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Technology Collaboration Programme on Advanced Motor Fuels

IEA Bioenergy
Technology Collaboration Programme



The Role of Renewable Transport Fuels in Decarbonizing Road Transport

Deployment Barriers and Policy Recommendations

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Summary / Abstract

*This report constitutes Part 4 of the report on "**The Role of Renewable Transport Fuels in Decarbonizing Road Transport**". In this report the term decarbonization includes all options to reduce GHG emissions and make road transport cleaner, including low(-fossil)-carbon energy carriers such as biofuels, e-fuels, and renewable electricity. This part of the report deals with barriers to the further implementation of renewable transport fuels and with policies to overcome these.*

In the light of climate change, there is an urgent need to decarbonize our societies. The transport sector, and within it in particular the road transport sector, is specifically challenging, as transport demand is growing, and so are the sector´s GHG emissions. Decarbonization includes all options to reduce GHG emissions and make road transport cleaner, including low(-fossil)-carbon energy carriers such as biofuels, e-fuels, and renewable electricity. None of these will be able to solve this grand challenge alone, and renewable transport fuels have an essential role in bridging the gap between GHG emission reduction targets and the prospected emission reductions.

Many low-carbon scenarios envisage an increase in the role of sustainable bioenergy. For example, in the IEA's 2°C Scenario (2DS), biofuels increase by a factor of 10 by 2060, providing 30 EJ in the transport sector. In this scenario, biofuels provide some 30% of transport energy, complementing increases in electricity and improvements in energy efficiency in the sector. This scenario also sees a rapid increase in the level of biofuels in the short term, with its contribution in the transport sector growing by a factor of 3 by 2030.

The IEA's World Energy Outlook New Policy Scenario (NPS) takes account of current and planned policy measures while the Sustainable Development Scenario (SDS) identifies a pathway through which the main energy-related components of the Sustainable Development Goals, as agreed by 193 countries in 2015, can be achieved. Comparison of these scenarios shows that current and proposed policies (as represented by the NPS scenario) are only likely to stimulate around 70% of the deployment level needed in the SDS scenario, even if proposed measures are actually put in place and effective. More ambitious targets and policy measures will be essential if biofuels are to be developed in a way that is compatible with scenarios such as the SDS.

Specific barriers to alternative transport fuels vary from country to country, depending on the policy and regulatory frameworks in place. Different fuels also face specific barriers depending on their level of technical and commercial maturity and their feedstock demands. Important barriers found through the assessments undertaken in this study, through the

discussion at the project workshop on 18 November 2019 in Brussels, and also from existing literature include:

- Well-established transport system to compete with
- Fluctuating policy drivers / lack of long-term stable policies
- Low public acceptance / perception of technical performance issues and sustainability concerns
- Incomplete set of policy measures
- The need to build up infrastructure for alternative fuels and alternative fuel vehicles such as FFVs, EVs, FCEVs
- Risks associated with biofuels, such as technical issues, economic competitiveness, ease of integration of fuels, availability of appropriate feedstock and meeting sustainability requirements

Long term and stable policy frameworks are essential to foster growth of renewable transport fuels. An appropriate policy portfolio would include measures to "level the playing field" by removing fossil fuel subsidies and putting effective carbon pricing mechanisms in place. Such a portfolio should also include specific targets for renewable fuels, and mechanisms to ensure that the fuels are competitive in the transport market, along with a stringent, evidence-based sustainability governance regime.

Additional measures are needed to promote fuels which are not yet fully commercialized, including mandatory obligations for deployment of emerging biofuels, dedicated financial mechanisms and instruments to facilitate technological development and subsequent market deployment, and targeted support for RD&D.

However, each government has to find the right alternative fuels and vehicles to go for, and to find the right set of policy measures for the particular national situation at a given time. There are no one-size-fits-all solutions to decarbonize transport. The only constant is that bold action needs to be taken now to reach decarbonization at the required level and speed.

Authors

This report constitutes Part 4 of the report on “**The Role of Renewable Transport Fuels in Decarbonizing Road Transport**”, a project that was initiated and carried out jointly by IEA Bioenergy and the Advanced Motor Fuels (AMF) TCP, with financial support of the European Commission. The project was Task 41 Project 10 under IEA Bioenergy and Annex 58 under AMF.

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Further to this part “Deployment Barriers and Policy Recommendations”, the following report parts have been published:

- Key Strategies in Selected Countries
- Production Technologies and Costs
- Scenarios and Contributions in Selected Countries
- Deployment Barriers and Policy Recommendations
- Summary Report

This report part was written by Adam Brown (Energy Insight Ltd), Andrea Sonnleitner and Dina Bacovsky (both BEST – Bioenergy and Sustainable Technologies GmbH).

The IEA Bioenergy TCP is an international platform of cooperation working in the framework of the IEA´s Technology Collaboration Programmes. IEA Bioenergy’s vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use.
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The Advanced Motor Fuels (AMF) TCP also is an international platform of cooperation working in the framework of the IEA´s Technology Collaboration Programmes. AMF´s vision is that advanced motor fuels, applicable to all modes of transport, significantly contribute to a sustainable society around the globe. AMF brings stakeholders from different continents

together for pooling and leveraging of knowledge and research capabilities in the field of advanced and sustainable transport fuels.
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Introduction

In the light of climate change, there is an urgent need to decarbonize our societies. The transport sector, and within it in particular the road transport sector, is specifically challenging, as transport demand is growing, and so are the sector´s GHG emissions. Decarbonization includes all options to reduce GHG emissions and make road transport cleaner, including low(-fossil)-carbon energy carriers such as biofuels, e-fuels, and renewable electricity. None of these will be able to solve this grand challenge alone, and renewable transport fuels have an essential role in bridging the gap between GHG emission reduction targets and the prospected emission reductions.

As discussed in detail in parts 1-3 of the overall report, the countries assessed are aware of the urgent need for decarbonizing their transport systems. However, the required level of decarbonization can only be reached with a set of measures, including biofuels, electric vehicles, and possibly e-fuels. There is sufficient feedstock available for the sustainable production of biofuels to be used in our vehicles to cover the demand of low-carbon scenarios. But why is the production and use of biofuels not yet growing as needed?

The following sections look at the role of biofuels within low-carbon scenarios and how these compare with present and anticipated deployment patterns at global and regional scales. Barriers to the widespread deployment of renewable fuels are discussed, and finally, policy recommendations on how to support the deployment are provided.

Biofuels deployment trends and ambitions

The use of established biofuels has been growing, and new fuels such as HVO and biomethane are beginning to reach significant levels. Future low-carbon scenarios depend on substantial increases in the levels of sustainable biofuels, but current deployment levels are not consistent with these scenarios. While a number of countries have well-developed biofuels strategies, the trajectories associated with the low-carbon scenarios will not be achieved unless more ambitious strategies are implemented in many more countries.

Current status of biofuels deployment

As is also described in detail in Part 2 of the overall report, “Production Technologies and Costs”, global production and use of biofuels is expected to continue to be dominated by established biofuels such as crop-based ethanol and biodiesel. However, there is a growing trend towards waste-based biodiesel that is favored by a number of policy measures (such as the EU’s Renewable Energy Directive and the Low-Carbon Fuel Standard in the USA) since it provides better overall green-house gas balances and has lower associated land-use change risks. Other biofuels are making a growing impact although the picture is very different between the types of new fuels. The production and use of HVO has been growing strongly, and biomethane use in transport has also grown, albeit from a low base. By contrast the production of cellulosic ethanol biofuels from cellulosic materials and the experience of producing biofuels from cellulosic materials by thermochemical routes is still at a low level due to technology and economic barriers. Production levels for ethanol are more than three orders of magnitude higher than for cellulosic ethanol and biofuels from thermochemical processes as illustrated by Figure 1 which shows production in 2019, but using a logarithmic scale.

Ethanol

Global production of ethanol in 2019 amounted to 114 billion liters (2.4 EJ).[1] Production and use is dominated by the USA (corn) and Brazil (sugarcane), who between them produced 83% of global production, and were also the major users. China’s production has risen rapidly in recent years, reaching an estimated 4 billion liters (85 PJ) in 2019. Production levels have also grown strongly in India (2 billion liters, 43PJ), overtaking Canada (1.9 billion liters, 40PJ) and Thailand (1.6 billion liters, 34 PJ). EU production amounted to some 4.2 billion liters (89 PJ) in 2019.

