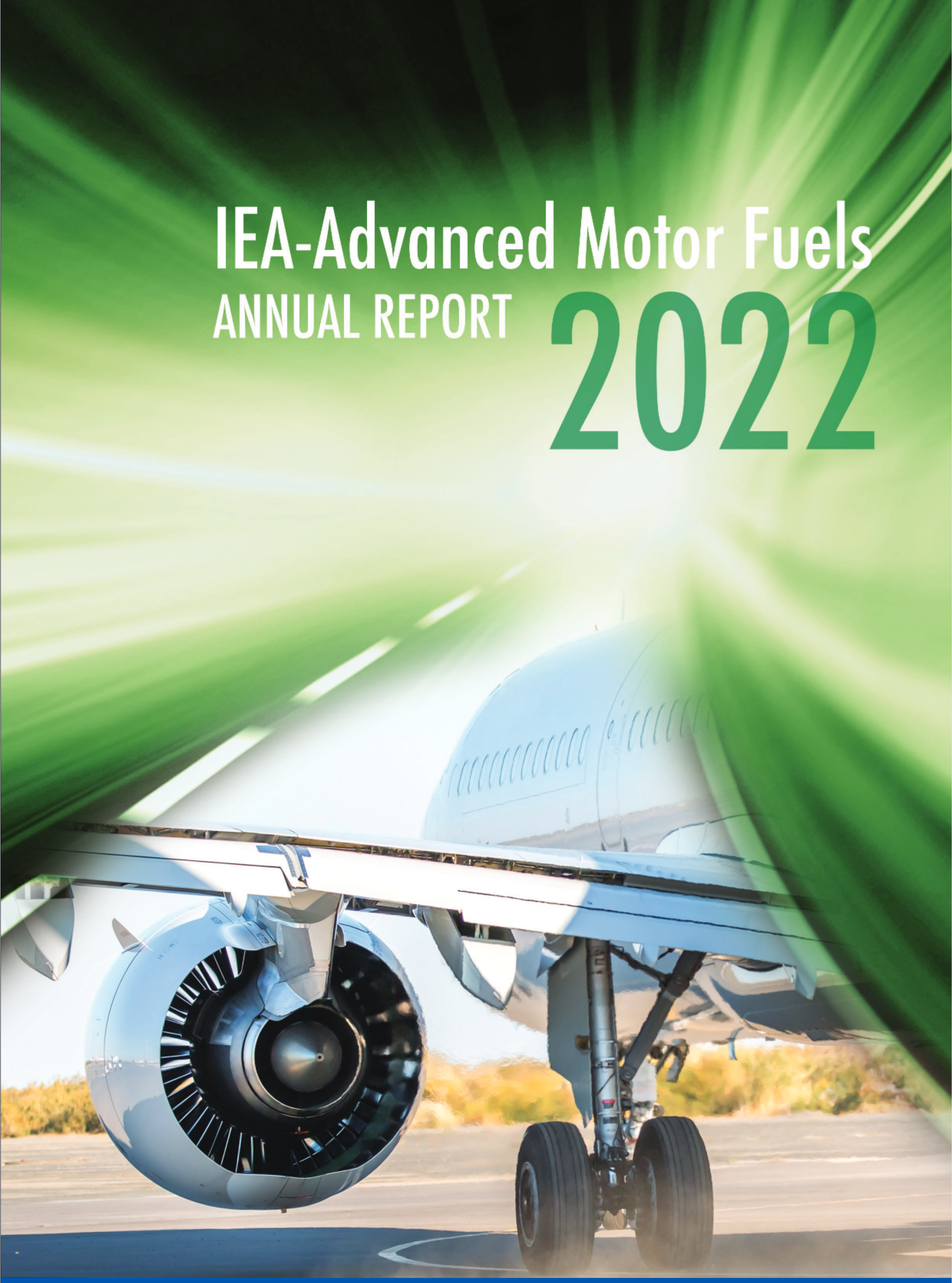

IEA-Advanced Motor Fuels

ANNUAL REPORT 2022

Technology Collaboration Programme

by iea

Chairperson's Message 2022

Jesper Schramm, Chair of the AMF TCP

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

In the past decade, public opinion and political decisions have moved toward applying electric vehicles rather than combustion engine-equipped vehicles for road transportation. AMF has historically focused on fuels for combustion engines. Therefore, AMF is in a period where transition to other forms of transport seems reasonable. There is still a need for updated knowledge on fuels for combustion engines, since demand for these fuels will exist for decades to come for passenger cars and, indeed, for heavy-duty vehicles for an even longer time. Furthermore, new fuels for marine applications and aviation have high priority worldwide. As a consequence of this transition, AMF conducts ongoing activities regarding e-fuels, marine fuels and aviation fuels.

The coronavirus pandemic has meant limitations in meeting physically at ExCo and Task meetings. AMF held the first hybrid meeting (online/onsite) after the crisis in October 2022 – an important experience, clearly showing the numerous benefits of meeting physically. On the other hand, we have become accustomed to online meetings, and this is also an important tool to enhance collaboration through more frequent meetings in the Task collaborations.

This year we haven't started or finished any Tasks. However, we have six active Tasks, and a couple of those will end in 2023. New Task proposals are being discussed, and I am very curious to follow the push forward that the outcome of Task 63 (SAF) will give us in relation to being a central collaboration platform for this important topic – hopefully, concluding with new Task proposals already in 2023.

Brazil joined the AMF in December 2022. Brazil is a unique fuel country, particularly due to the massive experience with ethanol application for road vehicles. I would like to welcome Brazil in this context, also because Brazil represents a continent in which we have had no representatives since Chile left the group. A couple of dedicated people from Brazil have led this process to a successful outcome, and I would like to express my gratitude to you, also, for a positive spirit in the period as observers for Brazil.

The IEA's Net Zero Emissions by 2050 Scenario is a pathway for the global energy sector to achieve net-zero CO_2 emissions by 2050. In the IEA homepage, the trends on "Tracking Clean Energy Progress" have outlined points of high importance in order to be able to follow the path. In this information site, among other things, long-distance transport sectors are seen as essential to develop for further transition to a net-zero emission future, and the net-zero transition involves a massive deployment of technologies under development today. It is also concluded that international collaboration is vital in order to achieve this goal. I see an important role for AMF in this context: delivering knowledge to the development of these sectors based on international technological expertise and mutual understanding. I wish to thank all people involved with AMF work in the past for their efforts and I am sure we contribute well to the goals for Net Zero by 2050 if we keep up the good work in the spirit of AMF.

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 on all levels of decision-making.

Highlights of Advanced Motor Fuels

Kim Winther, Subcommittee Strategy & Technology Chair

In the year 2022, the energy markets were extremely volatile due to the outbreak of war between Russia and Ukraine – two of the main energy suppliers on the Eurasian continent. As a direct result of the war, gas supplies from Russia to the EU were almost entirely cut off. This led a number of countries to rethink their entire energy supply strategy and refocus their efforts in renewable energies.

For the first time since 2019 AMF was able to conduct a physical meeting in 2022, which was held in Denmark. During this meeting, delegates were shown advanced biogas refining and large wind turbines for the production of PtX-fuels. Delegates also saw the hourly price of electricity on the Nord Pool exchange drop to zero while the wind was blowing steadily outside.

Among other events in 2022 was the launch of the B6.7H hydrogen engine for heavy trucks, which was presented by Cummins and Daimler. European truck manufacturer DAF won the 2022 Truck Innovation Award for the XF concept, also featuring a hydrogen combustion engine. At the same time, Toyota successfully operated a hydrogen combustion engine in a rally car for the entire season.

German sports car maker Porsche began the production of renewable gasoline in Chile and Neste Oil presented a renewable gasoline for the mass market. FIA announced the start of development of a carbon-neutral fuel for use in Formula 1 cars by 2026.

Container shipping operator Maersk increased its total number of build orders from eight to 19 large oceangoing vessels powered by methanol dual-fuel engines. Other shipping companies – Methanex Water Front Shipping, French CMA CGM, and Ocean Network Express (ONE) – are taking the same direction.

Ammonia engines are still in the test and development phase. However, announced commercialization plans have moved forward to the year 2023 for the Wärtsilä 25 marine engine and to 2024 for the MAN ME-LGI two-stroke ammonia engine. Korean Hyundai Heavy Industries Engines and Machinery Division (HHI-EMD) also took orders for the first six HiMSEN multifuel engines with reserved ammonia capability.

Sustainable fuels for the aviation industry are a new focal point of AMF. The potential of CO_2 reductions from airplanes remains largely untapped as sustainable fuels currently represent only 0.05% of total jet fuel consumption. In 2022 the journey for AMF began with the initiation of Task 63 "Sustainable Aviation Fuels."

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

Annual Report 2022 Production Notes

This Annual Report was produced by Kevin A. Brown (project coordination/management), Kathryn Jandeska (lead editor), Lorenza Salinas (document production), and Alison Mackey (cover design) of Argonne National Laboratory.

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

Country reports were delivered by the Contracting Parties:

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

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

Task 28	Information Service and AMF Website	Dina Bacovsky
Task 60	The Progress of Advanced Marine Fuels	Kim Winther
Task 61	Remote Emission Sensing	Åke Sjödin
Task 62	Wear in Engines Using Alternative Fuels	Jesper Schramm
Task 63	Sustainable Aviation Fuels	Doris Matschegg
Task 64	E-fuels and End-use Perspectives	Zoe Stadler

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

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Technology Collaboration Programme on Advanced Motor Fuels (AMF TCP)

The Need for Advanced Motor Fuels

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

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

It is also necessary that we understand the full impact of alternative energy solutions from a well-to-wheel perspective and use solid data for decision making.

Our Approach

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

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

By verifying existing data and generating new data, the AMF TCP is able to 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. With our broad geographical representation, we are able to take regional and local conditions into consideration when facilitating the deployment of new fuel and vehicle technologies.

About the AMF TCP

The AMF TCP is a Technology Collaboration Programme of the International Energy Agency (IEA). It comprises an international group of experts that enables governments and industries worldwide to lead programs and projects on a wide range of energy technologies and related issues (see also 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):

- Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) (Austria)
- Energy Research Office (Brazil)
- Environment Climate Change Canada (Canada)
- China Automotive Technology and Research Center (China)
- Technical University of Denmark (Denmark)
- The Technical Research Centre of Finland (Finland)
- Agency for Renewable Resources FNR (Germany)
- Ministry of Petroleum and Natural Gas (India)
- National Institute of Advanced Industrial Science and Technology (Japan)

- Organization for the Promotion of Low Emission Vehicles (Japan)
- National Traffic Safety and Environment Laboratory (Japan)
- Korea Institute of Energy Technology Evaluation and Planning (Republic of Korea)
- Institute for Diversification and Saving of Energy (Spain)
- Swedish Transport Administration (Sweden)
- Swiss Federal Office of Energy (Switzerland)
- United States Department of Energy (USA)

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

The AMF TCP work program is carried out through **Tasks:** 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. Task Managers participate in Executive Committee meetings to present updates on the progress of work in the Task. They are also responsible for pulling together individual contributions and producing the final report.

To support the work of the Executive Committee and to 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** takes the lead in 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** takes care of the daily management of the AMF TCP, organizes Executive Committee meetings, and serves 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. Meetings of the Executive Committee, the Strategy Subcommittee, and the Technology Subcommittee serve to discuss new developments and to identify knowledge gaps and implementation barriers. All delegates are encouraged to propose topics for new Tasks. Whenever three or more contracting parties support a proposal and sufficient funding is raised, a new Task can be established. This system allows for flexible adaptation of the annual work program, continuous development of AMF's scope, and reacting to any identified technology gaps or market barriers.

Current Work Program
Six projects were ongoing in 2022:
- Task 28: Information Service and AMF Website
- Task 60: The Progress of Advanced Marine Fuels
- Task 61: Remote Emission Sensing
- Task 62: Wear in Engines Using Alternative Fuels
- Task 63: Sustainable Aviation Fuels
- Task 64: E-fuels and End-use Perspectives

Cooperation with Other TCPs

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

- 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 each other's Executive Committee meetings, identifying fields of common interest, and participating in projects of other TCPs.

2 Ongoing AMF TCP Tasks

2.a
Overview of Tasks

Ongoing Tasks in 2022

Task Number	Title	Task Manager
28	Information Service and AMF Website	Dina Bacovsky
60	The Progress of Advanced Marine Fuels	Kim Winther
61	Remote Emission Sensing	Åke Sjödin
62	Wear in Engines Using Alternative Fuels	Jesper Schramm
63	Sustainable Aviation Fuels	Doris Matschegg
64	E-fuels and End-use Perspectives	Zoe Stadler

Task 60 concluded in 2022. The final report and key messages for this Task are available on the AMF TCP website, https://iea-amf.org/. All other Tasks will continue in 2023.

2.b
Task Reports

Task 28: Information Service and AMF Website

Project Duration	January 28, 2004 – Continuous
Participants **Task Sharing** **Cost Sharing**	 None All contracting parties: Austria, Brazil, Canada, China, Denmark, Finland, Germany, India, Japan, South Korea, Spain, Sweden, Switzerland, United States
Total Budget	EUR 55,000 (USD 60,019)
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 sources of news 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 / July 2022
- Prepare an Alternative Fuels Information System that provides concise information on alternative fuels and their use for transport. The system covers 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 various topics (e.g., strategies, proposals, decisions, and Executive Committee meetings of the AMF TCP).
- Since 2020, additional activities also include distributing news on social media. Follow AMF TCP on LinkedIn and Twitter.

Gasoline blending: Alcohols	Diesel blending: Renewables	Methane	Others
Task 56 (methanol) Task 54 (ethanol, methanol, butanol) Task 52, Part V (ethanol, methanol) Task 44 (ethanol, methanol) Task 35-2 (ethanol, butanol) Task 35-1 (ethanol) Task 1 (methanol)	Task 57 Task 52 Part IV (paraffins) Task 45 (paraffins) Task 38 (paraffins, esters) Task 37 (paraffins, esters) Task 34-1 (paraffins, esters) Task 31 (paraffins) Task 30 (paraffins, esters) Task 13 (esters) Task 10 (esters)	Task 57 (Trucks) Task 55 (On-road) Task 51 (Slip) Task 39 (HD) Task 37 (Buses) Task 22 (Cars) Task 6 (General)	*LPG:* Task 22 Task 5
Fuel ethers: Task 25	*Alcohols:* Task 57 (ED95) Task 46 (ED95, MD95) Task 35-1 (ethanol) Task 10 (ethanol emulsion) Task 1 (methanol)		*DME:* Task 47 Task 20 Task 14
Synthetic gasoline: Task 31	*Diesel/oxygenates:* Task 26 Task 18		

Fig. 1. Overview of AMF Work on Advanced Motor Fuels

Key Findings

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

The website covers background information on the AMF TCP and its participants, access to all AMF publications, details on 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 Fuel Information System (see figure above) or by identifying a relevant Task and checking the related report. Knowledge gained through AMF Tasks is frequently added to the Fuel Information System, which thus serves as a reference book for experts and laypersons alike.

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

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

The use of social media such as Twitter and LinkedIn is relatively new for AMF. Currently, every week one item is posted both on Twitter and LinkedIn. Items focus on statements from AMF Task reports and Task key messages, and they also promote the AMF newsletter.

Publications

In 2022, the AMF TCP published one electronic newsletter, posted it to the AMF TCP website, and distributed it through the national networks of the AMF Delegates.

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

Task 60: The Progress of Advanced Marine Fuels

Project Duration	November 2019 – November 2022
Participants **Task sharing** **Cost sharing**	 Austria, Canada, China, Denmark, Finland, Korea, Sweden, Switzerland, and USA Methanol Institute, USA
Total Budget	EUR 1,795,000 (USD 1,980,700)
Task Manager	Kim Winther Danish Technological Institute Email: kwi@teknologisk.dk
Website	https://www.iea-amf.org/content/projects/map_projects/60

Purpose, Objectives, and Key Question

In 2013, AMF released its first Task report on marine fuels (Task 41). This report highlighted the fact that no alternative fuel option existed without significant added cost or other serious impediments. The preferred fuel, HFO, was soon to be banned or restricted due to its high sulfur and fossil carbon content. Recent developments, however, have highlighted several new fuel options that should be assessed.

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

Activities

The last 4 of 10 virtual meetings were held in 2022. USA, China, Austria, and Korea were the main presenters at the meetings.

Key Findings

Following are highlights of the four main presentations held in 2022:

- **USA** reported that all work in engines and fuel is being redirected towards hard-to-decarbonize sectors. New programs will be built up to make low-carbon fuels available at U.S. ports. Adding marine vessels to the GREET® model is another focus point. Past focus has been on bio-intermediates, HTL, pyrolysis, and biocrudes. Some biofuels don't blend very well due to water content. Upgrading is necessary to make miscible blend stocks. An extensive corrosion study has been performed. The results look promising for blends of up to 50%. Acid numbers should be kept low. Good ignition was obtained with 5% biocrude. Biodiesel shows good results up to 25%. In higher blends, viscosity is reduced. Cetane increases with biodiesel. Oak Ridge National Laboratory also made a digital twin of a 2-stroke research engine. By 2050 a substantial amount of residue will come from sustainable aviation fuel (SAF) production, which could then be used for marine fuels. The GREET model, developed in 1995, calculates GHG, air pollution, and water and energy use for many fuels and is widely used for policy development. About 17 marine fuels have been covered so far. Novel pathways are catalytic fast pyrolysis of wood, landfill gas synthesis, HTL, and lignin-ethanol. A recent paper published WTH emissions of various marine fuels. Many of the new fuels have lower sulfur content than traditional marine fuels. The next paper to be published will deal with novel pathways from sludge and manure, CFP, and HTL. A carbon abatement cost below 200 $/ton$CO_2$ is possible.
- **China** presented a finished report titled "Assessment of Progress on Methanol Technology and Infrastructure for Fishing Vessels and Watercraft." The report details the Chinese fleet of fishing vessels and the potential for converting these to methanol fuel.
- **Austria** presented the HyMethShip project and the hydrogen-methanol propulsion concept with an onboard pre-combustion CO_2 removal system. They also presented a life cycle cost study of different marine fuels with potential impacts of a 150 EUR/ton CO_2 tax. Finally, they presented the LEC ENERsim energy systems optimization tool with a case for a marine power system.

- **Korea** presented ammonia dual fuel approaches with gasoline and diesel internal combustion engines along with combustion properties, transport, and storing systems for ammonia.

Publications

A final report of Task 60 will be available during the first half of 2023 and can then be downloaded on the AMF TCP website: https://www.iea-amf.org/content/projects/map_projects/60.

Task 61: Remote Emission Sensing

Project Duration	May 2020 – October 2023
Participants **Task sharing** **Cost sharing**	 China, Denmark, Finland, Sweden, Switzerland None
Total Budget	EUR 210,000 (USD 229,165)
Task Manager	Åke Sjödin IVL Swedish Environmental Research Institute Email: ake.sjodin@ivl.se
Website	https://www.iea-amf.org/content/projects/map_projects/61

Purpose, Objectives, and Key Question

The objective of this task is to evaluate and propose how remote emission sensing (RES) can be used – 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 CNG/LNG) designed to meet all adopted legislative emission limits (e.g., Euro 1/I – Euro 6/VI). However, 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 NO_x and 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): This, in practice, refers to the technologies already offered to the market by commercial providers for emission measurement services.
- Point sampling RES (Type 2 RES): In terms of measurement strategy, Type 2 RES is quite similar to Type 1/conventional RES, but it is still under development (i.e., not yet commercialized), and it demonstrates the best advantage for measuring PM emissions, both number and mass.
- Plume chasing RES (Type 3 RES): From a measurement strategy, this perspective is rather different from Type 1 and 2. Not as many vehicles can be measured per time unit, but the measurements on each vehicle have longer duration than those measured with Type 1 and 2. As a result, this RES is more useful to pinpoint 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 emission legislation and air pollution policy purposes. 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:

- An "up-to-date" view of the real-world emission performance of European and Chinese in-use fleets, demonstrating the impact of current emission 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
In 2022, the RES datasets available for the work of Task 61 continued to increase.

- The number of Type 1 RES records in the European CONOX database increased by more than 300,000 to about 1,800,000 records, due to new data from measurement campaigns carried out in Switzerland (Zürich), Germany (Frankfurt), and Italy (Milan).
- Additional measurements with Type 3 RES on heavy-duty trucks, and for the first time also on light-duty vehicles, have been carried out in several European countries (the Czech Republic, Germany, and Sweden).
- VTT collected and released real driving emission (RDE) data from previous onboard PEMS tests conducted in Finland. The data package included results from PEMS tests performed on a city route with four Euro 6 diesel passenger cars.

WP 2: Comparison and evaluation of the performance of different RES technologies
Following are highlights of 2022.

- Two reports have been published from the CARES RES characterization measurements campaign carried out at a test track in the Netherlands in June 2021, in which RES Type 1, Type 2, and Type 3 measurements were compared with PEMS (onboard) measurements and their ability to identify high-emitting vehicles was explored.
- The CARES city demonstration campaign in Prague and Brno, Czech Republic, was carried out in September 2022, where instruments representing RES Type 1 (the Opus RSD 5500), RES Type 2 (the CARES PN, BC, and NO_x sensors), and RES Type 3 RES (the CARES plume chasing instruments measuring NO_x and PN) were deployed, resulting in more than 100,000 vehicles measured. The campaign also involved pulling suspected high-emitting vehicles over for roadside inspections and a PEMS-equipped light-duty vehicle repeatedly passing the RES measurement sites.
- A total of 172 PEMS-chasing conjoint tests were conducted in Jiangsu Province to evaluate the accuracy of the plume chasing for HDDV emissions and to analyze the impact from meteorological variables and vehicle speed. In the experiments, various operating scenarios and vehicle types were considered.
- The high-fidelity hybrid LES/RANS solver for an accurate description of the plume dispersion by keeping the computational cost considerably low is still under development (testing and validation in progress). In fact, a study of multiple coupling methods of LES and RANS led to better performance. Additionally, parameter studies regarding RES using the validated but less accurate URANS model were concluded in a journal paper, which is currently under review. Comparisons to experimental data from various RES devices were initiated.

WP 3: Evaluation of using RES to detect individual high-emitting vehicles for enforcement
See some of the activities listed under WP1 and WP2 (relevant for high-emitter detection).

WP 4: Evaluation of using RES for emission legislation and air pollution policy purposes
See some of the activities listed under WP1 and WP2 (relevant for RES policy applications).

WP 5: Project coordination and management, synthesis, reporting, and dissemination
In 2022, activities and progress were reported in Executive Committee meetings 63 and 64. Two Task 61 work meetings were arranged in 2022.

Key Findings

- The RES Type 1 and 2 measurements carried out in Milan within the CARES project have revealed that, contrary to conventional belief, vehicles fueled by LPG and CNG show high real-world emissions of NO_x, CO, HC, and black carbon.
- RES Type 1 instruments may have problems measuring particularly PM and HC emissions accurately at low ambient temperatures (below +5 degrees C), due to the condensation of water vapor to water droplets in the diluting exhaust plume.

- Measurements carried out in 2022 in the Czech Republic by means of RES Type 3 in combination with roadside inspections reveal that tampering, defects, and software issues of the emission control systems of Euro V and Euro VI heavy-duty trucks occur quite frequently in Europe.
- A large sample of RES Type 3 measurements (~10,000 HDDVs in Shenzhen) indicated that the implementation of more stringent emission standards has significantly reduced the average NO_x and BC emission factors of local HDDVs.
- Effective ratio (ER) – a practical parameter – was proposed, which contains the displacement of the vehicle wake length and the wind speed fluctuations. The measurement results of chasing are in good agreement with that of PEMS when the ER is less than 1 – that is, high vehicle speed and low crosswind (normal to the driving direction) speed. Thus, the ER can be further used to identify the effective chasing data and improve the accuracy of chasing.
- The EMPA parameter study found that the most crucial volume that RES must capture is the core exhaust plume (CEP), which lies within the first 1.5-2 m behind the vehicle. Therefore, low measurement frequencies lead to few measurement points in the CEP and thus to a less robust estimation of the concentrations. A plane-measurement instrument always detects a higher fraction of the original exhaust gas (in terms of absorption) compared to a line-measurement instrument: approximately 70% more in the CEP and 95% more in the far downstream region. Increasing vehicle velocities result in a decreased size of the core exhaust plume (CEP) in all directions. Crosswind has little influence on the CEP. As both the wind and the distance from the tailpipe increase, the amount of pollutant that can be detected by RES devices decreases. Moreover, the interference of pollutant concentrations from multiple plumes in the longitudinal direction has a smaller effect on measurement accuracy than the increased turbulent intensity by the vehicle ahead.

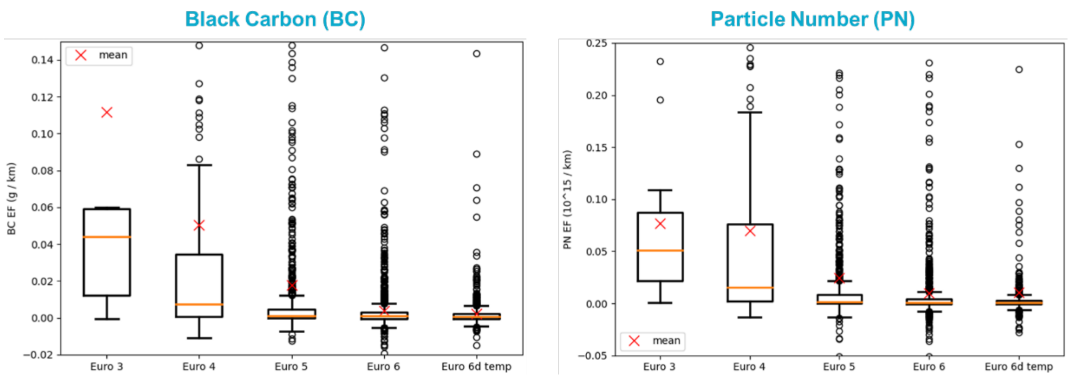


Fig. 1. Results from the First-ever RES Measurements of Black Carbon (BC) and Particle Number Emissions from Diesel Passenger Cars (Averages by Euro Standards in City of Milan)

Main Conclusions

- The earlier observed good agreement between RES Type 3 and PEMS measurements, in particular, has been confirmed in both Europe and China from new measurements conducted in 2022.
- Applications of the newly developed RES Type 2 sensors for BC and PN in several European cities have proved that these are crucial for complementing (commercial) RES Type 1 instruments to better understand real-world emissions of particulate matter.
- Further development of plume dispersion models and subsequent modeling exercises can be used for pinpointing advice on optimizing RES capture of the plume.

Publications

- Shen, Y., Zhang, Q., Wang, D., et al. Evaluation of a cost-effective roadside sensor platform for identifying high emitters[J]. Science of The Total Environment, 2022, 816:151609. https://www.sciencedirect.com/science/article/pii/S0048969721066857.
- Xiang, S., Zhang, S., Yu, Y.T., et al. Evaluation of the Relationship between Meteorological Variables and NO_x Emission Factors Based on Plume-Chasing Measurements[J]. ACS ES&T Engineering, 2023. https://pubs.acs.org/doi/full/10.1021/acsestengg.2c00317.

- Farren, N,, Carslaw, D., Knoll, M., Schmidt, C., Denis, P., Hallquist, Å. (2022) Measurement technology intercomparison and evaluation. CARES deliverable D1.1. https://cares-project.eu/wp-content/uploads/2022/10/CARES_D1_1_July22.pdf.
- Farren, N., Carslaw, D., Knoll, M., Schmidt, C., Denis, P., Hallquist, Å. (2022) Monitoring of vehicle tampering. CARES deliverable D1.2. https://cares-project.eu/wp-content/uploads/2022/10/CARES_D1_2-_July22.pdf.
- Qiu, M., and Borken-Kleefeld, J. (2022) Using snapshot measurements to identify high-emitting vehicles. *Environ. Res. Lett.* **17**, 044045. https://doi.org/10.1088/1748-9326/ac5c9e.
- Yang, Z., Tate, J. E., Rushton, C. E., Morganti, E., Shepherd, S. P. (2022) Detecting candidate high NOx emitting light commercial vehicles using vehicle emission remote sensing. *Sc. Tot. Env*., **823**, 153699. https://doi.org/10.1016/j.scitotenv.2022.153699.

Further upcoming project reports will be available for download on the website https://www.iea-amf.org/content/projects/map_projects/61.

