, the majority of announced plans for green hydrogen production have not yet progressed into implementation.

[32] Gasgade, "DNV Study: High Potential for Hydrogen in the Northern Baltic Sea Region," https://www.gascade.de/en/press/press-releases/press-release/dnv-study-high-potential-for-hydrogen-in-the-northern-baltic-sea-region

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 2024 despite another year marked by the ongoing Russian invasion of Ukraine and other challenging incidents, globally and on the national level. On a national level, the break-up of the German government in November 2024 can be considered the most challenging threat. The elections of the German Bundestag in February 2025 indicated a change in the German government. While the new government's progress and agenda cannot be predicted, it is likely that energy security and climate change mitigation will remain two of the key priorities of the new German government. Further, it can be expected that previously agreed legal frameworks such as the Climate Change Act or the Climate Action Programme will remain in force. Even if slight changes and amendments occur, the new government is likely to aim to continue the energy transition by remaining independent from Russian oil and gas, encouraging energy savings and costs reductions for renewable energies, building liquefied natural gas (LNG) terminals, and creating a bridge to hydrogen utilization.

Massive budget cuts for climate protection measures have been implemented in 2024 and are expected for the upcoming years as well. Due to a decision by the Federal Constitutional Court in November 2023, 60 billion Euros in the Climate Transformation Funds (KTF) was deemed not constitutionally compliant and had to be removed from the budget plans.[33] This caused a number of disruptions. For example, by the end of 2023, the purchase bonus for electric vehicles expired due to the necessary savings arising for e-mobility, causing strong sales decreases. However, the government agreed on a solution for further funding of climate and energy actions. Thus, for example, the hydrogen industry was funded with 1.27 billion Euros in 2024.

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.[34] For the first time, Germany managed to reach its GHG emissions goals in 2023 and could continue this trend in 2024. According to calculations of the Federal Environment Agency, the CO_2 emissions have further decreased in 2024 by 23 million tons (3.4 %) compared to 2023.[35] Thus, the government is optimistic that the nation can also reach its goals for 2030.[36] Notably, CO_2 reductions in 2024 could be achieved due to significant savings in the energy economy, industrial sector and agriculture whereas the transport and building sector missed their reduction goals.[37] The permissible emission budget for the transport sector is 85 million tonnes (Mt) carbon dioxide equivalent (CO_2-eq) in 2030. The federal government forecasts a cumulative compliance gap of 180 Mt CO_2-eq for the transport sector by 2030.[38]

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

[33] The Federal Government, 2023, "The Climate and Transformation Fund 2024: Create relief, secure future investments, shape transformation," https://www.bundesregierung.de/breg-en/news/agreement-budget-scholz-lindner-habeck-2249290, accessed 03.03.2025.

[34] 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, accessed 03.03.2025.

[35] Federal Environment Agency, 2025: Emission Data 2024: https://www.umweltbundesamt.de/sites/default/files/medien/11867/dokumente/emissionsdaten_2024_-_pressehintergrundinformationen.pdf, accessed: 14.04.2025

[36] 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, accessed 20.03.2024.

[37] Umweltbundesamt, "Greenhouse Gas Projections 2024," https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/thg-projektionen_2024_ergebnisse_kompakt.pdf, accessed 03.03.2025.

[38] Daily News, 2024,"Germany can achieve its climate target for 2030," https://www.tagesschau.de/inland/innenpolitik/deutschland-klimaziele-erreichbar-100.html, accessed: 20.03.2024.

sector of only 41–42% by 2030,[39] which translates to 98 to 95 Mt CO_2-eq GHG emissions in the transport sector by 2030.[40] A recast of the Klimaschutzgesetz (Climate Protection Act) came into force in July 2024, reducing the need for countermeasures in individual sectors when missing the target values.[41]

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.[42] 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.

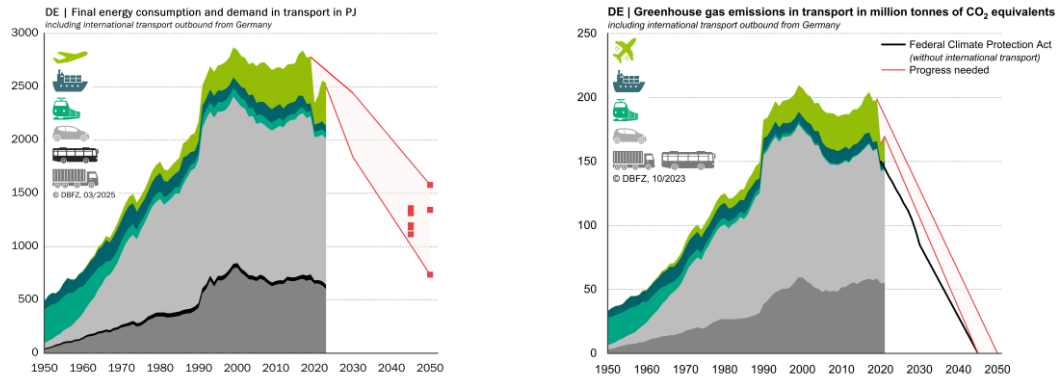

Figure 1. The massive gap between trends, targets, and scenarios in transport, 1990–2050[43] (Source: German Biomass Research Center [DBFZ]).

The main public drivers regarding policy in the transport sector remain the 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.[44] 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 (Table 1 provides a summary).[45]

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 November 20, 2023.[46] The revised RED sets an overall binding *renewable energy*

[39] The Federal Government, 2024, "Climate Action Programme 2030," https://www.bundesregierung.de/breg-en/issues/climate-action/klimaschutzprogramm-2030-1674080, accessed 04.03.2025.

[40] 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, accessed 04.03.2025.

[41] https://www.bundesregierung.de/breg-de/aktuelles/klimaschutzgesetz-2197410, accessed 10.03.2025.

[42] 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: 04.03.2025.

[43] Figure based on and updated: Schröder, Naumann (Eds.), 2023, 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: 04.03.2025.

[44] 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, accessed 04.03.2024.

[45] 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, accessed 04.03.2024.

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

target of at least 42.5% at 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.[47] The German government elaborated a draft law accordingly which was approved in July 2024.[48]

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

Importantly, the German government does not consider nuclear power a viable option; the last nuclear power plants were closed on April 15, 2023.[49] Germany's position on nuclear power is unlike that of many European countries, where nuclear power is considered an essential energy source.[50] 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. Germany submitted a final update of the NECP 2021-2030 to the Commission in August 2024.[51]

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 or FSRU (Floating Storage Regasification Unit) for LNG, which will later be used to

[47] Ibid.

[48] Federal Ministry for Economic Affairs and Climate Action, "Federal Government speeds up approval procedure for on-shore Wind Energy and Solar Energy," https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2024/07/20240724-genehmigungsverfahren-windenergie-an-land-solarenergie.html, accessed 03.03.2025.

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

[50] 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, accessed 04.03.2024.

[51] https://commission.europa.eu/publications/germany-final-updated-necp-2021-2030-submitted-2024_en, accessed 10.03.2025.

refuel ammonia.[52] The project's aim is to build a modern and sustainable infrastructure for maritime vessels. Likewise, the first German LNG terminal was inaugurated on December 17, 2022 in Wilhelmshaven. Overall, three LNG terminals are currently in use, while three LNG terminals are still under construction.[53] The capacity of all six units totals 30 billion m^3.[54]

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.[55] 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 advanced biofuel in line with the RED II. In this respect, Germany's strategy differs from the EU hydrogen strategy, which includes biomass as a renewable hydrogen source.[56] 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. 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.[57]

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.[58] 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.[59] 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.[60] The federal government supports the agreement and believes that it will provide German industry the necessary planning security.[61] However, it seems that the European Commission is willing to re-evaluate the envisaged measures and time frame as Commission's President Ursula von der Leyen declared that the Commission wants "to speed up work on the

[52] 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, accessed 04.03.2024.

[53] 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, accessed 08.05.2024.

[54] NDR, "How much LNG arrives in Germany?" https://www.ndr.de/nachrichten/info/LNG-Wie-viel-Fluessigerdgas-kommt-derzeit-in-Deutschland-an,lng632.html, accessed 03.03.2025.

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

[56] Ibid.

[57] 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, accessed 04.03.2025.

[58] 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, accessed 04.03.2025.

[59] Ibid.

[60] 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, accessed 04.03.2024.

[61] 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, accessed 04.03.2024.

2035 review, with full technology neutrality as a core principle" as well as to "propose a focused amendment to the CO_2 Standards Regulation."[62] This change of mindset might be influenced by the announcement of some car producers such as Porsche to focus more on combustion engines again instead of electric vehicles.[63] Thus, it fits into the picture that, despite a significant increase since 2017, the share of newly approved electric vehicles decreased dramatically in 2024.

In 2024, 380,609 BEVs (battery electric vehicle) were newly approved, which is a decrease of 27.4 % from 2023.[64] Taking into consideration electric vehicles powered by a plug-in hybrid engine or a fuel cell, 572,672 cars were newly approved in 2024. This is still a decrease of 18.2 % from the year before.[65] However, the share of cars with an alternatively powered drive (BEV, hybrid, plug-in hybrid, fuel cell, hydrogen, gas) is with 47.6 % comparably high among the newly approved cars in 2024.

Further, the available electric car series have increased in 2024 and more than 100 electric car series are available on the German market.[66] Interestingly, there is a wide selection of different electric models in the luxury segment,[67] indicating that car manufacturers are mostly aiming at consumers from a high socioeconomic class. As of February 2025, 69.1 million vehicles were registered in Germany as of January 1, 2024 (+1% compared to 2023), including 49.1 million passenger cars, 3.7 million trucks, 2.4 million towing vehicles, and 0,8 million buses.[68] Table 2 shows the number of passenger cars in Germany by fuel type for 2020–2024.

Table 2. Number of Passenger Cars in Germany by Fuel Type on January 1, 2020–2024

Year	Gasoline	Diesel	LPG	CNG	BEV	Hybrid	Plug-in
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
2024	30,235,032	14,142,184	313,723	77,421	1,408,681	2,911,262	921,886

LPG = liquefied petroleum gas, according to European fuel quality standard EN 589
CNG = compressed natural gas, according to German fuel quality standard DIN 51624
BEV = battery electric vehicle X = values not comparable *Source: KBA 2025.*[69]

There are 125,408 "normal" and 36,278 high-speed publicly accessible charging points in Germany.[70] To 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

[62] European Commission, 2025: Press statement by President von der Leyen on the Strategic Dialogue on the Future of the Automotive Industry, https://ec.europa.eu/commission/presscorner/detail/en/statement_25_656, accessed 04.03.2025.
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[64] Kraftfahrt-Bundesamt KBA (Motor Transport Authority), 2025: "New Approvals of passenger cars in 2024," https://www.kba.de/DE/Presse/Pressemitteilungen/AlternativeAntriebe/2025/pm03_2025_Antriebe_12_24_komplett.html, accessed 04.03.2025.
[65] Ibid.
[66] ADAC, 2025, "Overview: Which electric cars are currently available to buy?" https://www.adac.de/rund-ums-fahrzeug/elektromobilitaet/kaufen/elektroautos-uebersicht/, accessed 27.02.2025.
[67] Ibid.
[68] Kraftfahrt-Bundesamt KBA (Motor Transport Authority), 2025: "Annual balance 2024," https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/fz_b_jahresbilanz_node.html, accessed: 05.03.2025.
[69] Kraftfahrt-Bundesamt KBA (Motor Transport Authority), 2025: "Passenger cars on January 1, 2024 according to selected characteristics," https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/2024/2024_b_jahresbilanz_tabellen.html;jsessionid=B8BE4D5B03C5B663B1964163541F5521.live21301?nn=3532350&fromStatistic=3532350&yearFilter=2024&fromStatistic=3532350&yearFilter=2024, accessed 05.03.2025.
[70] Federal Network Agency, "Electromobility: Public charging infrastructure," https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/E-Mobilitaet/start.html, accessed 04.03.2025.

procurement of electric vehicles and tax measures, which ended in December 2023 — earlier than planned, due to shortages in the Climate Transformation Fund (KTF).[71]

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.[72] 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 May 1, 2023 ("Deutschlandticket" or "Germany, Ticket"), on buses, tramways, and metro and regional trains throughout Germany.[73] The ticket is a follow-up to the popular €9 ticket, which was available from June to August 2022, but is now available only 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.[74] From January 2025, the price for the "Deutschlandticket" increased to €58 per month. Despite the increased prices, the number of subscribers has slightly increased to 13.5 million. Approximately 8% are new subscribers who have never used public transport before.[75] 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 significantly less expensive.

Advanced Motor Fuels Statistics

The consumption of fuels in Germany — primarily diesel, petrol and biofuels — totaled 51.2 Mt in 2023 (Figure 2).[76] 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.

[71] Federal Office of Economics and Export Control, https://www.bafa.de/DE/Energie/Energieeffizienz/Elektromobilitaet/Neuen_Antrag_stellen/neuen_antrag_stellen.html, accessed 04.03.2025.
[72] Dr. Jipp, DLR, Presentation at "Fuels of the Future Conference" in Berlin on 23 January 2023.
[73] The Federal Government, "One ticket for all of Germany," https://www.bundesregierung.de/breg-de/aktuelles/deutschlandticket-2134074, accessed 04.03.2025.
[74] Ibid.
[75] 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, accessed: 04.03.2024.
[76] FNR, "Fuel consumption in Germany," https://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/biokraftstoffe/kraftstoffverbrauch-in-deutschland.html, accessed 04.03.2024.