[1] REN21 Global Status Report 2020

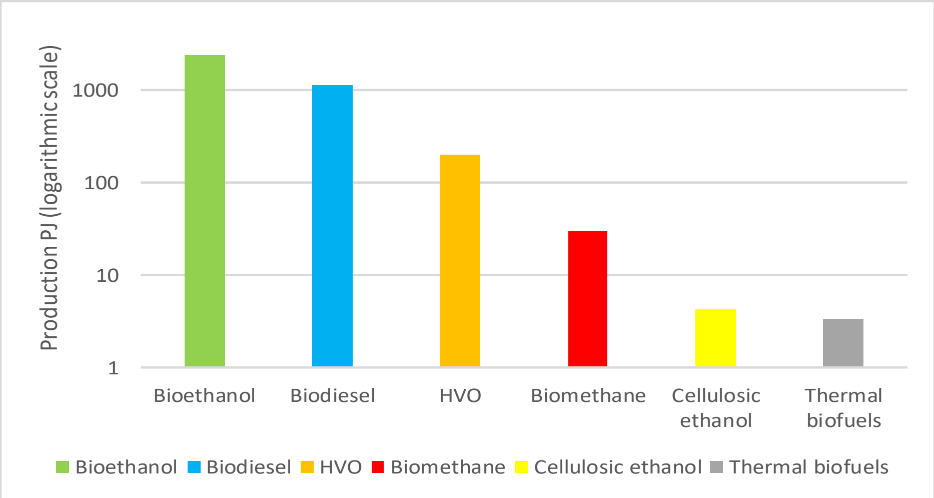

Figure 1: Global production levels of biofuels in 2019 (logarithmic scale), based on data in REN21, GSR, 2020

Biodiesel (FAME)

Global production of FAME biodiesel amounted to 41 billion liters (1.4 EJ) in 2019. Production of biodiesel is less geographically concentrated than ethanol, with the leading 5 countries between them contributing less than 60% of global production. In 2019, Indonesia became the largest producer with 17% of production, followed by the US (14%), Brazil (12%), Germany (8%) and France (6%).

HVO

HVO production has been growing rapidly, reaching around 6 billion liters (200 PJ) in 2018 and is expected to continue to grow rapidly over the next 5 years reaching between 13 and 17 billion liters (400-600 PJ), with some 5 billion USD of investment scheduled, mostly based on waste. The rapid growth can be put down to:

- successful and low risk technology, in some cases integrated with existing oil refinery operations,
- fuels which score highly in low-carbon based incentive schemes, when based on waste feedstocks such as UCO.
- fuels which can be easily integrated into existing fuel delivery and infrastructure system (“drop-in” fuels), offering advantages compared to FAME biodiesel,
- the prospect of making fuels for aviation (although production in 2018 was estimated at only 15 million liters)
- the increasing use of waste-based materials

However future growth may be constrained by the availability of suitable low-cost waste streams, although efforts are under way to develop alternative feedstock sources, for example from energy crops produced in ways which avoid negative land-use impacts.

Biomethane

Biogas is widely produced by anaerobic digestion of a wide range of wastes, residues and crops, with an estimated 150,000 largescale plants worldwide as well as some 50 million small-scale digesters used to provide energy for cooking in developing countries. Most biogas is still used directly to produce electricity or heat but there is a growing trend to refine the gas to biomethane by taking out the CO_2 and other components and producing a pipeline quality gas, with some 8.5% of biogas now treated in that way in over 700 plants worldwide.[2] The purified methane can then be used for heating or for transport, often being injected into the natural gas grid. The policies and incentives in place determine whether the fuel is used for heating or for transport where it can be used in cars and in vans and trucks. The USA and Europe (notably Sweden) are the major markets for biomethane in transport, but there is growing interest and activity in other areas, notably in China and India. Total current use in transport is estimated at only around 30 PJ in 2018.[3]

Biomethane shares many positive characteristics with HVO, with low-risk technology, producing a fuel which can score highly in incentive schemes especially when made from wastes. It is more suited to dedicated transport fleet use, since adapted vehicles and fueling infrastructure is needed, but also provides fuels which can offer local emission benefits compared to fossil diesel fuels, making it attractive for city delivery vehicles.

Cellulosic ethanol

Despite much investment in R&D and in demonstration plants, and high levels of support available for the fuels, the level of cellulosic ethanol production is still low (around 200 million liters/year, 4 PJ) with globally only four large scale plants in operation, although these are not so far reaching design capacity due to ongoing technical bottlenecks. Some further investments have been announced, and the IEA estimates that once the plants are built this could lead to production of some 1.7 billion liters.

By contrast with HVO and biomethane, technical barriers seem to be the main barriers to rapid progress with deploying cellulosic ethanol plants

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[2] IEA Renewables 2019

[3] REN 21 GSR 2019

Thermochemical production processes

A range of thermochemical processes are under development which can produce a range of biofuels from cellulosic feedstocks including timber and agricultural residues and municipal solid wastes. These include processes based on gasification (and synthesis) and pyrolysis (and upgrading). They can produce a range of fuels including methanol and other alcohols, methane, bio-gasoline and diesel and jet fuels. While many processes have been successfully demonstrated at pilot and pre-commercial scale, production of these fuels is currently very limited (less than 100 million liters) and even if plants under construction and development are successful then production would only amount to less than 1 billion liters (some 34 PJ). [4]

The main barriers to more widespread production of these fuels seems to be the need for successful large-scale demonstration plants to show that the processes are technically viable, and for sufficient financial support to make sure that these early plants can provide an adequate return in investment.

Biofuels ambitions in low-carbon scenarios

Bioenergy plays an important role in low-carbon scenarios, especially in the transport sector.

Comparison of the IEA's NPS and SDS scenarios for biofuels in transport show that current and proposed policies (as represented by the NPS scenario) are only likely to stimulate around 70% of the deployment level needed in the SDS scenario, even if proposed measures are actually put in place and effective. More ambitious targets and policy measures will be essential if biofuels are to be developed in a way that is compatible with scenarios such as the SDS.

Many low-carbon scenarios envisage an increase in the role of sustainable bioenergy. For example, in the IEA's 2°C Scenario (2DS) of its 2017 edition of the Energy Technologies Perspectives publication, which is consistent with a 50% chance of limiting future global average temperature increases to 2°C by 2100, biofuels increase by a factor of 10 by 2060, providing 30 EJ in the transport sector. In this scenario, biofuels provide some 30% of transport energy, complementing increases in electricity and improvements in energy efficiency in the sector as shown in Figure 2.[5]

This scenario also sees a rapid increase in the level of biofuels in the short term, with its

[4] IEA Renewables 2019

[5] IEA Technology Roadmap, Sustainable Bioenergy, 2017.

contribution in the transport sector growing by a factor of 3 by 2030.

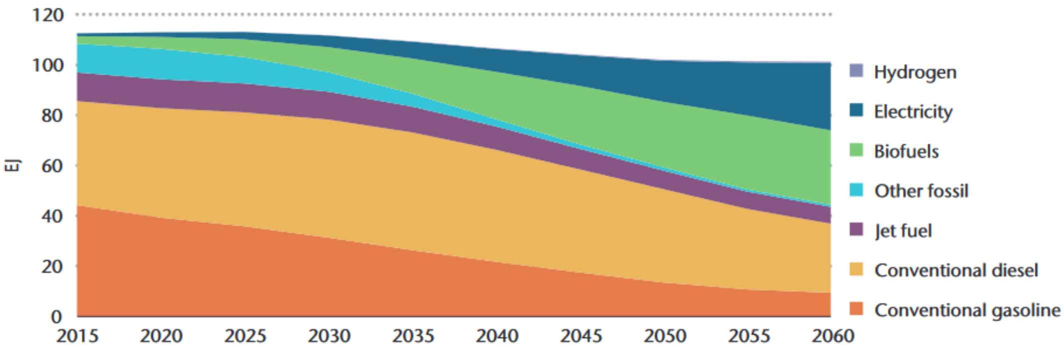

Figure 2: Role of biofuels in transport – IEA 2DS Scenario

In the International Renewable Energy Agency's (IRENA) REMap scenario, an increase in renewables and improvements in energy efficiency provide over 90% of the necessary energy-related CO_2 emission reductions to 2050.[6] In this scenario, bioenergy provides 22% of total global energy needs for transport.

If more stringent climate targets are to be achieved, then the important role of bioenergy is likely to be enhanced (particularly involving the production of bio-based fuels associated with carbon capture and storage or reuse).

IEA World Energy Outlook Scenarios

The IEA's World Energy Outlook (WEO) features three scenarios. These are the Current Policies Scenario (CPS), New Policies Scenario (NPS) and Sustainable Development Scenario (SDS). The main underlying features of these scenarios are as follows:

- The CPS is based solely on existing laws and regulations as of mid-2018, and therefore excludes the ambitions and targets that have been declared by governments around the world. It provides a baseline for the WEO analysis.
- The NPS provides an assessment of where today's policy frameworks and ambitions, together with the continued evolution of known technologies, might take the energy sector in the coming decades. The policy ambitions include those that have been announced as of August 2018 and incorporates the commitments made in the Nationally Determined Contributions under the Paris Agreement, but does not speculate as to further evolution of these positions.

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[6] IRENA ReMap 2018

Where commitments are aspirational, this scenario makes a judgement as to the likelihood of those commitments being met in full.

- The SDS, introduced for the first time in the 2017 edition of the WEO, starts from the assumption that selected key outcomes related to the main energy-related components of the Sustainable Development Goals, agreed by 193 countries in 2015, can be achieved and then works back to the present to see how they might be realized. The outcomes in question are:
  - Delivering on the Paris Agreement. The Sustainable Development Scenario is fully aligned with the Paris Agreement's goal of holding the increase in the global average temperature to "well below 2 °C".
  - Achieving universal access to modern energy by 2030.
  - Reducing dramatically the premature deaths due to energy-related air pollution.

  The Sustainable Development Scenario sets out the major changes that would be required to deliver these goals simultaneously. The 2018 edition also incorporated linkages between energy and water.

The WEO provides a detailed analysis of energy production and use by sector and by region for each scenario, looking out to 2040. The analysis here focuses on how the role of bioenergy in the transport sector evolves over time in the scenarios presented in WEO 2018.