Task 62: Wear in Engines Using Alternative Fuels

Project Duration	January 2022–December 2023
Participants **Task sharing** **Cost sharing**	China, Denmark, Finland, Germany, Switzerland
Total Budget	In-kind contributions corresponding to more than EUR 150,000 (USD 165,520)
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 are being intensively introduced in transportation sectors in recent years. That these fuels are responsible for causing special wear in engines is readily evident, but the problems become even more apparent after years of this fuel use. To prevent the onset of significant issues in the future, this Task evaluates excessive wear in internal combustion engines caused by the use of alternative fuels.

Our objective is to review ongoing related projects in the member countries in combination with a general literature review to evaluate which engine wear problems can be foreseen with the future use of alternative fuels.

We address the following key questions:

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

Activities

General literature review

Alternative fuels comprise several different fuels. In this study we conduct a general literature review, including all relevant alternative fuels. From there we focus on fuels that are specific to ongoing studies related to marine engine applications in the countries involved in the Task. This includes methanol, ammonia, and biooils, among others.

In the literature review we compile the available information and report it in a structured way in order to support future application of alternative fuels.

Online seminars

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

Key Findings

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

Main Conclusions

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

Publications

None so far.

Task 63: Sustainable Aviation Fuels

Project Duration	18 months / November 2021 – April 2023
Participants **Task sharing** **Cost sharing**	Austria, Brazil, China, Denmark, Germany, Switzerland, USA
Total Budget	EUR 200,000 (USD 218,252)
Task Manager	Doris Matschegg BEST – Bioenergy and Sustainable Technologies GmbH Email: doris.matschegg@best-research.eu
Website	https://iea-amf.org/content/projects/map_projects/63

Purpose, Objectives, and Key Question

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

Activities

Task 63 activities include a comprehensive description of the international status quo on sustainable aviation fuels, an analysis of the concrete situation in some task member countries, highlighting best-practice examples, and identifying international stakeholders.

Status quo

- Approved technology pathways and those in the ASTM certification process: description of certified technologies and those applying for certification, feedstocks and products, TRL, production costs, and GHG emissions over the life cycle.
- Production facilities: overview of facilities in operation, under construction, or planned; production capacities currently and projected; and technology providers.
- Application of sustainable aviation fuels: supplying airports, using airlines, announced supply agreements, announcements of supply agreements, and announcements by aircraft manufacturers.
- Legislation: national and EU commitments, international announcements, and agreements.
- Sustainable aviation fuels in the energy system: global demand, relation to other transport sectors and other energy intensive sectors, and projected development.

National assessments

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

Best-practice examples

- Bringing jointly selected examples of successful production and application of sustainable aviation fuels before the curtain so that other stakeholders in the field (airports, airlines, kerosene providers, etc.) can learn from them.
- Presenting best-practice examples through a series of three online seminars with different thematic focus (Feedstocks and Conversion, Supply and Operation, and Markets and Policy) where successful actors will describe how they have implemented the production or application of sustainable aviation fuels (SAF), the challenges they have faced, and how they have overcome them.
- Making recordings of seminars and presentations available online to disseminate their findings.
- Deriving lessons and recommendations for action from the examples presented and summarizing them in a report. Additionally, best-practice factsheets will be prepared and shared online.

Key Findings

Since Task 63 lays the foundation for collaborative research, the findings were rather broad and less specific. Key findings of Task 63 include:

- Main barriers for implementing SAF were confirmed within the Task, namely sustainable feedstock availability, comparably high production costs, and a lack of clear (international) regulations.
- Biogenic SAF is essential for decarbonizing the aviation sector, especially in the short term. HEFA is currently the main pathway, but until 2030 also Gasification-FT and ATJ will produce significant amounts. PtL will take longer to be fully commercial. However, all SAF technology pathways are needed to achieve sector targets.
- Scaling-up SAF capacities requires huge investments and risk sharing among stakeholders. Offtake agreements are one possibility for airlines to support SAF producers while securing their SAF supply. The number of offtake agreements has increased sharply in recent years, and this trend is expected to continue.
- SAF availability is very limited at the moment but, for example, the EU and USA have very ambitious plans for capacity increase (ReFuelEU Aviation, US Aviation Climate Goal). Worldwide, six production facilities are in operation, with Neste as market leader. In the United States the production forecast for 2027 is about 60 times higher compared to 2022.
- Even though EU nations share a common (proposed) framework, strategies among Member States vary (e.g., strong focus on e-fuels in Germany and Denmark).
- SAF blending is not a technological issue (even in the case of multi-blending) but an administrative one. There are three modes of SAF delivery: segregated delivery, mass balance, and book and claim. Whereas book and claim is in high demand, only a segregated system allows for reducing regional non-CO_2 effects.

Main Conclusions

The implementation of SAF is, first and foremost, an economic problem, not a technical one. If we want to achieve the aviation sector´s ambitious targets, we need to start investing now. The SAF price can be lowered only with a learning curve, and technologies can only be improved and optimized once they are in operation. Compliance with sustainability must be ensured along the entire value chain.

Publications

- Presentations of national workshop (German): https://www.iea-amf.org/content/events/web_seminars/workshop_task63?_ga=2.9562294.2023133732.1675851855-1344608938.1617287363
- Recordings and presentations of online seminars: https://www.iea-amf.org/content/events/web_seminars/webinars_task63?_ga=2.13838516.2023133732.1675851855-1344608938.1617287363
- Presentations of international workshop: https://iea-amf.org/content/events/web_seminars/workshop_task63_cebc?_ga=2.237554691.2023133732.1675851855-1344608938.1617287363

Task 64: E-fuels and End-use Perspectives

Project Duration	May 2022 – April 2024
Participants **Task sharing** **Cost sharing**	 Brazil, China, Denmark, Finland, Germany, Japan, Switzerland, USA None
Total Budget	EUR 200,000 (USD 218,252)
Task Manager	Zoe Stadler Eastern Switzerland University of Applied Sciences Email: zoe.stadler@ost.ch
Website	https://iea-amf.org/content/projects/map_projects/64

Purpose, Objectives, and Key Question

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

- Demo sites/pilot programmes: Consideration of different demo sites in different countries that focus on the development and improvement of e-fuel production technologies, including consideration of technology pathways, technological maturity, and case studies.
- CO_2 and H_2 resources: The availability of CO_2,water resources, and electricity sources in different countries, with assessment of national feedstock potential for e-fuel production.
- Application side: Experiences and challenges in the application of e-fuels, especially with regard to the use of e-fuels in aviation, maritime, and road transport.
- Regulations and standards: Norms, standards, and/or regulations for the use of e-fuels in various countries. Incentives and regulations that promote the production and use of e-fuels.
- Life-cycle assessments (LCA)/well-to-wheel (WTW): Methods for LCA and WTW in the different countries/regions (e.g., REDII in the EU). Typical and expected net GHG effects as well as other environmental impacts (e.g., water consumption) of e-fuel production and use.
- Techno-economic assessments (TEA): Costs of the different e-fuel production value chains in various countries, and methodology for economic calculation. Costs on the application side of the switch to e-fuels.
- Stakeholders: Actors from research, industry, and administration along the value chain (raw material supply, conversion technologies, e-fuel suppliers, e-fuel consumers) as well as bioenergy research centres and academic institutions.

Based on these questions and topics, workshops are organised in which key messages and joint conclusions are formulated. These will be incorporated into a final report, which will provide 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 is to support increased awareness concerning the importance and the global activities in the e-fuels field.

Activities

In the E-fuels Task, workshops are held four times a year on specific issues and (if possible) pilot plants are visited. The output of each workshop is a summary of common findings, which are then included in the final report. At the end of the Task, the main findings are presented at a web seminar. The duration of the Task is two years.

Key Findings

In 2022, two workshops were carried out within AMF Task 64. The key messages from these workshops are summarized in this section.

Resources

- Energy systems will follow a process of carbon intensity reduction, in an energy transition branded by strong competition (among different technological alternatives).
- The climate agenda will increasingly influence international trade and international relations.
- The global energy mix will be the most diverse the world has ever seen by 2050.
- There is a global technological race, with several routes and alternatives capable of assuming a relevant role in the energy transition, and we will probably face emerging industries coexisting and eventually replacing traditional technologies.
- Considering the importance of flexible paths for the energy transition (avoiding technological locks), Brazil, given all its potential, has great opportunities in the hydrogen economy.
- Countries like Brazil, which presents a great supply of renewable energy resources, will promote a greater international insertion and participation in the global decisions regarding energy.

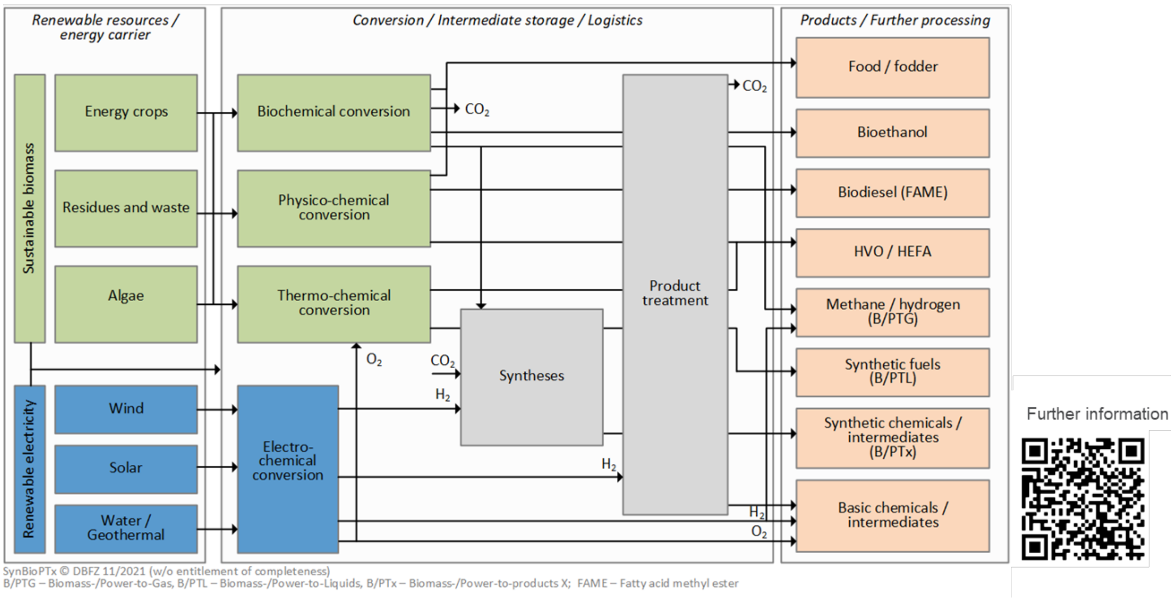


Fig. 2. Source: https://www.dbfz.de/Monitoring-EE-im-Verkehr/technologien

Strategic Elements to Push E-fuels into the Market

- Brazil: Brazil's goal is to increase the amount of e-fuels in general, but a commercial status has not been reached yet. There is a project with Thyssen-Krupp technologies in which electrolysers with a total capacity of 60 MW are installed. The plant will feed one of the largest green ammonia plants by capacity when production begins.
- Finland: The focus is placed on e-methane, e-methanol, paraffinic fuels, and e-diesel. Furthermore, carbon capture and utilization (CCU) is regarded as much more positive than CCS, given difficulties with the storage.
- Germany: Research and development on synthetic fuels is emphasized, especially for aviation. A platform to produce power-to-liquid with a production of 10,000 t/y is under development, with the goal of establishing hybrid multi-fuel refineries. With fuel synthesis (e.g., Fischer-Tropsch), usually multiple products are produced and all of them need to be used for economic reasons. Additionally, for the order of magnitude of renewable fuels needed, both biofuels and e-fuels will play an important role.
- Japan: Several kinds of national projects have recently started (SOEC, FT, and methanation).
- Switzerland: Sustainable aviation fuels (SAF) are promoted, in a collaboration of the federal offices for energy and civil aviation. The goal is to scale-up SAF in Switzerland.
- United States: SAF is regarded as an important e-fuel (mainly produced by alcohol-to-jet technologies). Otherwise, e-fuels aren't assumed to play a major role in the near future as their production is too small compared to other projects. In the United States, the Inflation Reduction Act (IRA) promotes the production of green hydrogen. The legislation goes into effect in 2024 and lasts for ten years. An SAF credit begins in 2023 and continues until 2027; to receive the incentive, an emissions reduction of 50% must be demonstrated. More initiatives for clean fuels will follow, which are expected to lead to many more activities.

Techno-economic Assessments

- Some electro-fuels, such as FT fuels or methanol, can be produced from high TRL or mature technologies.
- The key cost driver for electro-fuel production is the production cost of H_2, or syngas. The U.S. IRA provides a maximum \$3/kg tax credit for green H_2 production (depending on GHG emissions), providing a significant economic incentive to produce electro-fuels.
- In the United States, high-purity CO_2 from industrial sources serves as low-cost feedstock for electro-fuels production. With industrial CO_2, the potential electro-fuels production volume can exceed current demand for U.S. jet fuel and meet over one-third of diesel demand.

Life-cycle Assessments

- Setting up a consistent LCA system boundary for e-fuel production is important.
- Argonne has evaluated multiple e-fuel production (CO_2 utilization) pathways of various CO_2 feedstocks and conversion technologies using Argonne's GREET® model with the support of the U.S. Department of Energy.
- LCA results show that using renewable electricity and hydrogen is key to having low-carbon e-fuels.
- Regional distribution of CO_2 sources, renewable electricity, and renewable hydrogen (and/or freshwater) need further consideration.

E-fuel Projects in China

- Demonstration and pilot-scale e-fuel projects have been operated in China. However, firsthand operational data are rarely available for detailed sustainability and economic accounting.
- Methanol, gasoline, and aviation fuels are seen as products in the e-fuel projects, with methanol the most common product.
- Currently, the sources of hydrogen and CO_2 are not necessarily in the context of green energy (i.e., renewable H_2 and CCUS-CO_2). For example, COG-H_2 is regarded as feedstock.
- From a technological perspective, many research efforts have been concentrated in the development of catalyst systems – for example, improving the selectivity of methanol of CO_2 hydro-conversion technology.
- Educational institutions, chemical and energy enterprises, and automotive companies have participated in the track of e-fuel demonstration as well as H_2 equipment and CO_2 producers.
- China currently has no standard set specifically for e-fuel, although clear regulations exist with respect to the standards of various products contained in e-fuels.
- The high cost of e-fuels is still a challenge faced by the hydrogenation of CO_2 to methanol.
- Appropriate carbon pricing and low renewable power cost are critical to enhance the economic competitiveness of e-fuels in China.

Key Messages of E-methanol

- The driver of this fast implementation of e-methanol in the shipping industry stems from a strong customer pull.
- Demand for methanol will increase by five times until 2050, which will be met by using e-methanol, bio-methanol, and fossil-based methanol. The chemical industry is responsible for half of this demand.
- E-methanol has the lowest total cost of ownership (TOC) compared to other e-fuels, such as e-diesel, e-DME, or ammonia.

Main Conclusions

Various countries offer incentives to promote the production of e-fuels or hydrogen. In the United States, the Inflation Reduction Act could accelerate the development of e-fuels. Additionally, several countries promote SAF research and development.

3 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

So far, Austria has only been able to report declining GHG emissions in the transport sector from the years 2005 to 2012. Since then, emissions have risen steadily due to the growing volume of traffic. Fuel consumption in the years 2020 through 2022 indicate lower emissions; however, this is most likely due to the pandemic and the high energy prices and not a first proof of a successful transition of the Austrian mobility system towards alternative drivetrains.

According to the Environmental Agency Austria, in 2020, the transport sector in Austria showed GHG emissions of approximately 20.7 million tonnes of CO_2 equivalent. Compared to 2019, emissions decreased by 13.6%. This sharp decline was linked to the decline in passenger car mileage during the pandemic, which led to a drop in fuel demand.

In total, in 2020 biofuels substituted for around 6.08% of the fuels sold. This share exceeds the substitution target of 5.75% of fossil fuel on the market, as stipulated in the Fuel Ordinance; again, however, it represents a decline of 11% compared to the previous year. The relatively low sales volume of pure biofuels is due to the low competitiveness compared to fossil fuels. In 2020, the use of biofuels resulted in a reduction of approximately 1.33 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 contribute to the political target. For this reason Austria has adopted a number of measures, such as a newly designed taxation system that imposes a price on ecologically destructive activities. This system, enacted in 2021, introduces a CO_2 pricing system with a continuously increasing price path from EUR 30 (USD 32.74) per ton CO_2 (2022) up to EUR 55 (USD 60.02) per ton CO_2 (2025). From 2026 onward, an EU-wide CO_2 emissions trading system will replace national fixed price rates. In addition, an obligatory procurement of zero-emission vehicles by the public sector is taking effect. Other measures already in place are an increased Normverbrauchsabgabe (NoVA) tax and the "Right to Plug," which alleviates previous approval hurdles for the installation of charging stations in multi-apartment buildings.

Austria has also developed a number of national strategies in the area of transport, such as the Mobility Master Plan and the corresponding RDI Mobility 2030 Strategy. Complementary strategic plans for freight transport and hydrogen also are near completion. Despite significant efforts, a consistent overarching activity document listing measures, their expected contributions, and corresponding KPIs (fully describing the path to climate neutrality in 2040) is not available. An updated Austrian National Energy and Climate Plan reflecting the ambitious European Green Deal targets in the *Fit for 55* package (a 55% reduction of GHG emissions by 2030) might serve as the nucleus for an aggregation of all planned measures and an alignment of their expected impact contributions.

Austrian Integrated National Energy and Climate Plan (NECP)

The integrated NECP is a planning and monitoring instrument of the EU and its member states. It is intended to contribute to improved coordination of European energy and climate policy and serves as the central instrument for implementing the EU's renewable energy and energy efficiency targets for 2030. For Austria, the NECP includes measures supporting the increase of the share of renewable energy sources in the transport sector, whereby in Austria the biogenic share in relation to the energy content of diesel is about 6.3%, and for petrol currently about 3.4%; and taxes such as the NoVA tax, in which a bonus/penalty system for CO_2 emissions is levied when passenger cars are first placed on the domestic market (new car purchase or private import), which provides incentives to purchase vehicles with low CO_2 emissions.

Taxes and Incentives

In July 2008, Austria introduced the NoVA tax for new vehicles. As of March 2014, new cars that emit less than 87 g of CO_2/km are exempt from NoVA. Further reduction steps of 5g of CO_2/km per year are planned until 2024. Each additional gram results in a financial penalty of EUR 80 (USD 87.30) on the purchase price of a passenger vehicle. Pure biofuels are exempt from the mineral oil tax. CNG is exempt from the mineral oil tax as well but is subject to the lower natural gas tax.

Advanced Motor Fuels Statistics

Fleet Distribution and Number of Vehicles in Austria

In 2023 the third time in history the total fleet of motor vehicles registered in Austria passed 7 million, with 7.27 million registered motor vehicles – an increase of 0.75% or 54,444 vehicles compared to 2021. Passenger vehicles represent with 5.15 million vehicles (Table 1) the largest share of vehicles (70.9%).

Fleet numbers indicate a continuous trend toward advanced alternative propulsion systems, especially toward BEVs and HEVs (Figure 1). For instance, there were 110,225 BEVs and 147,968 HEVs in Austria in 2022, which shows a continuing positive trend from previous years, and which follows an exponential trajectory. The number of vehicles powered by compressed natural gas (CNG) and liquefied petroleum gas (LPG), including bivalent ones, shows a stable, but very moderate fleet level of 5,512 vehicles (2021: 5,787). There is a continuing slow decrease of bivalent vehicles to 2,947 (2021: 3,132) while the CNG vehicles fleet stays stable with 2,564 (2021: 2,654). With 62 (2020: 55) vehicles, the fuel cell electric vehicle (FCEV) fleet is still negligible.

Table 1. Austrian Fleet Distribution of Passenger Vehicles (M1) by Drivetrain, 2016–2022

Drivetrain	2016	2017	2018	2019	2020	2021	2022
Gasoline	2,031,816	2,074,442	2,133,473	2,173,772	2,190,388	2,192,128	2,189,530
Diesel	2,749,038	2,770,470	2,776,333	2,772,854	2,762,273	2,717,475	2,651,280
Electric	9,071	14,618	20,831	29,523	44,507	76,539	110,225
LPG	1	2	2	2	2	1	1
CNG	2,456	2,433	2,365	2,602	2,753	2,654	2,564
H_2	13	19	24	41	45	55	62
Bivalent gasoline/ ethanol (E85)	6,165	5,992	5,769	5,770	5,190	4,878	4,595
Bivalent gasoline/LPG	341	335	333	330	330	331	331
Bivalent gasoline/ CNG	2,574	2,773	3,177	3,143	2,978	2,801	2,616
Hybrid gasoline/ electric	18,696	26,039	34,086	45,645	68,983	108,978	148,284
Hybrid diesel/ electric	1,337	1,455	2,463	6,172	14,378	27,996	41,402
Total	4,821,508	4,898,578	4,978,856	5,039,854	5,091,827	5,133,836	5,150,890

Source: Statistik Austria.

New Registrations

In 2022, 215,050 (2021: 239,803) new passenger cars were registered, a decline of 10.3%, compared to 2021. New passenger car registrations are 34.7% below the level of the pre-crisis year 2019 and reached their lowest level in 43 years. The decline is linked to a continuation of the significant decrease in petrol and diesel-fueled passenger car registrations. The number of petrol-powered passenger cars fell to 78,567 (2021: 91,478), corresponding to a share of 36.5% (2022: 38.1%), and the number of diesel-powered passenger cars fell to 48,155 (2021: 58,263): a share of 22.4% (2021: 35.9%).

Despite the overall trend, at 88,368 (2021: 90,062) cars, the share of all alternatively powered passenger cars increased to 41.1% (2021: 37.6%), thus confirming the continued trend towards alternative drivetrains.

Among the alternative drive trains, a shift towards battery electric vehicles (BEV) was observed, as new registrations for petrol-hybrid passenger cars (40,704; share: 18.9 %) declined by 5.5%. New registrations for diesel-hybrid passenger cars declined by 0.9% (13,422; share: 6.2 %). Only new registrations of BEV passenger cars increased in absolute numbers in 2022: a 2.4 % increase, with 34,165 new registrations and a share of 15.9%. Yet, the number of newly registered BEVs (40,081) still does not match the increase in the total fleet number (plus 54,444 vehicles).

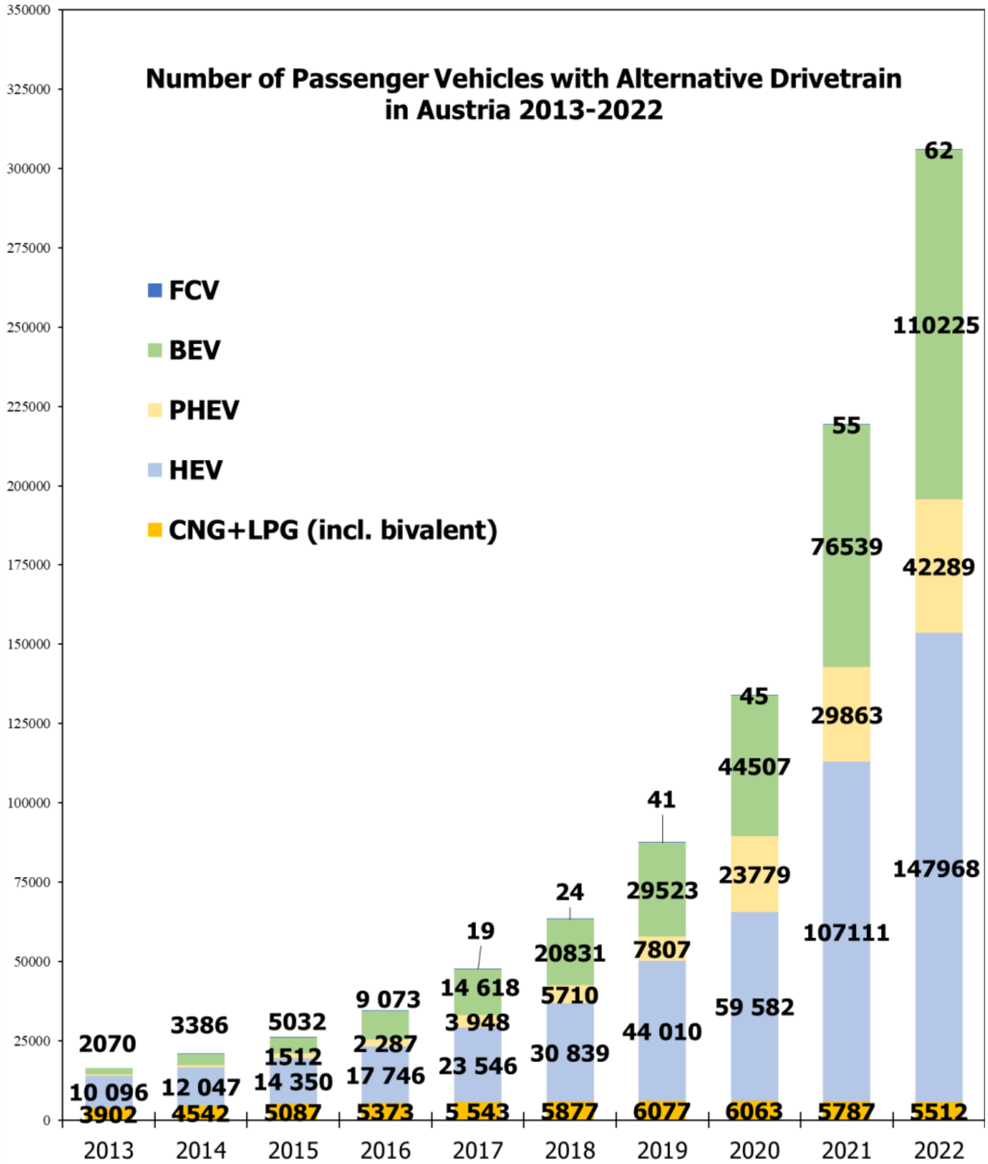


Fig. 1. Trends for vehicles with alternative drivetrains in Austria, 2013–2022
Source: Statistik Austria.

Average CO_2 Emissions of Passenger Cars

In 2022, the CO_2 emissions of newly registered passenger cars measured, on average, 134g/km (2021: 135g/km), based on the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) and excluding electric and hydrogen vehicles. The number drops to 112g/km (2021: 116g/km) if electric and hydrogen vehicles are included. The average emissions number for petrol-powered M1 vehicles is 138g/km (2021: 139g/km); diesel-powered passenger vehicles show an average of 149g/km (2021: 150g/km).

Development of Filling Stations

By the end of 2021, Austria had 2,748 publicly accessible filling stations. As an annual average for 2022, the price of gasoline for private use at a filling station was EUR 1.729 (USD 1.89) per liter; correspondingly, the price of diesel was EUR 1.820 (USD 1.99) per liter. With 119 public compressed natural gas (CNG) stations in 2022, the number of public CNG filling stations has continuously decreased in recent years (2021: 125). For liquified petroleum gas (LPG), 41 filling stations are available (2021: 39). In addition, three public liquified natural gas (LNG) filling stations operate, in Ennshafen (Upper Austria), Feldkirchen (Styria), and Vienna.

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

Research and Demonstration Focus

Energy Model Region

As part of the "Energy Model Region" initiative, made-in-Austria energy technologies are developed and demonstrated in large-scale, real-world applications with international visibility. In the coming years, the Austrian Climate and Energy Fund (KLIEN) intends to invest up to EUR 120 million (USD 131 million) in three Energy Model Regions. One such region—WIVA P&G— demonstrates the transition of the Austrian economy and energy production to an energy system based strongly on 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, called klimaaktiv mobil, supports the development and implementation of mobility projects and transport initiatives that aim to reduce CO_2 emissions. Since 2004, 21,000 climate friendly mobility projects have been funded. The klimaaktiv mobil website offers a map with details of each project. Total financial support until 2021 amounted to EUR 167.5 million (USD 182.8 million).

IEA Technology Cooperation Programmes Funding

Austria has been actively involved in the IEA Technology Collaboration Programmes (TCPs) since joining the IEA. The TCPs are seen as an important complement to Austrian national energy R&I activities and contribute via Task outcomes to national priorities. This programme fosters Austrian participation in the collaborative work within the IEA, disseminates results and facilitates networking activities.

R&I Mobility Strategy 2030

The R&I Mobility Strategy 2030 provides financial support for R&I projects and R&I activities for sustainable passenger and freight transport. The R&I Mobility Strategy 2030 focuses on four mission areas: Cities, Regions, Digitalization, and Technology. The annual budget ranges from EUR 15 million to 20 million (USD 16.3 million to USD 21.8 million). A project database is available online.