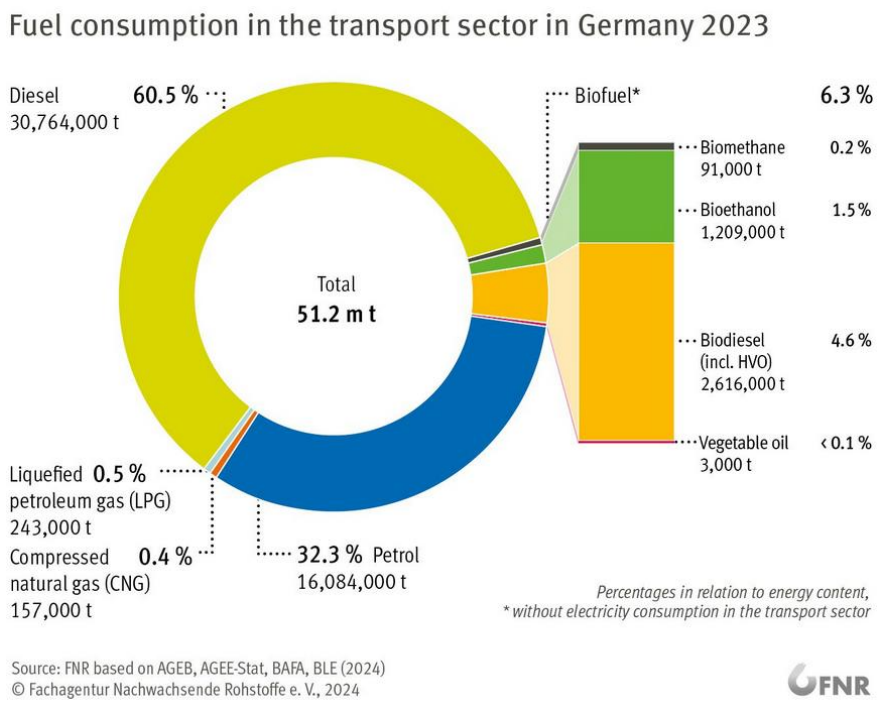

Figure 2. Fuel Consumption in the Transport Sector in Germany in 2023[77]

In 2023, 3.9 million tons of certified biofuels have been placed in the market in Germany. The overall savings in GHG emissions resulting from the use of all biofuels was 12 million tons of CO_2 equivalent, which equals 90% compared with fossil fuels.[78]

Table 3 shows the German domestic consumption of fuel and biofuel over the years since 2020. The figures refer to the fuel consumption in November of each year. It is clearly visible that the share of biodiesel admixture decreases significantly in November 2024. This trend can be observed all over the year 2024. The highest share of blending diesel fuel with biodiesel was reached in March 2024 (8.5 %) and then decreased month by month until the historic low of 3.9% since the introduction of the blending obligation in 2009. Further, the overall consumption of biodiesel and HVO decreased below 2 million tons from January to November 2024.[79] The reason for this decrease is seen in the double counting of biodiesel and HVO from certain waste categories towards the quota obligation and existing surplus GHG quotas.[80] This double counting could be addressed by the draft amendment of the Federal Emission Control Act, which will be elaborated by the new government in spring 2025.

[77] 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]), 2025.

[78] Federal Agency for Agriculture and Food "2023 Evaluation and Experience Report," https://www.ble.de/SharedDocs/Downloads/DE/Klima-Energie/Nachhaltige-Biomasseherstellung/Evaluationsbericht_2023.pdf?__blob=publicationFile&v=2, accessed 05.03.2025.

[79] UFOP, 2025: "Biodiesel admixture reaches all-time low," https://www.ufop.de/english/news/biodiesel-admixture-reaches-all-time-low/, accessed 07.03.2025.

[80] Ibid.

Table 3. Domestic consumption of biofuels, 2020–2024 (as of November each year, in 1,000 tons) [81]

	2020	2021	2022	2023	2024
Admixture, biodiesel (FAME), HVO	229.2	201.2	219.6	207.9	106,9
Diesel fuel	2,994	2,943.3	3,276.2	3,132.6	2,606.5
Diesel fuel + admixture	3,223.2	3,144.5	3,056.6	2,924.7	2,713.4
Share of admixture (%)	7.1	6.3	7.2	7.1	3.9
Bioethanol ETBE	7.4	10.3	9.7	8.7	7.4
Bioethanol, admixture	78.8	88.8	96.0	98.9	93.1
Bioethanol in total	86.2	99.1	105.7	107.6	100.5
Petrol	1,415.4	1,539	1,309.2	1,303.5	1,382
Petrol + Bioethanol	1,501.6	1,439.9	1,414.9	1,411.1	1,482.5
Share of Bioethanol in %	5.7	6.8	7.4	7.6	6.8

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).[82] Since 2022, the BMBF funded three lighthouse projects with a total funding of EUR 700 million (USD 764 million): H2Giga, H2Mare, and TransHyDE.[83] The H2Giga flagship project aims to mass-produce electrolysers for the production and scale-up 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.[84]

The BMDV funded 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.[85] EUR 640 million (USD 698 million) were used for research and development (R&D) projects.[86] 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. Funding is also available at the state level; for example, Baden-Württemberg funds various R&D projects through its renewable fuels strategy.[87] The budget of the KTF has been cut by 60 billion Euros due to the decision of the Federal Constitutional Court in November 2023. For 2024 a total amount of 49 billion Euros was available for activities financed by the KTF. This resulted

[81] Federal Office for Economic Affairs and Export Control (Bafa), 2025: "Official Mineral Oil Data," 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, accessed 05.03.2025

[82] https://www.kopernikus-projekte.de/en/home, accessed 06.03.2025.

[83] Federal Institute for Education and Research, "Welcome to Hydrogen Flagship Projects," https://www.wasserstoff-leitprojekte.de/home, accessed 04.03.2024.

[84] CARE-O-SENE, "Research for a green future: CARE-O-SENE – Catalyst Research for Sustainable Kerosene," https://care-o-sene.com/en/, accessed 04.03.2024.

[85] 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, accessed 04.03.2024.

[86] Federal Ministry for Digital and Transport, "From development to market ramp-up: Ministry launches new funding concept for renewable fuels," https://bmdv.bund.de/SharedDocs/DE/Artikel/G/Klimaschutz-im-Verkehr/neues-foerderkonzept-erneuerbare-kraftstoffe.html, accessed 04.04.2024.

[87] Baden-Wuerttemberg "International cooperation on climate-neutral fuels," https://www.baden-wuerttemberg.de/de/service/presse/pressemitteilung/pid/internationale-zusammenarbeit-bei-klimaneutralen-kraftstoffen, accessed 04.03.2024.

in less funding for R&D projects.[88] For example, R&D for electromobility will no longer be funded — a move that has been heavily criticized by universities and research institutes.[89]

Due to the early split of the federal government in November 2024 and the early elections to the German Parliament in February 2025, it is uncertain how things will develop and how the funding and research support will be shaped under new government. It might be assumed that climate change mitigation and adaptation and all the related topics as energy and transport transition will be in the focus of the new government and addressed accordingly. However, due to several national and global challenges, especially related to the further development in the United States as well as the formation of the new federal government in Germany, it is nearly unpredictable how thing will evolve and develop in the near future.

Outlook

The year 2024 has been one in which the threats and challenges of 2023 continued or even increased. The challenges on a national and international level have been mentioned earlier in this report. Thus, the support and funding of renewable energy sources and sustainable energy technologies are facing increasing competition with other urgent topics. In Germany, topics such as the economic crisis, migration, and national and international security are perceived as more and more important, especially against the backdrop of a Donald Trump presidency, the uncertain developments in Ukraine, and increasing nationalist tendencies in Germany and all over Europe. This becomes very clear when looking at the topics that were perceived as very important in the election campaigns in 2021 and 2025. While in 2021 climate change was perceived as most important,[90] in 2025 migration and inflation were perceived as the most important topics among German voters.[91]

This seems to indicate a shift of public and political perception and a turn towards topics such as security and economy that might displace or at least distract attention from topics such as climate change adaptation and mitigation activities or renewable sources. We cannot yet predict how things will develop. The old German Bundestag is currently debating a huge investment package of 500 billion euros for infrastructure and security/defense spending. But it is not clear whether it will be accepted since, for example, the Green Party argues that investments for climate protections and green transition are not addressed adequately.[92]

Taking all of this into consideration, it can be stated that 2025 will be an interesting but also a decisive year for Germany and Europe and for the topics of renewable energy source and green transition. Thus, next year's country report promises to be interesting.

Additional Information Sources

- Bundesverband der deutschen Bioethanolwirtschaft
- Bundesverband Bioenergie
- Bundesverband Regenerative Mobilität
- Verband der Deutschen Biokraftstoffindustrie
- Fachagentur Nachwachsende Rohstoffe e.V.
- Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

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88 Federal Ministry for Economic Affairs and Climate Action, 2023, "The Climate and Transformation Fund 2024: Create relief, secure future investments, shape transformation," https://www.bmwk.de/Redaktion/DE/Meldung/2023/20231221-haushalt-einigung-ktf-2024.html, accessed 04.03.2024.

89 "Continue practice-oriented research on electromobility," https://www.oeko.de/fileadmin/oekodoc/Offener-Brief_Bundesregierung_Haushaltskuerzungen_Elektromobilitaet.pdf, accessed 04.03.2024.

90 Konrad Adenauer Stiftung, 2021: "Bundestag Election in Germany on 26 September 2021," p. 8 https://www.kas.de/documents/252038/11055681/Bundestag+Election+in+Germany+on+26+September+2021.pdf/11c8cee6-4819-40aa-69c5-81e3b8da1e08?t=1633597927008, accessed 12.03.2025.

91 Deutsche Welle, "DW; 2025: German election: migration and economy key issues," https://www.dw.com/en/immigration-and-economy-key-issues-in-german-election/a-71702813, accessed 13.03.2025

92 Financial Times, "Germany´s Greens vow to block Friedrich Merz´s flagship spending package," https://www.ft.com/content/b89519e8-1008-408b-80fd-b8ddbcad15d7, accessed 13.03.2025.

- Deutsches Biomasseforschungszentrum gemeinnützige GmbH[93]
- eFuel Alliance

Major changes

- Split of the German government in November 2024, ending the coalition of Social Democrats, Liberals, and Greens, leading to advanced elections in February 2025. The elections resulted in a very likely coalition of Social Democrats (SPD) and Conservatives (CDU/CSU). The coalition negotiations indicated planned major investments in infrastructure and defence. Major changes related to energy and climate policies are not expected.
- Revision of the European Renewable Energy Directive and its transition into national law.
- End of subsidies for purchasing electric vehicles and other funding cuts arising from the decision of the Federal Constitutional Court in November 2023 related to the spending financed from the Climate Transformation Funds (KTF).
- Continuation of the subscription for public transport ("Deutschlandticket").

Benefits of participation in AMF

Participation in AMF offers members access to global information and expertise around advanced transport fuels and exchange of experience in implementing solutions in member countries.

[93] DBFZ Report No. 44, "Monitoring renewable energies in transport," https://www.dbfz.de/en/press-media-library/publication-series/dbfz-reports, accessed 04.03.2024.

India

Drivers & Policies

India is the third-largest consumer of oil in the world. India also 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.[1]

India's economy is projected to grow at an average annual rate of 4.9% per year in 2023 and 2050. According to the *IEA World Energy Outlook 2024*, during this period, primary energy is expected to increase significantly — by 55% under Stated Policies Scenario (STEPS) and by 36% under the Announced Pledges Scenario (APS). As result of this robust growth, India's share in global primary energy consumption rises from around 7% in 2023 to approximately 10% by 2050 in both scenarios. Coal's share in the energy mix is projected to decline sharply, from 46% in 2023 to 27% by 2050 under STEPS, and even further to 16% under APS. In contrast, renewable energy sees substantial growth, with compound annual growth rates (CAGR) of 5.3% and 6.43% under STEPS and APS, respectively. By 2050, renewables emerge as the largest source of primary energy, with their share rising dramatically from 15% in 2023 to 38% under STEPS and 58% under APS. Electricity generation also sees a major boost — nearly 2.9 times the 2023 level under STEPS and approximately 3.5 times under APS by 2050. Solar and wind power together will account for nearly 94% of that growth. Hydrogen, which starts from an almost negligible base, is expected to grow to 65 PJ under STEPS and 597 PJ under APS in terms of total final consumption.[2]

Currently, India imports approximately 88% of its crude oil and 51% of its natural gas requirements.[3] 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) Programme; Biodiesel Blending in Diesel Programme; 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 CBG obligations 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 obligations will be 1%, 3%, and 4% of total CNG [Transport(T)]/PNG [Domestic (D)] consumption for FYs 2025–26, 2026–27, and 2027–28, respectively. Beginning in 2028–2029, the CBG obligation 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) effective 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

With the heavy reliance on crude oil, India acknowledges the importance of alternative fuels that are better for the environment and cost-competitive with fossil fuels. This envisions the importance of alternative fuels in the Indian energy basket. 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.

Ethanol Blended Petrol Programme

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 ESY 2025–26. Following this initiative, the government has notified and allowed the oil marketing companies (OMCs) to sell E20, in accordance with the Bureau of Indian Standards (BIS) specification effective starting December 15, 2022. In line with its Ethanol Blending Roadmap, India launched E20 fuel in February 2023 and, by January 2025, almost all retail outlets across the country were selling E20 fuel. Under the EBP Programme, public sector OMCs achieved the highest-ever blending of ethanol in petrol (14.6%) in ESY 2023–24.