WEO – Biofuels in Transport

The three scenarios described above identify different pathways for energy in the transport sector and for the role of biofuels within it, as summarized in Table 1. Total transport energy continues to increase in both CPS and NPS scenarios until 2040, whereas in SDS growth slows to 2030 and declines by 3% by 2040. Biofuels use rises in all scenarios, but in the SDS biofuels use more than doubles by 2030 and triples by 2040 reaching 11% of transport energy needs by 2030 and 15% by 2040.

This implies that the current policy mix (as represented by CPS) and even the proposed policies represented in NPS will not deliver the biofuels contribution consistent with the more sustainable future represented by the SDS.

Table 1: Trends in transport energy in IEA WEO Scenarios

Scenario	Overall transport energy trend compared to 2017	Role of biofuels	
		Growth trend relative to 2017	% of total transport energy by 2030 and 2040
CPS	2030: Increases by 22% 2040: increases by 38%	2030: Increases by 51% 2040: Increases by 91%	2030: 4.5% 2040: 5.0%
NPS	2030: Increases by 18% 2040: increases by 27%	2030: Increases by 87% 2040: Increased by 156%	2030: 5.7% 2040: 7.2%
SDS	2030: Increases by 5% 2040: Declines by 3%	2030: Increases by 226% 2040: Increases by 308%	2030: 11.1% 2040: 15.1%

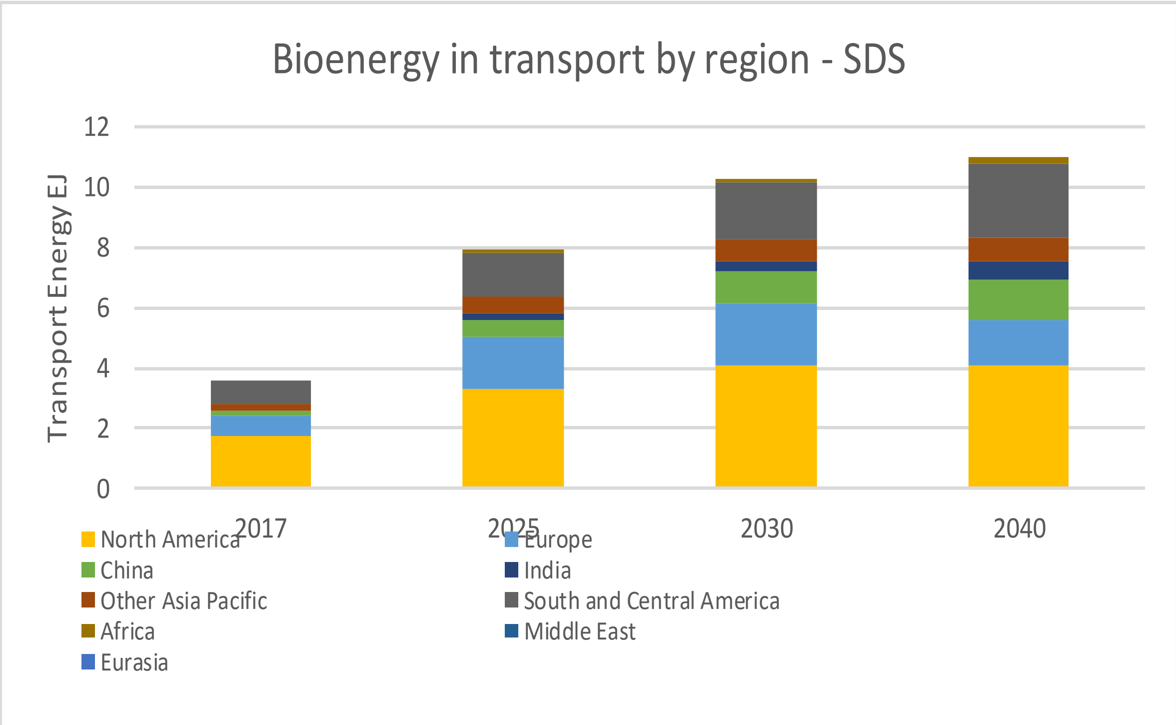

Figure 3: Bioenergy use by region – NPS and SDS

In the NPS, North America, Europe, South and Central America (notably Brazil), which today consume around 90% of all biofuels, remain the largest users. 70% of all biofuels will be consumed in these regions in 2040, and China will also become a major consumer of biofuels (10% of the total).

In the SDS scenario, biofuels use grows more rapidly, especially in China, India and other parts of the Asian Pacific Region, as shown in Figure 3. By 2040, North America, Europe and South America will make up just 54% of the world market, with China using 10% of the total biofuels and more significant uptake in other regions – notably in India and other parts of SE Asia.

On a global scale, even if all current policy commitments are fully implemented and effective, biofuels deployment will only reach some 70% of the level estimated as necessary within the SDS. To realize the levels needed within the SDS significantly more ambitious and effective policies will have to be put in place.

Biofuels Deployment Trends

Current rates of deployment as represented by the IEA's forecasts from now to 2024, indicate that in fact the growth in bioenergy in the transport sector is likely to be around half that projected even in the NPS scenario, emphasizing the need for an urgent effort to step up policy efforts in the biofuels sector.

Analysis of current and anticipated deployment trends for biofuels shows that while biofuels production and use has been growing, the growth rate is well below the rate implied even in the NPS, let alone the more ambitious trajectory required in any lower-carbon energy future.

The IEA publish an annual renewables market report which gives information on current deployment trends and also provides projections for the growth of each technology, including transport biofuels, for the next five years.[7] These projections are based on detailed bottom-up analysis of market factors in all the main markets. Global biofuels production and use has been growing at an average rate of around 5% since 2010, but at closer to 7% in 2018, when production reached record levels in the USA and Brazil, the two major producers.

Figure 4 shows the anticipated trends in total global biofuels production to 2024, and compares these to the 2025 figures in the WEO NPS and SDS scenarios. This shows that growth in biofuels forecast will be some 23% between 2018 and 2024 (around 4%/year). This compares unfavorably with the 45% growth anticipated in the NPS scenario and the projected growth between 2018 and 2024 will be a factor of 5 lower than that required to be in line with the SDS by 2025. More ambitious policy measures are clearly needed if biofuels are to play their full part in decarbonizing transport.

[7] IEA Paris Renewables 2019 (October 2019)

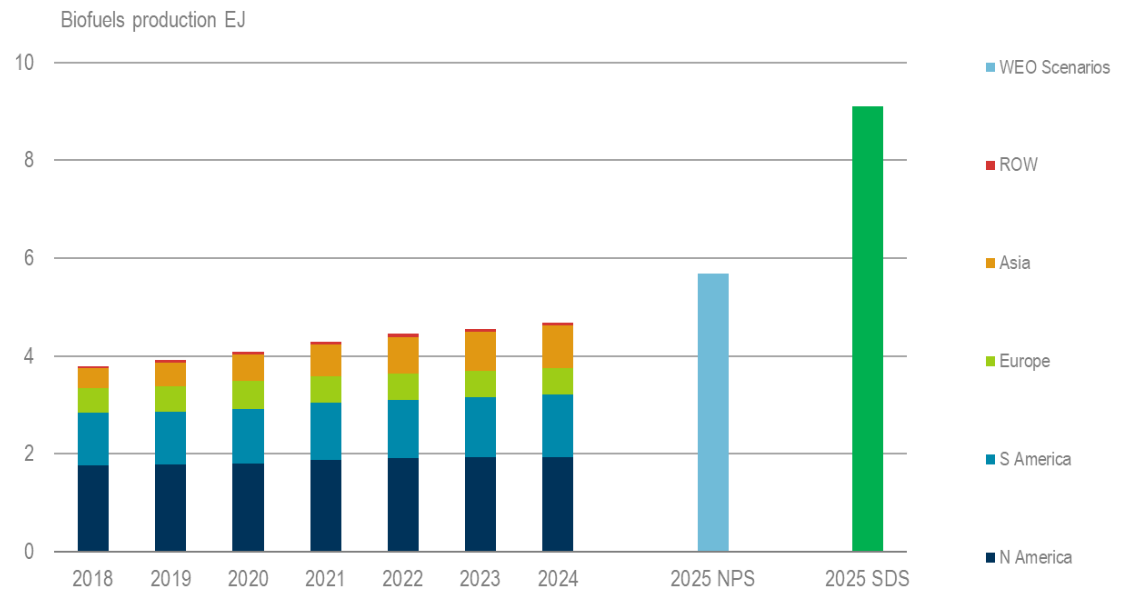

Figure 4: Comparison of projected biofuels growth to 2025 with WEO Scenarios, Source: IEA Renewables 2019 and WEO 2018

As Figure 4 indicates, projected growth is concentrated in Asia, and especially in China where there are plans to move towards a nationwide 10% blend of ethanol in gasoline (from about 2 % now) and for an increase in use of biodiesel. Growth is also expected in India where the 5% blending target for ethanol in gasoline was reached in 2018 and a level of 20% is targeted for 2030, and in SE Asia, especially for biodiesel fuels. Biofuels use in South America and especially Brazil is expected to be boosted by the RenovaBio program.

Growth in Europe is expected to be constrained by the limit on crop-based biofuels within the RED-II, which is unlikely to be offset by growth in emerging biofuels. Similarly, growth in the US will be constrained since the ethanol limit within the RFS has been reached and total gasoline consumption is expected to decline with improving vehicle efficiency standards. Biodiesel demand is expected to continuously grow in order to meet the more ambitious overall RFS2 standards, along with state led initiatives such as the California LCFS.