ERA-NET Bioenergy

In the European Research Area (ERA-NET) Bioenergy, Austria cooperates with Germany, Poland, and Switzerland in funding transnational bioenergy research and innovation projects. Austria's contribution to the recent 14th ERA-NET Bioenergy Joint Call amounts to EUR 0.8 million (USD 0.87 million).

Outlook

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

The areas of deployment, though, depend on the use case. Electrification is the preferred option for use cases with limited energy requirements, such as passenger cars or light-duty vehicles with limited mileage. Here, RDI funding schemes are not directed at improving ICE drivetrains any more. Funding programs therefore focus on biofuel and synthetic fuel topics for use cases with high-energy density demands, such as aviation or waterborne applications.

At the moment, Alternative Fuels Infrastructure Regulation (AFIR) is being discussed, which will outline a framework for the future deployment of charging and refueling infrastructure across the European Union. The document will include mandatory targets for member states instead of today's indicative targets.

Additional Information Sources

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

Brazil

Drivers and Policies

Brazil has had a long history with bioethanol since the 1970s, due to energy security reasons connected with the first oil crisis. As a result, the country has stimulated the production of ethanol and, since 2003, the use of hydrous ethanol in exclusive or fuel-flexible cars. Today, the allowed blend level of ethanol is 27% in regular gasoline (MAPA, 2015) and blend limits range between 18% and 27.5% (Law 13,033, 2014). Since 2005, Brazil also has 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. It is worth mentioning that Brazilian federal states apply differentiated consumption tax rates for gasoline (in general, higher rates) and hydrous ethanol (in a majority of the states, lower rates). Two recent public policies promote the production and consumption of biofuels: (1) the National Biofuel Policy, named RenovaBio (BRAZIL, 2017), operational since March 2020; and (2) the Fuels of the Future Program (CIVIL HOUSE, 2021), created in 2021.

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

Under the Paris Agreement, Brazil committed to reducing its domestic GHG emissions to 37% by 2025 and has declared its intention to reduce 43% of its emissions by 2030, both based on 2005 levels. At the 2021 UN Climate Change Conference, Brazil signed the Glasgow Climate Pact, committing to the long-term objective of reducing its emissions by 50% by 2030 and 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 with the 2°C temperature goal, especially, in the energy sector, achieving 45% of renewables in the energy mix by 2030 (IEA, 2022).[2]

Advanced Motor Fuels Statistics

Transport

Figures 1 and 2 provide an overview of the energy used in transport in Brazil, categorized by different fuels/energy carriers. It is important to note that Brazilian statistics define biogasoline (E27) as anhydrous bioethanol blended with gasoline and that hydrous ethanol is used in dedicated or flex-fuel vehicles (FFVs). Bioethanol represented 45% by energy of combined gasoline and ethanol use in 2021 in Otto cycle engines.

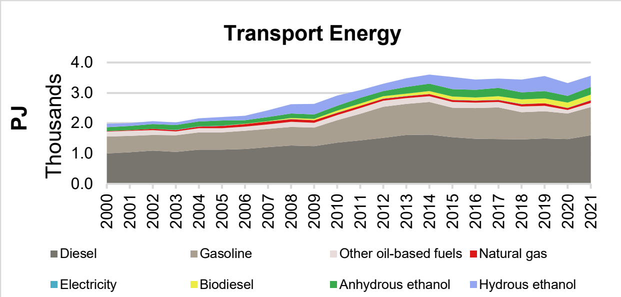
Transport fuel consumption in Brazil has stabilized over the past five years, and the use of biofuels has grown steadily over the past 20 years. In particular, the use of hydrous ethanol in FFVs has substantially increased. The consumption of anhydrous ethanol has grown with gasoline consumption, as 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 10.3% by energy of diesel consumption in 2021, as Figure 2 shows.

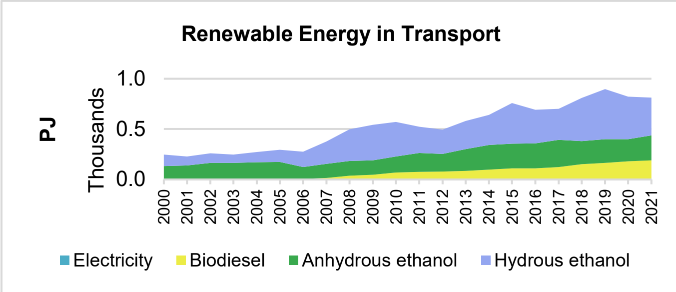
As also shown in Figure 1, electricity represents a share of 0.2% of total transport energy use in 2021. This is mostly in rail – there is no reporting of electricity used in road vehicles.

[1] The agriculture sector represents 27.4% of Brazil GDP (EPE, 2022)

[2] This includes:
- 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.





Figs. 1 and 2. Evolution of Transport Fuels in Brazil, 2000–2021
Source: EPE, 2022a.

Table 1 displays the growth of the Brazilian fleet from 2012 to 2021.

Table 1. Growth of the Brazilian Fleet, 2012–2021

Vehicle Stock	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Motor spirit cars	10^6	12,4	11,7	11,0	10,3	9,6	8,9	8,2	7,6	7,0	6,5
Diesel oil cars	10^6	1,5	1,7	1,8	1,9	2,0	2,1	2,2	2,3	2,5	2,6
Electricity cars	10^6	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,002
Other type of cars (hybrid)	10^6	0,000	0,001	0,002	0,003	0,004	0,007	0,010	0,021	0,038	0,066
Flex fuel cars	10^6	17,8	20,7	23,2	24,9	26,0	27,1	28,3	29,6	30,0	30,4

Source: EPE, 2022d.

Policy Framework

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

- **The Brazilian Alcohol Program (PROALCOOL),** created during the 1970s by the Brazilian government to increase the ethanol blending level to 25% in gasoline (E25) and introducing hydrous ethanol ("E100," approximately 95% ethanol and 5% water) for use in dedicated vehicles.
- **The Brazilian Program for Production and Use of Biodiesel (PNPB),** created in 2005 to further stimulate energy, economic, and social objectives and foster feedstock production among small farmers.
- **Flex fuel technology,** established in 2003, enabling 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% of anhydrous ethanol, or E27.[3] The government also mandated that biodiesel be added to fossil diesel: a final blend of roughly 11% in 2021 and, since April 2023, 12%.[4]
- **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 greenhouse gas emissions. The policy includes the additional objective of reducing dependence on mineral diesel.
- **Fuels of the Future Program,** created in 2021, aims to further increase the use of sustainable and low-carbon fuels to decarbonize the national transport energy matrix.
- **Federal and state tax differentiation** between renewables and fossil fuels[5], and establishing credit lines to support rural sugarcane producers and their cooperatives to select business plans and promote projects that contemplate the development, production, and commercialization of new industrial technologies for sugarcane biomass (E2G, gasification, and more).[6]

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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, 2023).

5 Regarding federal taxes, Cide has been zeroed for ethanol since 2004, while for gasoline, the incident value is R\$100.00/m³. Since 2017, the PIS/COFINS on ethanol imports and commercialization is R\$241.81/m³, and for gasoline, R\$ 792.5/m³. At the state level, ICMS has different rates in each Brazilian state. (EPE, 2022d)

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

- **Launch of the National Hydrogen Program (PNH2)** The Brazilian government identified the need to organize a strategy for developing the country's hydrogen economy, 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 motor fuel efficiency.
- **Federal government approval** of the framework of the Rota 2030 program (Law 13,755/2018) in December 2018 to foster efficiency and safety in vehicles produced in Brazil (BRAZIL, 2018).

Research and Demonstration Focus

Brazil has several government-backed mechanisms providing support for biofuels R&D and demonstration plants. Public and publicly oriented support totaled over BRL 200 million (USD 38 million) in 2020,[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. It is worth noting that, within the scope of the Fuels of the Future (CIVIL HOUSE, 2021) Technical Chamber – CT-CF, the government created and launched lines of financing for biofuels. Figure 3 illustrates the annual distribution of public investments in renewable energy, including research, development and innovation (RD&I), by source.

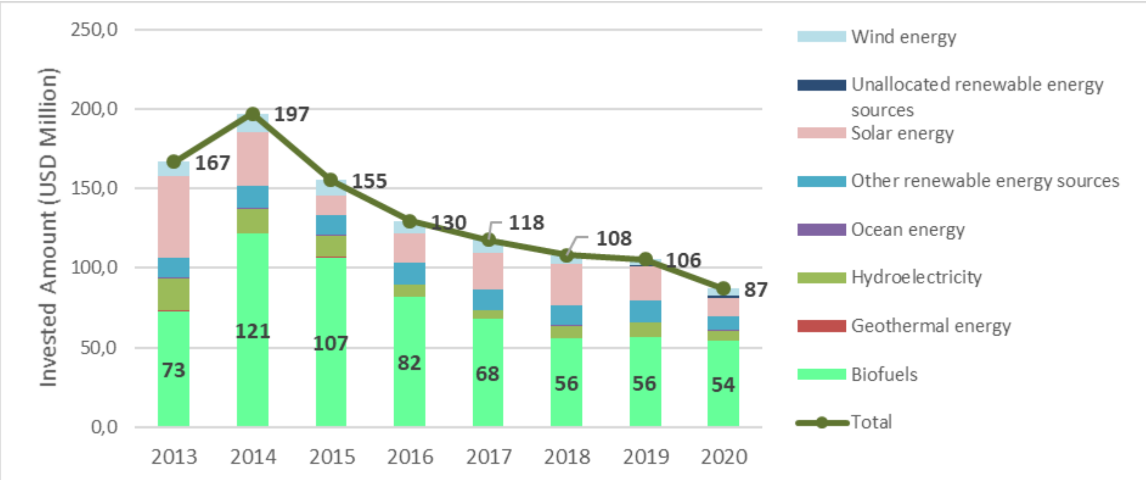

Fig. 3. Public Investments in Renewable Energy RD&I, 2013–2020
Source: EPE, 2023.

Figure 4 displays the total amount of public financing specific for the sugar-energy sector. In 2021, total disbursements of the Brazilian Bank for Economic and Social Development (BNDES) in the agricultural area for the cultivation of sugarcane totaled USD 78 million (or BRL 400 million)(BNDES, 2022).[10]

[7] Five thematic chambers were created to deal with different subjects: I - Strengthening of Scientific-Technological Bases; II - Training of Human Resources; III - Energy Planning – under the coordination of the Ministry of Mines and Energy; IV - Legal and Regulatory-Normative Framework; V - Opening and Growth of the Market and Competitiveness. The thematic chambers are responsible for formulating the Triennial Plan that will be approved in December by Coges-PNH2.

[8] The Carbon Offsetting and Reduction Scheme for International Aviation (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).

[9] The average 2022 USD to BRL exchange rate was 5.10 (Brazilian Central Bank, BCB, 2023).

[10] At the average 2022 USD to BRL exchange rate (BCB, 2023).

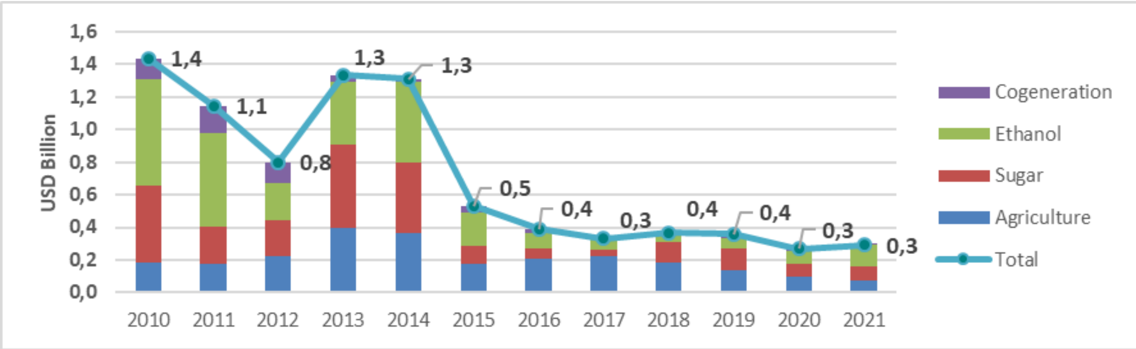

Fig. 4. Public Funding for Sugar-energy Sector
Source: Constructed by EPE from data provided by BNDES (2022).

Outlook

Figure 5 consolidates the demand for fuel ethanol and other (non-energy) uses, which grows at an annual rate of 4.2%, reaching 44.6 billion liters in 2032, with the major increase coming from the demand for hydrated fuel. When added to exports, 2.2 billion liters, the total value of ethanol amounts to 46.8 billion liters.

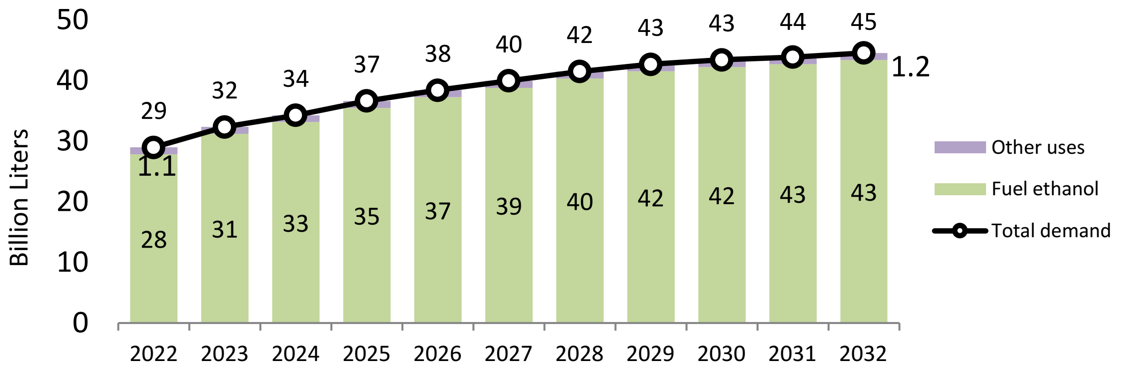

Fig. 5. Forecast of Total Ethanol Demand, 2022–2032
Source: EPE, 2022b.

The biodiesel demand projections of this study were obtained based on the forecast of the regional consumption of oil diesel type-B (EPE, 2022b) and the evolution of biodiesel blend (Figure 6).[11]

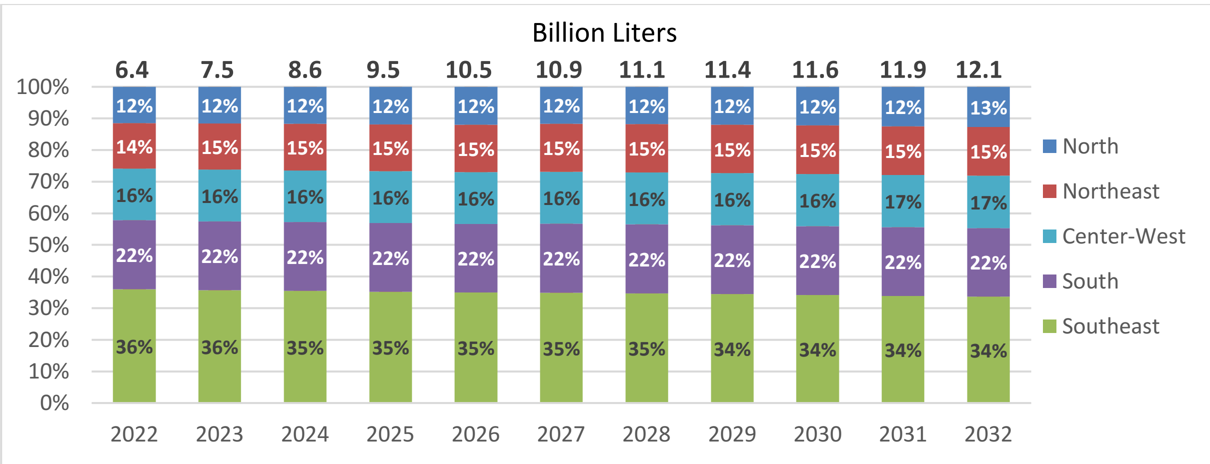

Fig. 6. Forecast of Total Biodiesel Demand with Regional Distribution, 2022–2032
Source: Based on EPE, 2022c.

[11] According to the recent CNPE definition on March 17, 2023 (MME, 2023), the biodiesel blend will change from 10% between January and March 2023 to 12% in April 2023, to 13% in April 2024, 14% in April 2025, and 15% in April 2026.

Projections for ethanol and sugar production presented in this study indicate a high amount of residues from this sector, which can be used for biogas production. The methodology applied to this item considered both the vinasse and filter cake as part of the straw and tips to produce biogas, which will be destined for biodigestion. In this case, the technical potential of biogas from residual sugarcane biomass through monodigestion reaches 34.9 billion Nm³ in 2032, representing 19.2 billion Nm³ of biomethane.

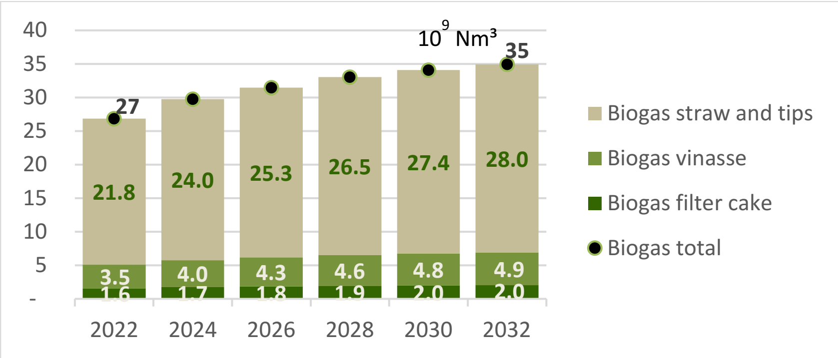

Fig. 7. Biogas Potential with Sugarcane Residual Biomass, 2022–2032
Source: EPE, 2022b.

By 2032, the Brazilian fleet should achieve 47.3 million vehicles, according to the EPE 10-Year Expansion Plan (EPE, 2022b).

Recent Developments

Brazil has two commercial E2G plants (Granbio and Raízen), with a nominal production capacity of 60 and 42 million liters per year, respectively (GRANBIO, 2022) (RAÍZEN, 2022). Granbio's Bioflex-I has been in operation since September 2014; it is forecasted to reach nominal capacity by 2024 and to validate the E2G production patent in Europe (NOVACANA, 2022b; 2022c). Raízen's Costa Pinto unit produced 24 million liters in 2021. The company has already announced the construction of eight more plants, each with a capacity of 82 million liters. The plant located in Guariba is expected to start operating in 2023 (COSAN, 2021) (NOVACANA, 2022d). Raízen communicated agreements to sell 460 million liters of E2G over nine years, in addition to the possibility of having up to 20 operational E2G plants by 2031 (RAÍZEN, 2021a).

With regard to biogas, its participation in the internal supply of energy is still timid (0.12%), but it has shown accelerated growth: 22% per year over the last five years (EPE, 2022a).

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Major changes

As in other parts of the world, the Covid-19 pandemic had significant impact on individual mobility and fuel consumption in Brazil, resulting in a marked decrease in gasoline and ethanol demand in 2020 and a recovery only for gasoline in 2021. From mid-2021 through all of 2022, Brazil's successful vaccination campaign helped restore demand for road fuels to 2019 levels, with an increase in diesel consumption.

Canada

Drivers and Policies

Clean Fuel Regulations

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

1. Actions throughout the lifecycle of a liquid fossil fuel that reduce its carbon intensity, by carrying out a Carbon Dioxide Equivalent emissions-reduction project.
2. Supplying low-carbon-intensity fuels.
3. Supplying fuel or energy to advanced vehicle technology.

The annual carbon intensity reduction requirements for gasoline and diesel will come into force on July 1, 2023, starting at 3.5 grams of carbon dioxide equivalent 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 of greenhouse gas pollution in 2030. In combination with the Government of Canada's $1.5 billion Clean Fuels Fund, the CFR will create incentives for the increased domestic production of low carbon intensity fuels. Alongside the federal policy, Canada has provincial renewable fuel and low carbon fuel requirement regulations which prescribe specific renewable fuels volumes and carbon intensity.

Renewable-fuels-related Standards

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

Table 1. CGSB Renewable Fuel-quality-related Standards

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

Greenhouse Gas Emission Regulations

In 2021 Canada completed a mid-term evaluation of the appropriateness of its standards for model years 2022 to 2025 under the *Passenger Car and Light Truck GHG Emission Regulations*, concluding that the U.S. standards established in 2020 that increased by roughly 1.5% per year were not stringent enough to meet Canada's climate goals. Canada is working with both the United States and the State of California to develop future LDV GHG regulations while intending to align with the most stringent LDV GHG tailpipe regulations in the United States, whether at the federal or state level. In March 2022, Canada published the 2030 Emissions Reduction Plan with a commitment to develop regulations to achieve 100% of new light-duty vehicles being zero-emissions vehicles (ZEVs) by 2035, with interim targets of at least 20% in 2026 and at least 60% in 2030. In December 2022, ECCC published proposed regulations to amend the *Passenger Car and Light Truck GHG Emission Regulations* to achieve those ZEV targets.

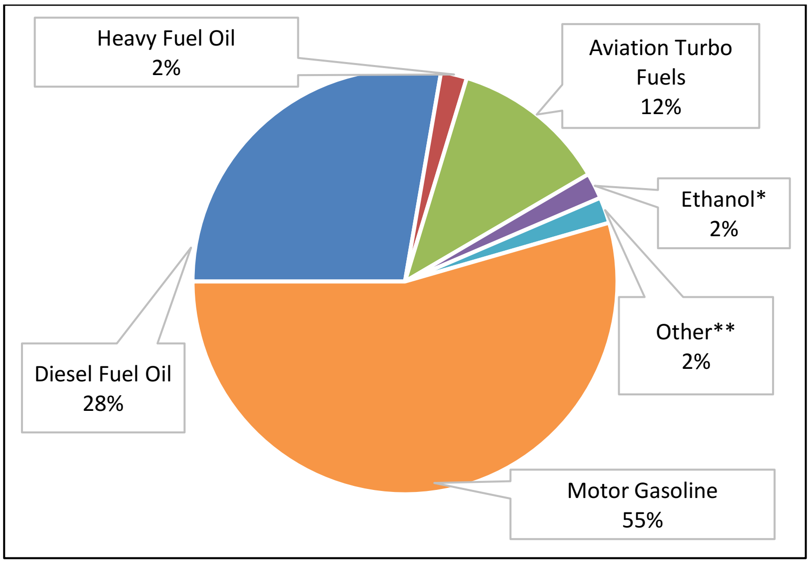
In 2018, Canada published the *Regulations Amending the Heavy-Duty Vehicle (HDV) and Engine Greenhouse Gas Emission Regulations*. The amendments established more stringent GHG emission standards for heavy-duty vehicles and their engines, starting with the 2021 model year. Consideration to the amendments introducing new GHG emission standards that apply to trailers hauled by on-road transport tractors are being assessed. Amendments are estimated to result in cumulative fuel savings of 27.7 billion liters with respect to the portion of the lifetime operation of model years 2020 to 2029 that occurs between 2020 and 2050.

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

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

Advanced Motor Fuels Statistics

Figure 1 shows energy use by fuel type in 2019 for transportation in Canada. Table 2 shows supply and demand for ethanol and biodiesel.



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

Fig. 1. Fuel Mix of the Canadian Transportation Sector, 2019

Table 2. Canadian Supply and Demand of Biofuels, 2021 (in millions of liters)

Parameter	Ethanol	Biodiesel
Canadian production	1,642	416
Imports	1,254	573
Exports	108	440
Domestic use	2,946	796

Research and Demonstration Focus

ecoTECHNOLOGY for Vehicles (eTV) Program
Transport Canada's Innovation Centre's eTV Program is an initiative that conducts in-depth safety and environmental performance testing on a range of new and emerging advanced passenger car and truck

technologies. The program investigates the performance of alternative-fueled vehicles, including renewable fuels, hybrid and electric, CNG, and hydrogen fuel cell vehicles.

Program of Energy Research and Development (PERD)
The Natural Resources Canada (NRCan) program PERD supports energy R&D conducted by the federal government and is designed to ensure a sustainable energy future for Canada. Key research areas focus on knowledge and technology that will help reduce the carbon footprint of fuels and emissions from transportation sources.

Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI)
Through NRCan's EVAFIDI program, $260 million was invested into public infrastructure to encourage the switch to low- or zero-emission vehicles. As of 2022, a total of 638 electric, hydrogen, and natural gas stations have been opened.

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

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

Incentives for Zero Emissions Vehicles Program (iZEV)
To encourage Canadians' adoption of ZEVs, the Government of Canada, led by Transport Canada, launched this program to provide incentives for consumers to buy ZEVs. In terms of total ZEVs on the road, steady annual progress towards the target of 100% ZEV sales by 2035 would translate to approximately 1.4 million ZEVs on the road by 2026 (about 5% of total light-duty vehicles on the road); 4.6 million on the road by 2030 (about 16%); and 12.4 million on the road by 2035 (about 40%).

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

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

Figure 2 shows how each key measure may contribute to the reduction of aircraft emissions by 2050.

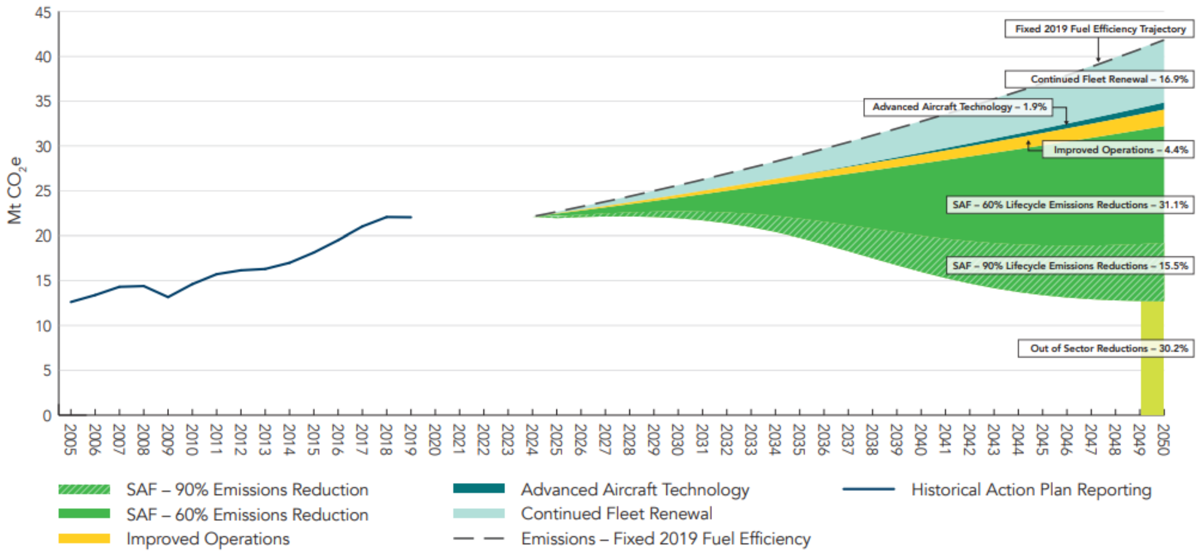


Fig. 2. 2050 Canadian Aircraft Emissions Forecast: A Vision to Net-Zero

Hydrogen Strategy for Canada

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

Outlook

As depicted in Table 3, the Canadian transportation sector comprises several distinct subsectors, and each exhibits different trends during the projected period. GHG emissions from cars, trucks, and motorcycles are projected to decrease by 20 Mt between 2005 and 2030, while those for heavy-duty trucks and rail are projected to increase by14 Mt.

Table 3. Transportation: GHG Emissions (Mt CO_2-eq)

Transportation Subsector	2005	2020	2030	Δ 2005 to 2030
Passenger Transport	**90**	**88**	**70**	**-20**
Cars, light trucks, and motorcycles	82	79	61*	-21
Bus, rail, and domestic aviation	8	9	9	1
Freight Transport	**62**	**73**	**73**	**11**
Heavy-duty trucks, rail	54	68	68	14
Domestic aviation and marine	8	5	5	-3
Other: recreational, commercial, and residential	**10**	**9**	**10**	**0**
Total	**162**	**170**	**153**	**-9**

*Projections based on current emissions standards for model years 2017 to 2025.

China

Drivers and Policies

China is making efforts to achieve peak carbon dioxide emissions and carbon neutrality targets before 2030, and carbon neutrality before 2060. China will promote the goals of new energy and clean energy development, actively developing solar energy resources, hydrogen energy resources, and other renewable energy resources. In addition, it would escalate the development of new energy resources, such as wind, solar, biomass, geothermal, ocean, and hydrogen energy.