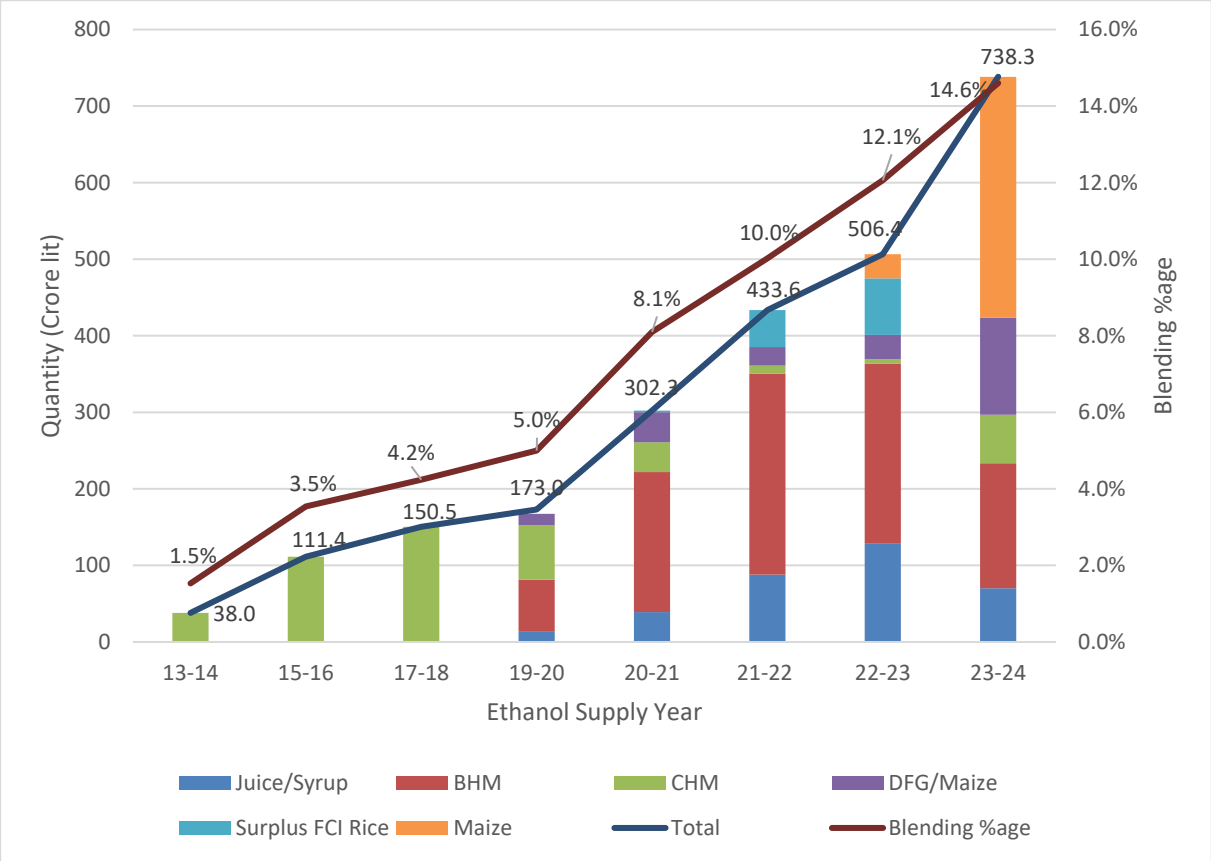
The Government of India has taken several steps to increase the production and use of ethanol, including permitting procurement of ethanol produced from damaged and surplus grains, sugar diversion, and non-food feedstocks. The government has adopted an administered price mechanism for ethanol procurement under the EBP Programme, provided incentives for use of maize as a feedstock by prioritizing its procurement and encouraging the establishment of dedicated ethanol plants (DEPs). OMCs have signed 232 long-term offtake agreements to add capacity of 7,920 million litres per annum. As of January 31, 2025, 86 DEPs have been commissioned with a design capacity of 5,360 million litres per year. Major developments in 2024 include constitution of a committee to develop a "Roadmap for Ethanol Blending beyond 2025," that explores the potential of alternative feedstocks such as sweet sorghum, sugar beet, and cassava. Interventions over the last decade have facilitated a corresponding increase in ethanol blending percentage from 1.53% to 14.6%, making India the third-largest producer of ethanol in the world (see Table 1 and Figure 1). During ESY 2023–24, ethanol distillation capacity has increased substantially, reaching a level of 16.83 billion litres per year in December 2024.

Table 1. Trends in Ethanol Procurement/Blending under EBP Program (Last 5 years)

Trend	Ethanol Supply Year (December to November)				
	2019-20	2020-21	2021-22	2022-23	2023-24[a]
Ethanol procured/blended by PSU OMCs[b] (in million liters)	1730	3023	4336	5085	7074
National average blending (percentage)	5.0	8.1	10.02	12.06	14.6

[a] From ESY 2023–24 onwards, ESY will be considered from November to October

[b] Public sector undertaking (PSU) OMCs (i.e., Indian Oil Corporation Ltd. [IOCL], Bharat Petroleum Corporation Ltd. [BPCL], and Hindustan Petroleum Corporation Ltd. [HPCL].



BHM: B-heavy molasses, CHM: C-heavy molasses, DFG: Damaged Food Grain, FCI: Food Corporation of India

Figure 1. Trends in Ethanol Procurement/Blending under EBP Programme, including different feedstocks (ESY 2013–14 to 2023–24)

Advanced Biofuels

The Government of India launched "Pradhan Mantri JI-VAN (JaivIndhan-Vatavaran Anukoolfasalawashesh Nivaran) Yojana," to provide financial assistance of approximately $250 million USD from 2018–19 to 2023–24 (now extended to 2028–29) to support commercial, as well as demonstration, projects for advanced biofuels. The amended scheme also includes advanced biofuels produced from lignocellulosic feedstocks (e.g., agricultural and forestry residues, industrial waste, synthesis [syn] gas, algae) in its scope. "Bolt on" plants and "brownfield projects" would also now be eligible to leverage their experience and improve their viability. Financial assistance of over $100 million US (908.25 crore INR) has been approved for six commercial and four demonstration 2G ethanol plants, including public and private sector companies. 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 2025.

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 (April 2021–March 2022) to 489.3 million litres in calendar year 2024.

The Government has set indicative targets of 1%, 2%, and 5% blending of SAF in ATF, initially for international flights, effective from 2027, 2028, and 2030, respectively. To achieve these targets, Indian refiners are investing in SAF production technology. OMCs are engaged in setting up various pilot/commercial scale facilities of nearly 332 kilotonnes per annum (KTPA) capacity.

Compressed Biogas

As part of an initiative under the National Policy on Biofuels 2018, 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 March 2025, 100 CBG plants with a total production capacity of around 700 metric tons (MT) per day have been commissioned; around 80 CBG plants are at various stages of construction. Sales of CBG have been initiated from more than 280 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 the CGD network on a pan-India basis. Under the CBG-CGD synchronization scheme, CBG sales have been initiated in 58 geographical areas of the CGD network.

In India, a "whole of government" approach has been adopted, in which various departments work together to foster the production of CBG. The approach includes assured prices for off-take of CBG through long-term agreements with OGMCs; the Umbrella Scheme of the National Bio Energy Programme by the Ministry of New and Renewable Energy, which inter-alia provided central financial assistance to all kinds of CBG/biogas plants; additional central assistance for municipal solid-waste-based CBG projects under Swachh Bharat Mission Urban 2.0; the inclusion of bio-manure produced from CBG plants as fermented organic manure and liquid fermented organic manure under Fertilizer Control Order 1985; market development assistance to promote organic fertilizer produced from CBG projects by the Department of Fertilizers; the inclusion of CBG projects under the "White Category" by the Central Pollution Control Board on a case-to-case basis; the inclusion of CBG projects under Priority Sector Lending by RBI; loan products from various banks to finance CBG projects; among others.

In addition, during calendar year 2024, the Government has introduced a scheme to support CBG producers in procurement of biomass aggregation machinery (BAM); the scheme for development of pipeline infrastructure (DPI) for injection of CBG into the CGD network; and a phase-wise mandatory obligation for sale of CBG in the CNG (T) and PNG (D) segments of the CGD network. The CBG obligations will be 1%, 3%, and 4% of total CNG(T)/PNG(D) consumption for FYs 2025–26, 2026–27, and 2027–28, respectively. From FY 2028–2029, the CBG obligation 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 electrolyser 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 green 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 oil and gas PSUs to set up green hydrogen projects across the country. Oil and gas PSUs have planned for 900-KTPA Green Hydrogen Projects (engineering, procurement, and construction [EPC] and build, own, operate [BOO] modes) by 2030. 42 KTPA tenders have been floated by PSU refineries, which are likely to be awarded in the first half of 2025. In July 2024, HPCL commissioned the first-ever green hydrogen plant in an Indian refinery, with a capacity to produce 370 TPA of green hydrogen. GAIL India Limited also commissioned a 4.3-ton per day (TPD) proton exchange membrane (PEM) electrolyser-based plant in Vijaypur, Madhya Pradesh.

International Cooperation

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 28 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.

GBA has also significantly enhanced its presence on the global pedestal by representation at international forums such as G20, International Forum on Sustainable Biofuels under the Italian G7 Presidency, COP28 (Dubai), COP29 (Baku), World Economic Forum (Switzerland), India Energy Week 2024 & 2025, and World Biogas Summit 2024 (UK).

India Energy Week (IEW) also gave fillip to the GBA. At IEW-25, GBA released a joint statement on sustainable biofuels, garnering endorsements from international organizations such as the International Energy Agency, Internation Energy Forum, World Economic Forum, World Biogas Association, and World Liquid Gas Association, reflecting India's commitment to integrating sustainable alternatives into its energy mix. GBA also launched a whitepaper highlighting the role of non-grain-based biofuels in India's energy transition.

International Partnership on Clean Energy Sector:
India and the United States continued to deepen their partnership through the Strategic Clean Energy Partnership (renamed as the Energy Security Partnership in February 2025). The September 2024 Ministerial Meeting marked significant advancements in clean energy collaboration.

India's commitment to clean energy extends to 2G/3G biofuels, green hydrogen, and other emerging fuels. In June 2024, India signed a Letter of Intent with Italy for collaboration in green hydrogen and sustainable biofuels.

In September 2024, India and Brazil released a joint statement on sustainable aviation fuel for coordinated position at international forum to promote SAF.

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 bioenergy in India through various schemes, with major emphasis on advanced biofuels. The IOCL R&D center has developed indigenous technology for conversion of lignocellulosic biomass to 2G ethanol based on simultaneous saccharification and co-fermentation (SSCF) with onsite enzyme production. The demonstration-scale plant is installed at Panipat and is undergoing commissioning. Multiple demonstration-scale plants focused on new technologies to produce advanced ethanol are supported under PM JI-VAN Yojana and are under construction.

India has undertaken several initiatives to increase the use of hydrogen in its energy mix. IOCL has undertaken an ambitious R&D project under the aegis of MoP&NG 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 TPD 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. IOCL will use these 15 indigenously manufactured/integrated hydrogen fuel cell buses to conduct a 20,000-km field trial on dedicated routes near Delhi's National Capital Region and the Gujarat Refinery.

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_2/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-3 fatty acids (docosahexaenoic acid, or DHA) and biodiesel. This value chain makes the overall process economically feasible.

IOCL commissioned a third generation (3G) ethanol production plant to produce around 128 KL/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 ATF from alcohol near Pune in Pirangut, which was inaugurated by the Union Minister of India.

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 set up 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. BPCL R&D is also working on long-term solutions for hydrogen storage and indigenous fuel cell systems, along with various academic institutes. BPCL R&D is scaling up indigenous alkaline electrolyser technology in collaboration with the Bhabha Atomic Research Centre (BARC). 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; CBG 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 public sector OMCs reached 7,074 million liters, resulting in the highest-ever average blending percentage of (14.6%) in ESY 2023–24. 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 ESY 2025–26. Since the government's announcement on E20 fuel in February 2023, ethanol blending in petrol has seen remarkable growth, supported by numerous proactive measures taken by the Government. Since January 2025, ethanol blending has been consistently over 19.5%. Also, E100 fuels have been made available at more than 400 retail locations across the country. Further, biodiesel procurement surged to its highest-ever level of 489.3 million litres during 2024 (January 2024–December 2024).

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 NG in 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.

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

- 1- IEA Indian Oil Market Outlook to 2030
- 2- IEA India dataset-2024.
- 3- www.ppac.gov.in for data on fossil fuels production, consumption, import and export
- www.mopng.gov.in for data related to the petroleum sector
- https://mnre.gov.in/ for data related to green hydrogen
- https://www.siamindia.com for data on the automotive industry
- https://dbtindia.gov.in/ for R&D related data Roadmap for Ethanol Blending in India 2020–25
- India Energy Scenario for 2023–24 by BEE
- National Policy on Biofuels – 2018 (amended in 2022).

Japan

Drivers and Policies

Since the previous revision of the Strategic Energy Plan in October 2021, the energy situation surrounding Japan has changed dramatically. In light of these changes, METI revised the Strategic Energy Plan in a manner that is consistent with the new target of reducing greenhouse gases by 73% in FY2040 (from FY2013). A Cabinet Decision was made on the Seventh Strategic Energy Plan on February 18, 2025, after going through the Public Comment Procedure and other processes.[94]

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."[95] 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 20-trillion-yen Green Innovation Fund has been established to encourage companies to take on ambitious challenges.[96] 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. [97]

In conjunction with the GX2040 Vision and the Plan for Global Warming Countermeasures, both of which were approved by the Cabinet, February 18, 2025, the government will strive to achieve stable energy supply, economic growth, and decarbonization simultaneously. In the road transport sector, the GX2040 vision is based on the pursuit of "variety of options" such as synthetic fuels and hydrogen, and newly stipulates that "with regard to fuel cell vehicles, emphasis will be placed on commercial vehicles," "additional support will be provided to priority regions," and "aiming for carbon neutral through the decarbonization of internal combustion engine fuels, and utilization of biofuels and synthetic fuels."[98]

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.[99, 100]

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.

For commercial vehicles, the following electrification targets were set:[101]

- 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.

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94 The Ministry of Economy, Trade and Industry, "Cabinet Decision on the Seventh Strategic Energy Plan," https://www.meti.go.jp/english/press/2025/0218_001.html.

95 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.

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

97 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.

98 METI, February 18,2025, https://www.meti.go.jp/press/2024/02/20250218004/20250218004.html (in Japanese)

99 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.

100 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.

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

Advanced Motor Fuels Statistics

Figure 1 shows the energy sources used in the transportation sector in Japan.[102] Oil-related energy accounts for 97.9% 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 8,051 FCVs.

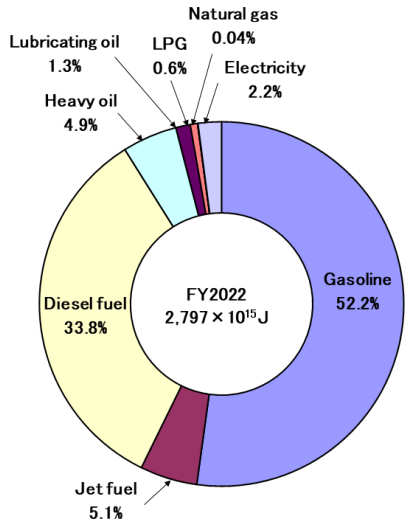

Figure 1. Energy Sources Used in the Transportation Sector in Japan, 2021

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

Vehicle Type	Methanol[103,104]	CNG[10,11]	Hybrid[10]	PHV[10]	EV[10,11]	FCV[10]	Vehicle Registration[105]
Passenger vehicles	3	8	12,444,651	252,552	191,615	7,748	38,752,774
Light, mid, and heavy-duty trucks	1	3,132	111,303	3	3,873	102	5,955,017
Buses	0	73	1,506	1	580	160	210,103
Special vehicles	1	884	15,365	356	376	41	1,661,030
Small vehicles	1	976	NA	NA	105,256	NA	31,755,793
Total	6	5,073	12,572,825	252,912	301,700	8,051	78,334,717

[102] 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.
[103] Automobile Inspection and Registration Information Association, as of March 2024 (in Japanese), https://www.airia.or.jp/publish/file/v19mrm00000019mo.pdf.
[104] Japan Light Motor Vehicle and Motorcycle Association, as of March 2024 (in Japanese), https://www.keikenkyo.or.jp/Portals/0/files/information/statistics/etc/kankatubetu_nenryobetuR0603.pdf.
[105] Automobile Inspection and Registration Information Association, as of March 2024 (in Japanese), https://www.airia.or.jp/publish/file/v19mrm0000000bx7.pdf.