This means that even the trajectory associated with the NPS scenario is unlikely to be achieved. The IEA also quote an accelerated forecast, which assumes more favorable market conditions and enhanced policies. In this more supportive environment, total biofuels production rises by some 47% by 2025, bringing the level close to that envisioned in the NPS scenario by that date.

In Part 1 of the overall report ("Key Strategies in Selected countries"), the key strategies for decarbonizing the transport sector has been described for a number of countries. The main aspects for USA, Germany, Sweden, Finland and Brazil are summarized in the following section.

USA

In the US, biofuels growth accelerated significantly between 2002 and 2011 due to the RFS and particularly the growth in the production and use of corn-based ethanol. More recently ethanol use has stabilized as the maximum level provided for under RFS2 (Renewable Fuels Standard) has been reached. Biodiesel production and use have been growing, promoted under the RFS and state level provision such as California's LCFS. (See Figure 5). Biogas from landfills and many other sources is increasingly purified to biomethane for use in pipelines and transport use. The use of HVO has also been growing. "Other biofuels" – including cellulosic ethanol – so far make up a small overall percentage of fuel use. Biofuel use is under pressure because of expected declines in US gasoline use, due to improved vehicle efficiencies, and by "blending waivers" which allow smaller refiners to avoid the need to blend ethanol in gasoline.

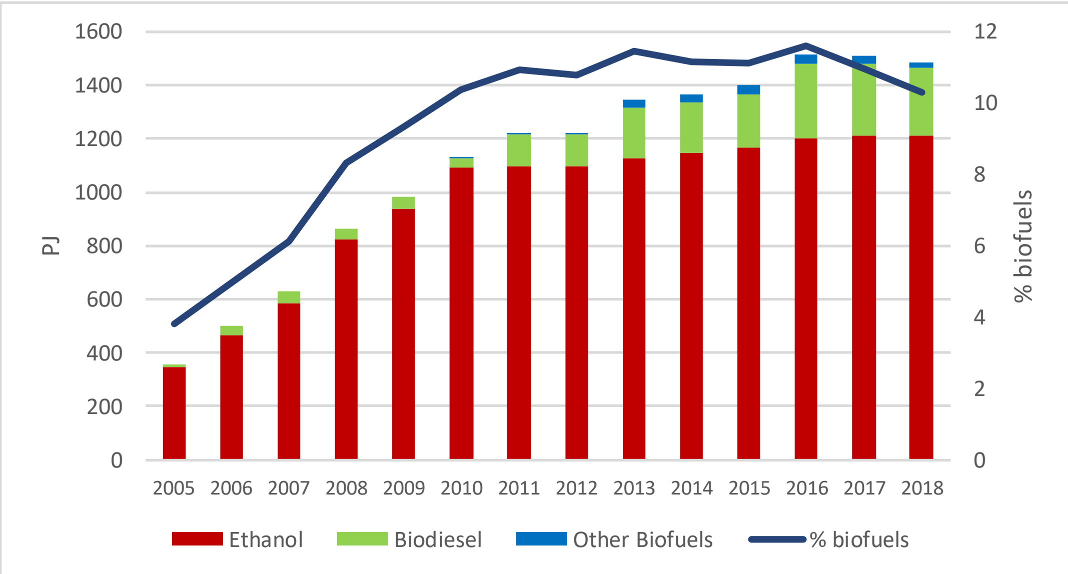

Figure 5: Bioenergy use in transport - USA

The Renewable Fuel Standard has provided a long-term steady policy impetus which has driven the growth in ethanol and biodiesel use, although the maximum level of corn ethanol allowed under the policy has now been reached. Provisions for cellulosic ethanol within the RFS has provided stimulus for other biofuels. The federal policy is being complemented by state level policies, including the LCFS (Low-Carbon Fuel Standard) in California, which provide additional impetus and which are designed to promote the most carbon efficient fuel options.

These market policies are complemented by a number of other measures, including a substantial RD&D effort and measures such as loan guarantees which aim to help the development and financing of riskier novel technologies at scale.

Germany

In Germany biofuels make up 5-6% of total transport energy use, with the percentage not rising significantly since 2010 (Figure 6).[8] 71% of the biofuels used in 2018 was biodiesel, with ethanol making up most of the balance. Biomethane contributed 1.2%.

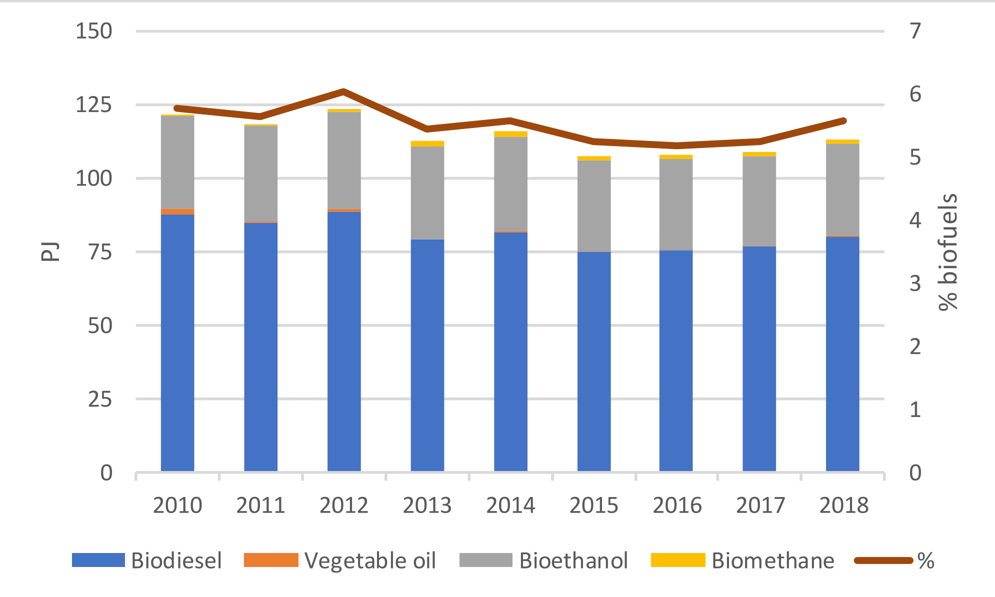

Figure 6: Bioenergy use in transport - Germany

In Germany, policies are aligned with those of the European Union Renewable Energy Directive and the Fuel Quality Directive. The principal measure to meet the targets in these Directives is the GHG-based quota system which was implemented in 2015. It obligates fuel supplier companies to sell the respective biofuel together with its fossil counterpart gasoline or diesel (which is usually done through blending), in order to produce a fuel mix which achieves a 3.5% GHG mitigation (compared to fossil gasoline and diesel mix) for the entire fuel sector from 2015, with increasingly stringent targets of 4% and 6% for 2017 and 2020

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[8] https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html

onwards. If these obligations are not met, penalties of about 47 EURct/kg CO_2 equivalent apply. Biofuels that are counted within the quota are subject to the full energy tax. Moreover, the regulations provide for a maximum limit of established biofuels and minimum quotas for advanced biofuels as well as counting electricity for transport.

Specific remaining barriers to widespread adoption of biofuels in Germany include the comparably low prices for fuels and mobility in Germany, and sensitivity amongst stakeholders to biofuels sustainability issues, coupled to a very strong push towards electricity for transport and for e-fuels. This is coupled to uncertainties regarding transposition of European REDII and ESR (effort sharing regulation) into national legislation.

Sweden

In Sweden biofuels use has grown strongly since 2010, rising from 5 to over 30% of transport fuel use by 2018. The rise is due to increased use of biodiesel, and in recent years to a growth in HVO use (Figure 7). These fuels provided 91% of the bioenergy used in 2018.[9] Sweden is the largest user of biomethane in transport in Europe, and this provides some 1.4% of transport energy needs. There was an earlier push to promote ethanol, both as E10 and higher blends, but recently ethanol consumption has been declining.

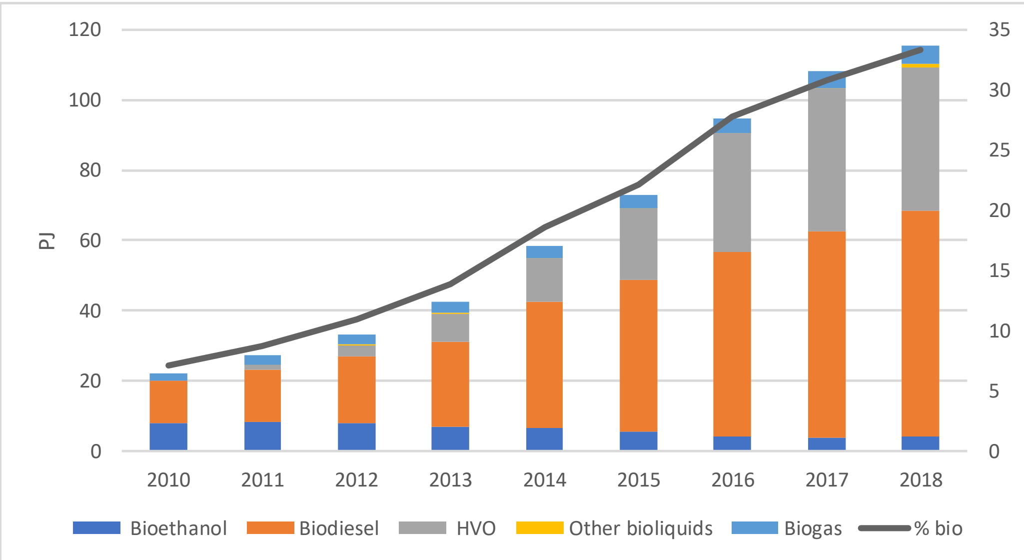

Figure 7: Bioenergy use in transport - Sweden

[9] Analysis based on date at https://www.energimyndigheten.se/en/facts-and-figures/statistics/

While consumption in Sweden has been rising strongly, there is very little indigenous production of biofuels, although some projects are under discussion and development. Fuels are imported – for example HVO from Finland. Policy uncertainty is seen as one of the major impediments to investment.