Opinions on Optimization of Energy Green Low Carbon Transformation System, Mechanism and Policy Measures

In February, the National Development and Reform Commission and National Energy Administration issued “Opinions on Optimization of Energy Green Low Carbon Transformation System, Mechanism and Policy Measures.” It discusses optimizing the energy clean substitution program in the transport field, driving the transformation of green low carbon in transport, optimizing the transport structure and introducing green low carbon transport facilities and equipment. China proposes to promote large-capacity electric public transport and vehicles using clean energies such as electricity, hydrogen, advanced biological liquid fuel, and natural gas. It intends to optimize layout and service facilities such as charging/battery swap, hydrogen filling, and gas filling (LNG) stations while reducing the cost of clean energy consumption in the transport field. China expects to carry out the construction of multi-energy fusion transport energy supply yard/stations, promote pilot demonstrations for energy interactions between the new energy vehicle and the power grid, and explore the collaborative development of vehicle/pillar and boat/shore.

Implementation Plan of Carbon Dioxide Emission Peaking in Industrial Field

In August, the Minisry of Industry and Information Technology, National Development and Reform Commission and the Ministry of Ecology and Environment jointly published and distributed the “Implementation Plan of Carbon Dioxide Emission Peaking in Industrial Field.” This plan proposes to promote energy-saving and new energy vehicles; enhancing the development of such vehicles operating as urban buses, taxis, postal service and express delivery vehicles, environmental sanitation, and urban logistic distribution; and increase the proportion of private new energy vehicles. The plan intends to carry out research, development, and demonstration applications of electric heavy-duty trucks and hydrogen fuel vehicles. It will speed up the construction of charging pillars and innovations in the battery swap mode, and establish a convenient and efficient battery charging network system ahead of schedule. Using international standards as a benchmark, China will formulate and revise its standards on the energy saving and emission reduction of motor vehicles. In 2030, the proportion of new energy vehicles and clean energy vehicles newly added should reach approximately 40%, and the carbon dioxide emission intensity of new passenger cars and commercial vehicles should be reduced by more than 25% and 20%, respectively, compared to 2020 levels.

Existing National Standards on Alternative Motor Fuels

- 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 will be implemented on May 1, 2022.
- GB/T 34548-2017, “The additive of methanol gasoline for vehicles,” was released on October 14, 2017, and implemented on May 1, 2018.
- GB/T 31776-2015, “Determination method of methanol content in methanol gasoline for motor vehicles,” was released on July 3, 2015, and implemented on October 1, 2015.
- GB/T 26127-2010, “Compressed coalbed methane as vehicle fuel,” was released on January 14, 2011, and implemented on June 1, 2011.
- GB/T 26605-2011, “Dimethyl ether for motor vehicle fuel,” was released on June 16, 2011, and implemented on November 1, 2011.
- GB 19159-2012, “Automotive liquefied petroleum gases,” was released on November 5, 2012, and implemented on April 1, 2013.
- GB 25199-2017, “B5 diesel fuels,” was released and implemented on September 7, 2017.
- GB 18351-2017, “Ethanol gasoline for motor vehicles (E10),” was released and implemented on September 7, 2017.

- GB/T 22030-2017, “Blendstocks of ethanol gasoline for motor vehicles,” was released and implemented on September 7, 2017.
- GB 35793-2018, “Ethanol gasoline for motor vehicles E85,” was released on February 6, 2018, and implemented on September 1, 2018.
- GB 18047-2017, “Compressed natural gas as vehicle fuel,” was released on September 7, 2017, and implemented on April 1, 2018.
- GB/T 40510-2021, “Bio-natural gas as vehicle fuel,” was released on August 20, 2021, and will be implemented on March 1, 2022.
- GB/T 34537-2017, “Hydrogen and compressed natural gas (HCNG) blended as vehicle fuel,” was released on October 14, 2017, and implemented on May 1, 2018.
- GB/T 37178-2018, “Coal-based synthetic natural gas for vehicle,” was released on December 28, 2018, and implemented on July 1, 2019.
- GB/T 37244-2018, “Fuel specification for proton exchange membrane fuel cell vehicles – Hydrogen,” was released on December 28, 2018, and implemented on July 1, 2019.
- GB/T 40045-2021, “Fuel specification for hydrogen powered vehicles – Liquid hydrogen (LH2),” was released on April 30, 2021, and implemented on November 1, 2021.

Advanced Motor Fuels Statistics

In 2022, the output of industrial –crude oil above designated size was 204.67 million tons in China, showing an increase of 2.9% year-on-year. Meanwhile, the country imported 508.28 million tons of crude oil, a decline of 0.9% year-on-year. A total of 675.90 million tons of crude oil were processed, representing a decline of 3.4% year-on-year. In 2022, China produced 217.8 billion cubic meters (m^3) of natural gas: an increase of 6.4% year-on-year. It imported 109.25 million tons of natural gas, representing a 9.9% decline year-on-year. By the end of 2022, the installed capacity of wind power and photovoltaic power generation in China exceeded 700 million kilowatts.

In 2022, China’s auto production and sales volume were 27.021 million units and 26.864 million units, respectively, with a year-on-year increase of 3.4% for production and 2.1% for sales. The production and sales volume of new energy vehicles were 7.058 million units and 6.887 million units, showing a year-on-year increase of 96.9% and 93.4%, respectively, and accounting for 25.6% of market share. The production and sales volume of hydrogen fuel cell electric vehicles were more than 4,000 units produced and 5,000 units sold. The sales volume of natural gas heavy-duty vehicles was 37,300 units and the top five provinces by sales were Shanxi, Xinjiang, Hebei, Shaanxi, and Ningxia.

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.

Shanxi Province has formed a green industrial chain system from methanol fuel production and supply to methanol vehicle production and application. Jinzhong, a city in Shanxi, is one of the earliest pilot cities in China to engage in the application of methanol fuel and methanol vehicles. After 30 years of development, Jinzhong has initially formed the industrial chain system of methanol production and development, equipment manufacturing, methanol transmission, and distribution. The promotion of methanol heavy trucks will help, the city to achieve low carbon emissions.

In August 2022, Jinzhong introduced an incentive policy for the promotion and use of methanol heavy trucks, providing a subsidy of RMB 30,000 Yuan per buyer. Jinzhong took the lead in incorporating methanol heavy trucks into “green card” management, and methanol heavy-duty trucks enjoy the same right of way as new energy vehicles. Jinzhong planned to build 16 methanol refueling stations by the end of 2022. In June 2022, Geely Jinzhong Base commenced production of methanol heavy trucks with an annual output of 10,000 units. In addition, more than 300 units of methanol heavy-duty trucks have been put into operation in Shanxi, Shaanxi, Xinjiang, Gansu, and Guiyang. In December 2022, 500 methanol heavy-duty trucks were delivered in Jinzhong.

In March 2022, Guizhou issued several policies and measures for promoting methanol gasoline vehicles. The goal is that by the end of 2023, the population of methanol vehicles will reach 25,000, with 100 methanol refueling stations for vehicle use; by 2025, the population is expected to reach 50,000, with 200 refueling stations. By July 2022, Guizhou had promoted about 17,000 methanol gasoline vehicles and more than 60 methanol refueling stations. Guizhou encourages government agencies to buy methanol gasoline vehicles for government use and promotes the application in the public area of taxis and online hailing cars. Private customers are encouraged to buy and use methanol cars.

Promotion of Hydrogen Fuel Cell Electric Vehicles Pilot Project
In September 2020, the Ministry of Finance, Ministry of Industry and Information Technology, Ministry of Science and Technology, National Development and Reform Commission, and the National Energy Administration jointly issued the "Notice on Developing Demonstrative Application of Fuel Cell Vehicles," supporting the key technology breakthrough and application of hydrogen fuel cell electric vehicles. In September 2021, the first batch of three fuel cell vehicle demonstration city groups was announced; the three groups are led by Beijing, Shanghai, and Foshan of Guangdong Province.

In January 2022, the second batch of two fuel cell vehicle demonstration city groups was approved. They are as follows:

1. The Hebei city group led by Zhangjiakou, together with 13 cities or districts such as Tangshan, Baoding, Handan, and Qinhuangdao.
2. The Henan city group led by Zhengzhou, together with 11 cities or districts such as Xinxiang, Luoyang, Kaifeng, Anyang, Jiaozuo, three districts of Shanghai (Jiading, Lingang, and Fengxian), Zhangjiakou, Weifang, and Foshan.

At this point, China has five fuel cell electric vehicles demonstration city groups; during the next four years, about 33,000 units of fuel cell electric vehicles would be promoted. The vehicle models are mainly buses, heavy-duty trucks, and special vehicles.

Outlook

China will consistently implement the strategy of carbon peaking and carbon neutrality, accelerate the green transition, and make contributions to combating global climate change.

New energy vehicles in China have entered a comprehensive market development stage. In the future, new energy vehicles will maintain a steady and positive development trend. The application scale of hydrogen fuel cell electric vehicles will grow fast. Natural gas vehicles and methanol gasoline vehicles will be encouraged where local resources are available; for example, Jinzhong in Shanxi Province will actively promote methanol-fueled heavy trucks and cars.

Additional Information Sources

- National Development and Reform Commission, https://www.ndrc.gov.cn/fggz/jjyxtj/mdyqy/
- China Association of Automobile Manufacturers (CAAM), http://www.caam.org.cn/
- China Automotive Technology and Research Center (CATARC), http://www.catarc.ac.cn/ac_en/index.htm
- Methanol Institute, A Brief Review of Chinas Methanol Vehicle Pilot and Policy, https://www.methanol.org/methanol-news-en/
- Ministry of Industry and Information Technology (MIIT), http://www.miit.gov.cn/
- http://www.cvworld.cn/
- http://jzkfq.sxjz.gov.cn/

Denmark

Drivers and Policies

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

Advanced Motor Fuels Statistics

General Energy Data Gross energy consumption has been relatively constant since 1990, with falling consumption of coal and increasing consumption of renewable energy (see Figure 1). Gross energy consumption peaked in 2007 at 873 petajoules (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 amounts in 2017. Coal consumption will fall considerably by 14% annually until 2030, due in particular to the expected stop in the use of coal in large-scale combined heat and power (CHP) production. In 2030, only the Fynsværket power station and the cement industry will consume large amounts of coal. However, some plants will retain the option for coal operation, although actual use is assumed to be limited.

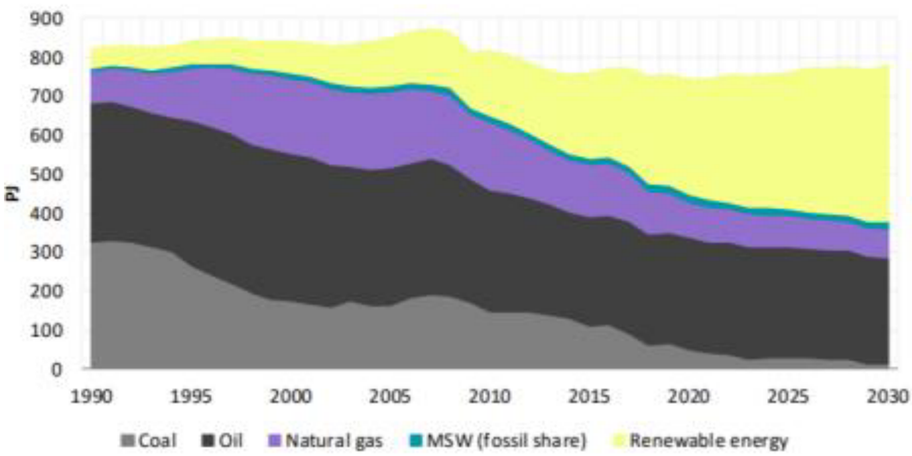


Fig. 1. Gross Energy Consumption by Type of Energy, 1990–2030 [in petajoules (PJ)].
The calculation for 1990-2017 has been adjusted for outdoor temperature/degree days relative to normal years (climate-adjusted) and electricity trade with other countries.

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).

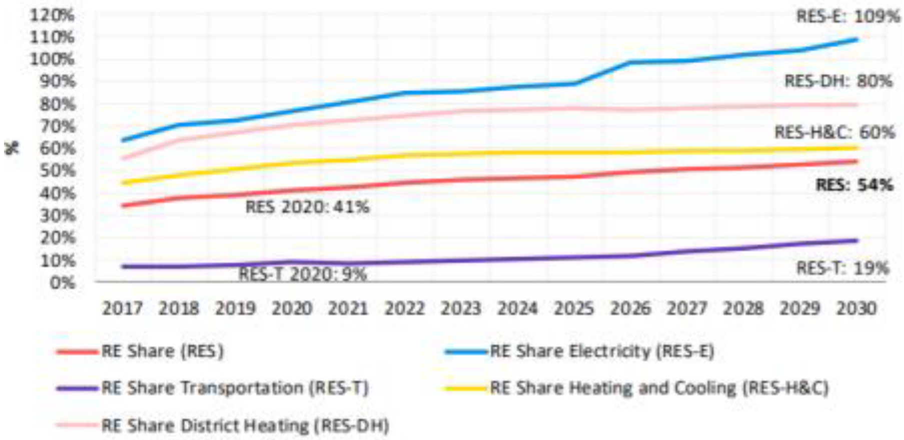


Fig. 2. Renewables Shares, 2017–2030 [%].
The renewables shares is calculated as defined in the RE Directive (Eurostat, 2018).

The RES and RES-T are subject to binding national EU targets 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.

Projections show that the RES is expected to be 41% in 2020, whereby Denmark will have met and exceeded its EU obligation for a 30% renewables share by 2020. The RES-T will reach 9% in 2020 – that is, a 1% shortfall compared to the 2020 RE Directive obligation of 10%. The overall RES will increase, reaching 54% by 2030. The trend depends on the deployment of offshore wind, onshore wind, and solar PV, and on the conversion of CHP plants to biomass, while 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 RES-E is expected to increase to 109% in 2030. This trend is particularly contingent on the offshore wind farms included in the 2018 Energy Agreement being commissioned by 2030. Updated expectations also exist regarding the deployment of commercial solar PV (ground mounted solar farms) and expectations regarding the replacement of older onshore wind turbines with fewer, more efficient turbines. The projection of onshore wind and solar PV deployment depends on the development 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 PPA/guarantees of origin. A high percentage of RES-E affects the calculation of the RES-T because the RE Directive uses a multiplication factor of 4 for the renewables share of electric road transport and a multiplication factor of 1.5 for the renewables share of electric rail transport.

With 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 to only a very limited extent. The blending ratio of biofuels in petrol and diesel is expected to be maintained at the current level in the absence of new measures. Fuel consumption for domestic air traffic is included in the calculation of the renewables share. The aviation sector has announced ambitious plans for biofuel blending, but as these announcements are neither binding nor reflect a profitable development pathway for companies in the absence of new measures, the plans 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 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 by 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.

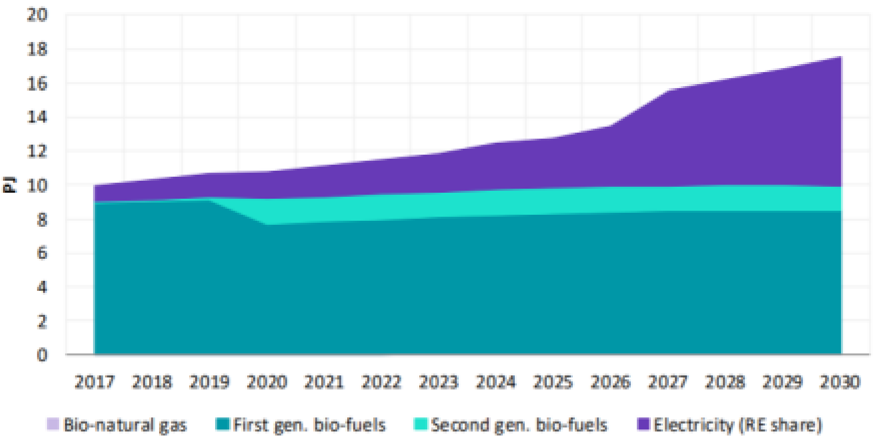


Fig. 3. Renewable Energy Consumption by the Transport Sector, 2017–2030 (in petajoules)

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 low-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.

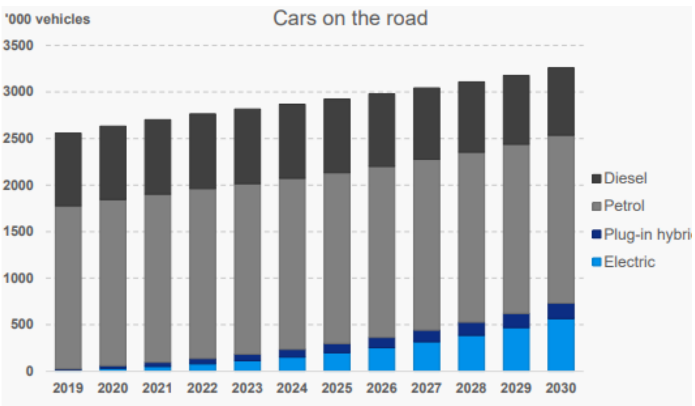


Fig. 4. Number of Cars by Technology, 2019–2030

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. This is due to inertia in the transition because of the relatively long lifetime of vehicles.

CO_2 Emissions from Road Transport

As shown in Figure 5, passenger cars contribute the most to road-transport emissions, followed by vans and lorries. Passenger cars account for around 60% of total road-transport emissions.

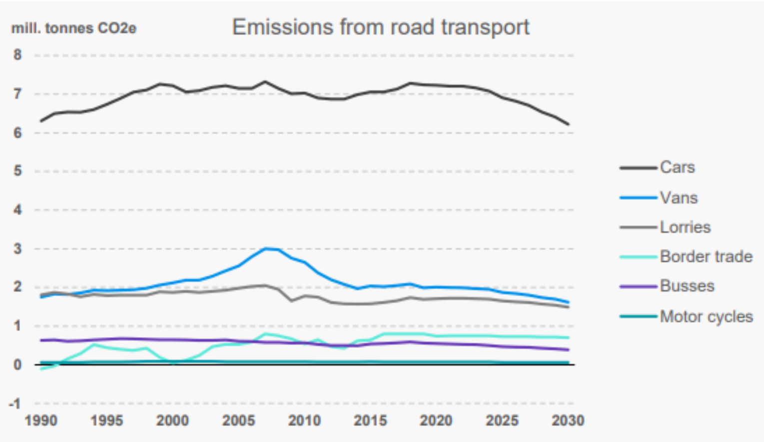


Fig. 5. Emissions from Road Transport, by Vehicle

Traffic work is expected to continue to rise for all types of vehicles. From 2019 to 2030, overall traffic for road transport is expected to increase by approximately 21%. Nevertheless, a reduction in GHG emissions is expected for all vehicle types during that time period, due primarily to continued energy-efficiency improvements for conventional vehicles, increased biofuel blending in petrol and diesel, and more transition to alternative fuels, especially electric cars. Blending with biofuels and other renewable fuels is assessed to provide a direct CO_2 reduction in 2030 of about 1.2 million tonnes compared to a development with no blending. Similarly, the replacement of conventional passenger cars with electric and plug-in hybrid cars is expected to reduce emissions by about 1.4 million tonnes of CO_2.

Research and Demonstration Focus

Research and Demonstration in Denmark are focused on electric vehicles and fuel cell vehicles for passenger cars. Several demonstration projects have been initiated. For HDVs, biofuels are the most obvious solution. However, liquid and gaseous electrofuels, which can store a surplus of wind turbine electricity, appear to be gaining attention. Research supporting the analysis of common energy and transport fuels production systems also has high priority.

Outlook

In Denmark, the transportation sector is still almost entirely dependent on oil. By 2050, however, the government aims to meet all Danish energy supply by 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 established, which will be a hub for 3 GW offshore wind farms and with the possibility of 10 GW in the long term, and will thus be able to cover the consumption of 10 million households. The wind turbines that will supply power to the island are expected to be larger than they are today, and will go 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, and it is part of the political agreements that electricity from the energy islands should be converted into new forms of energy (e.g., Power-to-X). This means that green power 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 able to be converted into other forms of energy, for example Power-to-X. 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 able to be converted into other forms of energy, for example 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

Finland

Drivers and Policies

Finland's 2016 energy and climate strategy calls for a 50% reduction of CO_2 emissions from transport by 2030, the reference year being 2005.[12] The 2019 Government Programme sets a new upper level: Finland will achieve carbon neutrality by 2035 and aims to be the world's first fossil-free welfare society.

In May 2021, the Ministry of Transport and Communications of Finland published a roadmap for fossil-free transport with the goal of halving GHG emissions from transport by 2030, using 2005 as the base year, and to achieve zero emissions by 2045. Roadmap measures include actions to support the procurement of electric and gas-powered vehicles, the distribution infrastructure, pedestrian and bicycle traffic, and public transport. Additionally, assessments cover the impacts of a stricter obligation to distribute renewable fuels, as well as the impacts of remote work, new transport services, and combined transports in freight traffic.[13]

In spring 2019, the biofuels obligation was revised and the 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. This explains the lower obligation for 2021 compared to 2020 (20%). A separate sub target for advanced biofuels also exists, following the RED II directive: 2% between 2021 and 2023. In 2021, Finland passed a law amending gaseous and liquefied biogas in the transport biofuels obligation beginning January 1, 2022, and passed a law amending electro-fuels in the biofuels obligation beginning January 1, 2023.[14,15] In September 2022, the government proposed that Parliament increase the renewable fuels blending obligation to 34% in 2030 and onward.[16] The original biofuels obligation (liquid biofuels) calls for 19.5% biofuels for on-road transportation in 2022. However, due to a sudden increase in fuel prices during the spring of 2022, the government decided to reduce the blending obligation by 7.5%, to 12% for 2022.

In addition, a separate renewable fuels obligation is set for non-road machinery diesel fuels. With the current level at 4%, 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.[17]

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 favors 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).[18]

The current government programme promotes renewable fuels utilization via fuel conversion kits. The government has also proposed national legislation modifications for promoting flexi-fuel (E85) and biomethane passenger car conversion kits installations.[19] However, the proposal leaves open the details regarding how motorists with converted cars can demonstrate compliance with safety and emissions.

Advanced Motor Fuels Statistics

In 2021, the energy consumption in domestic transport (all modes together) was 171 PJ, and energy consumption in road transport was 157 PJ, or 3.8 Mtoe (Table 1). Relative to the total final consumption of 1,358 PJ in 2021, the figures were 12.6% and 11.2%, respectively.[20]

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[12] https://tem.fi/en/energy-and-climate-strategy-2016
[13] https://www.lvm.fi/en/-/transport-emissions-can-be-halved-by-2030-through-national-and-eu-measures-1641099
[14] https://www.edilex.fi/verohallinnon_ohjeet/2020_1116.html
[15] https://tem.fi/-/biopolttoaineet-jakeluvelvoitteeseen
[16] https://www.eduskunta.fi/FI/vaski/HallituksenEsitys/Sivut/HE_174+2022.aspx
[17] https://www.eduskunta.fi/FI/vaski/HallituksenEsitys/Sivut/HE_297+2022.aspx
[18] Parkkonen, L. (2013). Taxation of petroleum products and vehicles in Finland. CEN/TC 19 Conference. Helsinki, May 27, 2013.
[19] https://www.finlex.fi/fi/esitykset/he/2022/20220291
[20] https://pxdata.stat.fi/PxWeb/pxweb/fi/StatFin/StatFin__ehk/statfin_ehk_pxt_12sz.px/

Table 1. Energy in Road Transport, 2021

	PJ	ktoe	Share of fuels (%)	Share of bio (%)
Petrol (fossil)	47.5	1135	30.1	
Biocomp. petrol	4.6	110	2.9	8.9 of petrol
Diesel (fossil)	81.3	1941	51.6	
Biocomp. diesel	23.2	554	14.7	22.2 of diesel
Natural gas	0.40	9.6	0.25	
Biomethane	0.51	12.1	0.32	56.1 of gas
∑ fuels	152.3	3761		18.0 of fuels
	PJ	**ktoe**	**Share of total (%)**	
Electricity	0.85	20.3	0.5	
∑ fuels	157.47	3638	99.5	
Total	**152.7**	**3,648**		

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

In terms of energy, the contribution of biofuels relative to the total amount of actual fuels is 18.0%, varying from 8.9% in petrol (mostly ethanol and some ETBE but also bio-naphtha; the statistics do not give details on this) to 56% in methane. The actual amount was 676, or 18.0% of the fuels, meaning that the greater part of the biofuels used was eligible for double counting.

The four major Finnish players in biofuels are Neste (the world's biggest producer of HVO), UPM, St1, and Gasum. The total production capacity of biofuels in Finland is some 540 ktoe.[21] Compared to the Finnish consumption of biofuels in 2021, consumption exceeds production. In 2020, total biofuels use in road transport was 402. However, it should be noted that Neste relies mainly on imported feedstocks, whereas UPM, St1, and Gasum use indigenous feedstocks. All Finnish biofuel producers have announced major increases in capacity, either in Finland or abroad.

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

[21] https://valtioneuvosto.fi/artikkeli/-/asset_publisher/10616/selvitys-biopolttoaineiden-kustannustehokkaat-toteutuspolut-vuoteen-2030

Table 2. Vehicle Fleet in Use at the End of 2022 (without two- and three-wheelers and light four-wheelers)[22]

Fuel	Cars	Vans	Trucks	Buses	Special vehicles
Petrol	1,851,355	9,141	2,248	20	267
FFV/ethanol	4,474	14	120	0	0
Diesel	719,927	331,612	89,691	10,472	1,309
Methane	7,038	785	269	63	0
Methane bi-fuel	8,566	324	101	0	0
BEV	44,889	1,556	25	550	0
PHEV petrol	98,353	185	0	0	0
PHEV diesel	5,685	73	0	2	0
Other	56	15	163	5	0
Total	2,740,343	343,705	92,617	11,112	1,576
Fuel	**Cars (%)**	**Vans (%)**	**Trucks (%)**	**Buses (%)**	**Special vehicles (%)**
Petrol	67.6	2.7	2.4	0.2	16.9
FFV/ethanol	0.2	0.0	0.1	0.0	0.0
Diesel	26.3	96.5	96.8	94.2	83.1
Methane	0.2	0.2	0.2	0.5	0.0
Methane bi-fuel	0.3	0.1	0.1	0.0	0.0
BEV	1.6	0.5	0.0	4.9	0.0
PHEV petrol	3.6	0.1	0.0	0.0	0.0
PHEV diesel	0.2	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.2	0.0	0.0

Table 3. Sales of New Passenger Cars, 2015–2022[23]

Year	Petrol	FFV	CNG	Diesel	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

In 2022, 81,694 new cars were sold – approximately 17% fewer than in 2021. Diesel shares of new sales continue to decline and in 2022 represented only 6.6%, compared to 35.7% in 2015. Increasing new sales of PHEVs stopped and totalled around 30% of total new sales. BEVs are becoming more popular, and sales have increased year over year. In 2022, BEVs represented about 18% of total new sales.

Finland has some 490 alternative-fueled trucks, including FFVs and bi-fuel vehicles. Methane-fueled trucks represent the greatest share. In addition, 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 LNG

[22] https://tieto.traficom.fi/fi/tilastot/ajoneuvokannan-tilastot?toggle=K%C3%A4ytt%C3%B6voimat
[23] https://www.aut.fi/tilastot/ensirekisteroinnit/ensirekisteroinnit_kayttovoimittain/henkiloautojen_kayttovoimatilastot

refueling infrastructure and increased offerings of heavy gas trucks, trucks fueled by LNG now operate on Finnish roads. The number of trucks fueled by CNG and LNG grew from 134 in 2020 to 269 in 2022. In the case of buses, the number of battery electric buses has surpassed the number of CNG buses. The increase of electric (city) buses has been rapid. The year 2020 saw a total of 87 electric buses and in 2022, already 550.

Research and Demonstration Focus

Below are presented some major national R&D projects where VTT is taking part. There are number of additional projects as well.

In 2020, Business Finland funded a new project on liquid electrofuels. The E-Fuel project (2021–2022) aims to develop integration of hydrogen production through high-temperature electrolysis with CO_2 sequestration and Fischer-Tropsch fuel synthesis; the project also includes research on end use.

The BIOFLEX project (2020–2022) explores how suitable fuel oils made from biomass and waste plastics are for power plants and ship diesel engines. The project studied the development of production processes as well as measurements of the emissions when using new biofuels in marine engines.

The Clean Propulsion Project (2021–2023), funded by Business Finland, focuses on developing maritime and non-road engine technologies for better efficiency and renewable fuels. The project has four focus areas:

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

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

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

1. Foresight and scenario investigation for offering guidance on possible future development paths.
2. Research on the most 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 for evaluating not only the technical attributes but also the economic feasibility.