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[106] 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 reach 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.[107]

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.[108] 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.[109]

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[110] and a heavy-duty LNG truck in October 2021.[111] Mitsubishi Corporation and Air Water Inc. have jointly developed Japan's first

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106 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.

107 Next Generation Vehicle Promotion Center (in Japanese), http://www.cev-pc.or.jp/suiso_station/index.html.

108 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/.

109 Toyota, November 11, 2023, "Evolution of Hydrogen Technology and Taking on New Challenges in Australia," https://global.toyota/en/newsroom/corporate/40081554.html.

110 Isuzu Motors Limited (in Japanese), https://www.isuzu.co.jp/product/cng/giga.html.

111 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.[112] 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. In October 2024, the cumulative number of LNG fillings into LNG-powered trucks reached 3,000, with a total filling volume of approximately 470 tons.

Biofuel

With respect to initiatives aiming to encourage the use of biofuels in Japan, sales of gasoline blended with ethyl tertiary-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).[113] 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).[114]

E-fuel

In order to achieve a cost lower than the price of gasoline for synthetic fuels in 2050, Japan will work on the 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.[115]

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.[116]

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.[117]

Alternative fuels research project promoted by the government

With the aim of early social implementation for the above alternative fuel use, the Next-Generation Environmentally Friendly Vehicles Development and Commercialization Project is promoted by Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The project started in 2002 and is currently in its sixth phase. Each stage is five years in length and has several research aspects. In the current phase the research aspects relating to alternative fuels use are hydrogen internal combustion engines, and compression ignition engines with synthetic carbon fuels, which origine is from Bio or Direct Air Capture.[118]

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[112] 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/.

[113] Japan Biofuels Supply LLP, https://www.jbsl.jp/english/objective/.

[114] Japan Alcohol Association (in Japanese), http://www.alcohol.jp/statis/import.pdf.

[115] 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.

[116] 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.

[117] https://actforsky.jp/.

[118] https://www.ntsel.go.jp/Portals/0/resources/forum/2024files/NTSELForum2024_LecPoster01.pdf (in Japanese).

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.

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 (RFS)

Since 2006, South Korea has been blending 0.5% biodiesel into diesel fuel. In July 2015, with the implementation of the Renewable Energy Fuel Blending Mandate under the Renewable Energy Act, the blending ratio has been gradually increased. Through the 2021 amendment of the law, the government established annual mandatory blending ratios up to 2030 (Table 1). These ratios are reviewed every three years, taking into account the development level of renewable energy technologies and fuel supply conditions. However, the review period may be shortened depending on the performance of the renewable energy fuel blending obligation and changes in domestic and international market conditions.

The annual mandatory blending volume is calculated as follows:

Annual mandatory blending volume = (Annual mandatory blending ratio) × [Domestic sales volume of transportation fuels (including blended renewable energy fuels)]

As of 2023, the annual production capacity of the nine companies producing biodiesel is 1.449 million kL, which exceeds the current distribution volume of approximately 911,000 kL. Considering the projected distribution volume up to 2030, it is expected that domestic supply will be sufficient without additional expansion.

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.

Starting from 2024, the blending ratio of biodiesel has been increased to 4%. This adjustment aims to enhance the utilization of renewable energy sources and contribute to reducing greenhouse gas emissions. The policy change reflects the government's commitment to promoting sustainable fuel alternatives and aligning with global carbon neutrality goals.

Additionally, the Eco-Friendly Biofuel Expansion Plan announced the introduction of next-generation biodiesel, with plans to increase the mandatory blending ratio from the current 5% to a maximum of 8%. Next-generation biodiesel refers to biodiesel produced by adding hydrogen to animal and vegetable oils, and it is currently undergoing demonstration research.

Advanced Motor Fuels Statistics

Table 2 lists the number and ratio of vehicles registered in Korea by year and fuel type from 2016 to 2024.

Table 2. Vehicles Registered in Korea, 2016–2024

Fuel	2016	2017	2018	2019	2020	2021	2022	2023	2024
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	26,297,919
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	12,419,660
	(46.29%)	(46.03%)	(45.81%)	(46.29%)	(46.83%)	(47.21%)	(47.04%)	(47.45%)	(47.23%)
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	9,100,840
	(42.06%)	(42.52%)	(42.80%)	(42.06%)	(41.01%)	(39.63%)	(38.03%)	(36.61%)	(34.61%)
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	1,849,816
	(9.94%)	(9.34%)	(8.77%)	(8.77%)	(8.12%)	(7.81%)	(7.42%)	(7.06%)	(7.03%)
HEV	233,216	313,856	405,084	506,047	674,461	908,240	1,170,507	1,542,132	2,024,481
	(1.07%)	(1.39%)	(1.75%)	(2.14%)	(2.77%)	(3.65%)	(4.56%)	(5.94%)	(7.70%)
CNG	38,880	38.918	38,934	38,147	36,940	35,208	32,780	30,352	27,058
	(0.18%)	(0.17%)	(0.17%)	(0.16%)	(0.15%)	(0.14%)	(0.13%)	(0.12%)	(0.10%)
EV	10,855	25.108	55,756	89,918	134,962	231,443	389,855	543,900	684,244
	(0.05%)	(0.11%)	(0.24%)	(0.38%)	(0.55%)	(0.93%)	(1.53%)	(2.10%)	(2.60%)
H_2	87	170	893	5,083	10,906	19,404	29,623	34,258	37,930
	(0.00%)	(0.00%)	(0.00%)	(0.02%)	(0.04%)	(0.08%)	(0.12%)	(0.13%)	(0.14%)
Other[a]	90,364	99,421	107,652	115,119	126,695	139,616	148,237	151,674	153,890
	(0.41%)	(0.44%)	(0.46%)	(0.49%)	(0.52%)	(0.56%)	(0.58%)	(0.58%)	(0.59%)

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

As of 2024, the cumulative number of registered vehicles in South Korea reached 26,297,919, marking a 1.34% increase (348,718 vehicles) compared to the previous year. The number of eco-friendly vehicles (EVs, hydrogen vehicles, and HEVs) continued to grow in 2024, following the trend from 2023 and accounting for 10.4% (2,746,655 vehicles) of the total registered vehicles. Notably, HEVs saw a 31.3% increase (482,349 vehicles) compared to 2023, while EVs increased by 25.8% (140,344 vehicles) over the same period. The government is working to expand domestic production of EVs and hydrogen vehicles in line with its revised target to promote 4.5 million units by 2030.

Research and Demonstration Focus

Biodiesel

Biodiesel is mainly made using waste cooking oil, animal oil, palm oil, and byproducts (palm fat acid distillate [PFAD]) of refined palm oil. Biodiesel, which has been in use since 2006, is distributed by mixing 4% (2024) in diesel for automobiles. Based on the total domestic sales and fuel mixing of the mixed obligators by year, the mixing performance ratios from 2020 to 2024 were 3.68%, 3.50%, 3.79%, 3.91%, and 4.40%, respectively, indicating that the target obligation ratio stipulated in the law has been achieved each year (Table 3).

Table 3. Year-over-year Performance of RFS Obligations for Transportation

Business Year	Domestic Sales Volume (A, kℓ)	New/Renewable Energy fuel Mixing Volume (B, kℓ)	Mixing Ratio (C=B÷(A)X100, %)
2020	21,906,168	805,652	3.68
2021	22,493,713	787,653	3.50
2022	21,763,725	824,898	3.79
2023	21,407,619	836,058	3.91
2024	20,709,447	911,142	4.40

Source: Korea Petroleum Quality & Distribution Authority (K-Petro).

As the mandatory blending volume of biodiesel in South Korea increases, the overall supply capacity is also rising (Table 4). However, due to the sufficient supply relative to the current domestic biodiesel demand, the supply capacity has slightly declined. In 2023, the conversion factor for biodiesel was not announced, so it was recorded in tons of oil equivalent (toe).

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
2023	692,374 toe	1,277,580

Source: Ministry of Trade, Industry and Energy/Korea Energy Agency, "2023 New/Renewable Energy Supply Statistics."

Hydrogen and Electricity

Under the "First National Strategy for Carbon Neutrality and Green Growth," the South Korean government has set a target to deploy 4.5 million electric and hydrogen vehicles by 2030. To achieve this goal, the government is promoting purchase subsidies and tax incentives for electric and hydrogen vehicles; differentiating subsidies based on performance factors such as driving range per charge; and reviewing tax support measures considering the environmental impact of vehicles. Additionally, the Low-Emission Vehicle Supply Mandate will be restructured to focus on zero-emission vehicles and, from 2023, the government will implement a flexible compliance system and contribution fees to further boost the supply of zero-emission vehicles.

By 2030, the government aims to significantly improve the driving range and durability of electric and hydrogen vehicles, enhance energy efficiency, and develop ultra-fast charging technology capable of fully charging high-voltage EVs within five minutes. Furthermore, the development of 5-ton and 10-ton hydrogen-powered special-purpose vehicles, ultra-compact EVs, and medium-sized electric trucks and buses will be promoted to support market entry for small and medium-sized enterprises (SMEs).

To diversify hydrogen mobility, the government plans to ensure durability and driving range equivalent to internal combustion engine vehicles by 2030 and establish a mass production system for hydrogen passenger, commercial, and special-purpose vehicles. Additionally, subsidies will be concentrated on commercial vehicles and ships, while the zero-emission vehicle purchase mandate and mandatory public sector procurement ratio will be increased to accelerate the transition to eco-friendly fuels.

Ammonia

The Korea Institute of Machinery & Materials (KIMM), in collaboration with Hyundai Motor Company and Kia, successfully developed the world's first 2-liter class pure ammonia direct injection engine. This groundbreaking engine can utilize ammonia, a hydrogen carrier, as a direct fuel source without requiring additional processing. It employs a high-pressure liquid injection system to ensure the stable supply of large volumes of ammonia fuel. Moreover, it can be used without additional combustion enhancement devices or additives.

HD Hyundai Heavy Industries has developed the world's first high-pressure direct injection ammonia dual-fuel engine (HiMSEN, H22CDF-LA). Compared to conventional low-pressure premixed systems, it offers enhanced output (1.4–2.2 MW) and improved fuel efficiency, while significantly reducing greenhouse gas emissions, including N_2O. Additionally, HD Korea Shipbuilding & Offshore Engineering has successfully applied its proprietary Integrated Ammonia Scrubber, achieving a significant reduction in ammonia emissions. The company is also developing the H32CDF-LA engine, which will have an output of 3.6–5.4 MW.

The Korea Institute of Energy Research (KIER) has pioneered an ammonia decomposition-based clean hydrogen production technology that achieves zero carbon dioxide emissions. This innovation enables the production of high-purity hydrogen that meets international standards for hydrogen fuel cell vehicles without generating any carbon emissions.

e-Fuel (Synthetic Fuel)

The Ministry of Environment of Korea is preparing a roadmap for synthetic fuel manufacturing standards and an emission certification system to facilitate the introduction of e-fuel. Research is currently underway to establish fuel quality standards, testing methods, emission components, and testing procedures for synthetic fuel.

The Ministry of Trade, Industry, and Energy held the "Renewable Synthetic Fuel (e-Fuel) Research Council," where the government, industry, academia, and research sectors gathered to present policy and technical challenges for achieving carbon neutrality through the use of e-fuel.

The Korea Institute of Machinery and Materials (KIMM) has reduced the amount of catalyst required for e-fuel production by 30% and developed a microchannel reactor with 30 times the capacity of conventional reactors. The microchannel reactor is about one-fifth the size of traditional reactors, enhancing reactor integration and enabling a modular configuration. This allows for easier reactor control and improved stability.

Outlook

The South Korean government is laying the groundwork for the introduction of new types of transportation fuels, such as e-fuel and ammonia, while also expanding the blending ratio of existing biofuels, continuing its efforts toward carbon neutrality.

Biodiesel
The South Korean government plans to gradually increase the mandatory biodiesel blending ratio, targeting 8% by 2030 under the Eco-Friendly Biofuel Expansion Plan. In 2024, the blending ratio was raised to 4%, and next-generation biodiesel, produced by hydrogenating animal and vegetable oils, is currently undergoing demonstration research.

Alternative fuels
South Korea is developing methanol dual-fuel engines through HD Hyundai Heavy Industries to reduce emissions from ships and is also working on engine development and optimization to utilize methanol combustion in the automotive industry.

Additionally, Korea is securing technologies for producing new automotive fuels such as ammonia and e-fuel, while simultaneously researching utilization technologies to improve combustion efficiency and reduce emissions, aiming to diversify carbon-neutral fuel options.

Additional Information Sources

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

Spain

Drivers and Policies

The main policy instrument aimed at fostering the consumption of advanced motor fuels in Spain is the renewable fuels quota obligation, regulated by means of Ministerial Order TED/728/2024. 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 renewable fuels. 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 2024, the fee was updated to EUR 2,029 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 2024 target (in energy content) was 11%. In 2019, the double-counting of some biofuels came into play. Ministerial Order TED/728/2024includes 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 2024, it established a mandatory target of 0.5% 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 2024, this limit was set at 3%.

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 has been 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 2024 (provisional data).

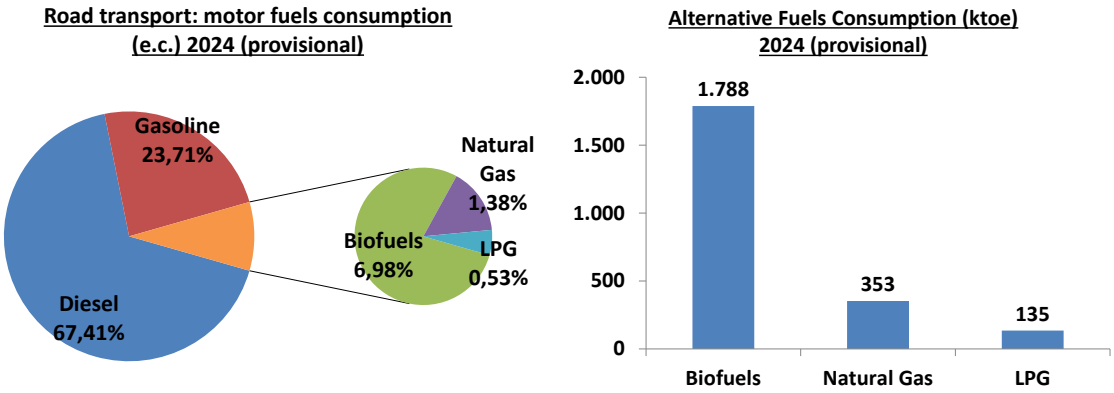

Figure 1. Fuel consumption (share in energy content) in Spain in 2024 (Sources: Ministry for Ecological Transition and Demographic Challenge, Enagás, National Markets and Competition Commission).