The main driver for biofuels use in Sweden is energy and CO_2 taxation, from which biofuels are exempt. However, tax exemption for biofuels is governed by EU state aid rules. The EU Commission has approved tax exemptions for biofuels in Sweden until 2020. The level of support allowed is also governed by state aid rules and is unstable. At the moment, there are no decisions on how the main policy instruments for biofuels will look 2021 and beyond and this is clearly a source of uncertainty.

Finland

Finland has very few oil and gas resources but a longstanding tradition of using bioenergy, based on its significant forestry resources and linked to its forestry industry sector. It has three major producers of biofuels – Neste producing HVO, mostly from imported feedstocks, UPM producing renewable diesel from tall oil and St1 producing ethanol. In addition, biomethane is produced for transport use.

In 2018 biofuels provided some 9.4% of road transport energy needs, providing 11% of diesel requirements, and 6% of gasoline requirements via E5, E10 and E85. In addition, biomethane provided 59% of the methane used in transport (although this makes up only 0.2% of road transport energy use). While the level of renewable fuels within the gasoline sector has remained fairly constant in recent years, the level of biofuels in the diesel sector has varied significantly,

Finland has established a number of ten-year targets including the intention to reduce the use of imported oil by 50% during the 2020s, and increasing the share of renewable transport fuels to 40% by 2030 (including double-counting).

The 2016 Finnish national energy and climate strategy for 2030, calls for a 50% reduction of CO_2 emissions from transport by 2030, the reference year being 2005. Three key measures to reduce emissions are:

- Improving the energy efficiency of the transport system
- Improving the energy efficiency of vehicles
- Replacing oil-based fossil fuels with renewable and/or low-emission alternatives

The main measures to drive this change are:

- An increase in the biofuels blending obligation so that the physical share of biofuels (energy content) in road transport fuels will be increased to 30%, and there is a separate sub target for advanced biofuels of 10%. In addition, a 10% biocomponent obligation was set for light fuel oil.
- **CO_2 based vehicle taxes**: In 2019, the minimum purchase tax is 2.7% (BEVs) and maximum 48.9% (WLTP CO_2 >360 g/km)[10]. The progressive CO_2 tax is a strong indirect support to BEVs and PHEVs.

Brazil

Brazil has a long experience of widespread use of biofuels, notably ethanol from sugar cane, encouraged by a strong blending mandate and the ready availability of 100% ethanol. Most cars in Brazil are flex fuel vehicles which can opt for either gasoline blends or pure ethanol depending on the price at the pump, which depends on the relative costs of ethanol and gasoline. Biodiesel use has also been growing. There are two large-scale cellulosic ethanol plants co-located with conventional sugar cane distilleries but these are still to reach design output.

Overall biofuels use in transport has remained stable in recent years. Significant growth is expected with the introduction in 2020 of the RenovaBio program. This introduces a tradeable certificate scheme based on GHG reductions in the transport sector, which will incentivize low-carbon fuels in the transport sector.

[10] https://www.vero.fi/globalassets/henkiloasiakkaat/autoverotus/verotaulukko-1a_1365_2018.pdf

Barriers to widespread deployment

Specific barriers to alternative transport fuels vary from country to country, depending on the policy and regulatory frameworks in place. Different fuels also face specific barriers depending on their level of technical and commercial maturity and their feedstock demands. Analysis of the barriers experience suggests that the critical issues include: technical issues, economic competitiveness, ease of integration of fuels, availability of appropriate feedstock, meeting sustainability requirements and perception of associated sustainability risks.

Barriers to the implementation of alternative transport fuels are multifold and differ from fuel to fuel and from country to country. While fuels at TRL 9 face barriers such as production costs, stimulating policies, and mobilization of sustainable biomass feedstock, fuels at lower TRL levels still face technical and economic challenges.

The current transport system has been optimized in the past 100 years, and offers predictable income to the established stakeholders, while the infrastructure required for the future transport system still has to be built, with higher costs and risks associated and unclear and risky business cases.

A multitude of fuel production pathways is under consideration for the future transport system, and they differ with respect to potential feedstock availability, production costs, GHG emission reductions offered, and their compatibility with the existing fleet. Every country has to find its own optimum fuel mix, depending on national demand of fuel types, national biomass availability, national biofuel production capacity, and the possibility and cost of imports.

Detailed information on policy measures can be found in Part 1 of the overall report, “Key Strategies in Selected Countries”.

Lessons learned from past market introductions of alternative fuels

Another ongoing project with the Advanced Motor Fuels TCP is AMF Annex 59: Lessons Learned from Alternative Fuels Implementation. It aims to identify barriers to the market launch of alternative transport fuels from specific market launch examples of a couple of countries.

The examples of alternative fuels and vehicles market introductions that were assessed in AMF Annex 59 are depicted in Figure 8.

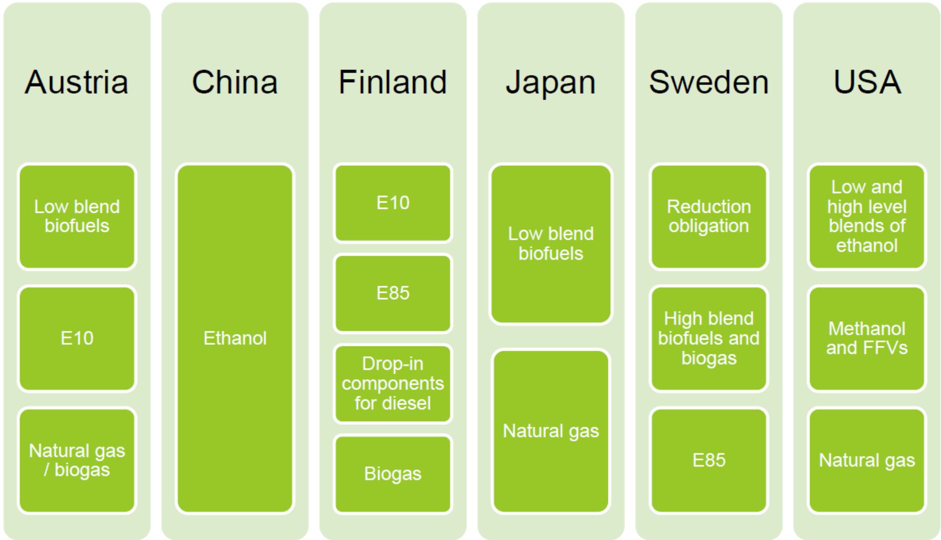

Figure 8: Overview of country-specific case studies in AMF Annex 59

Although at the time of writing, the AMF Annex 59 has not been finalized, preliminary findings are described below. Findings from Germany – although not part of that project – have been added.

Austria

In Austria the introduction of E10 was stopped weeks before market entry. The main implementation barriers were the public discussion on food/feed vs. fuel and a discussion on engine compatibility. In addition, initial negative reactions on the E10 market introduction in Germany influenced the opinion of the general public in Austria. This negative public perception and motorist associations opposing the market introduction are perceived as the main barriers to the market introduction in Austria.

Another case study dealt with CNG vehicles. They were successfully introduced into the market but, due to missing acceptance of the general public, the number of vehicles and gas stations decreases. These two case studies indicate that the public opinion and acceptance as well as the political will are essential for a positive market implementation.

Finland

In Finland the main implementation barriers are a tax problem for renewable fuels and the lack of availability of FFVs (Flex Fuel Vehicles). On the EU level, minimum taxes are set in €/l. Finland has a transparent and fair tax system for liquid fuels consisting of energy tax, CO_2 tax and bonus for reduced local emissions. This system also considers heating value and CO_2 emission. The EU minimum tax is higher than the Finnish tax system sets and therefore unfair for those biofuels with a low heating value. This tax problem makes commercial utilization of these kinds of biofuel impossible.

In Finland E85 is available in most parts of the country. However, sales of E85 has stagnated, as there is no offering of new flex-fuel vehicles anymore.

Japan

The implementation barriers found in Japan could be divided into legal issues, consumer (market)-driven policies and external factors. In Japan the Quality Assurance Law and Alternative Fuel Law were enacted to spread biofuels in Japan since 2010. However, these laws do not mandate the introduction of alternative fuels, they only create the possibility and set the framework and standards. If the introduction is not obligatory, incentives to attract consumers to the introduction are necessary, but such incentives were missing for biofuels for consumers.