Outlook

Finland has to reduce its CO_2 in the non-ETS sector by 39% by 2030. This puts pressure on emission reductions in transport. Biofuels – or, in more general terms, renewable fuels – are seen as a very important element in emission reductions in transport. With its new liquid biofuels mandate written into law in spring 2019, Finland is one of the few countries with a fixed biofuels policy articulated through 2030. In parallel with increasing the amount of biofuels, energy efficiency and electrification in transport are promoted as well.

In the newest government program, much attention is given to the circular economy and biogas, so the country has the political will to promote the use of biomethane in transport. Opening up the gas market (gas transmission and sales separated) as of 2020, a new pipeline connector to Estonia, and terminals for LNG important open up new possibilities for methane in stationary as well as mobile applications on land and at sea.[24] Currently, the Finnish LNG vessel fleet encompasses some 10 LNG-fueled ships, including passenger and cargo ships, one icebreaker, and one border patrol vessel. At the end of 2020, a biogas obligation for transport and heating gas was proposed. If passed, the new law would require that future biogas be mixed in the national gas grid.

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

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

To support e-fuels production, over 2400 MW of new wind power capacity was installed during 2022. At the end of 2022, the total peak power capacity of wind power was around 5700 MW in comparison to around 12 000 MW capacity of traditional sources (CHP, condensing power, hydro, and nuclear). Wind power capacity is expected to be increased to around 9000 MW by 2025.[25]

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

[24] https://figas.fi/en/gas-market
[25] Investment decision made before 4.1.2023

Germany

Drivers and Policies

Germany has set significant targets to reduce GHG emissions on the EU and national levels (e.g., European Green Deal and Federal Climate Change Act); the transition towards decarbonization is ongoing. The year 2022 was marked by the Russian invasion of Ukraine. As a response, the federal government is committed to ending Germany's reliance on Russian oil, coal, and gas as quickly as possible.[26] Overall, energy security was identified as the number-one priority, while also continuing to take strong action for climate change mitigation. High energy prices and a strong push for reliable and sustainable sources of energy affected Germany's transport sector to a large extent in the past year.

In the Climate Change Act Germany set binding target savings of at least 65% of GHG emission by 2030, compared to 1990, and aims to reach the ambitious goal of becoming carbon neutral by 2045.[27] The permissible annual emission budget for the transport sector is 85 Mt CO_2-eq in 2030.While national and sector-wide GHG emission 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 are specified in the Climate Action Programme 2030. These measures are targeted to contribute a GHG emissions reduction in the transport sector of only 41-42% by 2030.[28] This translates to 98 to 95 Mt CO_2-eq. GHG emissions in transport by 2030.[29] Although Germany has already taken comprehensive climate measures, further efforts are required to achieve the set goal of CO_2 savings formulated in the Climate Change Act.[30] Figure 1 illustrates the massive gap between trends and targets in the transport sector, highlighting that significant action has to be taken quickly to reach the GHG emission target of 85 Mt CO_2-eq. by 2030.

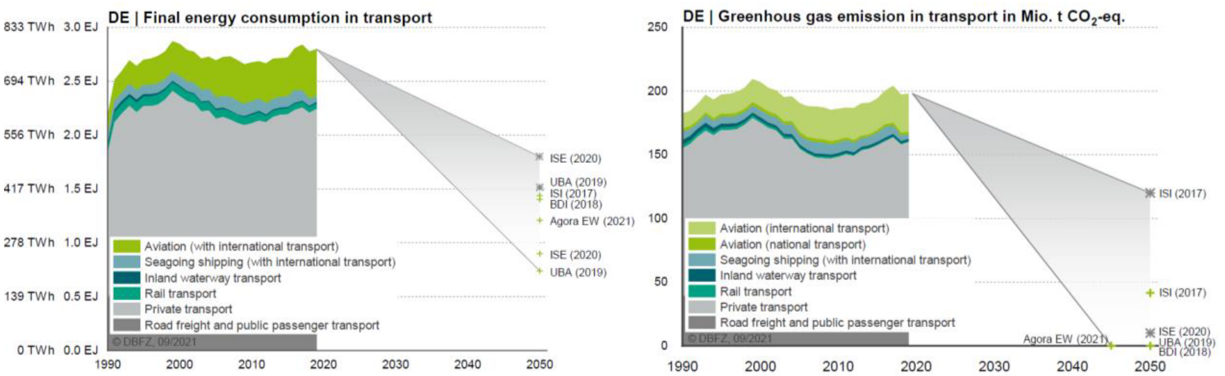

Fig. 1. The massive gap between trends and targets in transport, 1990-2050[31]
Source: DBFZ.

The main public drivers regarding policy in the transport sector remain the revised EU Renewable Energy Directive (RED II) and the Fuel Quality Directive (FQD), which are implemented by the Federal Emissions Control Act (BImSchG §37) and the GHG mitigation quota. The FQD is defined by EU Member States to implement GHG reduction targets for fuels placed on the market. By 2020, target reduction was set for 6% through renewable fuels, including the crediting of up to 1.2% upstream emission reductions (UER) (UER 2018). Fuel suppliers are obliged to report GHG emissions for the

[26] https://www.bundesregierung.de/breg-de/themen/klimaschutz/energieversorgung-sicherheit-2040098, last accessed 28.02.2023.
[27] https://www.bundesregierung.de/breg-de/themen/klimaschutz/climate-change-act-2021-1936846, last accessed 28.02.2023.
[28] https://www.bundesregierung.de/breg-en/issues/climate-action/klimaschutzprogramm-2030-1674080, last accessed 27.02.2023.
[29] https://www.bundesregierung.de/resource/blob/974430/1679914/e01d6bd855f09bf05cf7498e06d0a3ff/2019-10-09-klima-massnahmen-data.pdf?download=1, last accessed 28.02.2023.
[30] https://www.dbfz.de/pressemediathek/publikationsreihen-des-dbfz/dbfz-reports/dbfz-report-nr-44, last accessed 28.02.2023.
[31] DBFZ Report No.44, https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_44_EN.pdf, last accessed 28.02.2023.

fuels they have placed on the market.[32] RED II formally became national law in September 2021 by continuing the GHG mitigation quota and increasing this quota incrementally from 7% in 2022 to 25% by 2030.[33] A summary is given in Table 2. There are ongoing discussions on amending the GHG mitigation quota, for example, by including a phase-out of crop-based biofuels by 2030 as well as higher multipliers for e-mobility and efuels (as discussed in the Outlook). The requirements outlined in the RED on sustainability and balancing GHG emissions are transposed into national law by the biofuel sustainability ordinance (Biokraft-NachV)). Trilogue negotiations between the Parliament, the Council, and the Commission on the RED are still ongoing.[34] Once an agreement has been reached, the federal government will implement the measures nationally.

Table 2. 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 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 (PTX/e-fuels, RFNBO)	Use in refineries and as fuel with twofold counting
Electricity	Threefold counting, adjustment mechanism factor 0.5 to 1.5
Upstream Emission Reduction (UER)	GHG mitigation through UER with maximum 1.2% until 2026

To decarbonize the transport sector, high priority has recently been given to the enforcement of hydrogen and liquefied natural gas (LNG) infrastructure along the most important middle- and long-distance road networks and the expansion of the charging infrastructure for electric vehicles. The Federal Ministry for Economic Affairs and Climate Action (BMWK) invested EUR 62 million in the construction of three bunker vessels (refueling ships) for LNG, which at a later stage will be used to refuel ammonia.[35] The project's aim is to build a modern and sustainable infrastructure for maritime vessels. Likewise, the first German LNG terminal was inaugurated on 17 December 2022 in Wilhelmshaven. Four additional LNG terminals will be available by winter 2023/2024.[36] Overall, the federal government is sowing the seeds for a transition in the maritime sector.

The application of hydrogen as a transport fuel is one of the main strategies to reach GHG quotas, as outlined in the National Hydrogen Strategy from June 2020. By 2030, a total hydrogen demand of 90 to

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32 https://www.dbfz.de/fileadmin/user_upload/Referenzen/Statements/Hintergrundpapier_Weiterentwicklung_THG-Quote.pdf, last accessed 28.02.2023.

33 https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&start=//*[@attr_id=%27bgbl121s4458.pdf%27]#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl121s4458.pdf%27%5D__1646058705951, last accessed 27.02.2023.

34 https://www.europarl.europa.eu/legislative-train/spotlight-JD21/file-revision-of-the-renewable-energy-directive, last accessed 27.02.2023.

35 https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221223-habeck-hands-over-funding-notices-eur62-million-for-the-construction-of-three-innovative-lng-bunker-vessels.html, last accessed 27.02.2023.

36 https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221217-first-german-lng-terminal-inaugurated-in-wilhelmshaven.html, last accessed 27.02.2023.

110 TWh (approximately 2.7 to 3.3 million metric tons) shall be met, of which about 14 TWh (0.4 million metric tons) are to be produced in Germany.[37] 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. This is different from the EU hydrogen strategy, which includes biomass as a renewable hydrogen source.[38] The strategy highlights the overall critical stance of the federal government towards using biomass for renewable fuel production.

The PtL-Roadmap was published in May 2021 and outlines Germany's efforts to expand the production of sustainable aviation fuel from renewable energy sources.[39] The federal government, federal states, and industry representatives agreed in particular that electricity-based, power-to-liquid (PtL) kerosene from renewable energy sources plays 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.[40] The country intends to achieve the target through technological development, establishing uniform sustainability criteria, and supporting the market ramp-up.

On the contrary, when it comes to on-road vehicles, 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 toward electric vehicles.[41] The federal government supports the agreement and believes that it will gives the German industry the necessary planning security.[42] The number of electric vehicles and plug-ins has significantly increased since 2017 (see Advanced Motor Fuels Statistics below); today, 25% of newly purchased vehicles are either electric or plug-in.[43] Nevertheless, the restructuring of the transport sector continues to be very slow. It is predicted that 40 million vehicles with combustion engines will still be in use in 2030, and that the year 2045 will continue to see vehicles with combustion engines, due to the difficulty of electrifying certain areas of transport.[44]

In early 2023, 115 electric car series are available on the German market.[45] More than 80 of those models come from German manufacturers.[46] As of December 2022 there are 63,806 "normal" and 12,755 high-speed publicly accessible charging points in Germany.[47] To make electric vehicles more attractive, the federal government decided to provide additional impetus for e-mobility. The overall package consists of temporary purchase incentives until the end of 2025, additional funds for the expansion of the charging infrastructure, and additional efforts in the public procurement of electric vehicles and tax measures.[48] In 2020, the federal government decided to increase the incentive until 1 January 2023, making a clear commitment to strengthening national e-mobility.

While the political direction is clear, consumers offer various reasons for being hesitant to invest in non-combustion engine vehicles. Mile coverage and prices for refueling are the most important factors when purchasing a vehicle, hence limiting consumers' willingness to purchase a vehicle running on renewable fuels.[49] 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

[37] https://www.dbfz.de/pressemediathek/publikationsreihen-des-dbfz/dbfz-reports/dbfz-report-nr-46, last accessed 28.02.2023.
[38] Ibid.
[39] https://bmdv.bund.de/SharedDocs/DE/Anlage/G/ptl-roadmap-englisch.pdf?__blob=publicationFile, last accessed 27.02.2023.
[40] Ibid.
[41] https://www.europarl.europa.eu/news/en/press-room/20221024IPR45734/deal-confirms-zero-emissions-target-for-new-cars-and-vans-in-2035, last accessed 27.02.2023.
[42] https://dserver.bundestag.de/btd/20/050/2005047.pdf, last accessed 27.02.2023.
[43] https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_44_DE.pdf, last accessed 27.02.2023.
[44] Ibid.
[45] https://www.adac.de/rund-ums-fahrzeug/elektromobilitaet/kaufen/elektroautos-uebersicht/, last accessed 27.02.2023.
[46] https://www.bmwk.de/Redaktion/DE/Dossier/elektromobilitaet.html/, last accessed 27.02.2023.
[47] https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/E-Mobilitaet/start.html, last accessed 27.02.2023.
[48] https://www.bundesregierung.de/breg-de/themen/energiewende/kaufpraemie-fuer-elektroautos-erhoeht-369482, last accessed 27.02.2023.
[49] Dr. Jipp, DLR, Presentation at "Fuels of the Future Conference" in Berlin on 23. January 2023.

renewable fuels for them to consider these fuels, while in reality 69% of respondents refuel at only 2-3 gas stations.[50] This shows a discrepancy between what is expected and actual mobility behavior. It can also be noted that electric vehicles are purchased mostly by consumers of a high socioeconomic class, as Tesla models Y and 3 ranked first and second among electric car models sold in 2022.[51]

With regard to public transport, the federal government implemented measures including the introduction of a 9-euro public transport ticket, which ticketholders could use during June, July, and August 2022 on buses, tramways, and metro and regional trains throughout Germany. The ticket was introduced to make public transport more attractive and to counter the high energy prices; approximately 52 million tickets were sold.[52] Although heavily criticized by the opposition and public transport providers, the government called the ticket a success and announced that a follow-up ticket will be introduced in 2023.[53]

Advanced Motor Fuels Statistics

The consumption of biofuels in Germany totaled 52, 2Mt in 2022, primarily with low-level blends of biodiesel, hydrotreated vegetable oil (HVO), bioethanol, and biomethane (Figure 2).[54] Moreover, to a minor extent, biomethane is used for compressed natural gas (CNG). Due to the absence of incentives, there is 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.

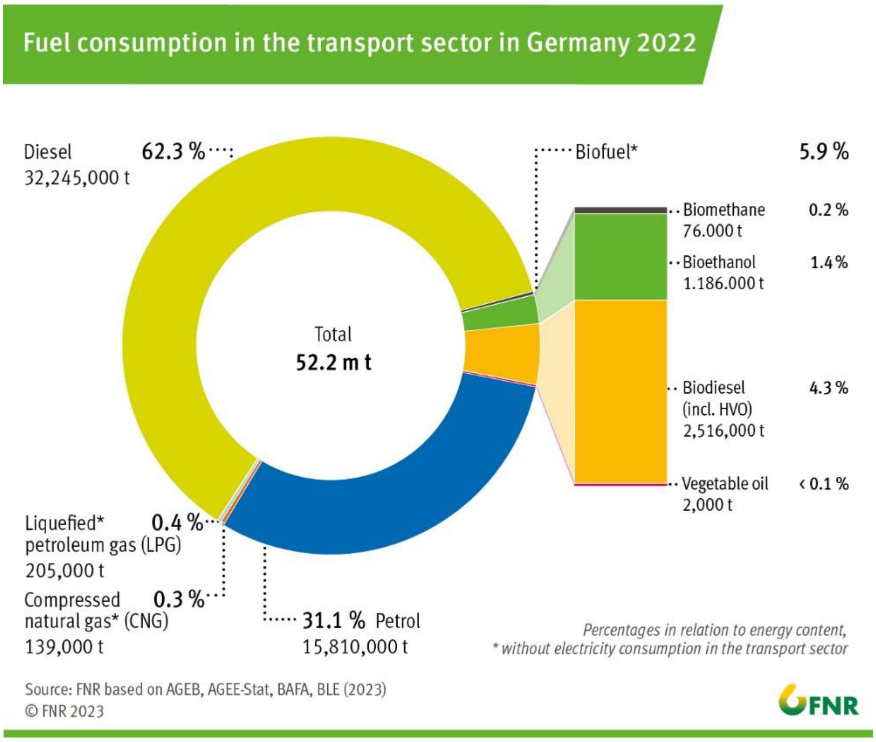

Fig. 2. Fuel Consumption in the Transport Sector in Germany in 2022[55]

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50 Ibid.
51 https://www.now-gmbh.de/wp-content/uploads/2023/01/KBA_Report_12-2022.pdf, last accessed: 27.02.2023.
52 https://www.vdv.de/bilanz-9-euro-ticket.aspx, last accessed: 28.02.2023.
53 https://bmdv.bund.de/SharedDocs/DE/Artikel/K/9-euro-ticket-beschlossen.html, last accessed: 27.02.2023.
54 https://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/biokraftstoffe/kraftstoffverbrauch-in-deutschland.html, last accessed: 27.02.2023.
55 Federal Office for Economic Affairs and Export Control; BAFA et al. (Federal Statistics Office [Destatis], DVFG [German LPG Association], the Federal Ministry of Finance [or BMF], Agency for Renewable Resources [Fachagentur Nachwachsende Rohstoffe e.V., or FNR]), 2021.

Tables 1 and 2 show the 2013–2022 trends for biofuels and biofuel blends sales. The overall savings in GHG emissions of all biofuels (pure) was 83% compared to fossil fuels and the prediction is that number will remain at this high level.[56] The increasing GHG savings of biofuels demonstrate that the physical demand for biofuels to comply with the GHG quota decreased.

Table 1. Trends in German Biodiesel Sales (FAME, HVO, FT-BtL), 2013–2022 (in Mt)[57]

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

Table 2. Trends in German Bioethanol Sales, 2013–2022 (in Mt)[58]

Sale	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
E85	0.014	0.010	0.007	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ethanol	1.041	1.082	1.049	1.047	1.045	1.077	1.055	0.972	0.995	0.966
ETBE	0.154	0.139	0.119	0.129	0.111	0.110	0.088	0.126	0.157	0.120
Total	1.209	1.231	1.177	1.176	1.156	1.187	1.177	1.098	1.152	1.086

A total of 67.7 million vehicles were registered in Germany as of January 1, 2022 (+1.3 %), including 48.5 million passenger cars, 3.5 million trucks, 2.3 million towing vehicles, and 80,225 buses.[59] Table 3 shows the number of passenger cars in Germany by fuel type for 2016-2022. The number of hydrogen-powered cars increased from 808 (2021) to 1,211 (+49.9%). A total of 346,765 LPG-powered cars were registered: a share of 0.7%. CNG-powered cars had a share of 0.2%. Interestingly, bigger and heavier cars are becoming more popular, with a 12.2% increase in SUVs. On average, Germany has 717 cars per 1,000 inhabitants.[60] For comparison, Austria has 566 cars per 1,000 inhabitants.[61]

Table 3. Number of Passenger Cars in Germany by Fuel Type on January 1, 2016–2022

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

LPG = liquefied petroleum gas according to European fuel quality standard EN 589
CNG = compressed natural gas according to German fuel quality standard DIN 51624
EV = electric vehicle X = values not comparable *Source: KBA 2022.*[62]

56 https://www.ble.de/SharedDocs/Downloads/DE/Klima-Energie/Nachhaltige-Biomasseherstellung/Evaluationsbericht_2019.pdf?__blob=publicationFile&v=4, last accessed: 27.02.2023.
57 Bafa Official Mineral Oil Data, 2022 Data from November 2022, https://www.bafa.de/SiteGlobals/Forms/Suche/Infothek/Infothek_Formular.html?nn=8064038&submit=Senden&resultsPerPage=100&documentType_=type_statistic&templateQueryString=Amtliche+Daten+Mineral%C3%B6ldaten&sortOrder=dateOfIssue_dt+desc, last accessed 27.02.2023.
58 Ibid.
59 https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/fz_b_jahresbilanz_node.html, last accessed 21.03.2023.
60 https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html, last accessed 28.02.2023.
61 https://www.statistik.at/statistiken/tourismus-und-verkehr/fahrzeuge/kfz-bestand, December 2022, last accessed 28.02.2023.
62 https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Jahrebilanz_Bestand/2022/2022_b_jahresbilanz_tabellen.html?nn=3532350&fromStatistic=3532350&yearFilter=2022&fromStatistic=3532350&yearFilter=2022, last accessed 27.02.2023.

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).[63] In 2022, the BMBF funded three lighthouse projects with a total funding of EUR 700 million (USD 764 million, H2Giga, H2Mare, and TransHyDE).[64] 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.[65]

The BMDV funds research on renewable fuels, with EUR 1.54 billion (USD 1.68 billion) available for 2021–2024, consisting of resources from the Climate and Transition Fund (KTF) and the National Hydrogen Strategy.[66] Importantly, EUR 640 million (USD 698 million) will be used for R&D projects.[67] This funding program scope also includes advanced biofuels. In 2022 a call on renewable fuels for the maritime sector (electric and bio-based) was published.[68] Funding is also available at the state level; for example, Baden-Württemberg funds various R&D projects through its renewable fuels strategy.[69]

Outlook

With RED II currently under revision, more ambitious GHG mitigation quotas can be expected in the future.[70] Nevertheless, when it comes to implementing the directive nationally, no major adaptation is expected as ambitious targets are already in place. The ongoing debate on biofuels ("food vs. fuel") has been reignited by the Green party with a proposal by the Ministry of Environment in January 2023 to phase out crop-based biofuels by 2030.[71] So far, biofuels account for 4% of German transport fuel consumption. To meet the 2030 climate target, GHG emissions of the transport sector will have to be reduced by 43% in 2030, in relation to 2022.[72] It seems inevitable that all types of fuels are needed.[73]

As incentives for purchasing electric cars decreased in 2023 compared to previous years, electricity prices have increased strongly. With the ban on purchasing new combustion engine cars going into effect only as of 2035, no major increase in the sales of electric cars can be expected in the near future. After the success of the 9-euro ticket, a follow-up ticket is expected to be introduced in 2023. Whether this will lead to a change of mobility habits is questionable.

The Russian invasion of Ukraine was a wake-up call for the federal government, not just with regard to territorial security but also energy security. Guaranteeing energy security while continuing to implement ambitious climate targets will be a mammoth task.

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[63] https://www.bmbf.de/bmbf/shareddocs/pressemitteilungen/de/2021/10/111021-Ariadne.html, last accessed 27.02.2023.
[64] https://www.wasserstoff-leitprojekte.de/home, last accessed 27.02.2023.
[65] https://care-o-sene.com/en/, last accessed 27.02.2023.
[66] https://bmdv.bund.de/DE/Themen/Mobilitaet/Klimaschutz-im-Verkehr/Alternative-Kraftstoffe/alternative-kraftstoffe.html, last accessed 27.02.2023.
[67] https://bmdv.bund.de/SharedDocs/DE/Artikel/G/Klimaschutz-im-Verkehr/neues-foerderkonzept-erneuerbare-kraftstoffe.html, last accessed 27.02.2023.
[68] https://www.now-gmbh.de/wp-content/uploads/2022/12/Foerderaufruf-strombasierte-Kraftstoffe-fuer-maritime-Anwendungen.pdf, last accessed 27.02.2023.
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[70] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en, last accessed 27.02.2023.
[71] https://www.euractiv.com/section/biofuels/news/food-vs-fuel-german-ministries-clash-over-role-of-conventional-biofuels/, last accessed 28.02.2023.
[72] Ibid.
[73] i.e. 11,1 Million Tons CO2-eq.was saved in 2021 due to biofuels, https://www.ble.de/DE/Themen/Klima-Energie/Nachhaltige-Biomasseherstellung/Informationsmaterial/informationsmaterial_node.html, last accessed 27.02.2023.

Additional Information Sources

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- Bundesverband Bioenergie, https://www.bioenergie.de/
- Bundesverband Regenerative Mobilität, www.brm-ev.de/en
- Verband der Deutschen Biokraftstoffindustrie, www.biokraftstoffverband.de
- Fachagentur Nachwachsende Rohstoffe e.V., https://biokraftstoffe.fur.de/
- Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie, https://www.now-gmbh.de/
- Deutsches Biomasseforschungszentrum gemeinnützige GmbH, www.dbfz.de[74]
- eFuel Alliance, https://www.efuel-alliance.eu/de/

Major changes

- Energy security and climate change mitigation identified as the main priority by the federal government.
- New research and innovation funding schemes started in 2022. A major focus on hydrogen, as three hydrogen lighthouse projects were funded.
- Reignition of debate about biofuels (“food vs. fuel”).

Benefits of participation in AMF

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

[74] DBFZ Report No. 44 https://www.dbfz.de/en/press-media-library/publication-series/dbfz-reports, last accessed 27.02.2023.

India

Drivers & Policies

India is the third-largest oil consumer in the world after China and the United States. However, its per-capita energy consumption is among the lowest in the world, at 0.6 tons of oil equivalent (toe) as compared to the global average of 1.79 toe per capita, or one-third of the world average. Primary energy is expected to grow strongly, more than doubling from 2019 to 2050. Average growth per year ranges from 2.5% to 2.7%. As a result of strong growth, India accounts for 13% to 14% of the global primary energy consumption in 2050 across all scenarios, up from around 7% in 2019.

The share of coal in total primary energy has been broadly stable around 2019 levels (45%) over the past 40 years. However, coal's share declines in all scenarios, reaching between 6% and 34% by 2050. Renewable energy growth is strong, averaging 4%-6% per annum. As a result, renewable energy becomes the largest source of primary energy in 2050 in Accelerated and Net Zero, and the second largest in New Momentum (after coal). Renewable energy is expected to represent between 31% and 66% of total primary energy in 2050. The share of natural gas in total primary energy grows in all scenarios, increasing from 5% in 2019 to 12% in 2050 in New Momentum, supported by coal-to-gas switching in power, industry, and heavy road transport demand.

Currently, India imports approximately 86% of its petroleum product requirement. Growing concern about the import dependence for fuel requirement in tandem with environmental pollution issues has driven the need for alternative fuels. India plans to reduce import dependency in the oil and gas sectors by adopting a five-pronged strategy, which includes increasing domestic production, adopting biofuels and renewables, establishing energy efficiency norms, improving refinery processes, and demand substitution.

Since 2014, the Indian government has undertaken multiple interventions to promote biofuels through structured programs such as the Ethanol Blended Petrol (EBP) program, Biodiesel Blending in diesel, and SATAT (Sustainable Alternative Towards Affordable Transportation), an initiative for promotion of Compressed Biogas (CBG). India introduced a National Policy on Biofuels-2018(subsequently amended in June 2022), which envisages achieving 20% blending of ethanol in petrol by Ethanol Supply Year (ESY) 2025-26 and 5% blending of biodiesel in diesel by 2030.

The major feature of the policy is the categorization of biofuels as "basic biofuels" (e.g., first-generation "1G" ethanol, biodiesel, etc.) and "advanced biofuels" (e.g., 2G ethanol, drop-in fuels, etc.) to expand the scope of raw material for ethanol production.

Advanced Motor Fuels Statistics

India's primary energy mix is dominated by fossil fuels and that will continue to be the case in the near future. Currently, oil and gas account for around 35% of India's energy consumption; this is expected to decrease to 31% by 2040. However, from existing levels, absolute consumption is expected to double for oil and to triple for gas. Energy demand across the transport sector is the highest across major sectors in terms of end usage.

The Indian government has been promoting and encouraging the use of advanced motor fuels in the transport sector. In this endeavor, the blending of biofuels, which are sustainable and have lesser emissions compared to fossil fuels, is being promoted in petrol, diesel, and natural gas. Loans for the construction of oil extraction/processing units for production of biofuels, their storage and distribution infrastructure, and loans to entrepreneurs for setting up CBG plants were classified under priority sector lending by India's Central Bank on September 4, 2020.

With a view to decarbonize the transport sector, the Indian government is promoting the use of biofuels. The "Roadmap for Ethanol Blending in India 2020–25" provides guidance to meet the target of 20% blending of ethanol in petrol by 2025–26. In line with the Ethanol Blending roadmap, India has launched E20 fuel at 84 retail outlets of oil marketing companies in 11 states and union territories.

Ethanol Blended Petrol (EBP) Program
Under the Ethanol Blended Petrol (EBP) program, the PSUOMCs (Public Sector Undertaking Oil Marketing Companies) have achieved 10.02% blending of ethanol in petrol in ESY 2021–22. Further, the government has already notified and allowed the oil marketing companies (OMCs) to sell E20 (i.e., 20% ethanol blended with petrol), as per BIS specification effective from 15 December 2022.

The Government of India has taken several measures to increase the production and use of ethanol, which includes permitting procurement of ethanol produced from other non-food feedstock besides molasses (such as cellulosic) and lignocelluloses materials (such as cotton stalk, wheat straw, rice straw, bagasse, bamboo, etc.), including petrochemical route, subject to meeting the relevant BIS standards. It allows the use of sugarcane and food grains (maize and surplus stocks of rice with the Food Corporation of India) for conversion to ethanol; administered a price mechanism for procuring ethanol under the Ethanol Blended Petrol (EBP) Programme, including an enhanced ex-mill price; lowered the GST rate to 5% on ethanol for the EBP Programme; amended the Industries (Development & Regulation) Act for free movement of ethanol across states for blending, etc. These steps facilitated improvements in the blending of ethanol in petrol from 154 million liters during ESY 2012–13 to around 4336 million liters during ESY 2021–22, thereby achieving average blending of 10.02% in petrol during ESY 2021–22 (see Table 1).