Figures 2, 3 and 4 provide information on the feedstocks used to produce biofuels consumed in Spain in 2024 (provisional data).

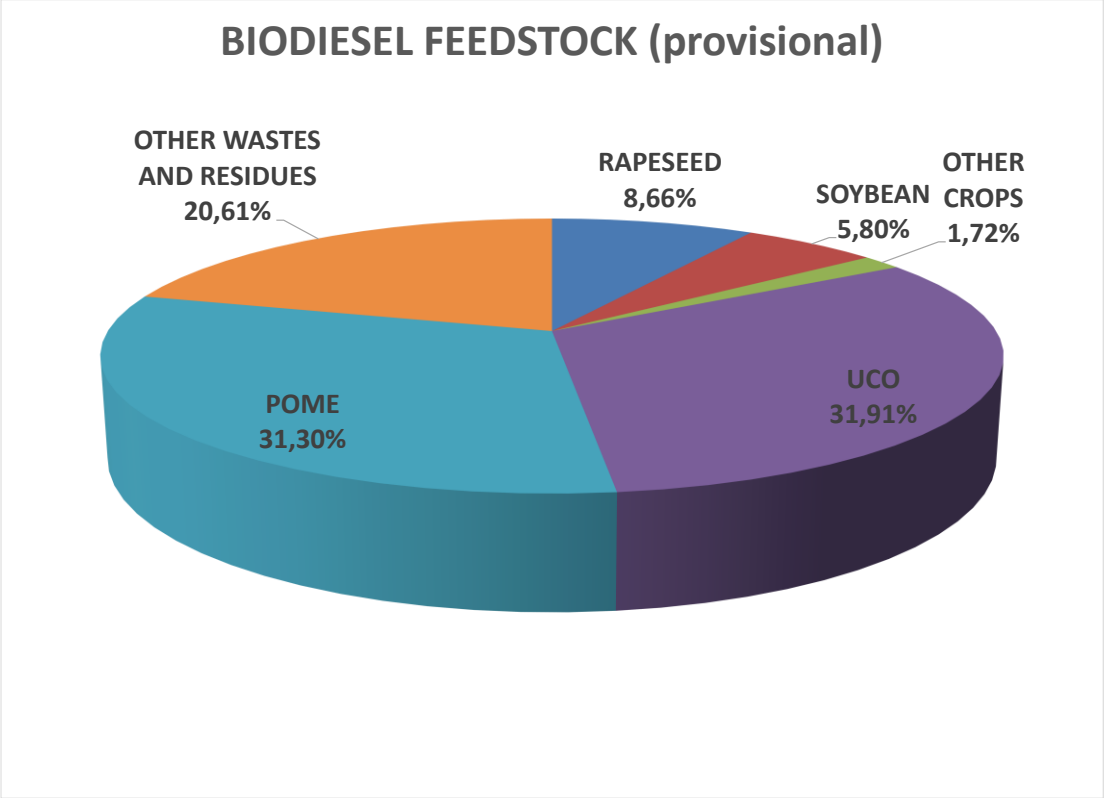

Figure 2. Feedstock of biodiesel consumed in Spain in 2024 (Source: Ministry for Ecological Transition and Demographic Challenge).

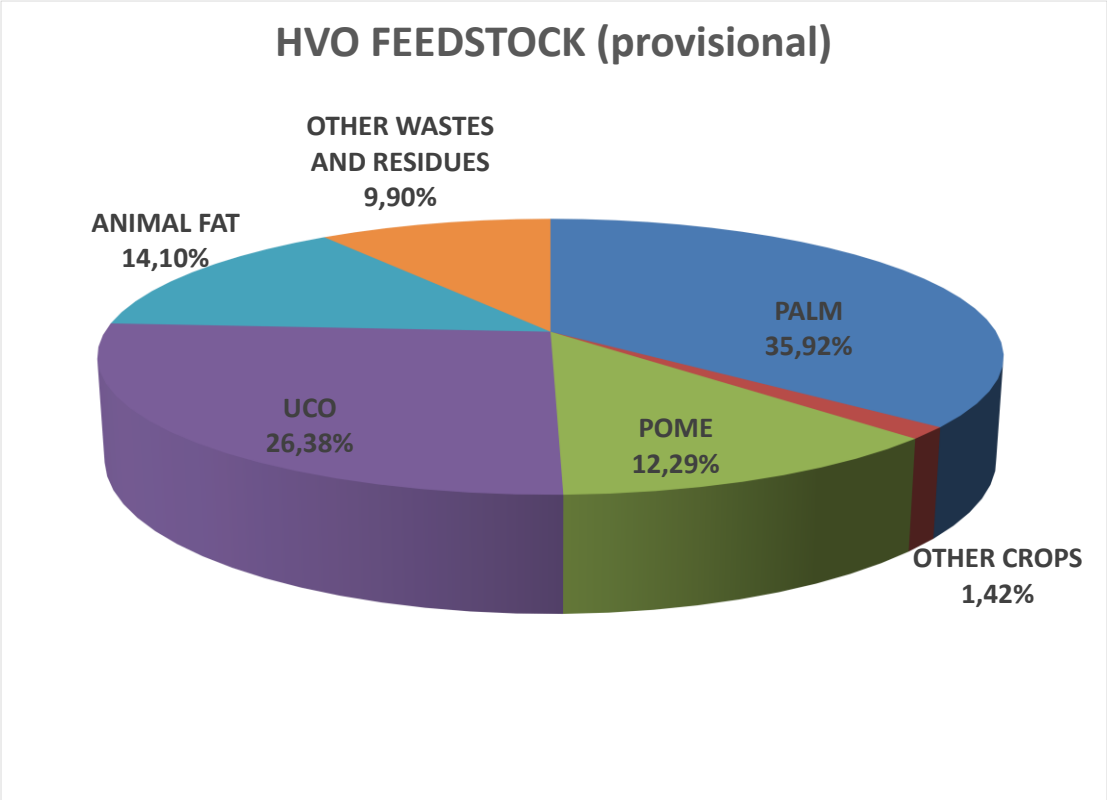

Figure 3. Feedstock of HVO consumed in Spain in 2024 (Source: Ministry for Ecological Transition and Demographic Challenge).

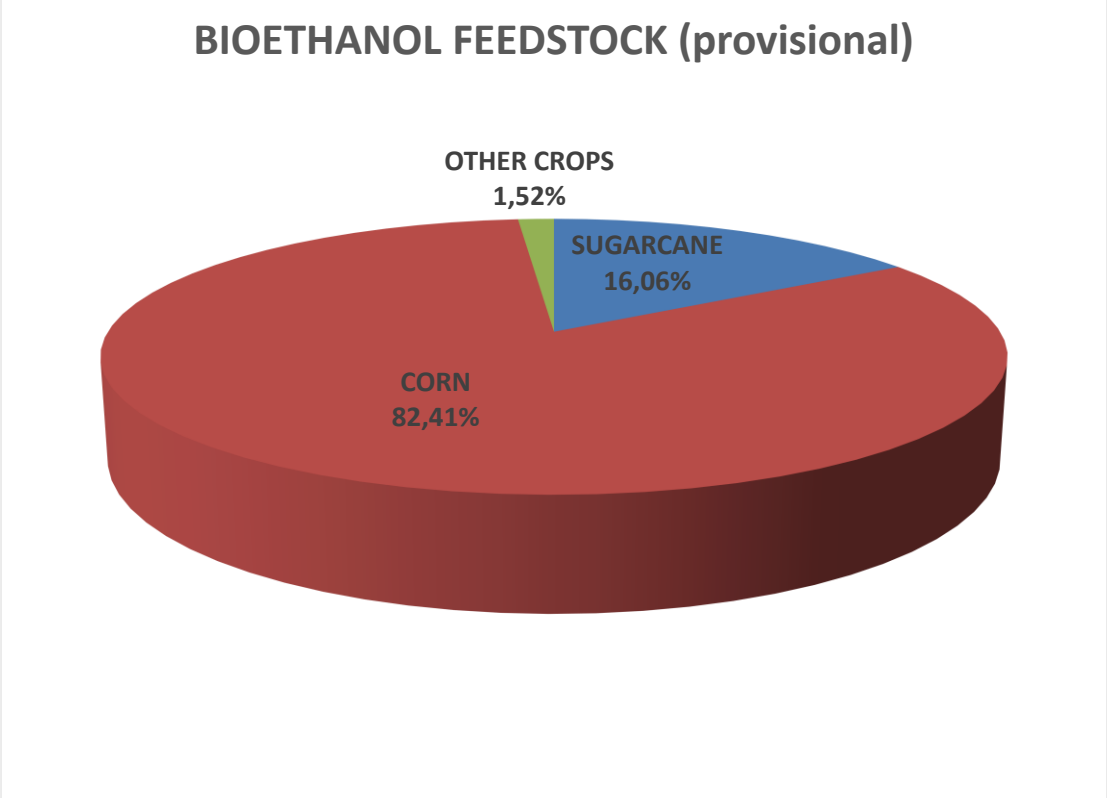

Figure 4. Feedstock of bioethanol consumed in Spain in 2024 (Source: Ministry for Ecological Transition and Demographic Challenge).

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 *2024–2027 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 integrated *National Energy and Climate Plan 2023–2030* (NECP), approved by the Spanish Government in September 2024, 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% 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 integrated NECP, in 2030 the share of renewable energy in transport in Spain will be 28% with a GHG emissions reduction of 16.3%, well above the target established in the directive (14.5%). The contribution of biofuels from food and feed crops will be 1.5%, and advanced biofuels and biogas will reach 6.9% while the combined share with RFNBO will be 17.3%.

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 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

- Publication of the updated *National Energy and Climate Plan*, which includes shares of renewable energy in transport and GHG emissions reduction to be reached in 2030.
- Publication of the Ministerial Order TED/728/2024, which regulates the obligation of biofuels and other renewable fuels in the transport sector.

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 (LDVs) with a bonus of up to SEK 50,000 (USD 4,769). 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 was the reduction obligation — an obligation for fuel suppliers to reduce GHG emissions from sold volumes of petrol and diesel fuels by incorporating biofuels. In 2024, the reduction obligation was reduced to 6% for petrol from 7.8% and to 6% for diesel from 30.5%. The biofuels included in the reduction obligation system are subject to the same energy and CO_2 taxation as fossil fuels. In 2024, the Swedish government decided to increase the reduction obligation, beginning on July 1, 2025, to 10% for both petrol and diesel to contribute further to the Swedish commitment; in accordance with the EU's Effort Sharing Regulation, this reduction obligation is to be applied until 2030. Sweden has abolished the corresponding reduction obligation for aviation fuel because these fuels will be managed by ReFuel EU Aviation.

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 9.5 million tons in 2024. The main reasons for the reduction are the increased energy efficiency of new vehicles, electrification, and renewable motor fuels.

The fleet of alternative-fueled passenger cars totaled around 870,000 at the end of 2024 (see Figure 1). In addition, automakers have produced an increasing share of conventional diesel vehicles fueled with hydrotreated vegetable oil (HVO)100. However, no statistics are currently available on the size of this share.

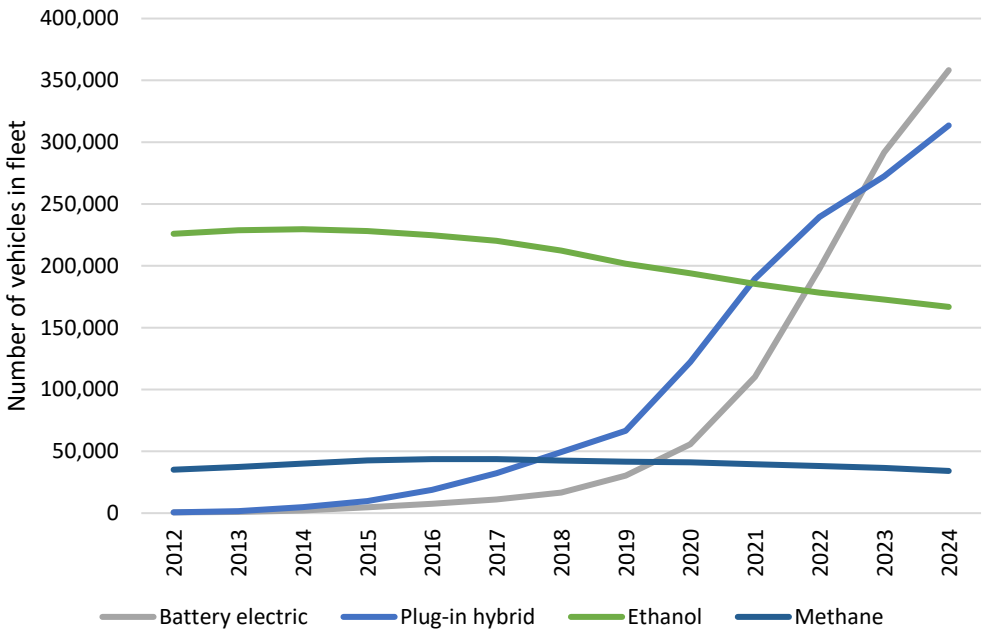

Figure 1. Number of Advanced Motor Fuel Passenger Cars in the Swedish Fleet, 2012–2024

Alternative-fueled vehicles correspond to 17.5% of the total fleet of passenger cars (excluding diesel cars that can be fueled with HVO100). Light commercial and heavy-duty vehicles make up 6.9% and 4.7% of the total fleet, respectively. However, vehicles registered as other than petrol- or diesel-fueled number 28.6% 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 11.7 terawatt hours (TWh), or nearly 17% of the transportation fuels sold during 2024 (see Figure 2). Approximately 68% of the renewable fuel used in Sweden during 2024 was HVO and fatty acid methyl ester (FAME).