The external factor was the nuclear accident in 2011, since when the top priority is on securing electricity power and the spread of biofuels has a low priority. This shows how important policy measures are and that they have to interlock to overcome the first big peak of implementation barriers.

Sweden

The reduction obligation in Sweden, which is described in detail in Part 1 of the overall report, is very dependent on availability and price of drop-in fuels and sets both a floor and roof on the use of biofuels for low blends. There are no incentives to go above the reduction obligation. The fuel tax exemption for biofuels is not in line with EU regulation and therefore very short-term and can only be given if biofuels are more expensive than fossil fuels.

For E85 the barriers are the small market for dedicated vehicles and negative public attitude combined with reports on technical problems. This shows that knowledge and information are important as well as long-term perspective of policy instruments.

USA

In the USA the changing priority of policies made a market implementation of biofuels in particular and alternative fuels in general difficult. The societal benefit that the government prioritized and that was in favor of biofuels has changed over the past several decades. In the 1970s and 80s, in times of oil embargo, the main driver for biofuels was energy security and energy diversity. In the 90s, the driver shifted to air quality benefits. In the 2000s and 2010s the priority changed to GHG benefits, and most recently it changed again to economic advantages. Any time that biofuels were seen as a solution to a problem, the established fossil fuel industry adapted: First, new oil and gas supplies were discovered and their prices fell; then improved automotive technologies in terms of fuel quality, after-treatment systems, and engine control delivered less-polluting vehicles; and finally, biofuels face competition from other alternatives to reduce GHG emissions, such as BEVs (Battery Electric Vehicles and PHEVs (Plug-in Hybrid Electric Vehicles). Also, current low crude oil prices diminish any economic advantages of biofuels.

Germany

Barriers mentioned for Germany include comparably low prices for fuels and mobility, uncertainties regarding the transposition of European RED II and ESR (effort sharing regulation) into national legislation, the climate protection program that is focusing on advanced biofuels based on residues and e-fuels, a push towards electro mobility, and acceptance issues from different stakeholders. It seems that in Germany sustainability is still hardly driven by costs, but from a fuel perspective also the price impact of fuel specific GHG mitigation could be seen with the implementation of the GHG quota system from 2015 onwards.

Barriers generic to all countries

The findings from the country case studies in the AMF Annex 59 project were clustered to 5 groups of implementation barriers in an echo of the Argonne checklist[11] categories. Many of the implementation barriers are interconnected. Some of the listed points are influenced or even caused by other listed implementation barriers from a different category. The multitude of interconnections is very complex and therefore not shown here. The main implementation barriers which could be found in most of the partner countries are listed in Figure 9:

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[11] Risch, C. E., Santini, D. J., and Johnson, L. R. Using Checklists to Assess Your Transition to Alternative Fuels: A Technical Reference. United States: N. p., 2016. Web. doi:10.2172/1344887

Technical issues / Infrastructure

- Assurance of technical performance and compatibility with the existing fleet
- Availability of dedicated vehicles (e.g. FFV)
- Access to repair infrastructure and refueling infrastructure for dedicated vehicles

Politics / Authorities

- Negative basic attitude of politics and push of electromobility
- No obligation for alternative fuels
- Inconsistent and changing policy and priorities
- Lack of long term perspective in policy instruments

Costs / Economics

- Missing incentives for consumers and unclear tax incentives/legislation in future
- Investment costs for dedicated vehicles and second-hand value
- Alternative Fuel infrastructure cost, production costs and capacity
- Comparably low prices for fuels and mobility
- Inertia in the market

Consumers / Public

- Missing awareness and/or acceptance in general public
- Negative perception in public and fundamental scepticism
- Public discussion on Food/Feed/Fuel
- Discussion and rumours on engine compatibility concerns
- Missing incentives for consumers

Figure 9: Barriers to the market introduction of alternative fuels, as found in AMF Annex 59

Barriers to advanced biofuels

A recent study from the International Renewable Energy Agency (IRENA) (Advanced Biofuels – What Holds Them Back[12]) analyses current barriers to investment in advanced biofuels, based primarily on a survey of industry executives and decision makers. The study focuses on cellulosic ethanol and HVO as fuels, and finds that different fuels face different

[12] IRENA Advanced Biofuels – What Holds Them Back, November 2019, https://www.irena.org/publications/2019/Nov/Advanced-biofuels-What-holds-them-back

barriers (as discussed above). The report highlights the following as main barriers to future advanced biofuels deployment.

- Regulatory uncertainty stands out as the most important impediment to investment in advanced biofuels given the long timescale associated with projects. This was particularly the case in Europe; now the provisions of RED-II are considered to provide a sound basis for some further investment in advanced biofuels.
- Transport sector decarbonization calls for accepting several fuel alternatives simultaneously rather than resorting to a single, all-encompassing solution. The specific barriers for the further development of different fuels differ, especially between those affecting drop-in fuels and other fuels such as cellulosic ethanol, which will may face uneven cost competition from first-generation ethanol producers in a declining market. The creation of an enabling environment for advanced biofuel deployment therefore requires much more nuanced and multifaceted regulation than for other forms of renewable energy.
- Low subsidy levels, high financing costs and limited availability of finance are seen by many executives as barriers in the current market.
- Straight forward tax- or obligation-based regulatory systems can be effective and applicable, particularly for countries just starting to promote advanced biofuels. For example, in Sweden, the rapid switch from fossil fuels to biofuels was driven by tax exemptions on biofuels, and high carbon and energy taxes on fossil fuels. Technology-neutral fuel standards, such as those in California (US) and those planned for Brazil, are also favored by most industry executives. The Californian experience has been a positive one, in that state legislation has created continued stability and project developer confidence. It has also clearly diversified transport fuel sources, such that there has been a substantial increase in the deployment of ethanol, HVO, biomethane and electricity. A fuel-neutral carbon intensity-based mandate system provides a fair platform for advanced biofuels to compete.
- Many industry executives consider the introduction of sustainability standards and certification schemes to have been a positive development, boosting markets for advanced biofuels. However, they question the accuracy and reliability of common methods for estimating GHG emissions, land-use change and indirect land-use change. They would welcome a more harmonized certification system verifying the sustainability credentials of their products.

Expert opinions expressed during the policy workshop

On 18 November, 2019, the preliminary results of this project were presented at a workshop in Brussels and discussed with stakeholders. Around 70 participants attended the event, representing mainly the biofuels industry and related research organizations, but also energy- or climate-related authorities and the automotive industry. The fossil fuel industry, however, was unfortunately not represented.

Barriers cited by these experts included:

- Lack of long-term stable policies
- Problems with conflicting details in regulations, e.g. EU state aid rules conflicting with biofuel taxation
- Technological risk of biofuel technologies

They also provided ideas for adapting the policy framework. The main requests were:

- to install some sort of carbon price
- to focus on the carbon intensity of renewable fuels
- to get the oil majors involved,
- to establish a requirement to phase out fossil fuels in the transport sector, and
- to allow the automotive industry to count the GHG emission reductions offered by the use of renewable fuels against their CO_2 fleet targets (which could then be strengthened).

The automotive industry made a strong statement that if accounting for the use of renewable fuels would be possible, they would be very motivated to issue guarantees for the use of high blends or pure biofuels in their engines/vehicles. (The CO_2 fleet targets would then have to be strengthened, as to still also support the goal of introducing electric vehicles.) In fact, the penalties that automakers face from failing to comply with the CO_2 fleet targets in the EU are much higher than any carbon price under discussion nowadays.

Reflections

Reflecting the assessments carried out in this project, findings from AMF Annex 59, findings from the IRENA study, the discussion at the project workshop, and also other existing literature, the following barriers seem to be most important:

- Well-established transport system to compete with
- Fluctuating policy drivers / lack of long-term stable policies

- Low public acceptance / perception of technical performance issues and sustainability concerns
- Incomplete set of policy measures
- The need to build up infrastructure for alternative fuels and alternative fuel vehicles such as FFVs, EVs, FCEVs
- Risks associated with biofuels

Well-established transport system to compete with

What we are looking for if we are to reach the required level of decarbonization, is the transition into a new transport system that uses multiple alternative fuels in a range of vehicles. This new, complex system has to compete with the current system, which has been established and optimized over the past 100 years and offers predictable income to the established stakeholders, while the infrastructure required for the future transport system still has to be built, with higher costs and risks associated and unclear and risky business cases. Table 2 lists features of the current and the future transport system.

Table 2: Current and future road transport system

Current road transport system	Future road transport system
Well-performing fuel/engine/after-treatment combinations	Adaptation of fuel/engine/after-treatment system required
Established material compatibility	Ev. lack of material compatibility
Many vehicle models available	Few models available
Robust vehicle repair infrastructure	New repair knowledge required
Good driving range	Sometimes lower driving range
Well-established fuel production	Fuel production infrastructure has to be built
Limited number of fuel options provided	Large variety of alternative fuels
Ubiquitous refueling infrastructures	Refueling infrastructure has to be built and might not be profitable
Existing fleet uses existing fuels	New fleet has to be built up

The system of stakeholders in the established transport sector (as depicted in Figure 10) includes the fossil fuel industry and fuel marketers, the automotive industry and vehicle marketers, and the consumers freight sector and private car owners. In the new system, new stakeholders come into the picture, such as biomass producers and biofuel producers, and existing stakeholders are expected to adapt their businesses to produce alternative fuels and alternative vehicles. Doing so is not economic for any of these stakeholders unless policies set regulations to offset the increased production and infrastructure costs. As a result, the biofuels market depends on political interventions. Thus, it is of major importance that policy sends strong signals and keeps up the support for renewable fuels over a long period of time. Workshop participants even called for targets for renewable fuels in 2040 and 2050 to be communicated already now.