To promote the establishment of distilleries in states low in ethanol, OMCs have signed Long Term Off-take Agreements (LTOA) with 131 project proponents for dedicated ethanol plants in ethanol-deficient states. This will help to avoid transporting ethanol over long distances and supply fluctuations to meet blending requirements. In addition, the government has notified various ethanol interest subvention schemes from July 2018 to April 2022 for sugar mills and molasses and grain-based stand-alone distilleries to facilitate entrepreneurs to set up new distilleries or expand existing ones in all states, including those having a shortage of ethanol. During ESY 2021–22, ethanol distillation capacity has increased from 7.2 billion litres per annum to 9.47 billion litres per annum, i.e., a 30% increase. The government has also provided separate pricing for maize-based ethanol to promote this feedstock.

Table 1. Trend in Ethanol Procurement/blending under EBP Program

Ethanol Blending Petrol Program						
Particulars	Ethanol Supply Year (Dec to Nov)					
	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22
Ethanol procured/blended by PSU OMCs* (in million liters)	665	1505	1886	1730	3023	4336
National average blending (percentage)	2.0%	4.2%	5.0%	5.0%	8.1%	10.02%

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

2G Ethanol Program
The government of India has notified the "Pradhan Mantri JI-VAN (Jaiv Indhan-Vatavaran Anukoolfasalawashesh Nivaran) Yojana," which will provide financial assistance of approximately $300 million USD for the period from 2018–19 to 2023–24 for supporting commercial projects as well as demonstration projects for 2G ethanol projects. India's government has allowed the procurement of ethanol produced from other non-food feedstock besides molasses, like cellulosic and lignocellulosic materials. The 2G feedstocks include agri-residues such as rice and wheat straw, cane trash, corn cobs and stover, cotton stalk, bagasse, and empty fruit bunches (EFB). Furthering this decision, oil PSUs are setting up 2G ethanol bio-refineries in various parts of the country. A 2G ethanol plant in Panipat was dedicated to the nation on World Biofuel Day, 10 August 2022. Projects at Bhatinda (Punjab), Bargarh (Odisha), and Numaligarh (Assam) are in advanced stages of construction and are likely to become operational in 2023 and 2024.

Biodieseland Sustainable Aviation Fuel (SAF)
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 the standards specified by the

Bureau of Indian Standards' "Guidelines for sale of Biodiesel for blending with High Speed Diesel for transportation purposes 2019" were notified on 1 May 2019.
The government had constituted a committee in June 2021 to take forward the Sustainable Aviation Fuel (SAF)/Bio-Aviation Turbine fuel (Bio-ATF) program. The committee has investigated various aspects of the Bio-ATF program and recently submitted a report currently under examination by the Ministry of Petroleum and Natural Gas (MoP&NG). To promote SAF, oil marketing companies are setting up plants at three locations:1) Mangalore Refinery and Petrochemicals Ltd,, Mangaluru16 Tons Per Day (TPD), with IIP Dehradun technology), 2) Indian Oil Corporation Ltd. (IOCL) Pune (10 TPD, with Gevo through Praj Alcohol to Jet (ATJ) technology), and 3) IOCL Panipat (236 TPD, with Lanzajet ATJ technology). These plants are likely to become operational between 2025 and 2027.

Compressed Biogas (CBG)
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 further selling to automotive and commercial customers.

As of December 2022, OGMCs have issued 3,826 Letters of Intent to potential entrepreneurs for procurement of CBG and commissioned 40 CBG plants under the SATAT initiative. The sale of CBG has been initiated from 97 retail outlets. Compressed biogas is being supplied to industrial customers, and CBG injection in the CGD network also has started.

Under this initiative, various enablers have been provided to increase the production of CBG. These include establishing an assured price for offtake of CBG with long-term agreements by OGMCs, Central Financial Assistance to CBG/biogas plants under Umbrella Scheme of National Bio Energy Programme of Ministry of New and Renewable Energy. Other developments involve the inclusion of bio-manure produced from CBG plants as Fermented Organic Manure (FOM) and Liquid Fermented Organic Manure (LFOM) under Fertilizer Control Order 1985; the inclusion of CBG projects under "White Category" by Central Pollution Control Board (CPCB) on a case-to-case basis; the inclusion of CBG projects under Priority Sector Lending by RBI; and loan products from various banks for financing CBG projects; directions from Department of Fertilizers for mandatory offtake of FOM by fertilizer companies; and other initiatives.

MoP&NG has issued guidelines for the commingling of domestic gas for supply for the Compressed Natural Gas (Transport) and Piped Natural Gas (Domestic) segments of City Gas Distribution (CGD) Networks for synchronizing CBG with CNG in the CGD Network.Under the CBG-CGD synchronization scheme, CBG sales have been initiated in 12 geographical areas of the CGD network.

Hydrogen
The National Hydrogen Mission was launched on India's 75th Independence Day, 15 August 2021. The mission aims to aid the government in meeting its climate targets and making India a green hydrogen hub. This initiative will help India to meet its production target of 5 million tons of green hydrogen by 2030 and the related development of renewable energy capacity. In addition, the Indian government has approved the National Green Hydrogen Mission with a total financial outlay of approximately 2.5 billion USD, which includes an outlay of about 2.2 billion USD in incentives for green hydrogen production and eletrolyser manufacturing; the rest will be used for pilot projects, R&D, and other mission components. MoP&NG has further directed oil and gas marketing companies to introduce green hydrogen in the refineries as a feedstock at various locations. The pilot projects for setting up green hydrogen plants in the refineries have been developed.

Research and Demonstration Focus

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

India has taken several initiatives with respect to the greater use of hydrogen in the energy mix. The first piloted use of H-CNG (hydrogen fuel mixed with compressed natural gas) as transportation fuel occurred at Rajghat Bus Depot, New Delhi. Under this pilot, 50 buses in Delhi operated on a blended H-CNG mixture. The trial showed encouraging results in terms of significant emission reduction and fuel economy improvement.

Indian Oil Corporation Ltd. has undertaken an ambitious R&D project under the aegis of MoPNG at a cost of $18.3 million USD. It is the first scientific project in India to address all aspects of the value chain of hydrogen-based mobility. Four demo units of hydrogen production units amounting to 1 ton per day will also be set up. Of these, three plants will be based on renewable sources (biomass gasification, reforming CBG, and solar PV-based electrolysis) to produce green hydrogen. To utilize green hydrogen produced from this demo plant, 15 fuel cell buses are being developed jointly along with India's leading heavy-duty vehicle manufacturer. The initial testing of buses is underway by OEMs; two buses will be supplied by March 2023. IOCL R&D will use these 15 indigenously manufactured/integrated hydrogen fuel cell buses to conduct a 20,000 kms field trial in Delhi NCR.

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 per day using gas fermentation technology. Anaerobic gas fermentation technology will convert CO_2 into acetic acid, and aerobic fermentation technology will convert acetic acid into highly valuable omega-3fatty acids (docosahexaenoic acid, or DHA) and biodiesel. This value chain makes the overall process economically feasible.

IOCL is also setting up an ethanol production plant to produce around 128 KL per day of ethanol using gas fermentation technology from pressure swing absorption off gases at Panipat Refinery.

In aviation, Spice Jet operated the first flight using 25% biojet fuel between Dehradun to Delhi on 27 August 2018. Biojet fuel used in the flight was developed by laboratory in CSIR-IIP, Dehradun, using Jatropha seeds. After the flight's success, the government decided to set up demonstration plants for the future growth of Bio-ATF in the country.

Currently, 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; the commercial production of biojet fuel, compressed biogas from biomass, food waste, and municipal solid waste; cost-effective biofuels from industrial waste gases; and green hydrogen.

Outlook

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

Ethanol blended by PSU OMCs reached 4,336 million liters of ethanol in ESY 2021–22. OMCs achieved an average blending percentage of 10.02% during ESY2021–22. With the rollout of roadmap for 20% ethanol blending (E20) in India and the commitment shown by all stakeholders, the projected annual demand of ethanol is targeted at over 10 billion liters by 2025–26. The retailing of E100 fuel has commenced on a pilot basis at three retail outlets in Pune, Maharashtra. Based on the response of these pilot retail outlets, further expansion is planned.

The SATAT initiative will help to reduce India's dependence on fossil fuels and increase the share of gas in primary energy consumption. This initiative will help to integrate the vast retail network of companies with upcoming CBG projects. It has the potential to replace more than 50% of gas imports.

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

Additional Information Sources

- www.ppac.org.in for data on fossil fuels production, consumption, import and export
- www.mopng.gov.in for data related to petroleum sector
- www.mnre.gov.in for data on R&D projects
- https://www.siamindia.com for data on automotive industry
- www.dbtindia.nic.in
- www.iocl.com for data on R&D projects
- 1-BP Outlook 2023 edition, India
- Roadmap for Ethanol Blending in India 2020–25

Japan

Drivers and Policies

On October 22, 2021, the Cabinet approved the Sixth Strategic Energy Plan for submission to the Diet.[75] The Plan includes two key themes:

1. Showing the approach to an energy policy of achieving carbon neutrality by 2050 announced October 2020, with the GHG emission reduction target of greenhouse gas emissions by 46% in FY 2030 from its FY 2013 levels, while continuing strenuous efforts in its challenge to meet the lofty goal of cutting its emission by 50%, as announced in April 2021.
2. Presenting initiatives to ensure stable supply and reduce energy costs based on the major premise of ensuring safety, in order to solve challenges facing Japan's energy supply and demand structure while taking action against climate change.

In accordance with the Sixth Strategic Energy Plan, the Diet passed the "Bill for the Act of Partial Revision of the Act on the Rationalization etc. of Energy Use and Other Acts in Order to Establish Stable Energy Supply and Demand Structure" on May 13, 2022. In addition, the Act on the Rationalization of Energy Use (e.g., improving energy consumption per unit) was expanded to include non-fossil energy. It calls for specific operators to develop medium- to long-term plans to transition to non-fossil fuel energy.[76]

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."[77] The strategy specifies 14 promising fields that are expected to grow, and provides them with action plans from the viewpoints of both industrial and energy policies. Japan upholds an ambitious goal while showing realistic pathways toward it wherever possible. A 2 trillion-yen Green Innovation Fund has been established to encourage companies to take on ambitious challenges.[78]

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.[79, 80]

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

As for commercial vehicles, the following electrification targets were set:[81]

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

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

76 Ministry of Economy, Trade and Industry, March 1, 2022, "Cabinet Decision on the Bill for the Act of Partial Revision of the Act on the Rationalization etc. of Energy Use and Other Acts in Order to Establish Stable Energy Supply and Demand Structure," https://www.meti.go.jp/english/press/2022/0301_004.html

77 Ministry of Economy, Trade and Industry, 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

78 https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/pdf/1_budget.pdf

79 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

80 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

81 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.[82] Oil-related energy accounts for 97.7% 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, CNG, hybrid, EVs, and FCVs currently constitute the environmentally friendly vehicles.

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 6,981 FCVs.

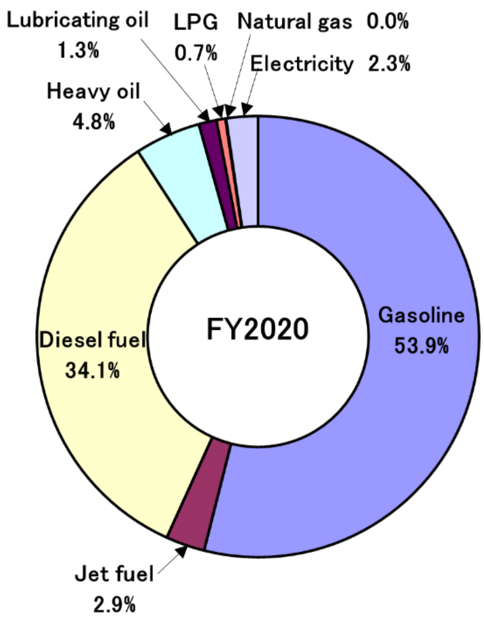

Fig. 1. Energy Sources Used in the Transportation Sector in Japan, 2020

Table 1. Penetration of Environmentally Friendly Vehicles Owned in Japan, March 2022

<table>
<tr><th>Vehicle Type</th><th>Methanol[83,84]</th><th>CNG[9,10]</th><th>Hybrid[85]</th><th>EV[11]</th><th>FCV[11]</th><th>Vehicle Registration[86]</th></tr>
<tr><td>Passenger vehicles</td><td>2</td><td>8</td><td>HV:10,630,750
PHV: 174,231*</td><td>138,325</td><td>6,981</td><td>39,017,038</td></tr>
<tr><td>Light-, mid-, and heavy-duty trucks</td><td>1</td><td>3,928</td><td rowspan="3">73,211</td><td rowspan="3">1,877</td><td>NA</td><td>5,938,350</td></tr>
<tr><td>Buses</td><td>0</td><td>119</td><td>NA</td><td>216,416</td></tr>
<tr><td>Special vehicles</td><td>1</td><td>1,272</td><td>NA</td><td>1,633,622</td></tr>
<tr><td>Small vehicles</td><td>1</td><td>1,447</td><td>2,322,201**</td><td>21,161</td><td>NA</td><td>31,308,530</td></tr>
<tr><td>Total</td><td>5</td><td>6,774</td><td>13,200,393</td><td>161,363</td><td>6,981</td><td>78,113,956</td></tr>
</table>

*PHVs are not included in the number of HV.

**The sales number of HEV small vehicles for the last 10 years, including the current fiscal year, is shown because there is no publicly available information on the number of HEV small vehicles owned.

[82] Energy White Paper 2022, Agency for Natural Resources and Energy, June 2022 (in Japanese)

[83] Automobile Inspection and Registration Information Association, as of March 2022 (in Japanese), https://www.airia.or.jp/publish/file/r5c6pv0000010qt2-att/05_teikougai.pdf

[84] Japan Light Motor Vehicle and Motorcycle Association, as of March 2022 (in Japanese), https://www.keikenkyo.or.jp/information/attached/0000042686.pdf

[85] Next Generation Vehicle Promotion Center (NeV), as of March 2022 (in Japanese), http://www.cev-pc.or.jp/tokei/hoyuudaisu.html

[86] Automobile Inspection and Registration Information Association, as of March 2022 (in Japanese), https://www.airia.or.jp/publish/file/r5c6pv000000z01x-att/r5c6pv000000z02c.pdf

Research and Demonstration Focus

Hydrogen

With regard to the use of hydrogen in mobility, support is being provided for the spread of fuel cell vehicles and the development of hydrogen stations. In addition, 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 to apply. In the future, the spread of fuel cell vehicles and the systematic development of hydrogen refueling stations will be accelerated. In particular, the cumulative number of fuel cell trucks installed is expected to be up to 15 million units by 2050, amounting to 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 fuel cell vehicles, fuel cell buses, and fuel cell trucks.

Nationwide as of December 2022, hydrogen stations for fuel cell vehicles operated in 164 locations.[87]

In response to such actions, the NEDO HySTRA pilot project (the marine transportation and unloading of liquid hydrogen produced in Australia and delivered to Japan) was initiated in May 2021 as part of the activities of the CO_2-free Hydrogen Energy Supply-chain Technology Research Association.[88] The world's first liquefied hydrogen carrier, the Suiso Frontier, departed Victoria, Australia, on January 28, 2022, marking a significant milestone of the Hydrogen Energy Supply Chain 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, VIC, to Kobe, Japan. For the pilot project, 99.999% pure hydrogen has been produced from Latrobe Valley coal and biomass via gasification, trucked to Hastings, cooled to -253 degrees C, and subsequently liquified to less than 800 times its gaseous volume to create highly valuable liquefied hydrogen.

Hydrogen engines can leverage well-established internal combustion engine technologies. Therefore, they are seen as having high potential for commercialization at lower cost. Activity in the Japanese industrial sector in 2020 featured the announcement of joint research on a single-cylinder hydrogen engine with a 5-liter stroke volume aimed at large engines conducted by Mitsubishi Heavy Industries Engine & Turbocharger (MHIET) of the Mitsubishi Heavy Industries Group and the National Institute of Advanced Industrial Science and Technology (AIST).[89]

Natural Gas

Approximately 79% 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 announced the Giga, a heavy-duty truck fueled by compressed natural gas, in December 2015.[90] The introduction of this vehicle is expected to increase the use of NGVs for long-distance transportation. Aiming to further extend the running range, Isuzu Motors Limited released heavy-duty LNG trucks in October 2021, with a running range of more than 1,000 km; the CO_2 emissions from these trucks are reduced by about 10%, compared to the latest diesel trucks.[91]

Biofuel

With respect to initiatives aiming to encourage the use of biofuels in Japan, sales of gasoline blended with ethyl tert-butyl ether (ETBE) in FY 2021 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).[92] According to trade statistics, approximately 67,000 kL of ethanol were imported (mainly from Brazil) in FY 2021 as raw material for ETBE (equivalent to roughly 148,200 kL of ETBE).[93]

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[87] Next Generation Vehicle Promotion Center (in Japanese), http://www.cev-pc.or.jp/suiso_station/index.html
[88] CO_2-free Hydrogen Energy Supply-chain Technology Research Association, https://www.hystra.or.jp/en/project/
[89] Mitsubishi Heavy Industries Ltd. (in Japanese), https://www.mhi.com/jp/news/210121.html
[90] Isuzu Motors Limited (in Japanese), https://www.isuzu.co.jp/product/cng/giga.html
[91] Isuzu Motors Limited (in Japanese), https://www.isuzu.co.jp/newsroom/details/20211028_01.html
[92] Japan Biofuels Supply LLP, https://www.jbsl.jp/english/objective/
[93] Japan Alcohol Association (in Japanese), http://www.alcohol.jp/statis/import.pdf

Six private companies established “Research Association of Biomass Innovation for Next Generation Automobile Fuels” on July 20, 2022. This association promotes technological research on the use of biomass as well as the efficient production of bioethanol fuel for automobiles through the optimized circulation of hydrogen, oxygen, and CO_2 during production to achieve a carbon-neutral society.[94]

E-fuel

In order to achieve a cost lower than the price of gasoline for synthetic fuels in 2050, the commercialization of synthetic fuels will be worked out. In addition to improving the efficiency of existing technologies (reverse shift reaction plus FT synthesis process) and designing and developing production facilities, innovative new technologies and processes (e.g., co-electrolysis, Direct-FT) will be developed in order to establish 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.[95]

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 in order to commercialize synthetic fuels through public-private partnership.[96]

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 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.[97]

Outlook

In a “Green Growth Strategy towards 2050 Carbon Neutrality,” the electrification of automobiles will be promoted. Comprehensive measures will be taken to achieve 100% electrified vehicles (electric vehicles, fuel cell vehicles, plug-in hybrid vehicles, hybrid vehicles) 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 emission through the production, use, and disposal of automobiles in 2050.

Additional Information Sources

- The Ministry of Economy, Trade and Industry, Overview of Japan’s Green Growth Strategy Through Achieving Carbon Neutrality in 2050, January 2021, https://www.meti.go.jp/english/press/2020/pdf/1225_001a.pdf

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.

[94] Six Private Companies Establish “Research Association of Biomass Innovation for Next Generation Automobile Fuels,” July 20, 2022, https://global.toyota/en/newsroom/corporate/37543537.html?_ga=2.238844416.1634822074.1672032845-1414364891.1672032845

[95] 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

[96] 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

[97] https://actforsky.jp/

Republic of Korea

(Note: This report was provided in 2021.)

Drivers and Policies

The Korean government established the fifth basic plan for the development and use of new and renewable energy technologies in December 2020. This basic plan aims to increase the share of new and renewable energy among final energy by 2034, and plans to increase the supply of energy for transportation from 700,000 tons of oil equivalent (toe) in 2019 to 1.3 million toe in 2034.

Korea implemented the Renewable Fuel Standard (RFS) program in July 2015. This program mandates the mixing and supply of biodiesel to diesel fuel, and petroleum refiners and petroleum exporters and importers must mix and sell according to a set ratio. The mixing ratio of biodiesel to diesel fuel is shown in Table 1. Beginning in 2015, the annual blending obligation ratio is reviewed every three years, taking into account the technology development level of new and renewable energy and the fuel supply and demand situation.

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

Year	Blending Ratio
2015	0.025
2016	0.025
2017	0.025
2018	0.03
2019	0.03
2020	0.03
Jan. 2021 – Jun. 2021	0.03
Jul. 2021 – Dec. 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

Note: To determine the compulsory blending amount by year, multiply the compulsory blending ratio by year times the domestic sales volume of transportation fuel, including mixed renewable energy fuels.

Effective January 1, 2018, the mixing ratio was changed to 3%. In 2020, policy makers considered changing the mixing ratio from 3% to 3.5%, but decided to maintain the existing mixing ratio. In 2021, the amended RFS program announced that the blending ratio will be raised to 0.05, step by step, by 2030. In the future, an improved system to provide flexibility in fulfillment of obligations (e.g., deposit and deferral) is expected to be introduced.

In the case of bioethanol for use in gasoline vehicles, empirical studies have been conducted along with biobutanol, but the timing of introduction is not clear as the exact pilot operation plan or supply plan has not been confirmed. In the case of ship fuels, effective January 1, 2020, the sulfur content was limited to 0.5% or less due to introduction of the Convention on the Prevention of Marine Pollution (MARPOL). However, on January 1, 2021, the Korean government announced enforcement decree No. 42 of the Marine Environment Management Act, which changed the standard for the sulfur content of the fuel of ships sailing in Korea to less than 0.5%.

In addition, effective September 1, 2020, the Special Act on Air Quality Improvement in Port Areas has been enforced. Accordingly, for large ports such as Incheon, Pyeongtaek, Dangjin, Busan, Ulsan, Yeosu, and Gwangyang, the sulfur content of ships moored at the ports must be used with fuel of 0.1% or less. However, if an emission gas reduction device (desulfurization facility) is installed on the ship and the emission of sulfur compounds is within the standard value, there are no restrictions on the use of fuel.

GHG emissions for international flights are regulated through the International Civil Aviation Organization (ICAO), a subsidiary of the United Nations. On September 23, 2016, the Korean government declared it would participate in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) system, and considered introducing a GHG reduction/management system in 2021. The Korean government promotes technical support for eco-friendly aircraft and the development of fuel to replace existing aviation fuel.

Advanced Motor Fuels Statistics

Table 2 shows the number and ratio of vehicles registered in Korea by year and by fuel from 2014 to 2021.

Table 2. Vehicles Registered in Korea, 2014–2021

Fuel	2014	2015	2016	2017	2018	2019	2020	2021
Total	20,117,955	20,989,885	21,803,351	22,528,295	23,202,555	23,677,366	24,365,979	24,911,101
Gasoline	9,587,351	9,808,633	10,092,399	10,369,752	10,629,296	10,960,779	11,410,484	11,759,565
	(47.66%)	(46.73%)	(46.29%)	(46.03%)	(45.81%)	(46.29%)	(46.83%)	(47.21%)
Diesel	7,938,627	8,622,179	9,170,456	9,576,395	9,929,537	9,957,543	9,992,124	9,871,951
	(39.46%)	(41.08%)	(42.06%)	(42.52%)	(42.80%)	(42.06%)	(41.01%)	(39.63%)
LPG	2,336,656	2,257,447	2,167,094	2,104,675	2,035,403	2,004,730	1,979,407	1,945,674
	(11.61%)	(10.75%)	(9.94%)	(9.34%)	(8.77%)	(8.77%)	(8.12%)	(7.81%)
HEV	137,522	174,620	233,216	313,856	405,084	506,047	674,461	908,240
	(0.68%)	(0.83%)	(1.07%)	(1.39%)	(1.75%)	(2.14%)	(2.77%)	(3.65%)
CNG	40,457	39.777	38,880	38.918	38,934	38,147	36,940	35,208
	(0.20%)	(0.19%)	(0.18%)	(0.17%)	(0.17%)	(0.16%)	(0.15%)	(0.14%)
EV	2,775	5,712	10,855	25.108	55,756	89,918	134,962	231,443
	(0.01%)	(0.03%)	(0.05%)	(0.11%)	(0.24%)	(0.38%)	(0.55%)	(0.93%)
H2	-	29	87	170	893	5,083	10,906	19,404
		(0.00%)	(0.00%)	(0.00%)	(0.00%)	(0.02%)	(0.04%)	(0.08%)
ETC*	74,567	81,488	90,364	99,421	107,652	115,119	126,695	139,616
	(0.37%)	(0.39%)	(0.41%)	(0.44%)	(0.46%)	(0.49%)	(0.52%)	(0.56%)

*Other fuels (kerosene, alcohol, solar, LNG) and towed vehicles (trailers, etc.)

In 2021, new car sales reached 1.75 million units due to high demand for individual car purchases during the COVID-19 pandemic, but the number of deregistration vehicles reached 1.2 million units, a net increase of 545,000 units.

Registered vehicles using internal combustion engines increased by about 3% compared to the previous year; vehicles using liquid petroleum gas (LPG) also increased, as laws permitting civilian purchase of LPG vehicles were changed.

However, because of strengthened emissions regulations and problems with fine dust, diesel vehicles decreased by about 1.2%. The number of registered eco-friendly vehicles is steadily increasing due to the reduction in exemption for the supply of eco-friendly vehicles and the support of individual consumption tax to revitalize domestic sales.

In 2020, the share of domestic sales of eco-friendly vehicles accounted for about 12% of the total, exceeding 10% for the first time in history. In 2021, more eco-friendly vehicles are registered. In particular, the increase in HEV, EV, and hydrogen vehicles is considerable. By car type, hybrid cars increased by about 34%, electric cars by about 71%, and hydrogen cars by about 78%.
The number of hydrogen vehicles supplied has increased by 11 times since 18 years ago, and from 2019 to 2020, the number of hydrogen vehicles was maintained as the number one in the world.

Figure 1 displays Hyundai Motors' Nexo FCEV, produced in Korea and exported abroad. Figure 2 shows Hyundai's ELEC CITY, a hydrogen city bus.

Fig. 1 Hyundai FCEV Nexo

Fig. 2. Hyundai FCEV ELEC CITY

Research and Demonstration Focus

Marine Fuel
Effective January 1, 2020, and due to an amendment to MARPOL, marine fuel is limited to 0.5% m/m or less in sulfur content. The Korean government promoted the establishment of a desulfurization facility, expansion of the supply of low-sulfur fuel, and the use of liquified natural gas (LNG). In line with the new regulation, technology development and private investment in low-sulfur oil production and emission reduction technologies (e.g., scrubber) have increased.

In April 2020, SK Energy started operating the Residual Oil Desulfurization Facility (VRDS), an eco-friendly low-sulfur fuel production facility built in 2017. S-OIL Corporation also began supplying low-sulfur oil through facility expansion.

Jet Fuel
Several industries, academia, and research institutes have conducted studies on sustainable aviation fuel (SAF), including the Next Generation Biomass Research Center and the Advanced Technology Research Institute. The Agency of Defense Development has conducted research since 2016 on applying bio-aircraft oil derived from vegetable oil to jet engines through domestic technology.

In 2017, Korean Air became the first Korean airline to use sustainable aviation fuel, flying from Chicago to Incheon, Korea.

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

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

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

Hydrogen and Electricity

Korea accumulated about 231,000 electric vehicles in 2021 and aims to increase the proportion of eco-friendly, domestically produced vehicles to 33% by 2030. Its goal is to electrify all types of vehicles, from sedans to SUVs and medium-sized trucks of 5 tons or more, increasing the mileage of a single charge to over 600 km and tripling the charging speed.

Through the next-generation hydrogen fuel system development project, the government is pushing to increase the fuel efficiency of hydrogen vehicles by more than 30% by investing USD 24 million by 2024.

After Korea piloted hydrogen-fueled city buses, mass production began in July 2020. The government plans to expand the application to long-distance buses and supply 4,000 hydrogen electric buses by 2025.

Outlook

The MARPOL amendment has led to the regulation of sulfur content in marine oil to 0.5% since 2021, and to 0.1% in some large seaports. Other plans include establishing a foundation for using SAF, such as revising legislation, systems, and infrastructure, to implement CORSIA.