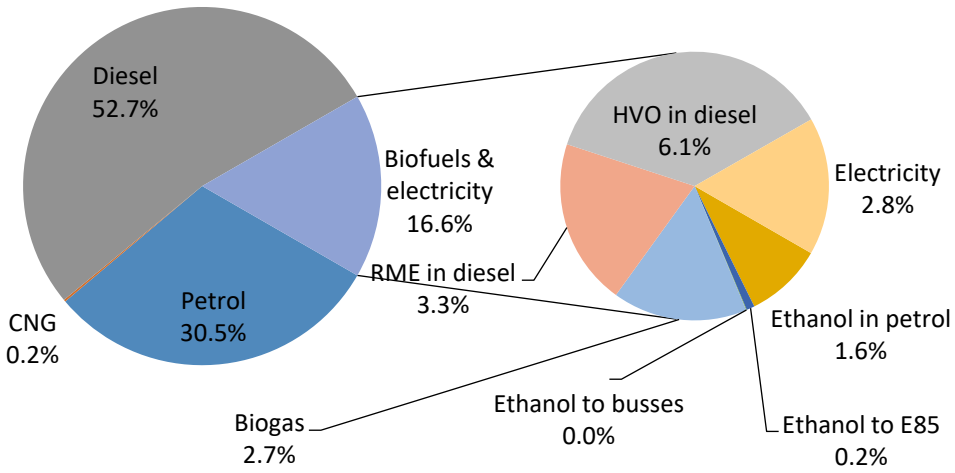

Figure 2. Fuel Consumption (in TWh) within the Road Transport Sector, Preliminary Statistics, 2024

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 2023, the raw materials were, to a large extent, animal waste (65%), with the remaining shares consisting of used cooking oil, sewage sludge, industrial waste, and other. The majority of feedstocks for HVO are imported, as shown in Figure 3. The average GHG emissions from HVO use in Sweden during 2023 corresponded to around 7.7 g carbon dioxide equivalent (CO_2e) 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 many other vegetable oils for the Nordic climate.

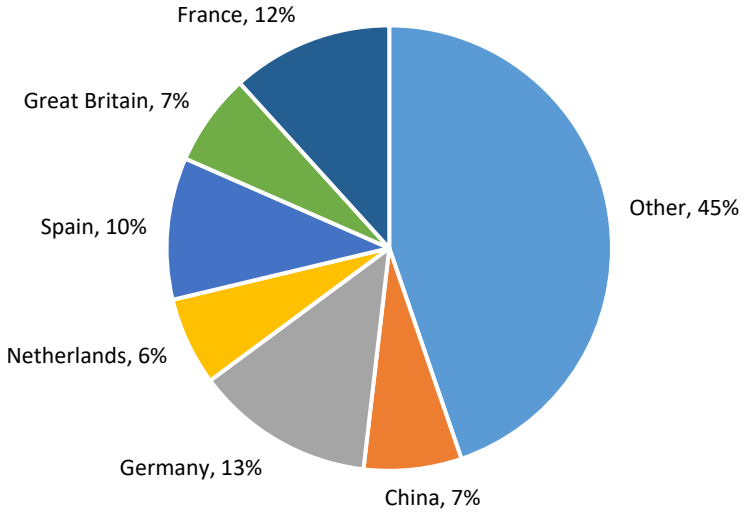

Figure 3. Country of Feedstock Origin for HVO Consumed in Sweden, 2023

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 climate goal established in Sweden is ambitious, 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 will 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 act 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. On March 15, 2024, an amended version of the revised CO_2 Act was passed by Parliament and brought into force.

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 the Act passed the parliament in June 2022, opponents successfully filed a referendum against it. But in June 2023, the Swiss public voted (with 59.1%) in favor 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 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 was held in June 2024. The revision of the Acts was accepted with 68.7% approval.

CO_2 Emission Regulations for Cars

Carbon dioxide (CO_2) emissions regulations for new cars apply in Switzerland just as they do in the European Union (EU). Until 2020, the measurement procedure and limit values of the New European Driving Cycle (NEDC) applied. Since 2021, the CO_2 emissions of vehicles have been determined according to the WLTP (World Harmonized Light-Duty Vehicles Test Procedure). The average CO_2 emissions of newly registered passenger cars must not exceed 118 g CO_2/km. This target decreases to 93.6 g CO_2/km in 2025 and to 49.5 g CO_2/km in 2030. A CO_2 target regulation for heavy-duty vehicles (HDVs) will also come into force for the first time in 2025. Importers of new HDVs must reduce average emissions by 15% compared with the reference values set out in the EU regulation and by 30%

[119] Fedlex, Energy Law SR 730.0, https://www.fedlex.admin.ch/eli/cc/1999/27/de
[120] Swiss Federal Office of Energy (SFOE), "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 Act on Climate Protection Goals, 2022, "Innovation and Strengthening Energy Security."
[123] SFOE, 2021, "Federal Act on a Secure Electricity Supply from Renewable Energy Sources."

beginning in 2030. 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.

The average CO_2 emissions of all cars in 2023 amounted to around 112.7 g CO_2/km — more than 8 grams lower than in 2022 (120.9 g CO_2/km) and, for the first time, well below the target value of 118 g CO_2/km (Figure 1). This emissions reduction had a positive effect on the penalty, which dropped from EUR 16.4 million (USD 17.2 million) in 2022 to EUR 1.82 million (USD 1.97 million) in 2023.[124] This reduction is attributable to the further electrification of the Swiss new passenger car fleet. The proportion of new electric (20.7%) and new hybrid passenger cars (36.7%) amounted to 57.4% in 2023.

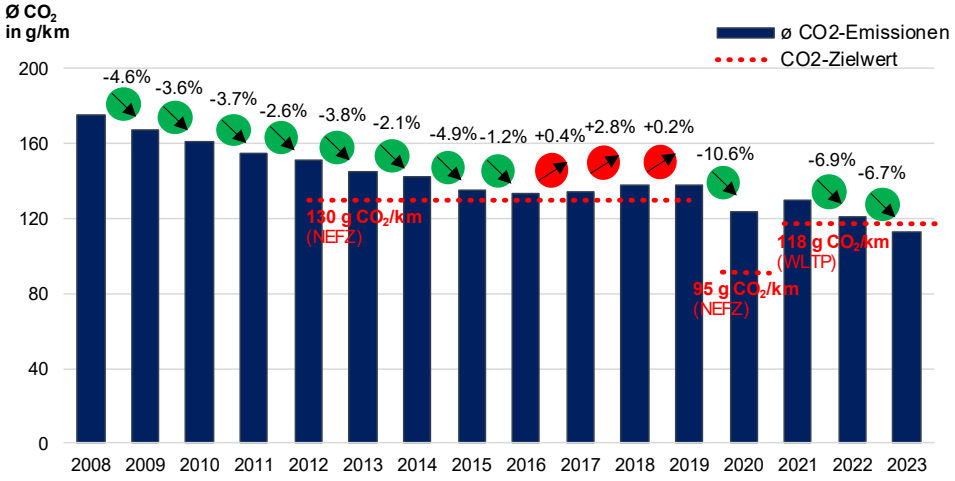

Figure 1. Average annual CO_2 emissions of passenger cars registered for the first time and reduction rates from 2008–2023. The arrows and percentages show the change compared with the previous year.

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 2023 was 20%; the rate increased to 23% in 2024.[125] 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 up to EUR 0.77 (USD 0.83) per liter, compared with fossil fuels. The mineral oil tax reduction is valid until the end of 2030.[126] To offset the loss of tax revenue from this tax cut, the fossil fuel tax will be gradually increased until 2037.

[124] SFOE, 2024, "Vollzug der CO_2-Emissionsvorschriften 2023."
[125] FOEN (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: March 15, 2024.

Advanced Motor Fuels Statistics

The following numbers and statements are based on 2023 statistics.

Energy and Fuels

Final total energy consumption in Switzerland in 2023 amounted to 767,450 terajoules (TJ), which represents a small increase of 0.3% compared with the previous year. The 5-year comparison (2019 vs. 2023) shows a decrease in Switzerland's total energy consumption of 8.7%, which corresponds to 66 TJ. The decline was mainly caused by reduced use of petroleum products and natural gas (minus 70.1 TJ or 15.7 %). In the case of petroleum products, there was a decrease of 9.7% in use of motor fuels and 27% in use of heating oil. The decline in natural gas use was 21%. The climatic differences between 2019 and 2023 (calculated using the heating degree index [HDD]) show a lower heating demand of 7.8%. In summary, the climate-adjusted consumption of fossil fuels has fallen by approximately 15%. Electricity consumption increased only slightly, by 4.1 TJ or 2.0%, during this period.

Gasoline and diesel consumption increased by a total of 0.3% (gasoline +3.3%, diesel -2.1%). Sales of aviation fuels rose by 15.9% compared with 2022 — but were still 13.8% lower than in 2019. Overall, fuel consumption was 4.7% higher than in 2022. Transport fuels account for 35% of total Swiss energy consumption; all fossil fuels were imported (Figure 2).

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 251.3 million in 2023.

In 2023, 152.4 million liters of biodiesel and 98.7 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. In 2023 we see a slight increase to 185,000 liters. Pure vegetable oil fuel use is almost negligible (24,000 liters). Upgraded biogas as a transport fuel remained at a low level (2.4 million kg).[127]

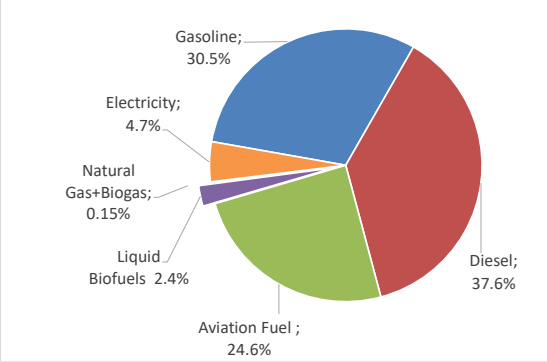

Figure 2. Shares of Energy Sources in Energy Consumption for the Transportation Sector in Switzerland, 2023[128]

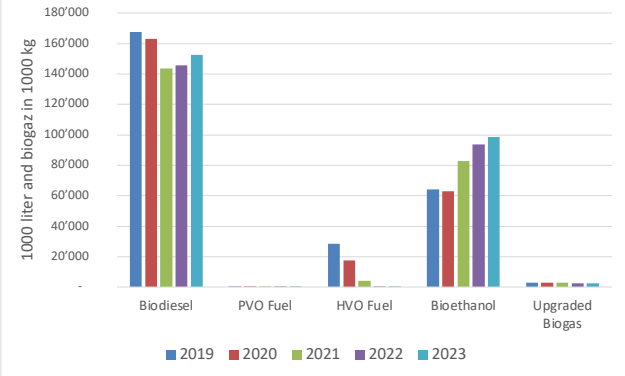

Figure 3. Use of Biofuels as Motor Fuels in Switzerland, 2019–2023

Only 14.5 million liters of biodiesel were produced in Switzerland; the remaining 137.9 million liters were imported (Germany, 65.2%; China, 11.9%; Austria, 10.1%; France, 8.2%; Japan, 4.0%; Greece, 0.2%;). All bioethanol is imported (Poland, 35.7%; Germany, 15.8%; Italy, 15.1%; Sweden, 11.4%; The Netherlands, 9.9; Norway, 4.9%; United States, 4.6%; Ukraine, 2.6%).[129] The small amount of HVO used in Switzerland is imported from Austria and Finland.

[127] SFOE, 2024, "Schweizerische Statistik erneuerbarer Energien 2023."
[128] SFOE, 2024, "Gesamtenergiestatistik 2023."
[129] Swiss Custom Administration, 2024, "T2.8 Biogene Treibstoffe 2023."

The total amount of biogas produced and used in Switzerland in 2023 was 134.0 million kg. Only 33.3 million kg has been upgraded and fed into the natural gas grid. Of this, 2.4 million kg has been sold as biogas for cars, and the remainder (92.8%) was used for heating residential buildings or in industry. Compared with the amount produced, demand for biogas as a motor fuel is very low. A total of 6.9 million kg of natural gas was used as fuel — 28.2% less than in 2019 (Figure 4).

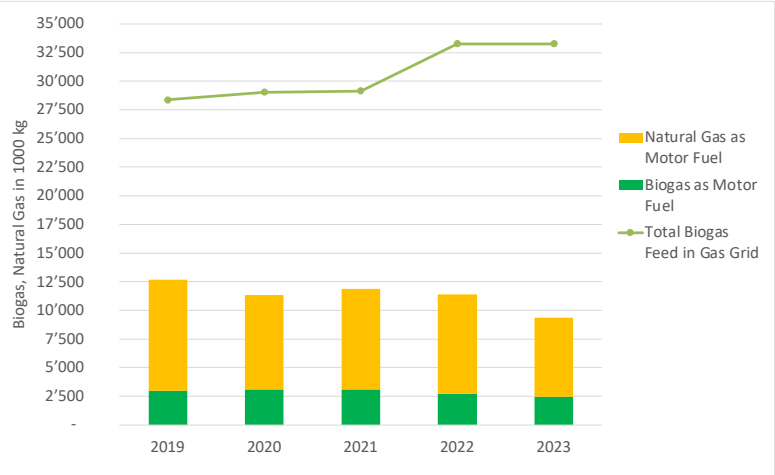

Figure 4. Development of Natural Gas and Biogas as Motor Fuel for Cars and Total Upgraded Biogas Fed into the Natural Gas Grid (green line)

Motor Vehicles

In 2023, 356,538 motor vehicles were newly registered in Switzerland, representing an increase of 10.6% over 2022 and a decrease of 12.9% compared with 2019. New registrations of passenger cars increased by 11.6%. The number of newly registered hybrid cars rose 23.7%, and electric car registrations increased by 30.7%. Sales of gasoline-fueled cars decreased slightly (by 1.2%), and sales of diesel-fueled cars dropped by 10.0%. Compared with 2019 totals, sales of cars powered only by fossil fuels declined by 59.8%. In contrast, sales of hybrid vehicles rose by 256%, and sales of electric vehicles increased by 302% in the same period (Figure 5).

Despite the steep rise in sales of electric and hybrid passenger cars, their share of the total (4,760,948) is still very small. Figure 6 illustrates this fact, using passenger cars as an example. Hybrid vehicles have a share of 7.6% of the total passenger car fleet, whereas the share of electric vehicles amounts to 3.3%. Most of the electricity used in the transport sector (85%) is for railroad transportation (Figure 2).