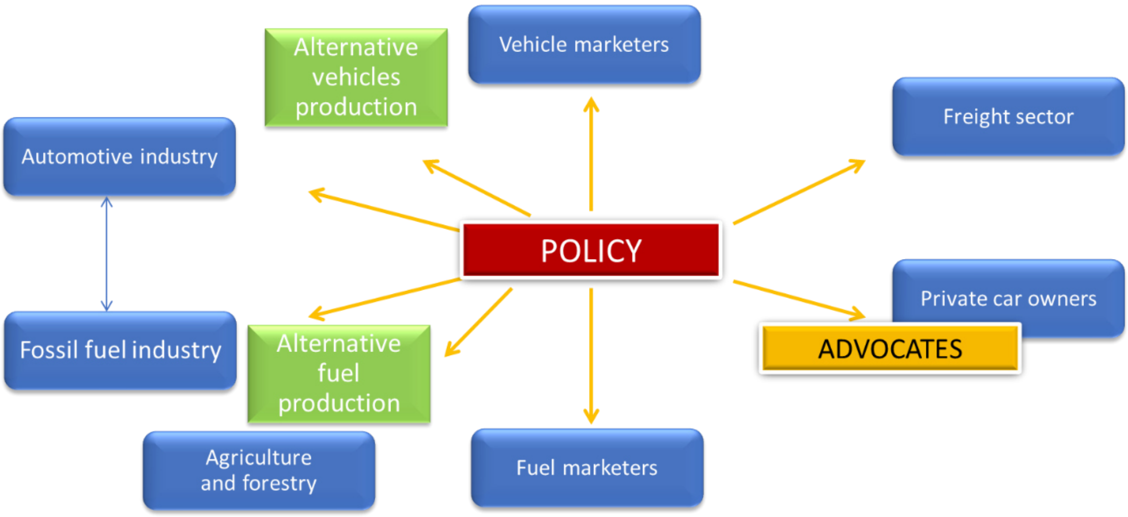

Figure 10: Multitude of stakeholders involved in the market implementation of alternative fuels and vehicles

Fluctuating policy drivers

However, policy drivers are often fluctuating, as described earlier for the example of the USA. Through improvements in the existing system, the driver towards renewable fuels became weaker and ineffective, and the new fuels and vehicles, not yet fully established, vanished from the market again.

Public perception

Another very important aspect is the public perception of new fuels. The debate around the implications that large-scale production of biofuels could have on GHG emissions through direct and indirect land use change (LUC and iLUC) has stalled the growth of established biofuels production and use in Europe. And although EU policy has been adapted and now includes measures to safeguard the sustainability of biofuels, the public image of biofuels remains severely damaged.

Incomplete set of policy measures

For the market introduction of alternative fuels and vehicles it is also important to provide a set of carefully balanced policy measures that considers all stakeholders in the transport system and offers benefits to each of them. Also, the very details of regulations can create serious problems, as currently is the case with EU state aid rules that are in conflict with tax benefits for biofuels.

As to not forget any of the multiple stakeholders in the transport sector, Argonne National Laboratory has developed a checklist that can be used to assess whether everyone´s needs have been considered[13]. While it might be obvious to talk to the fossil fuel industry and also to the automotive industry, a group that can rather easily be forgotten is private car owners. While freight operators act based on economic considerations and this is their main business, private car owners often lack sufficient insight into the pros and cons of the multitude of vehicle and powertrain/fuel options. Their knowledge is rather based on what is reported in the media, with magazines of motorist associations often playing a major role. The influence of these advocates should not be underestimated, and they should be involved in efforts to introduce alternative fuels and vehicles.

Infrastructure requirements

Renewable fuels can, depending on their chemical nature, be applied in engines as low blends, high blends, or neat, as drop-in fuels or with the need for adapted engines or vehicles. Also they can be produced in stand-alone biofuel production facilities, or through co-processing in refineries, or from CO_2 and hydrogen in e-fuels facilities. The introduction of renewable fuels to the market always requires investment in some type of new infrastructure, be it biofuel or e-fuel production facilities, adaptation of refineries, adaptation of engine and vehicle production systems, purchase of alternative fuel vehicles, or adaptation of fuel pumps. These investments will be made by different actors from within the broad range of stakeholders involved, and they will only be made if the actors can define their business case. Policy makers should be aware of these multiple options and they need to find the solution that works best for their country.

Risks associated with the take-up of low-carbon fuels

Different fuels face different barriers which need to be recognized in designing policy

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[13] Risch, C. E., Santini, D. J., and Johnson, L. R. Using Checklists to Assess Your Transition to Alternative Fuels: A Technical Reference. United States: N. p., 2016. Web. doi:10.2172/1344887

portfolios to promote more widespread deployment. These relate to

- Technical risk
- Economic competitiveness
- Ease of integration of fuels
- Availability of appropriate feedstock, meeting sustainability requirements
- Perception of associated sustainability risks

Technical risk

The production of ethanol, biodiesel, HVO and biomethane from a wide range of crops, residues and wastes has been fully demonstrated and, with due care, technical risks are minimal. On the other hand, there are still few cases of successful production of cellulosic ethanol and biofuels from thermochemical processes such as pyrolysis and gasification.

Economic competitiveness

The costs of producing ethanol, biodiesel, HVO and biomethane are understood and heavily dependent on the feedstock costs, and in general are significantly higher than those of the fossil fuels that they aim to replace, in the absence of financial mechanisms designed to offset the GHG and other environmental benefits associated with their production and use.

The costs of emerging biofuels are currently higher than those of established biofuels, but with scope for reduction as deployment grows and experience develops. In the short- to medium-term they will need higher level of support than established biofuels if their deployment is to grow.

Ease of integration

Ethanol and biodiesel can readily be blended with fossil fuels up to a certain level, but beyond that vehicle modifications and specific distribution systems may be needed. These issues can be successfully addressed (as in Brazil for example). Biomethane also requires specific vehicle fleets and distribution networks, whereas HVO and some products from thermochemical processes can be tailored as “drop-in fuels” to replace diesel and other fuels including jet fuel.

Sustainable feedstock availability

While in principle it would be possible to enhance production of feedstocks for ethanol and biodiesel production, concerns about the land-use impacts of some established biofuels feedstocks have led to constraints on their more widespread production and use of such fuels in some regions (such as the constraint on “crop-based biofuels” within the EU RED-II). While a clear evidence-based sustainability governance framework is important for all biofuels, this is particularly so for these crop-based fuels, whereas there is less “in principle” opposition to fuels based on wastes, residues and other cellulosic feedstocks so long as they are sustainably produced and used.

The growth of HVO production is increasingly based on waste-based feedstocks such as UCO and industry bioproducts, but there are limits to the extent that such materials can be sourced. Future growth may have to be based on specifically produced materials.

Summary

Table 3 summarizes the points above, highlighting key barriers to more widespread deployment.

Table 3: Main risks for biofuels

	Technology risk	**Economic Competitiveness**	**Fuel integration**	**Sustainable Feedstock availability**
Ethanol				
Biodiesel				
HVO				
Biomethane				
Cellulosic ethanol				
Thermochemical biofuels				

Key:

	No significant barrier
	Some barriers
	Major barriers

Policy requirements for increased renewable fuels deployment

Long term and stable policy frameworks are essential to foster growth of renewable transport fuels. An appropriate policy portfolio would include measures to "level the playing field" by removing fossil fuel subsidies and putting effective carbon pricing mechanisms in place. The portfolio also includes specific targets for low-carbon fuels, and mechanisms to ensure that the fuels are competitive in the transport market, along with a stringent, evidence-based sustainability governance regime.

Additional measures are needed to promote fuels which are not yet fully commercialized, including mandatory obligations for deployment of emerging biofuels, dedicated financial mechanisms and instruments to facilitate technological development, subsequent market deployment, and targeted support for RD&D.

Policies have been and will continue to be essential to foster the growth of renewable transport fuels, as is discussed in more detail in Part 2 of the overall report ("Production Technologies and Costs").

Policies used include blending mandates, excise tax reductions or exemptions, renewable or low-carbon fuel standards, as well as a variety of fiscal incentives and public financing mechanisms. The countries that have achieved the most success in growing the production and use of biofuels have used a mixture of market-pull and technology-push policies.

While the production and use of transport biofuels has more than doubled over the last decade, progress in expanding biofuels production remains well below the levels required to decarbonize transport significantly. Several factors continue to impact the effectiveness of biofuels policies such as relatively low petroleum and fossil fuel prices, uncertainty about future policy and funding programs to support established and emerging biofuels, the inconsistent regulation of global trade of biofuels and continuing concerns related to food security, land use change and overall sustainability.

Enabling framework for low-carbon bioenergy technologies

An appropriate policy and regulatory environment is needed to support the expansion of bioenergy in general, even for technologies which are mature. The features that are desirable to provide a supportive enabling framework for low-carbon technologies in general, and which can promote deployment at low cost, have been identified and apply especially to transport biofuel options.[14] These are summarized below.