Additional Information Sources

- K-Petro, www.kpetro.or.kr
- Korea Register, www.krs.co.kr
- Ministry of Trade, Industry and Energy, www.motie.go.kr
- Korea Automobile Manufacturers Association, www.kama.or.kr

Spain

Drivers and Policies

The main policy instrument aimed at fostering the consumption of advanced motor fuels in Spain is the biofuel quota obligation. Wholesale and retail operators of fuels, as well as consumers of fuels not supplied by wholesale or retail operators, are obliged to sell/consume a minimal quota of biofuels. Each obligated subject must prove compliance by presenting a number of certificates to a national certification entity, the Ministry for Ecological Transition and Demographic Challenge. Certificates have a value of 1 TOE. They can be carried over to the following year (up to 30% of the annual obligation) and can also be traded. If the biofuel quota obligation is not met, a penalty fee applies (in 2021 the fee was updated to EUR 1,623/certificate). In case of over-compliance (some 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 exceeding their set quota obligation. Royal Decree 1085/2015, on the promotion of biofuels, established these mandatory targets for sale or consumption. The 2022 target (in energy content) was 10%. In 2019, the double-counting of some biofuels came into play, and in 2020 the National Markets and Competition Commission (CNMC) published a list of feedstocks that, converted to biofuels, qualify to meet 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 2022, it established a maximum limit of 7.2% for biofuels produced from food and feed crops as well as a mandatory target of 0.2% for advanced biofuels (according to the definition included in the Directive [EU] 2018/2001 on the 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%.

In March 2022 the Spanish Government approved the Biogas Roadmap, which identifies the challenges and opportunities for the development of this renewable gas. It aims at multiplying by 3.8 biogas production in Spain by 2030, exceeding 10.4 TWh. Regarding feedstock, the focus is on waste (agricultural, agri-food industries, municipal waste, and sewage sludge).

The development of biogas is particularly relevant in the current European context and it will contribute to reduce energy dependency. As for the use in transport, biomethane consumption will also facilitate fulfilling the objective of the National Integrated Energy and Climate Plan (NECP) 2021-2030 (share of renewable energy in transport of 28% and share of advanced biofuels of 3.69% by 2030).

The Biogas Roadmap includes 45 specific measures in five lines of action: regulatory instruments, sectoral instruments, economic instruments, transversal instruments, and promotion of research, development, and innovation. Regarding transport, it is envisioned that the quota system will be updated to enable biomethane to be counted towards the obligation, and 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 grant 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." It is intended to identify the challenges and opportunities for the full development of renewable hydrogen in Spain, providing a series of measures aimed at boosting investment action, taking advantage of the European consensus on the role that this energy vector 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 envisaged 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 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 using renewable hydrogen fuel cells and supply points at the top five ports and airports by volume of goods and passengers.

The Spanish Alternative Energy Vehicle Incentive Strategy 2014-2020 is the framework for programs intended to promote the purchase of electric, liquefied petroleum gas (LPG), natural gas, and bifuel vehicles.

Advanced Motor Fuels Statistics

Biofuels account for the largest part of alternative transportation fuel in Spain. The main contribution corresponds to biodiesel (FAME), the second most used biofuel is HVO, and the third one is bioethanol. Other alternative fuels consumed in Spain are natural gas and LPG. Figure 1 shows the share (in energy content) of fuels consumed for road transport in 2022.

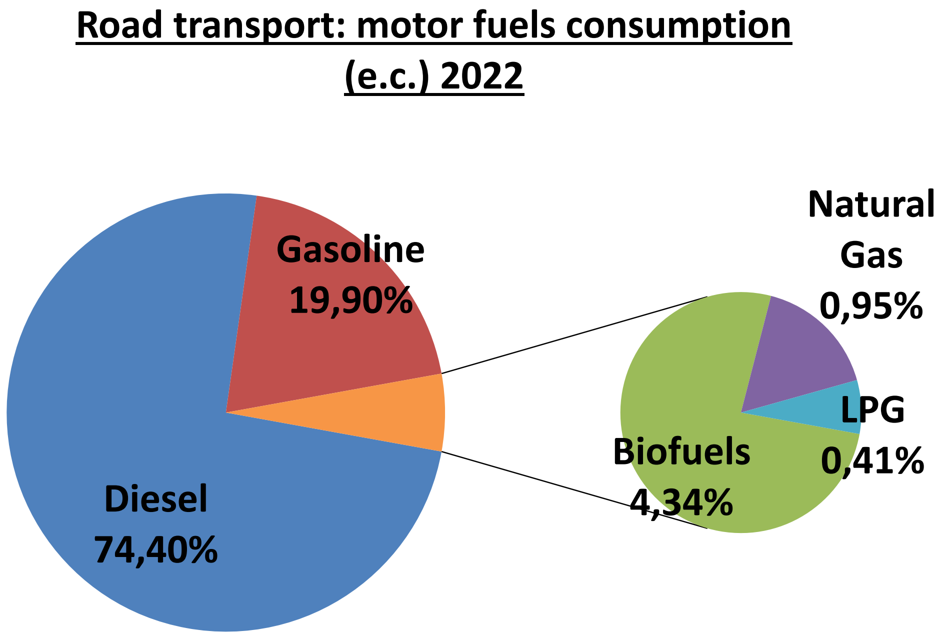

Fig. 1. Fuel Consumption (share in energy content) in Spain in 2022.
Sources: CORES, GASNAM.

Figure 2 displays alternative-fuels consumption in 2022.

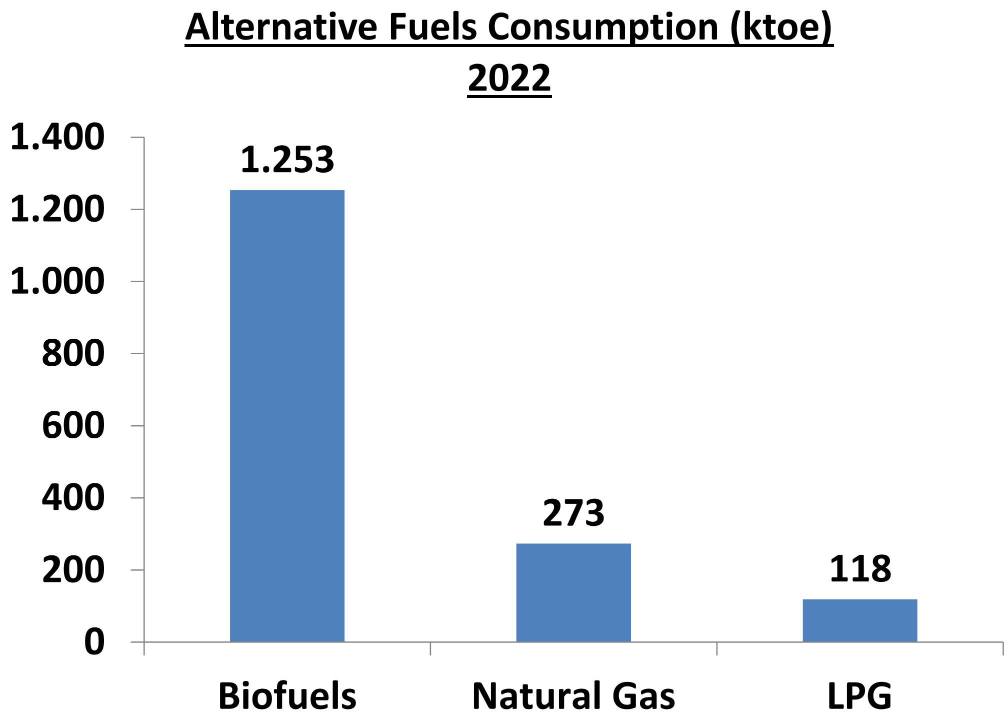

Fig. 2. Alternative Fuel Consumption (ktoe) in Spain, 2022.
Sources: CORES, GASNAM.

Table 1 shows the number of public filling stations selling alternative fuels.

Table 1. Filling Stations for Alternative Fuels in Spain

Alternative Fuel		Number of Filling Stations
Biodiesel blends	B20 or lower	34
	B30 or higher	3
Bioethanol blends	E25	1
	E85	4
LPG		858
Natural gas	CNG	132
	LNG	84

Sources: MITECO (Geoportal).

Research and Demonstration Focus

The Spanish State Scientific and Technical Research and Innovation Plan 2017–2020 is the main instrument for developing and achieving the objectives set in the Spanish Strategy for Science and Technology and Innovation 2013–2020, as well as those set in the Europe 2020 Strategy. The plan identified eight major challenges for Spain. The energy sector, including transport, is specifically addressed in the following ones: "Safe, efficient, and clean energy," "Bioeconomy: sustainability of primary and forestry production systems, food safety and quality, marine and maritime research, and bio-products," and "Sustainable, intelligent, connected, and integrated transport." The plan includes actions and funding mechanisms aimed at promoting research, development, and innovation (RDI) activities, which are in line with the Strategic Energy Technology Plan (SET Plan). Regarding advanced motor fuels, research and innovation projects within this State Plan shall address the priority activities included in the SET Plan Action 8 for Bioenergy and Renewable Fuels for Sustainable Transport.

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 integrated National Energy and Climate Plan 2021–2030 (NECP), submitted to the European Commission under the Regulation on the governance of the energy union and climate action (EU/2018/1999), 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 develop and promote sustainable commercial development of biomass technology. It addresses tasks related to biomass resources, production processes, and final uses (e.g., biofuels for transport, biogas and biomass for electricity generation and thermal uses, bioproducts). It also carries out activities regarding sustainability, a regulatory framework, and social, environmental, and economic impacts, including rural development, bioeconomy, circular economy, and climate change mitigation. The Spanish Hydrogen Technology Platform (PTE-HPC) aims 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

The Directive (EU) 2018/2011, on the promotion of energy from renewable sources, sets a specific target for the transport sector. Member States must require fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy. The contribution of biofuels produced from food and feed crops is limited to a maximum of 7%. Within that 14%%, there is a dedicated sub-target for advanced biofuels (which are produced from feedstocks listed in Part A of Annex IX of the directive). These fuels must be supplied at a minimum of 0.2% of transport energy in 2022, 1% in 2025, and at least 3.5% by 2030. A specific methodology for the calculation of such shares (including different multipliers for some technologies) is provided in the directive.

According to the integrated National Energy and Climate Plan (NECP), in 2030 the share of renewable energy in transport in Spain will be 28%, well above the target established in the directive. The contribution of biofuels from food and feed crops will be 6.8% and advanced biofuels will reach 3.69%. The NECP is currently being updated and these figures will be modified in order to comply with the requirements in the recast Renewable Energy Directive (under development) and in accordance with new legislation on the biofuel quota obligation (Ministerial Order ITC/1342/2022 establishes decreasing limits for biofuels produced from food and feed crops from 2023).

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

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

The NECP includes a specific measure for the promotion of biofuels in transport. It consists of several actions aimed at supporting biofuels production and consumption, inter alia, mandatory targets, aid programs for advanced biofuels facilities, and consumption objectives for aviation biofuels. In this regard, the Law on Climate Change and Energy Transition also contains provisions on the establishment of a quota obligation for sustainable fuels, including aviation fuels.

Additional Information Sources

- Bioplat: Spanish Biomass Technology Platform, https://bioplat.org/
- CNMC: National Markets and Competition Commission (in Spanish), http://www.cnmc.es/
- CORES: Corporación de Reservas Estratégicas (Oil Stockholding Agency) (in Spanish), https://www.cores.es
- GASNAM: Spanish Association of Natural Gas for Mobility (in Spanish), https://gasnam.es/

- Geoportal (MITERD): Filling Stations (in Spanish), https://geoportalgasolineras.es/geoportal-instalaciones/Inicio
- IDAE: Instituto para la Diversificación y Ahorro de la Energía (Institute for Energy Diversification and Saving) (in Spanish), https://www.idae.es/
- MITECO: Ministry for Ecological Transition and Demographic Challenge (in Spanish), www.miteco.gob.es
- PTE-HPC: Spanish Hydrogen Technology Platform (in Spanish), https://www.ptehpc.org/

Major changes
Royal Decree 1085/2015 was modified in 2022 to respond to the needs to implement the measures and achieve the ambitious objectives established in the integrated National Energy and Climate Plan 2021–2030, in accordance with its Objective Scenario and with the share of renewable energy in transport for the year 2030 established by the Directive (EU) 2018/2001. New mandatory targets for biofuels (in energy content and including double-counting for some biofuels) were established: 10.5% in 2023, 11% in 2024, 11.5% in 2025, and 12% in 2026. Mandatory targets for advanced biofuels were set: 0.3% in 2023, 0.5% in 2024, 1% in 2025, 1.2% in 2026, and 3.5% in 2030.

Ministerial Order ITC/1342/2022 was issued in 2022 to establish the maximum limit for biofuels produced from food and feed crops: 3.5% in 2023, 3% in 2024, and 2.6% in 2025.

Royal Decree 376/2022 (establishing sustainability requirements for biofuels, bioliquids, and biomass fuels in accordance with Directive (EU) 2018/2001) was published.

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, the transport industry must be freed of its dependency on fossil fuel. Several measures are needed, 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 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 during the year 1990. To achieve net-zero emissions, flexibility measures are included. For the transport sector, a reduction in emissions of at least 70% by 2030 compared with 2010 (not including domestic air travel) has also been adopted.

In mid-2018, the Swedish government introduced what was known as a *bonus-malus system,* under which environmentally adapted vehicles with relatively low 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.

Another important measure introduced in mid-2018 is the reduction obligation, which entails an obligation for fuel suppliers to reduce GHG emissions from sold volumes of petrol and diesel fuels by incorporating biofuels. In 2022, the reduction obligation was 7.8% for petrol and 30.5% for diesel. For 2030, the levels are 28% for petrol and 66% for diesel. The biofuels included in the reduction obligation system are subject to the same energy and CO_2 taxation as fossil fuels. Biofuels outside the reduction obligation scheme have reduced taxes. As of July 1, 2021, aviation fuels were also subject to the reduction obligation which, in 2022, stood at 1.7%. The new Swedish government intends to lower the reduction obligation according to EU-minimum levels, with new reduction levels expected to be announced in 2023.

Advanced Motor Fuels Statistics

Since 1990, the number of passenger cars in Sweden has increased from approximately 3.5 million vehicles to 5.0 million vehicles. At the same time, GHG emissions from passenger cars were rather stable, remaining at around 13 million tons from 1990 to 2007. However, since 2007, emissions have decreased significantly and stood at about 9.4 million tons in 2021. The main reason for the reduction is the increased energy efficiency of new vehicles and renewable motor fuels.

The fleet of alternative-fueled passenger cars totaled around 520,000 at the end of 2021 (see Fig. 1). In addition, automakers have produced an increasing share of conventional diesel vehicles to be fueled with HVO100. However, no statistics are currently available on the size of this share.

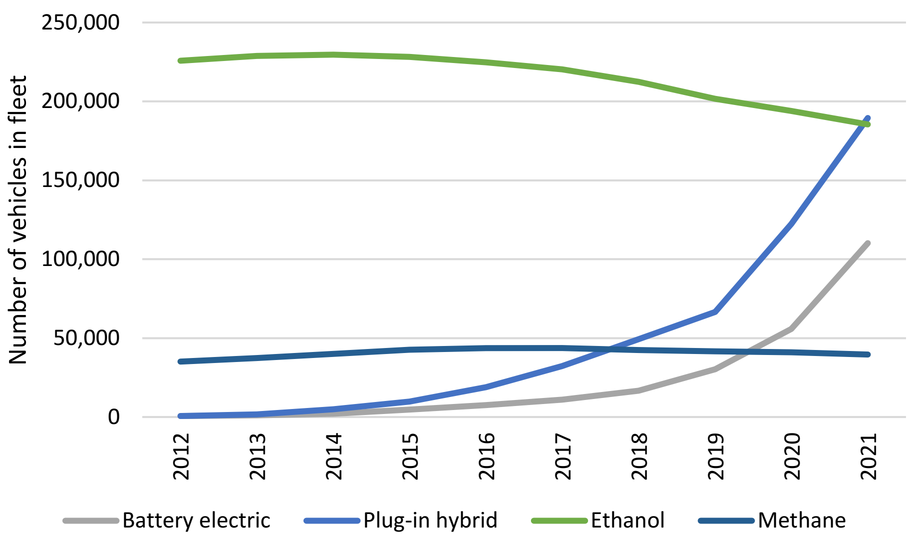

Fig. 1. Number of Advanced Motor Fuel Passenger Cars in the Fleet, 2012–2021

Alternative-fueled vehicles correspond to 11% of the total fleet of passenger cars (excluding diesel cars that can be fueled with HVO100). Light commercial and heavy-duty vehicles make up 3% and 2% of the total fleet, respectively. However, vehicles registered as other than petrol- or diesel-fueled is around 27% of the bus fleet. Diesel-registered buses make extensive use of HVO100.

The use of renewable biofuels and electricity for transport in Sweden amounted to 20.6 terawatt hours (TWh), or 29% of the transportation fuels sold during 2022 (see Fig. 2). Approximately 65% of the renewable fuel used in Sweden during 2022 was hydrotreated vegetable oil (HVO) and fatty acid methyl ester (FAME).

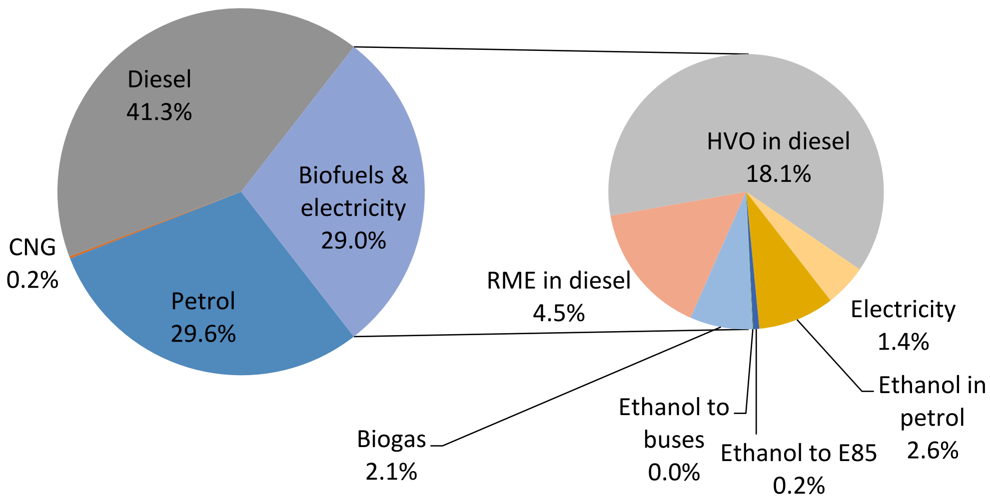

Fig. 2. Fuel Consumption in TWh within the Road Transport Sector, Preliminary Statistics, 2022

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 2021, the raw materials were, to a large extent, animal waste (63%), with the remaining shares consisting of crude tall oil, palm oil, rapeseed oil, and palm fatty acid distillate, in descending order. The majority of feedstock for HVO is imported, as shown in Figure 3. The average GHG emissions from HVO use in Sweden during 2020 corresponded to around 8g carbon dioxide equivalent (CO_2-eq) per megajoule (MJ).

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

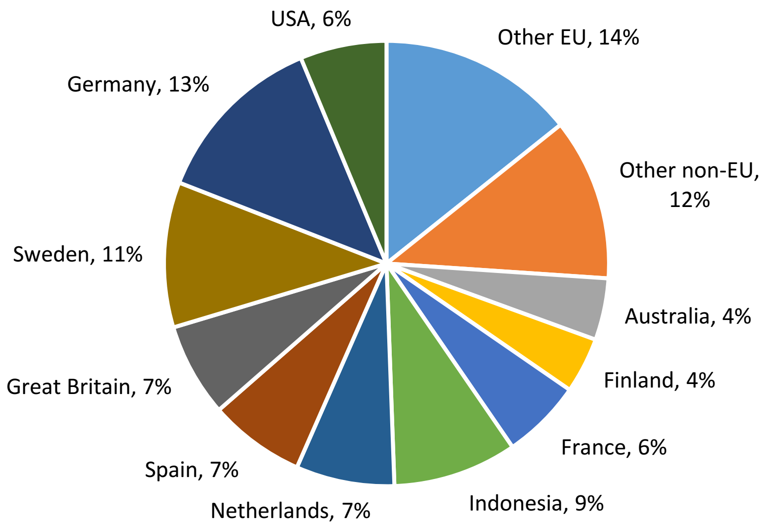

Fig. 3. Country of Feedstock Origin for HVO Consumed in Sweden, 2021

Research and Demonstration Focus

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

- *Biogas Solutions Research Center (*biogasresearchcenter.se*)*
- *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: Pågående uppdrag och satsningar (energimyndigheten.se)
- Research program for transport-efficient society, 2018-2023, on a system level. The call does not accept projects that focus on technology development of vehicle or engine technologies.

Outlook

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

Additional Information Sources

- Swedish Energy Agency, http://www.energimyndigheten.se/en/
- The Swedish Knowledge Centre for Renewable Transportation Fuels, http://www.f3centre.se/

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

Important drivers for the transformation of the Swiss energy system according to the federal government's Energy and Climate Strategy 2050 are the Energy Act, the Electricity Supply Act, and the CO_2 Act.[98] Targets are to gradually phase-out nuclear energy, increase energy efficiency, ramp up renewables, and achieve net-zero greenhouse gas emissions by 2050.

Laws are periodically adapted to new boundary conditions or strengthened in their effect in order to keep track on the recent development. New or revised acts are subject to an optional referendum and can be rejected by the public. That happened to the revised CO_2 Act, which was rejected in June 2021. At the same time, the Federal Council approved a dispatch on the Federal Act on a Secure Electricity Supply from Renewable Energy Sources.[99] With this bill, which entails a revision of the Energy Act and the Electricity Supply Act, the government aims to support Switzerland's transition to a sustainable and climate-friendly energy system while also ensuring a high level of security of supply. Large-scale electrification is needed in transport and heating (heat pumps) if Switzerland is to meet the goals of the Energy Strategy 2050 and its long-term climate strategy. This calls for a rapid and substantial increase in the use of renewables in domestic power generation.

Further measures are also needed to improve grid and supply security. The Federal Council aims to create a legal basis for greater planning certainty and incentives to invest in expanding renewable electricity production and grid integration. In 2022 the parliament discussed the draft law and, under the impact of the energy crisis, added numerous amendments to further accelerate the construction of renewable power generation facilities.

Based on an initiative submitted in November 2019, the Federal Council elaborated a Federal Act on Climate Protection Goals, Innovation and Strengthening Energy Security.[100] The draft law was submitted to parliament for consideration in June 2021 and passed in mid-2022. Because a referendum was successfully filed against it, a referendum will be held in the summer of 2023.

The energy crisis caused by the Russian invasion of Ukraine in 2022 had an impact on the debates in the parliament. The risk of an electricity shortage and a gas supply failure in winter requires a significant increase of domestic power generation from renewable sources, the need for renewable fuels, and a reduction of the energy consumption. However, the revised laws must be balanced in order not to fail a referendum.

CO_2 Emission Regulations for Cars

CO_2 emission regulations for new cars apply in Switzerland just as they do in the EU. As of 2021, under the World Harmonised Light-Duty Vehicles Test Procedure (WLTP), the average level of emissions from cars registered in Switzerland for the first time may not exceed 118 gCO_2/km, while the maximum level of CO_2 emissions from delivery and light articulated vehicles (collectively referred to as *light commercial vehicles)* will be 186 gCO_2/km. These targets correspond to those previously applied based on the New European Driving Cycle (NEDC) measurement procedure of 95 gCO_2/km for new cars and 147 gCO_2/km for new light commercial vehicles. Each importer's vehicle fleet must comply with an individual target based on these values. If the target is exceeded, the importer will pay a penalty. In 2021 the average CO_2 emissions of passenger cars achieved 129.8 gCO_2/km and exceeded the target value by 11.8 gCO_2/km and was 58.7% lower than in 2020 (28.6 gCO_2/km). This had a positive effect on the penalty that dropped from EUR 122.5 million (USD 144.9 million) in 2020 to EUR 26.0 million (USD 30.7 million) in 2021.[101] The narrowing of the gap between the target maximum CO_2 emissions and the emissions of newly registered vehicles was influenced primarily by a significant decline in sales of gasoline and diesel vehicles and a marked increase in hybrid and electric vehicles.

[98] https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050.html/
[99] SFOE, 2021, Federal Act on a Secure Electricity Supply from Renewable Energy Sources.
[100] Bundesgesetz über die Ziele im Klimaschutz, die Innovation und die Stärkung der Energiesicherheit, 30.09.2022,
[101] SFOE, 2022, “Vollzug der CO_2-Emissionsvorschriften 2021.”

CO_2 Emissions Compensation: Motor Fuels

Importers of fossil motor fuels are required to compensate a certain amount of the CO_2 emissions caused by transport. They may carry out their own projects or acquire certificates. The compensation rate in 2021 was 12% and will rise to 23% in 2024.[102] From 2022 onwards, a minimum of 15% must be compensated by domestic measures. The Swiss Petroleum Association established the Foundation for Climate Protection and Carbon Offset (KliK). It 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 as Switzerland is under no obligation to blend fossil fuels; this is the only driver for blends.

Mineral Oil Tax Reduction for Natural Gas and Biofuels

To support the target for CO_2 emissions, a reduction – or even an exemption – for environmentally friendly motor fuels was enacted in 2008. Biofuels that satisfy minimum environmental and social requirements are completely or partially exempt from the mineral oil tax. As a result, the tax reduction for biofuels is now EUR 0.69 (USD 0.82) per liter, compared to fossil fuels. The mineral oil tax reduction is valid until the end of 2024.[103] To offset the loss of tax revenue from this tax cut, the fossil fuel tax will be gradually increased until 2028.

Advanced Motor Fuels Statistics

The following numbers and statements are based on 2021 statistics.

Final total energy consumption in Switzerland in 2021 amounted to 797,720 terajoules. This represents an increase of 6.7% compared to the previous year, which was heavily impacted by the coronavirus pandemic; energy consumption in 2020 was down 10.6% compared to 2019. In 2021, the situation had normalized somewhat and energy consumption increased again.

Gasoline and diesel consumption increased by a total of 1.6% (gasoline 2.2%, diesel 1.1%). Sales of aviation fuels increased markedly by 11.1%. However, this is still 42% lower than in 2019, i.e., before the pandemic. Overall, fuel consumption was thus 2.9% higher than in 2020. Transport fuels account for 30% of total Swiss energy consumption; all fossil fuels were imported. See Figure 1.

In 2021, 350,056 motor vehicles were newly registered in Switzerland. This represents an increase of 3.9% over 2020, but it is 14.6% less than new registrations in 2019. New registrations of passenger cars increased slightly, by 1.5%. The number of newly registered hybrid (+61.7%) and electric cars (+50.9%) rose again. Sales of gasoline-fueled cars dropped by 15.31% and sales of diesel-fueled cars dropped by 37.1%. Compared to 2019 totals, sales of those cars declined by 50.9%.

Despite the steep rise in sales of electric and hybrid passenger cars, their share of the total (4,688,235) is still very small. Figure 2 illustrates this fact, using passenger cars as an example. Hybrid vehicles have a share of 4.3% of the total passenger car fleet, whereas the share of electric vehicles amounts to 1.5%. Most of the electricity used in the transport sector is for railroad transportation.

[102] https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/compensation/motor-

[103] Mineralölsteuergesetz (MinöStG), Stand: January 1, 2022.

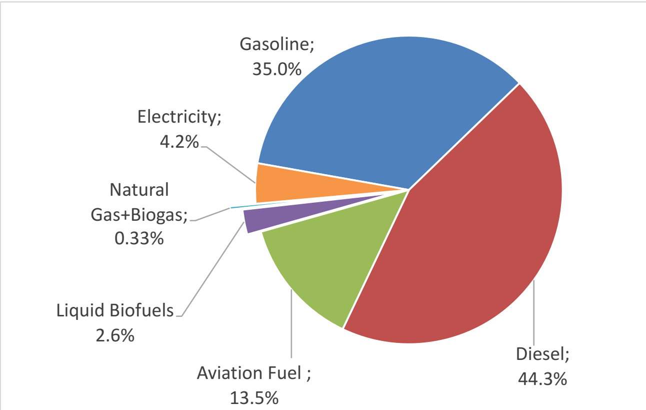

Fig. 1. Shares of Energy Sources in Energy Consumption for the Transportation Sector in Switzerland, 2021[104]

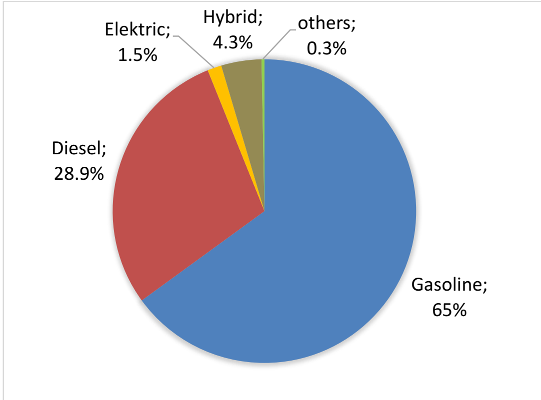

Fig. 2. Passenger Car Share by Fuel, 2021. Total Amount is 4,688,235[105]

As mentioned, importers of fossil motor fuels started blending fossil fuels with biofuels in 2014. The use of liquid biofuels rose from 29.4 million liters in 2014 to 230.5 million in 2021.