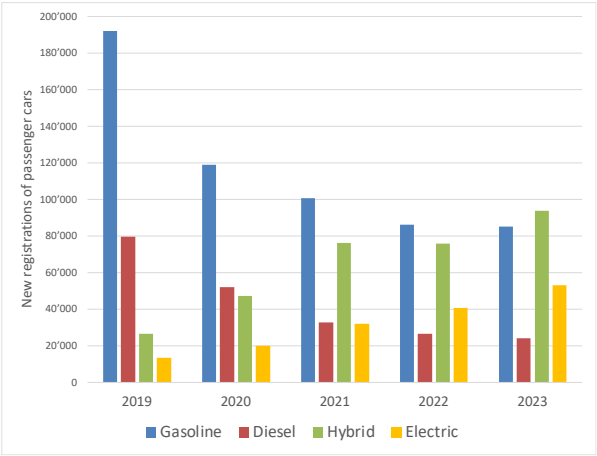

Figure 5. New Registrations of Passenger Cars by Fuel

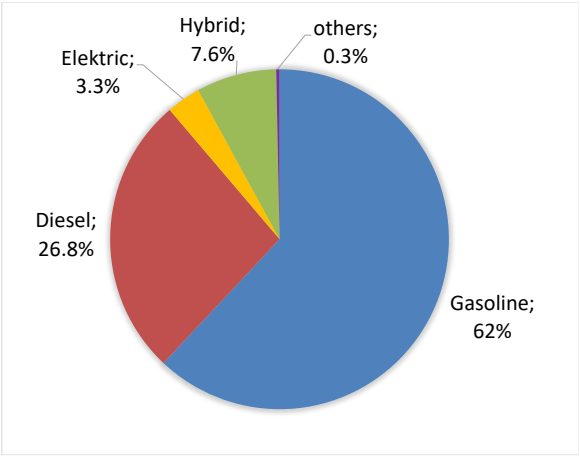

Figure 6. Passenger Car Share by Fuel, 2023 (Total Number is 4,760,948)

Research and Demonstration Focus

The 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.[130]

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

The federal government's planned cost-cutting measures will reduce the budget for energy research and cut the program for pilot and demonstration projects. These cuts particularly affect combustion research, which also includes advanced motor fuels.

According to Scenario ZERO Basis (of the Swiss Energy Perspectives 2050+), after 2050, the transport sector should be operated without fossil fuel. That means reductions from 197.3 PJ gasoline, diesel, and natural gas plus 7.2 PJ biofuels and 13.7 PJ electricity in 2023 to 71.9 PJ renewable fuels and 60.7 PJ electricity in 2050 (data without fuels for aviation, which totaled 71.2 PJ in 2023). Figure 7 displays final energy demand.

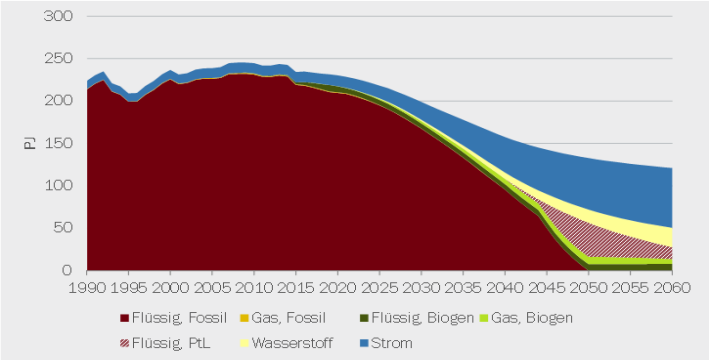

Figure 7. Final Energy Demand of Domestic Transport (Scenario ZERO Basis, Excluding International Aviation)[131]

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 (IC) 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 also investigated.

SWEET refuel.ch: Renewable Fuels and Chemicals for Switzerland (2023–2030)[132]

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 project to investigate how investment security can be improved by closing this knowledge gap. 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.

[130] SFOE, "Energy Strategy 2050," https://www.bfe.admin.ch/bfe/de/home/politik/energiestrategie-2050.html.
[131] SFOE, 2022, *Energy Perspectives 2050+*, Technical Report.
[132] Swiss Federal Office of Energy, "SWEET: reFuel.ch," https://www.sweet-refuel.ch/.

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 — was installed at the experimental facilities of R&D Moteurs in France. The research team will quantify ammonia slip and nitrous oxide (N_2O) emissions and perform emission measurements of secondary and particulate formations.

E-Methanol compression-ignition combustion (2023–2027)[133]
Renewable methanol is a technically and economically promising solution to achieve net-zero CO_2-free IC 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. The researchers will evaluate the feasibility and limitations of e-methanol using an optically accessible test bench to investigate the underlying mechanisms under relevant pressure, temperature, and flow conditions, as well as different injection strategies. In addition, researchers will evaluate ignition-promotion concepts that could be required.

Exhaust analytics for low GHG impact fuels (2023–2025)[134]
This project will investigate the exhaust gas emissions of different combustion processes using (renewable) low-GHG fuels. A flexible engine test facility is used to examine the application of such fuels (i.e., methanol, ammonia) under engine-relevant pressure, temperature, and flow conditions, as well as varying combustion processes. The research team is assessing the use of appropriate exhaust gas analytical instrumentation to ensure that the emissions data obtained during engine development can be validated. The project will provide a coordinated input to the regulatory and standardization debate so that the IC engine industry can recommend emission analysis technologies to the regulatory authorities.

Combustion system with alternative pre-chamber fuels (2024–2026)[135]
The need to make IC engines more efficient, while reducing emissions and improving their ability to operate reliably with new synthetic fuels, has led to the development of a new, advanced combustion process: Spark-Assisted Compression-Ignition (SACI). Combined with an active pre-chamber, SACI can reliably control the auto-ignition of the premixed cylinder charge, resulting in an efficient combustion process suitable for new, difficult-to-burn synthetic fuels or very lean air-fuel mixtures. The aim of this project is to investigate the influence of the reactivity of the pre-chamber fuel on the hot reactive jets and the subsequent (partial) auto-ignition of the main chamber charge. Hydrogen is used for high reactivity and ammonia for low reactivity in the pre-chamber.

N_2O Exhaust Gas Treatment in Ammonia Engines II (2024–2027)[136]
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 NOx, NH_3, and N_2O have been measured on prototypical large engine setups. The aim of this continuation project is to follow up on analysis and understanding of catalyst behavior in the complex exhaust gas containing these components, allowing researchers to propose recommendations to reduce pollutant emissions from prospective NH_3-fueled engines. Researchers are studying catalysts based on Fe-exchanged zeolites by analyzing the influence of acidic properties on catalytic activity, as well as by exploring the effects of hydrothermal and chemical aging. In addition, the exhaust gas composition of real NH_3 engines is considered, for example by including other pollutants such as hydrocarbons in the model gas investigations in the laboratory.

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133 FHNW ITFE (University of Applied Sciences Northwestern Switzerland, Institute of Thermal and Fluid Engineering), "EMOCION – E-Methanol Compression Ignition Combustion," project 502699 in ARAMIS (Administration Research Actions Management Information System), https://www.aramis.admin.ch/Texte/?ProjectID=53959.

134 FHNW ITFE, "EXHALE – Exhaust Analytics for Low GHG Impact Fuels," project SI/502712 in ARAMIS, https://www.aramis.admin.ch/Texte/?ProjectID=54053.

135 FHNW ITFE "SACI II – Combustion system with alternative pre-chamber fuels," project 502840 in ARAMIS, https://www.aramis.admin.ch/Texte/?ProjectID=55940.

136 PSI (Paul Scherrer Institute), "N_2Ooff II – N_2O exhaust gas treatment in ammonia engines – II," project SI/502902 in ARAMIS, https://www.aramis.admin.ch/Texte/?ProjectID=56158.

Outlook

The share of electric or plug-in hybrid cars in Switzerland continues to rise: their sales share was 28.0% in 2024. The demand for large electric vehicles for municipal use, local public transport, and freight transportation is also increasing. The demand for fossil fuels will therefore further decrease, and electricity consumption will increase. The number of charging stations for electric vehicles is growing commensurably with the growing fleet of electric vehicles.

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 yet clear which of these fuels is the most suitable and will prevail.

Cooperative 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 also of great importance here.

Major changes
In June 2024, the Swiss public voted in favour of the new Act on a Secure Electricity Supply from Renewable Energy Sources.

In 2023, sales of motor vehicles increased by 10.6% compared with 2022. Sales of gasoline- and diesel-fueled passenger cars declined by 3.3%; sales of hybrid cars rose by 23.7%; and 30.7% more electric passenger cars were sold. A total of 255,900 passenger cars were sold in 2023. Of these, 42.6% were gasoline- and diesel-fueled vehicles, 36.7% were hybrid vehicles, and 20.7% were electric vehicles. These sales had a positive effect on the average CO_2 emissions from newly registered passenger cars, which at 112.7 g CO_2/km were below the target value of 118 g CO_2/km for the first time!

Sales of biofuels increased slightly but remain low (3.5%) compared with the consumption of diesel and gasoline.

Benefits of participation in AMF
The future of IC 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

Background

Vehicles move the American economy. Each year in the United States, vehicles transport 18 billion tons of freight — about $55 billion worth of goods each day[137] — and move people more than 3 trillion vehicle-miles.[138] Growing our economy requires transportation, and transportation requires energy. The transportation sector accounts for approximately 27% of total U.S. energy needs[139] and the average U.S. household spends over 15% of its total family expenditures on transportation,[140] making it, as a percentage of spending, the costliest personal expenditure after housing. Transportation is critical to the overall economy, from the movement of goods to providing access to jobs, education, and healthcare.

The transportation sector has historically relied heavily on petroleum, which supports over 90% of the sector's energy needs today,[141] and, as a result, surpassed electricity generation to become the largest source of greenhouse gas emissions in the country.[142]

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.[143] 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.[144]

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.[145] 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 20.7 billion gallons in 2023 to 21.7 billion gallons in 2024, as fuel consumption continued to grow after the first year of the pandemic.

[137] Bureau of Transportation Statistics, DOT, Transportation Statistics Annual Report 2020, Table 4-1, https://www.bts.gov/tsar.
[138] Davis, Stacy C, and Robert G Boundy. Transportation Energy Data Book: Edition 40. Oak Ridge, TN: Oak Ridge National Laboratory 2022. https://doi.org/10.2172/1878695. Table 3.09 Shares of Highway Vehicle-Miles Traveled by Vehicle Type, 1970-2019.
[139] Ibid. Table 2.02 U.S. Consumption of Total Energy by End-use Sector, 1950-2021.
[140] Ibid. Table 11.1 Average Annual Expenditures of Households by Income, 2020.
[141] Ibid. Table 2.03 Distribution of Energy Consumption by Source and Sector, 1973 and 2021.
[142] Environmental Protection Agency, Draft U.S. Inventory of Greenhouse Gas Emissions and Sinks, 1990-2019, Table 2-11. Electric Power-Related Greenhouse Gas Emissions and Table 2-13. Transportation-Related Greenhouse Gas Emissions.
[143] EIA, *EIA Monthly Energy Review*, March 2024.
[144] Ibid.
[145] EPA, 2025, *EPA Moderated Transaction System*, February 2025.

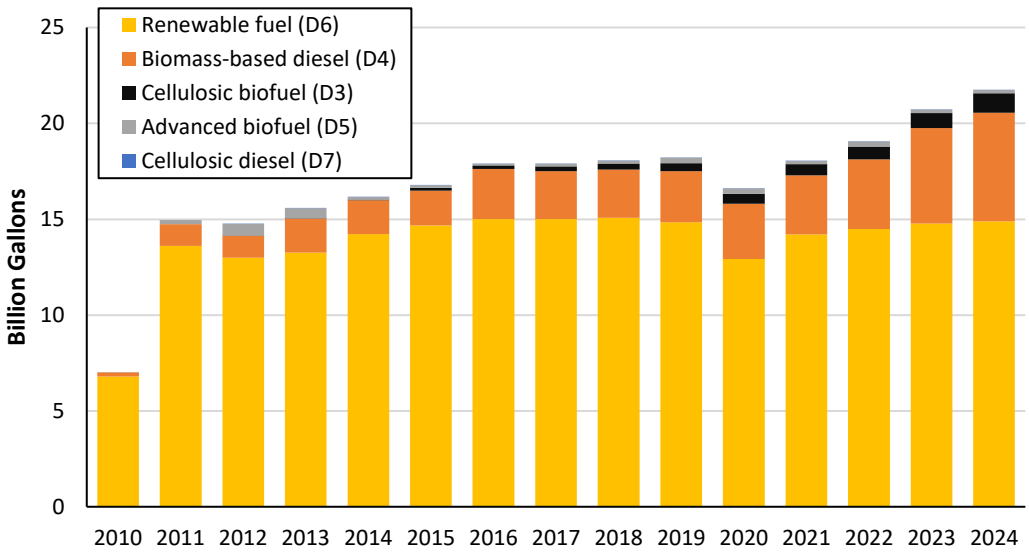

Figure 1. Renewable Fuel Volumes Resulting from U.S. Renewable Fuel Standard

Electric Vehicles

Sales of plug-in hybrid electric vehicles (PHEVs) and BEVs in 2024, totaling 1,569,430, were an 8% increase over 2023.[146] In addition, sales of HEVs (non-plug-in) were up 37% in 2024, totaling 1,609,035.[147] As of March 2025, consumers could choose from 144 available plug-in models for model year 2025.[148]

Alternative Fuel Infrastructure

The DOE's Alternative Fuels Data Center provides the number of alternative fuel refueling stations in the United States.[149] As Table 1 shows, exclusive of electric recharging stations, the total number of alternative fueling stations in the United States increased by 61% between 2012 and 2024. However, the number of compressed natural gas (CNG) and liquefied natural gas (LNG) stations decreased slightly in 2024. The total number of public and private non-residential EV recharging outlets jumped by over 1500% over this period, with a 24% gain in 2024.

[146] Argonne National Laboratory, 2025, "Light Duty Electric Drive Vehicles Monthly Sales Updates."
[147] Ibid.
[148] DOE, 2025, Alternative Fuels Data Center, "Availability of Hybrid and Plug-In Electric Vehicles."
[149] DOE, 2025, "Alternative Fueling Station Counts by State."

Table 1. U.S. Alternative Fuel Refueling Stations by Type, 2012–2024 (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
2024	1,792	1,361	4,705	218,214	77	75	2,825	655	229,704	11,490

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

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

Research and Development Focus

The DOE's Vehicle Technologies Office (VTO) sponsors R&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 in internal combustion engine vehicle area comprises the following: conducting research in fuels and advanced combustion engines, improving match between engines and fuel characteristics, and increasing engine and vehicle efficiencies. This research covers a very broad range of fuel, engine, and vehicle technologies.