- Level the playing field
    - Abolition of subsidies for the production and use of fossil fuels.
    - Wider introduction and improvement of ways of pricing-in the environmental externalities caused by fossil fuel use, through a carbon pricing regime. To be effective this needs to cover all energy sectors and scales of operation and reflect the real societal cost of carbon emissions.
    - Systematic removal of barriers to low-carbon energy production in the taxation and wider regulatory system, which can be major barriers slowing down low-carbon technology deployment. These include unnecessarily strict state aid regulations, which can unnecessarily prevent measures aimed at favoring low-carbon technologies, but which have no impact on international competitiveness.
- A favorable enabling policy environment for bioenergy with the following features:
    - A long-term stable policy and regulatory framework that provides certainty about the market for an extended period (10 to 15 years), sufficient to justify investment in a series of production plants.
    - Clear and specific targets for the use of sustainable bioenergy as part of a national strategy, plan or roadmap and which cover transport fuels, heat and electricity generation.
    - Ensuring that bioenergy producers have access to the relevant markets (e.g. to be able to access the transport fuel market).
    - Appropriate mechanisms to stimulate low-carbon energy production, which provide sufficient revenue to offset the difference in costs between biofuels and fossil fuels, taking into account carbon pricing and other such measures. There needs to be confidence that such mechanisms will be sufficiently stable to attract finance at competitive terms.
    - Measures to avoid non-financial barriers to deployment, such as appropriate and clear regulations relating to planning, environmental permitting and energy market access.

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[14] IEA Technology Roadmap: Sustainable Bioenergy, 2017

- Stringent but stable and science-based sustainability governance regimes, which are based on proven and globally accepted good bioenergy practices.
- Recognition of the social benefits of bioenergy, such as rural employment and income, and the contribution that bioenergy can make to energy security and diversity.
- Appropriate regulations relating to the integration of bioenergy (for example, the regulations and standards that apply to biofuel/ gasoline or diesel blends).

The general policy principles discussed above apply to both established and newly commercializing technologies that will be needed to deliver low-carbon visions for biofuels in transport. However appropriate policy and regulatory measures will be needed to help the new technologies to mature and avoid the “valley of death” between prototype or pilot plant operation and full commercial deployment.

Additional measures for not fully commercialized technologies

Significant barriers stand in the way of the investment needed to demonstrate the necessary new technologies at scale and to bring costs down. These include the technical risks associated with scaling up to full-size commercial plants (for example, large-scale cellulosic biomass-to-ethanol plants that have initially encountered problems scaling up). In addition, commercial and financial barriers result from early plants not having benefited from technology learning, causing their outputs to be more expensive than both their fossil fuel and other renewable energy competitors, and other more established bioenergy technologies.

This means that technology-neutral measures (such as an increased price for carbon emissions), while useful by discriminating against fossil options, are unlikely to promote the commercialization of the technologies needed to meet longer-term needs, and on their own may lock in less desirable technology choices (e.g. established rather than emerging biofuels).

Bioenergy has specific characteristics that make a number of these barriers more significant than for other new sustainable energy technologies. For example, most bioenergy technologies are not modular (as they are for solar PV or wind), and so a relatively larger investment is needed to demonstrate commercial-scale bioenergy and biofuel plants. The sums involved are beyond the balance sheet capabilities of many energy companies and also beyond the budget of many national RD&D programs.

Additional measures are needed to promote the development of these fuels and processes, since these will not initially be able to compete in a "technology-neutral" policy environment. These can include:

- Mandatory obligations for deployment of emerging biofuels and for specific subcategories that are at different stages of technical and market maturity.
- Appropriate and dedicated financial mechanisms and instruments to facilitate technological development and subsequent market deployment. These can include loan guarantees, and ways of bridging the initial cost differences between the novel energy sources and more established ones (fossil or other bioenergy).
- Support for RD&D focused on priorities identified in previous sections.

Policy best practice

There is a well-established body of experience which has successfully led to the deployment of established biofuels in a number of countries, while there is so far less experience of successful promotion of emerging biofuels, particularly because there are not yet many successful production plants which demonstrate that the technical challenges can be overcome. The following sections therefore look at the portfolios of policy measures for the two classes of biofuel separately.

Established biofuels such as ethanol, biodiesel, HVO and biomethane

The analysis of global and national trends above highlights that biofuels production and use is still dominated by established biofuels, such as ethanol from corn, sugar and other starch and sugar-based crops, and biodiesel from oils and fats, where the technologies are well proven. Expansion of the use of these fuels is possible but there are concerns in some countries about the implications for land use in expanding production of the necessary feedstocks. Significant expansion would also require measures to enable these fuels to be used at higher blend levels in transport, although the possibility of doing this has already been demonstrated in Brazil.

The production and use of HVO is growing rapidly. HVO production is based on proven technologies, and can produce "drop-in fuels", so avoiding integration problems and opening the way to the production of fuels for applications such as aviation and shipping. Biomethane is being more widely used in the transport sector, but requires separate infrastructure and adapted vehicles.

The main elements of policy portfolios which have been successfully adopted include:

- Blending mandates which make a percentage of biofuels mandatory. These are widely in place but not always effective if there are insufficient penalties for non-compliance, and arrangements to share any additional costs amongst market players (such as a certificate scheme). The mandates also need to be consistent with fuel specifications and blending regulations.
- There is growing trend to move to systems which incentivize transport fuels based on their GHG impacts (such as the Californian LCFS, the Brazilian RenovaBio scheme and various programs in Europe). These provide a significant incentive to move to higher biofuels blend levels and to encourage the development of more GHG efficient fuels.
- Strict but consistent sustainability guidelines are needed to ensure fuels meet necessary environmental, social and economic goals.

Emerging biofuels

The range of emerging biofuels – including cellulosic ethanol and thermochemical fuels based on gasification/pyrolysis – are important since they allow access to lignocellulosic feedstocks for biofuels production. These are likely to be required in order to scale up biofuels production to the levels consistent with their role in low-carbon scenarios. Successful operation of these processes on a large scale is not yet well established, although a number of new plants have been announced and are in process of being constructed.

While the initial production of these fuels will require high levels of support either for producing or using the fuels, these higher incentives may not be enough in themselves to resolve the technical barriers involved. For example, in the US the support available for cellulosic ethanol from the RFS2 and LCFS values the fuel at nearly 3 times the price of gasoline, but production and use of these fuels is so far restricted[15]. There will be no further investment at scale until the technology is demonstrated commercially at scale.

Policy measures which can support the introduction of these processes include:

- Separate obligations for new fuels with high rewards to reflect likely high cost of first successful plants (e.g. US RFS2 provision for cellulosic fuels)
- Continuing support for RD&D, recognizing especially the extended period likely

[15] IEA Bioenergy Potential for Cost Reduction of Advanced Biofuels

to be needed in order to commission novel plants and to solve problems which inevitably arise when operation at commercial scale commences.

- Risk guarantees such as those available within the US can help reduce the financial risk associated with constructing large scale first of a kind facilities.

Final remarks

Each government has to find the right alternative fuels and vehicles to go for, and to find the right set of policy measures for the particular national situation at a given time. There are no one-size-fits-all solutions to decarbonize transport. The only constant is that bold action needs to be taken now to reach decarbonization at the required level and speed.

Abbreviations

2DS	IEA 2 Degree Scenario, compatible with the goal of limiting global heating to 2°C by 2100
ALIISA	Model used by VTT to calculate the future composition of vehicle fleets in this study
AMF	Advanced Motor Fuels
B5, B7,…	Diesel blends with x% FAME
BEV	Battery electric vehicle
CNG	Compressed natural gas
CPS	IEA Current Policies Scenario
E5, E10,…	Gasoline blends with x% ethanol
ESR	Effort Sharing Regulation
EUR	Euro
EV	Electric vehicle
FAME	Fatty acid methyl ester
FCEV	Fuel cell electric vehicle
FFV	Flex-fuel vehicle, capable of using either gasoline or high-blend ethanol (or pure hydrous ethanol in the case of Brazil)
FQD	Fuel Quality Directive
GHG	greenhouse gases
HDT	Heavy duty truck
HDV	Heavy duty vehicles
HEFA	Hydrotreated esters and fatty acids
HEV	Hybrid electric vehicle
HVO	Hydrotreated vegetable oils
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LCFS	Low-carbon Fuel Standard, Californian regulation
LDT	Light duty truck
LDV	Light duty vehicles
LPG	Liquefied petroleum gas (auto gas)
LUC	Land-use change
MDT	Medium duty truck
NPS	IEA New Policies Scenario
PHEV	Plug-in hybrid electric vehicle

PV	Photovoltaic
RED	Renewable Energy Directive, EU regulation
RED-II	Recast of the Renewable Energy Directive, EU regulation
RFS	Renewable Fuel Standard, US regulation
SDG	Sustainable Development Goal
SDS	IEA Sustainable Development Scenario
SE Asia	South-East Asia
TCP	Technology Collaboration Programme (of the IEA)
TRL	Technology Readiness Level
TTW CO_2 emissions	Tank-to-wheel CO_2 emissions, i.e. tailpipe emissions
UCO	used cooking oil
USD	United States (of America) Dollar
WTT CO_2 emissions	Well-to-tank CO_2 emissions, i.e. upstream emissions from fuel or electricity production
WTW CO_2 emissions	Well-to-wheel CO_2 emissions, i.e. WTT and TTW combined