In 2021, 143.5 million liters of biodiesel and 82.7 million liters of bioethanol were used (see Figure 3). Hydrotreated vegetable oil (HVO) has been used in Switzerland only since 2016. It achieved a maximum in 2018 with 34.1 million liters and dropped to 4.2 million liters in 2021. Pure vegetable oil fuel is almost negligible (0.030 million liters). Upgraded biogas as a transport fuel remained at a low level of 3.1 million kg.[106]

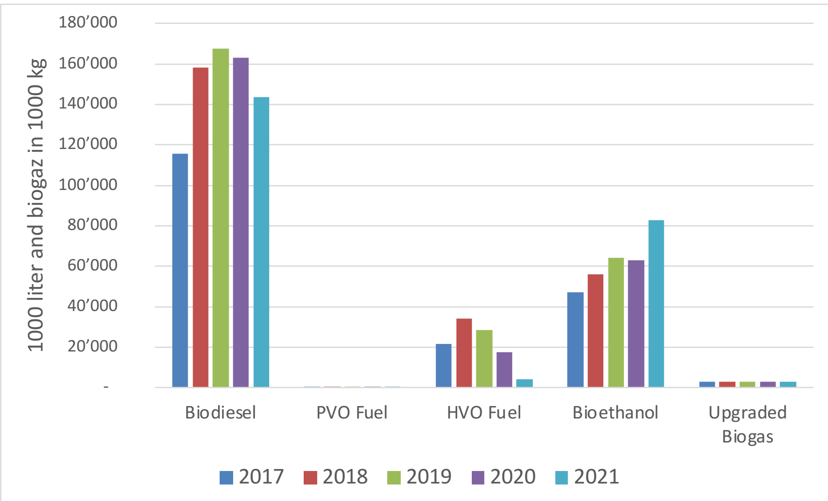

Fig. 3. The Use of Biofuels as Motor Fuels in Switzerland, 2016–2020

Only 9.9 million liters of biodiesel were produced in Switzerland; the remaining 133.6 million liters were imported (Germany, 40.0%; Japan, 33.3%; China, 11.7%; France, 9.6%; Austria, 4.8%). All bioethanol is imported (Poland, 43.9%; Germany, 13.7%; Norway, 13.2%; Sweden, 11.6%; Italy, 11.4%; United States, 6.2%).[107] Hydrotreated vegetable oil is mostly imported from the United States (99.8%), with the rest from Sweden and Finland.

The total amount of biogas produced and used in Switzerland in 2021 was 116 million kg. Only 29.1 million kg has been upgraded and fed into the natural gas grid. Of this, 3.1 million kg has been sold as biogas for cars, and the rest for heating. Almost all biogas used as motor fuel in cars is upgraded biogas fed into the natural gas grid. Figure 4 shows the development of the use of biogas and natural

[104] SFOE, 2022, "Gesamtenergiestatistik 2021."
[105] Swiss Federal Statistical Office (BFS), 2022, "Mobility and Traffic."
[106] SFOE, 2022, "Schweizerische Statistik erneuerbarer Energien 2021."
[107] Swiss Custom Administration, 2022, "T2.8 Biogene Treibstoffe 2021."

gas as motor fuels in cars. Despite an increasing amount of biogas fed into the natural gas grid, the demand for it as a motor fuel remains low: 89.4% of biogas is used for residential heating.[108]

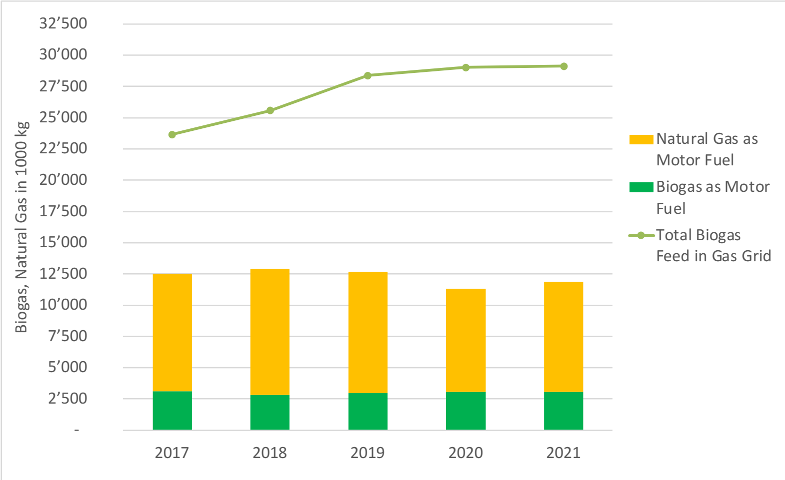

Fig. 4. Development of the Use of Natural Gas and Biogas as Motor Fuel for Cars and Total Upgraded Biogas Fed into the Natural Gas Grid (green line)

Research and Demonstration Focus

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

- The main focus of the Energy Research Programme is on development and application.
- The Pilot and Demonstration Programme promotes the testing and implementation of new technologies, solutions, and concepts.
- The purpose of the programme SWEET – "**SW**iss **E**nergy research for the **E**nergy **T**ransition" – is to accelerate innovations that are key to implementing Switzerland's Energy Strategy 2050 and achieving the country's climate targets.[109]

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

According to scenario ZERO Basis of the Swiss Energy Perspectives 2050+ until 2050 the transport sector should be operated without fossil fuel. That means a reduction from 200 petajoules (PJ) gasoline, diesel, and natural gas plus 7 PJ biofuels and 10.6 PJ electricity in 2021 to 71.9 PJ renewable fuels and 60.7 PJ electricity in 2050 (data without fuels for aviation). Figure 5 displays final energy demand.

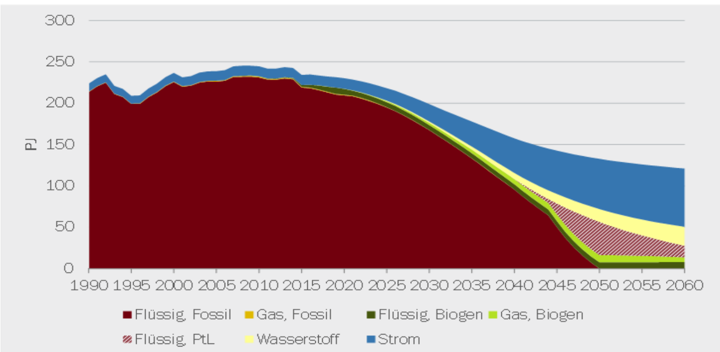

Fig. 5. Final Energy Demand of Domestic Transport (Scenario ZERO Basis, Excluding International Aviation)[110]

[108] Association of the Swiss Gas Industry, 2022, "VSG-Jahresstatistik."
[109] https://www.bfe.admin.ch/bfe/de/home/politik/energiestrategie-2050.html
[110] SFOE, 2022, Energy Perspectives 2050+, Technical Report

Therefore, in the transport sector the priority is electrification of passenger cars and public transport and the use of non-fossil fuels for the rest. The projects mentioned below cover the production, storage, and distribution of the fuels as well as their highly efficient use in internal combustion engines and gas turbines and exhaust gas after-treatment. The combustion and engine-relevant properties of biogas, hydrogen (H2), dimethyl ether (DME), polyoxymethylene dimethyl ether (OME), and ammonia (NH3) are investigated.

The following projects have recently been launched or are successfully active:

Sustainable Chemical Transport Fuels for Switzerland (2021–2024)[111]
The role and perspectives of sustainable chemical transportation fuels within a net-zero Swiss energy system are evaluated. To this end, a techno-economic, environmental, and social life cycle assessment of a comprehensive portfolio of chemical fuels – including hydrogen, biogenic, sun-to-liquid, and power-to-gas/liquid fuels – will be conducted and integrated into a scenario-driven energy system analysis. Due to limited sustainable primary energy resources for such fuel production in Switzerland, the analysis will be performed on a global level to identify plausible sources and locations for fuel production and import pathways.

E-Fuels: International Exchange of Research Findings and Activities (2021–2025)[112]
This project conducts an international exchange on the topic of e-fuels for transportation. Both the needs of the participating countries and their expertise will be gathered. The exchange should enable individual countries to fill the knowledge gaps of other countries with their expertise and, conversely, benefit from the expertise of other countries. One goal of this project for Switzerland is to gain knowledge about e-fuels through the exchange at both the national and international level. This will enable Switzerland to get a picture of the state of development of e-fuels on a global level and to deduce which research gaps still exist. The content of this project is a compilation of previous findings from Switzerland and the coordination of the international exchange of information. The project contributes to IEA AMF Task 64.

SWEET: Sustainable Fuels and Platform Chemicals (2023-2030)[113]
At the end of 2022, the SWEET Call 2-2022, “Sustainable Fuels and Platform Chemicals,” was launched and is expected to start in 2023. Researchers are to investigate how Switzerland can meet its future needs for sustainable fuels and platform chemicals. Technologies for production, transport, distribution, storage, and use are to be further developed. Researchers also are to show how the additional potential of Swiss farmyard manure can be profitably used for the production of sustainable fuels and platform chemicals.

N_2O Exhaust Gas Treatment in Ammonia Engines (2022–2025)[114]
NH_3 is considered a promising fuel for large engines and, in particular, for international shipping applications, as no CO_2 is produced from its combustion. However, high concentrations of the pollutants NO_x, NH_3, and N_2O can be released. This project aims to develop recommendations for exhaust after-treatment systems that reduce pollutant emissions from NH_3-fueled engines. Catalytic experiments will be performed in a wide range of concentrations of pollutants and other feed components (O_2, H_2O, etc.) as well as temperature in order to provide recommendations for after-treatment setups and catalyst compositions depending on these operating conditions. The project will include a general screening of suitable catalysts, but currently Fe-exchanged zeolites seem most promising to remove N_2O and NO_x from exhaust gases with the help of NH_3.

Use of LBG (Liquefied Biogas) for Swiss Heavy-Duty Transport («HelloLBG») (2019-2023)[115]
The central objective of this project was to investigate whether and how LBG can be used in heavy-duty transport in Switzerland in an ecologically and economically sensible way. For this purpose, the energy demand and emissions during the entire value chain, from the production of LBG to transport and storage to its use in the vehicle, were investigated. This well-to-wheel analysis not only determined

[111] https://www.aramis.admin.ch/Texte/?ProjectID=49507
[112] https://www.aramis.admin.ch/Texte/?ProjectID=49314
[113] https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/funding-program-sweet/calls-for-proposals-overview/sweet-call-2-2022.html
[114] https://www.aramis.admin.ch/Texte/?ProjectID=51133
[115] https://www.aramis.admin.ch/Texte/?ProjectID=44233

the direct CO_2 emissions, but also took into account additional relevant greenhouse gas emissions as CO_2 equivalents. During fuel combustion, further pollutant emissions, for example NO_x and particulate matter, were also measured. For this purpose, two trucks with different engine technologies for LNG as fuel – high pressure direct injection (HPDI) and spark ignition (SI) – and an LNG filling station were purchased and examined specifically for the project. In a tank-to-wheel analysis, measurements have shown a GHG reduction of as much as 17 % (liquefied methane compared to diesel). In the well-to-wheel analysis, a GHG emissions reduction of up to 80% could be determined. An estimation of LBG production costs in possible Swiss plants shows that reasonable production costs are achievable. The biggest impact lies in the costs of biogas production.

Fig. 6. LNG Service Station in Weinfelden, Switzerland
Source: https://www.cng-mobility.ch/beitrag/lidl-weiht-erste-schweizer-lng-tankstelle-ein/

Outlook

The sharp rise in energy prices in 2022, the obvious dependence on energy imports, and the associated risk of an electricity shortage and a gas supply failure in winter: all of these impact implementation of the Swiss Energy Strategy 2050. Along with a strong increase in renewable electricity production, the production and procurement of non-fossil fuels has also become more important. In addition to the transportation sector, a need for secure power supply is also emerging. Sales of electric passenger cars will continue to grow strongly. Demand for large electric vehicles will be mainly confined to the municipal sector and to public transport.

For the remaining transport systems powered by combustion engines (like long-distance transport, marine transport, and different off-road applications), research institutes and industry are looking for the most suitable solutions. The focus is especially on H_2, but also on NH_3, methanol, and DME. The challenge is that it is not clear which of these fuels are best suited and will become established. Collaboration between research and development of renewable fuels and the use in combustion systems is important.

Major changes
In 2022 the Swiss parliament passed a new Act on Climate Protection Goals, Innovation and Strengthening Energy Security that will be subject to a referendum in 2023.

In 2021, sales of motor vehicles were still significantly lower (-14.6%) than before the 2019 onset of the coronavirus pandemic. Compared to 2019, sales of gasoline- and diesel-fueled cars declined by 50.9%, but 190% more hybrid and 143% more electric passenger cars were sold. The share of gasoline and diesel vehicles sold in 2021 decreased to 55%, while hybrid vehicles accounted for 32% and electric vehicles for 13%. These sales had a positive effect on the average CO_2 emissions from newly registered passenger cars. It exceeded the target value by 11.8 gCO_2/km and was 58.7% lower than in 2020 (28.6 gCO_2/km).

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

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

United States

Drivers and Policies

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

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

In 2022, the U.S. Department of Energy (DOE), Department of Transportation, Environmental Protection Agency (EPA), and Department of Housing and Urban Development signed a joint memorandum of understanding to formalize the Administration's commitment to collaboration and coordination on transportation decarbonization. The four agencies published a decarbonization strategy for the entire transportation sector to guide future policymaking and research, development, demonstration, and deployment in the public and private sectors.[116] The blueprint's strategy is built upon five guiding principles:

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

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

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

The DOE Technology Integration Program is a government-industry partnership that supports local decisions to reduce petroleum use and GHGs in the transportation sector through the use of alternative fuels, hybrid and electric-drive vehicles, idle reduction technologies, smarter driving practices, and improved fuel economy measures. Data from the Technology Integration Program for 2021 reveal that the program saved 956 million gasoline gallons equivalent (GGE), including 645 million GGE from alternative fuels/vehicles and 106 million GGE from electric and hybrid vehicles.

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

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

fuels. On December 1, 2022, the EPA proposed to very slightly increase total renewable fuel volumes from 20.6 billion gallons in 2022 to 20.8 billion gallons in 2023.[117] In addition, the EPA proposed that 2024 and 2025 volumes be set to 21.9 billion gallons and 22.7 billion gallons, respectively. The 2023 proposed value is significantly lower than the original target of 36 billion gallons in the RFS legislation, which envisioned much more robust growth in cellulosic fuel production than has materialized.

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

The State of California developed the Low-Carbon Fuel Standard (LCFS) to reduce the average carbon intensity of its transportation fuels by 10% from 2010 to 2020. In 2019, California extended the LCFS to 2030 with reduced carbon intensities for transportation fuels by an additional 10% reduction. Using life-cycle analysis, different carbon intensities were developed for different fuels, including alternative fuels and biofuels. With both the RFS and LCFS, a significant volume of biofuels – about 2.6 billion GGE – was used in California in 2021, which was 27% higher than 2020.

Advanced Motor Fuels Statistics

The U.S. Energy Information Administration (EIA) estimated that total U.S. transportation energy consumption for 2022 was 27,534 trillion British thermal units (Btu), 2% higher than in 2021.[118] 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 1,565 trillion Btu during 2022, natural gas for 1,291 trillion Btu, electricity for 64 trillion Btu, and propane for 5 trillion Btu.[119]

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.[120] 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 18.0 billion gallons in 2021 to 19.0 billion gallons in 2022, as fuel consumption continued to rebound after the first year of the pandemic.

[117] EPA, 2022, Proposed Renewable Fuel Standards for 2023, 2024, and 2025, December 1, 2022.
[118] *EIA Monthly Energy Review*, March 2023.
[119] Ibid.
[120] EPA, 2023, EPA Moderated Transaction System, February 2023.

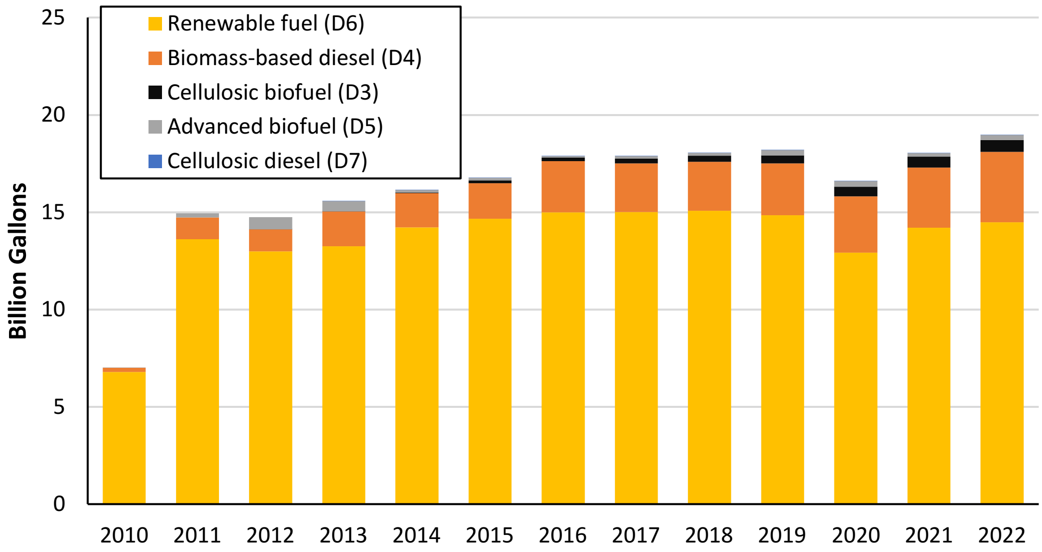

Fig. 1. Renewable Fuel Volumes Resulting from U.S. Renewable Fuel Standard

Electric Vehicles

Sales of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) in 2022, totaling 918,464, resulted in the largest sales year in U.S. history.[121] However, hybrid electric vehicles (non-plug- in) were down slightly in 2022, totaling 769,178.[122] As of February 2023, consumers could choose from 81 available plug-in models for model year 2023, down from 138 for model year 2022.[123]

Alternative Fuel Infrastructure

The DOE's Alternative Fuels Data Center provides the number of alternative fuel refueling stations in the United States.[124] As seen in Table 1, exclusive of electric recharging stations the total number of alternative fueling stations in the United States increased by 47% between 2012 and 2022. However, the number of compressed natural gas (CNG), liquefied natural gas (LNG), and liquefied petroleum gas (LPG) stations decreased slightly in 2022. In 2022, the DOE began collecting renewable diesel station data. The total number of public and private non-residential electric vehicle recharging outlets jumped by over 900% over this period, with a 10% gain in 2022.

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

Year	BD	CNG	E85	Electric Outlets[a]	H2	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

[a] Total number of recharging outlets, not sites.
[b] Renewable diesel station data collection began in 2022

[121] Argonne National Laboratory, 2023, "Light Duty Electric Drive Vehicles Monthly Sales Updates."
[122] Ibid.
[123] DOE, 2023, Alternative Fuels Data Center, "Availability of Hybrid and Plug-In Electric Vehicles."
[124] DOE, 2023, "Alternative Fueling Station Counts by State."

Research and Demonstration Focus

The DOE's Vehicle Technologies Office (VTO) sponsors research, development, demonstration, and deployment (RDD&D) in a broad range of technologies for all levels of vehicles and transportation systems. Areas of active research include energy storage, electric drive, materials, powertrain and fuels for non-road applications, mobility systems, and technology deployment. The current report covers research in fuels and advanced combustion engines for the purpose of displacing petroleum-derived fuels, matching engines and fuel characteristics better, and increasing engine and vehicle efficiencies. This research covers a very broad range of fuel, engine, and vehicle technologies. The summary provided here focuses on fuels and fuel effects and is based on a report summarizing the findings and impact of a multi-year project.[125]

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

As documented in the multi-agency decarbonization blueprint, VTO research and development in engines and fuels will now focus exclusively on off-road applications, including rail, marine, aviation, and off-road equipment for agriculture, mining, construction, and forestry. While it is recognized that engines will continue to be used in on-road transportation for years, VTO powertrain research for such applications will focus on battery electrification and hydrogen fuel cell-powered vehicles.

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

The DOE has begun to make significant investments in sustainable aviation fuels (SAF) to help decarbonize the U.S. aviation sector. The U.S. federal government has established a SAF Grand Challenge with a goal of 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050.[126] The DOE, the Department of Transportation, and the Department of Agriculture are leading the grand challenge to develop a comprehensive strategy for scaling up new technologies to produce SAF on a commercial scale.

Outlook

The EIA's *Annual Energy Outlook 2023* projects decreasing on-road transportation energy use from 2021 through 2043 due to mandated increases in fuel efficiency and the increase in use of electric vehicles. However, growth in travel demand, largely due 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.[127] The EPA's GHG emission standard for light-duty vehicles (LDVs) incentivizes the introduction of efficient vehicle technologies and electrified vehicles including PHEVs, BEVs, and FCEVs. The federal government and the auto industry anticipate electrification of the U.S. LDV fleet by 2050. Low-carbon fuels in internal combustion engines can help decarbonize long-haul trucks, the aviation sector, and the marine sector.

[125] DOE, 2022, The Road Ahead Toward a Net-Zero-Carbon Transportation Future Findings and Impact, DOE/EE-2359, June 2022.
[126] DOE, 2021, www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge
[127] Energy Information Administration, Annual Energy Outlook 2023, eia.gov/outlooks/aeo/

Additional Information Sources

- Oak Ridge National Laboratory, "Transportation Energy Data Book," tedb.ornl.gov/
- DOE, Federal and State Laws and Incentives, afdc.energy.gov/laws/
- EIA, *Monthly Energy Review,* Energy Information Administration, eia.gov/totalenergy/data/monthly/
- DOE Technology Integration Program, www.cleancities.energy.gov/
- DOE BETO program, energy.gov/eere/bioenergy/

4 Further Information

4.a
About the International Energy Agency

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

The IEA Energy Technology Network

The IEA Energy Technology Network (ETN) is composed of 6,000 experts participating in governing bodies and international groups managing 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): technologies and processes to improve efficiency in the buildings, electricity, industry, and transport sectors.
- Working Party on Fossil Fuels (WPFF): cleaner use of coal, improvements in gas/oil exploration, and carbon capture and storage.
- Fusion Power Coordinating Committee (FPCC): fusion devices, technologies, materials, and physics phenomena.
- Working Party on Renewable Energy Technology (REWP): technologies, socioeconomic issues, and deployment policies.

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

The 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 on 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 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 work and your country is already a member, please contact your respective Executive Committee (ExCo) representative.

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

4.b.iii
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Dina	Bacovsky	Secretary	secretariat@iea-amf.org
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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 2022

Task 60: The Progress of Advanced Marine Fuels

The work in Task 60 was completed in 2022, publication of the final report and the Key Messages is under preparation. This and all other publications from AMF TCP can be found on the website.

4.d How to Join the Technology Collaboration Programme on Advanced Motor Fuels

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, secretariat@iea-amf.org.

The Secretary will provide you with details on 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 11,214).
- Funding for an ExCo 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 10,913 to USD 109,135).

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 Technology Collaboration Programme on Advanced Motor Fuels.

4.e Partnerships

Collaboration with the International Transport Forum (ITF)

The International Transport Forum at the OECD is an intergovernmental organization with 63 member countries. It 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. It acts as a platform for discussion and pre-negotiation of policy issues across all transport modes and it analyzes trends, shares knowledge, and promotes 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 helps give greater visibility to the outputs of the AMF TCP.

This closer 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, which 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), 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 takes into account 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 taken into account, 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
AFIR	Alternative Fuels Infrastructure Regulation
AFV	Alternative fuel vehicle
B20	Biodiesel
BETO	Bioenergy Technology Office (United States)
BEV	Battery electric vehicle
BMBF	Federal Ministry of Education and Research (Germany)
BMDV	Federal Ministry for Digital and Transport (Germany)
BMWi	Ministry of Economic Affairs and Energy (Germany)
BMWK	Federal Ministry of Economic Affairs and Climate Action
CBG	Compressed Biogas India
CEP	Core exhaust plume
CERT	Committee on Energy Research and Technology (IEA)
CFR	Clean Fuel Regulations (Canada)
CGSB	Canadian General Standards Board
CHP	Combined Heat and Power (Denmark)
CHT	Centre for High Technology (India)
CI	Carbon intensity
CNG	Compressed natural gas
CNMC	National Markets and Competition Commission (Spain)
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CTS-RD	Clean Transportation System-Research and Development Program (Canada)
DBT	Department of Biotechnology (India)
DF	Dual fuel
DHA	Omega-3 fatty acid (India)
DME	Methanol/dimethyl ether
DOE	U.S. Department of Energy
E85	85% Ethanol in Gasoline Fuel
E100	Pure anhydrous ethanol
EBP	Ethanol blended petrol
EFB	Empty Fruit Bunches (India)
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ER	Effective ratio
ERA-NET	European Research Area Bioenergy
ESY	Ethanol supply year
ETBE	Ethyl tertiary-butyl ether
ETN	Energy Technology Network (IEA)
eTV	ecoTechnology for Vehicles (Canada)
EU	European Union
EV	Electric vehicle
EVAFID	Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (Canada)
FAME	Fatty Acid Methyl Ester
FCV	Fuel cell vehicle

FFV	Flex-fuel vehicle
FOM	Fermented organic manure
FQD	Fuel Quality Directive (Germany)
GHG	Greenhouse gas
HDV	Heavy-duty vehicle
HEV	Hybrid electric vehicle
HFS	Hydrogen fueling station
HHI-EMD	Hyundai Heavy Industries Engines and Machinery Division
HPDI	High pressure direct injection
HVO	Hydrotreated vegetable oil
ICAO	International Civil Aviation Organization
ICE	Internal combustion engine
IEA	International Energy Agency
IOCL	Indian Oil Corporation Limited
KLIEN	Austrian Climate and Energy Fund
KliK	Foundation for Climate Protection and Carbon Offset (Switzerland)
KTF	Climate and Transition Fund
LBG	Liquefied biogas
LCA	Life cycle assessment
LCFS	Low-Carbon Fuel Standard (United States)
LDV	Light-duty vehicle
LFOM	Liquid fermented organic manure
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MARPOL	International Maritime Pollution Prevention Convention
METI	Ministry of Economy, Trade and Industry (Japan)
MIIT	Ministry of Industry and Information Technology (China)
MoPNG	Ministry of Petroleum and Natural Gas (India)
NECP	National Energy and Climate Plan
NEDC	New European Driving Cycle
NGV	Natural gas vehicle
NIPII	National Innovation Programme Hydrogen and Fuel Cell Technology (Germany)
NO_x	Nitrogen oxide(s)
NoVA	Normverbrauchsabgabe (Austria)
NRCan	Natural Resources Canada
OMC	Oil marketing company
OME	Polyoxymethylene-dimethylether
PCF	Pan-Canadian Framework on Clean Growth and Climate Change
PEMS	Portable Emission Measuring System
PERD	Program of Energy Research and Development (Canada)
PHEV	Plug-in hybrid electric vehicle
PN	Particle number
PSU	Public Sector Units
PTE-HPC	Spanish Hydrogen Technology Platform
PtL	Power to Liquid
PtX/P2X	Power to X (Germany)
PV	Ground mounted solar farm
PVO	Pure vegetable oil

R&D	Research and Development
RD&D	Research, Development, and Demonstration
RDE	Real Driving Emission
RED II	Renewable Energy Directive II (Germany)
RES	Renewables, total share of (Denmark)
RIN	Renewable Identification Numbers (United States)
RFR	Renewable Fuels Regulations (Canada)
RFS	Renewable Fuel Standard (Korea, United States)
SAF	Sustainable aviation fuel
SATAT	Sustainable Alternative Towards Affordable Transportation (India)
SET Plan	Strategic Energy Technology Plan (Spain)
SFOE	Swiss Federal Office of Energy
SIF	Strategic Innovation Fund (Canada)
TCP	Technical Collaboration Program (IEA)
TGA	Techno-economic assessment
UER	Upstream Emissions Reductions (Germany)
VRDS	Residual Oil Desulfurization Facility (Korea)
VTO	Vehicle Technologies Office (United States)
WLTP	Worldwide Harmonized Light Vehicle Test Procedure
WTW	Wheel-to-well
ZEV	Zero-emission vehicle

Units of Measure

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