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.[150] 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 lower emissions of long-haul trucks, the aviation sector, and the marine sector.

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

[150] Energy Information Administration, 2023, *Annual Energy Outlook 2023*.

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 32 members, 13 association countries, and 4 accession countries seeking IEA membership (as of December 2024). 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 Agency is governed by the IEA Governing Board, which is supported through a number of specialized standing groups and committees. For more information, 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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In numerical order by Task.

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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 2024

40 Years of AMF Collaboration

IEA's TCP on Advanced Motor Fuels (AMF) celebrated its 40th Anniversary in 2024, a milestone that motivated its leaders to compile a report and develop a website summarising the evolution, activities, and achievements of AMF. Beginning in 1984 as the "Alcohol and Alcohol Blends as Motor Fuels" TCP, the programme later evolved to "Alternative Motor Fuels" and finally "Advanced Motor Fuels," while retaining its original acronym. The report and website document AMF's comprehensive approach to attaining clean, sustainable, and energy-efficient transport and its evolutionary shift from activities related to fuels for road vehicles, to non-road mobile machinery, shipping, and aviation — moving toward modes of transportation that are difficult to electrify.

The author of this short history of AMF is Dr. Nils-Olof Nylund, Senior Advisor at VTT Technical Research Centre of Finland. Dr. Nylund is well familiar with AMF, serving as the Finnish Delegate to AMF from 1990–2020, and as the Committee Chair or Vice Chair for some 20 years.

Strategic Work Plan 2025–2030

AMF TCP is helping the transport sector achieve sustainability and reduce the impacts of the sector on the environment. AMF TCP has a strong international network that fosters collaborative research, development, and deployment of advanced motor fuels and provides unbiased information on clean, energy-efficient, and sustainable fuels and related engine and vehicle technologies. The Strategic Work Plan for 2025–2030 outlines the thematic focus and planned work for this period.

End of Term Report 2020-2025

The End of Term Report covers the period 2020–2025 and provides an overview on the work conducted within AMF during this period.

Task 61: Remote Emission Sensing

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

The project evaluates and compares the performance and applicability of different types of RES technologies to identify high-emitting vehicles. Project deliverables include the following:

- Final Report, March 2024
- Key Messages, May 2024
- Website

Task 62: Wear in Engines Using Alternative Fuels

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, many problems only appear after years of application. The goal of this Task was to identify and present an overview of potential wear issues to prevent major surprises in the future.

The Task evaluated excess wear in internal combustion engines caused by the use of alternative fuels. The objectives were to review ongoing related projects in the member countries and conduct a general literature review to evaluate which engine wear problems will likely occur with future application of alternative fuels. Project deliverables include the following:

- Final Report, October 2024
- Final Report on H/C Influence, October 2024
- Key Messages, October 2024
- Website

Task 64: E-fuels and End-use Perspectives

The focus of Task 64 was to exchange information on the production and application of different e-fuels and evaluate the corresponding regulatory framework and standards.
Based on several questions and topics, Task members organized workshops to formulate key messages and joint conclusions. These were incorporated into a final report that provides an overview of ongoing activities worldwide, as well as past and present technical, economic, and regulatory challenges and best-practice examples. Next to information sharing, the report aims to increase awareness about the importance of, and global activities in, the e-fuels field. Project deliverables include the following:

- Final Report, November 2024
- Key Messages, June 2024
- 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)
APS	Announced Pledges Scenario (India)
ARAMIS	Administration Research Actions Management Information System (Switzerland)
ATF	aviation turbine fuel
ATJ	alcohol-to-jet
ATV	all-terrain vehicle
B100	biodiesel (100%)
B20	biodiesel (20%)
BAM	biomass aggregation machinery
BARC	Bhabha Atomic Research Centre (India)
BCB	Banco Central De Brasil
BEST	Bioenergy and Sustainable Technologies GmbH
BETO	Bioenergy Technology Office (United States)
BEV	battery electric vehicle
BHM	B-heavy molasses
BIS	Bureau of Indian Standards
BIS	Bureau of Indian Standards
BMBF	Federal Ministry of Education and Research (Germany)
BMDV	Federal Ministry for Digital and Transport (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)
BNDES	Brazilian Bank for Economic and Social Development
BOO	build, own, operate
BPCL	Bharat Petroleum Corporation Ltd.
BRL	Brazilian real
CAAM	China Association of Automobile Manufacturers
CAGR	compound annual growth rate
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
CEPEA	Center for Advanced Studies in Applied Economics (Brazil)
CERT	Committee on Energy Research and Technology (IEA)
CET	Clean Energy Transition (Partnership) (Austria)
CFR	Clean Fuel Regulations (Canada)
CGD	city gas distribution
CGSB	Canadian General Standards Board
CHJ	catalytic hydrothermolysis jet
CHM	C-heavy molasses
CHP	combined heat and power
CHT	Centre for High Technology (India)
CI	carbon intensity (Canada)
CNG	compressed natural gas

CNPE	Brazilian Energy Policy Council
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COFINS	Contribution for the Financing of Social Security (Brazil)
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSIR-IIP	Council of Scientific and Industrial Research – Indian Institute of Petroleum
DBFZ	German Biomass Research Center
DBT	Department of Biotechnology (India)
DEP	dedicated ethanol plant
DETEC	Department of the Environment, Transport, Energy and Communications (Switzerland)
DFG	damaged food grain
DHA	docosahexaenoic acid
DLR	German Aerospace Center
DME	methanol/dimethyl ether
DOE	U.S. Department of Energy
DPI	development of pipeline infrastructure
DTI	Danish Technological Institute
DTU	Technical University of Denmark
E100	pure anhydrous ethanol
E25	25% ethanol in gasoline
E27	biogasoline
E2G	second-generation ethanol
E85	85% ethanol in gasoline
EBP	Ethanol Blended Petrol Programme (India)
EDAR	emissions detection and reporting
EF	emission factor
EIA	U.S. Energy Information Administration
EIP	Energy Innovation Program (Canada)
EMOCION	E-Methanol Compression Ignition Combustion (Switzerland)
EPA	U.S. Environmental Protection Agency
EPC	engineering, procurement, and construction
EPE	Energy Research Office (Brazil)
ERA	European Research Area
ESY	ethanol supply year (India)
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
EUWP	Working Party on Energy End-use Technologies (IEA)
EV	electric vehicle
EVAFIDI	Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (Canada)
EXHALE	Exhaust Analytics for Low GHG Impact Fuels (Switzerland)
FAME	fatty acid methyl ester
FCEV	fuel cell electric vehicle
FCI	Food Corporation of India
FCV	fuel cell vehicle
FFV	flexible fuel vehicle
FHNW	University of Applied Sciences Northwestern Switzerland
FNR	Agency for Renewable Resources (Germany)
FOEN	Federal Office for the Environment (Switzerland)
FOM	fermented organic manure
FPCC	Fusion Power Coordinating Committee (IEA)
FQD	Fuel Quality Directive (Germany)

FSRU	Floating Storage Regasification Unit
FT	Fischer-Tropsch
FY	financial year (India)
FY	fiscal year
GBA	Global Biofuels Alliance
GDP	gross domestic product
GFP	Green Freight Program (Canada)
GHG	greenhouse gas
GX	green transformation (Japan)
H_2	hydrogen
HC-HEFA	hydroprocessed hydrocarbons, esters and fatty acids
HCNG	hydrogen and compressed natural gas
HD	heavy duty
HDD	heating degree index (Switzerland)
HDV	heavy-duty vehicle
HEFA	hydroprocessed esters and fatty acids
HEV	hybrid electric vehicle
HFS	hydrogen fueling station
HGV	heavy goods vehicle (Sweden)
HHI-EMD	Hyundai Heavy Industries Engines and Machinery Division
HPCL	Hindustan Petroleum Corporation Ltd.
HVO	hydrogenated vegetable oil
HySTRA	CO_2-free Hydrogen Energy Supply-chain Technology Research Association (Japan)
IC	internal combustion
ICAO	International Civil Aviation Organization
ICE	internal combustion engine
IDAE	Institute for Diversification and Saving of Energy (Spain)
IEA	International Energy Agency
IEW	India Energy Week
iHAPC	Integrated Hydrogen-Argon Power Cycle Project (Finland)
IMO	International Maritime Organization
IOCL	Indian Oil Corporation Ltd.
ITFE	Institute of Thermal and Fluid Engineering (Switzerland)
IWG	Implementation Working Group
KCK	Kompetenscentrum katalys (Sweden)
KETEP	Korea Institute of Energy Technology Evaluation and Planning
KIER	Korea Institute of Energy Research
KIMM	Korea Institute of Machinery & Materials
KLIEN	Austrian Climate and Energy Fund
KliK	Foundation for Climate Protection and Carbon Offset (Switzerland)
KPI	key performance indicator
KTF	Climate Transformation Fund (Germany)
LAS	loading arm system (Japan)
LBM	liquefied biomethane
LCA	life-cycle assessment
LCFPP	Low-carbon Fuel Procurement Program
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)
MeOH	methanol
METI	Ministry of Economy, Trade, and Industry (Japan)
MHDV	medium- and heavy-duty vehicle
MIIT	Ministry of Industry and Information Technology (China)
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MMA	Ministry of Environmental and Climate Change (Brazil)
MoP&NG	Ministry of Petroleum and Natural Gas (India)
MOVER	Green Mobility and Innovation Program (Brazil)
N_2O	nitrous oxide
NDC	Nationally Determined Contribution (Brazil)
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
NECP	National Energy and Climate Plan (EU)
NEDC	New European Driving Cycle
NEDO	New Energy and Industrial Technology Development (Japan)
NEHG	National Emissions Trading Act of 2022 (Austria)
NEV	new energy vehicle
NGV	natural gas vehicle
NH_3	ammonia
NIPII	National Innovation Programme Hydrogen and Fuel Cell Technology (Germany)
NoVA	Normverbrauchsabgabe (Austria)
NO_x	nitrogen oxide(s)
NRCan	Natural Resources Canada
NRMM	non-road mobile machinery
NRSC	non-road steady cycle
NTSEL	National Traffic Safety and Environment Laboratory (Japan)
NZAB	The Net-Zero Advisory Body (Canada)
OGMC	oil and gas marketing company (India)
OMC	oil marketing company (India)
Paten	Programa de Aceleração da Transição Energética (Brazil)
PCF	Pan-Canadian Framework on Clean Growth and Climate Change
PEE	Programas de Eficiência Energética (Brazil)
PEM	proton exchange membrane
PEMS	portable emissions measurement sampling
PERD	Program of Energy Research and Development (Canada)
PFAD	palm fat acid distillate
PHBC	Low Carbon Emission Hydrogen Development Program (Brazil)
PHEV	plug-in hybrid electric vehicle
PHV	plug-in hybrid vehicles
PLANTE	Plano Nacional de Transição Energética
PM	particulate matter
PNBP	Program of Production and Use of Biodiesel (Brazil)
PNG	piped natural gas (India)
PNH_2	National Hydrogen Program (Brazil)
PNTE	National Energy Transition Policy
PPA	power purchase agreement
PPI	Investment Partnerships Program (Brazil)
PRD	Pressure Regulation Directive
PSI	Paul Scherrer Institute (Switzerland)
PSU	public sector undertaking (India)
PTE-HPC	Spanish Hydrogen Technology Platform
PTI	periodic technical inspection
PtL	power to liquid

PtX/P2X	power to X (Germany)
PV	photovoltaic (solar)
R&D	research and development
R&I	research and innovation
RAMP	rapid acidification for methane production
RBI	Reserve Bank of India
RD&D	research, development, and demonstration
RD&I	research, development, and innovation
RED II	Renewable Energy Directive II
RED III	Renewable Energy Directive III
RED	Renewable Energy Directive
RES	remote emission sensing
RES	renewables, total share of (Denmark)
RES-DH	renewables shares for district heating
RES-E	renewables share for electricity consumption
RES-H&C	renewables share for heating and cooling
RES-T	renewables shares for transport
REWP	Working Party on Renewable Energy Technology (IEA)
RFNBO	renewable fuels of non-biological origin
RFS	Renewable Fuel Standards (Korea)
RIN	Renewable Identification Numbers
RTDI	research, technological development, and innovation
SACI	spark-assisted compression-ignition
SAF	sustainable aviation fuel
SATAT	Sustainable Alternative Towards Affordable Transportation (India)
SBCE	Sistema Brasileiro de Comércio de Emissões (Brazil)
SCE	standard coal equivalent (China)
SCR	selective catalytic reduction
SEK	Swedish krona
SFOE	Swiss Federal Office of Energy
SI	spark injection
SIF	Strategic Innovation Fund (Canada)
SIP	synthetic isoparaffins
SPK-A	synthetic paraffinic kerosene
SPK-FT	synthetic paraffinic kerosene – Fischer-Tropsch
SRIA	Strategic Research and Innovation Agenda
SSCF	simultaneous saccharification and co-fermentation
STA	Swedish Transport Administration
STEPS	Stated Policies Scenario (India)
SWEET	**SW**iss **E**nergy research for the **E**nergy **T**ransition
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
VAT	value added tax
VTO	Vehicle Technologies Office (United States)
VTT	The Technical Research Centre of Finland

WLTP	World Harmonised Light-Duty Vehicles Test Procedure
WPFF	Working Party on Fossil Fuels (IEA)
WVA P&G	Wasserstoffinitiative Vorzeigeregion Austria Power & Gas
ZEV	zero-emission vehicle
ZEVIP	Zero Emissions Vehicle Infrastructure Program (Canada)

Units of Measure

€	Euro(s)
Btu	British thermal unit(s)
g	gram(s)
g/km	gram(s) per kilometer(s)
kg	kilogram(s)
kL	kiloliter(s)
km	kilometer(s)
ktoe	kilotonne(s) of oil equivalent
KTPA	kilo-tonne(s) per annum
mbd	million barrel(s) per day
MJ	megajoule (s)
MMT	million metric ton(s)
MPa	megapascal(s)
Mt	million ton(s)
Mtoe	megatonne(s) of oil equivalent
Nm^3	normal cubic meter(s)
PJ	petajoule(s)
TJ	terajoule(s)
toe	tonne(s) of oil equivalent
TPD	tonne(s) per day
TWh	terawatt hour(s)