RENEWABLE FUELS INCENTIVE POLICIES

A survey of how governments encourage renewable fuels and lessons for renewable LPG

WLPGA

LPG EXCEPTIONAL ENERGY

The World LPG Association (WLPGA)

The WLPGA was established in 1987 in Dublin and unites the broad interests of the vast worldwide LPG industry in one organisation. It was granted Category II Consultative Status with the United Nations Economic and Social Council in 1989.

The WLPGA promotes the use of LPG to foster a safer, cleaner, healthier and more prosperous world.

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Contents

Glossary

CHP	Combined heat and power
CO	Carbon monoxide
CO_2	Carbon dioxide
DME	Dimethyl ether
EU	European Union
FAME	Fatty acid methyl esters
GHG	Greenhouse gas
Gt	Gigatonne
HEFA	Hydroprocessed esters and fatty acids
HVO	Hydrogenated vegetable oil
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
Kg	Kilogramme
kt	Thousand tonnes
kWh	Kilowatt hour
LGE	Liquid Gas Europe
LPG	Liquefied petroleum gas
MSW	Municipal solid waste
Mt	Million tonnes
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
NDC	Nationally determined contribution
NOx	Nitrous oxides
R&D	Research and development
RED	Renewable Energy Directive (European Union)
RFS	Renewable fuel standard
RPS	Renewable portfolio standard
PV	Photovoltaic
rDME	Renewable dimethyl ether
rLPG	Renewable LPG
SAF	Sustainable aviation fuel
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value-added tax
WLPGA	World LPG Association

Executive summary

Renewable fuels are set to play a vital role in the global energy transition. Their importance has been growing rapidly in recent years. Global production of biogasoline and biodiesel – based mainly on agricultural crops – has expanded more than tenfold since 2000. Output of renewable diesel using second-generation hydrogenated vegetable oil (HVO) technology has also started to take off. Supply of biogas – the other main type of renewable fuel available today – grew briskly through to the early 2010s, but growth has slowed since. Renewable fuels are currently made almost entirely by processing biomass, but new synthetic fuels based on hydrogen are also expected to contribute to decarbonising sectors that are hard to electrify in the long term, notably long-distance transport and heavy industry.

Rising supply of and demand for renewable fuels, centred on the United States, Europe and Brazil, has been driven mainly by government incentive policies. In most cases, strong policy support has been necessary to compensate for the higher cost of making biofuels compared with conventional petroleum-based alternatives. The case for supporting these fuels rests largely on their environmental benefits, as well as their ability to enhance energy security and bring broader economic and social benefits. Tailpipe emissions of nitrogen oxides, sulphur dioxide, carbon monoxide and particulates from biofuels are generally low compared with gasoline and diesel, while burning biogas pollutes far less than oil or coal. Greenhouse-gas (GHG) emissions from using renewable fuels can also be significantly lower depending on the type of fuel, production route and location.

Renewable liquefied petroleum gas (LPG), or rLPG – LPG derived from production processes that use biomass or other renewable energy sources as feedstock – is an emerging renewable fuel. RLPG can, in principle, be produced in many different ways, using different types of thermal and chemical processes, but only one of these technologies – HVO – is in full commercial use today. The HVO process involves the hydrogenation of vegetable oil or animal fat to produce renewable diesel or jet kerosene, yielding small volumes of rLPG – typically 5-7% by weight of the renewable diesel. Some plants separate out and commercialise the rLPG as a premium product. Output of rLPG from HVO plants, which amounts to around 450 000 tonnes per year at present, is set to continue to grow in the near term. New production pathways being developed today will be needed to expand supply substantially in the longer term given limitations on sustainable supplies of vegetable oil and animal fat feedstocks.

As with other renewable fuels, the main attraction of rLPG is that, as it is derived from renewable biomass, it can help reduce greenhouse-gas emissions if it is substituted for fossil LPG. Depending on the type of feedstock used and how it is produced, the carbon footprint of rLPG can be up to 80-90% smaller than that of petroleum-derived LPG. A major advantage of rLPG is that it is chemically identical to conventional LPG, making it a genuine "drop-in" fuel that can be used in its pure form or blended into conventional LPG in all applications, ranging from vehicles to boilers, without any need for modifications to supply infrastructure or end-use equipment. RLPG offers all the other benefits that conventional petroleum-based LPG already provides as an efficient, portable, clean, versatile and accessible energy source.

There are several ways in which governments can and do encourage the production and use of renewable fuels. Financial incentives are the main type of instrument. Such incentives can be directed at the fuels themselves or at the technologies that use them. Supply-side incentives can take the form of capital grants, soft loans or rapid depreciation for investment in production facilities. Demand-side incentives can take the form of a lower rate of excise duty, carbon tax (reflecting the smaller carbon footprint of renewable fuels) and/or sales or value-added tax (VAT), or a complete exemption. They also include cost-based feed-in tariffs or regulated prices guaranteed under long-term contracts for power and heat generated at plants fuelled with biogas or for biomethane injected into the gas grid to make them competitive with other fuels. Feed-in tariffs have been a major driver of the deployment of renewable energy generally around the world.

Regulatory measures have also proved extremely effective in promoting renewable fuels. The most direct type of regulatory intervention, and one used in a growing number of countries, is formal mandates on the use of renewable fuels, such as minimum blending requirements for biofuels and renewable portfolio standards (RPSs). Such mandates are sometimes accompanied by tradeable certificate schemes, whereby the obligation to meet a blending requirement or portfolio standard can be met by buying a certificate for a given volume in an organised marketplace, with certificate supplies by companies that exceed their mandate. Restrictions on the sale or installation of technologies that use fossil fuels, such as bans on the sale of conventional cars or oil- and gas-fired boilers, are also being used to expand opportunities for renewable-fuel technologies, such as biomethane-fired boilers or low-carbon hydrogen fuel cell cars.

Governments can support the research and development (R&D), demonstration and deployment of renewable fuel technology. Information dissemination and education can also form a key element of government-incentive programmes for clean technologies, including renewable fuels. And the deployment of renewable fuel related equipment and vehicles by the government itself through procurement programmes can be a powerful tool to build critical market mass for increasing the deployment of renewables more generally.

There is a large degree of convergence in the types of policies and policy instruments used to incentivise the production and use of renewable fuels across the countries surveyed in this report: Brazil, France, Germany, Thailand and the United States. This reflects to a large extent the policy lessons learned in countries that were early movers in promoting biofuels countries and the transfer of that experience to other countries. Financial incentives are the most commonly used instrument, having been proven to be highly effective in stimulating their use. Most countries combine those incentives with mandates or standards such as biofuel blending obligations and RPSs for biogas/biomethane. The other main type of policy support for renewable fuels in those countries is public funding of R&D and demonstrations of emerging technologies.

Reaping the benefits of rLPG calls for supportive, clear and predictable policy, regulatory and legal frameworks to encourage investment in developing and producing rLPG and other bioenergy technologies that yield rLPG as a co-product. Energy and climate policies everywhere need to be strengthened to promote all types of renewable fuel to meet global climate goals and enhance energy security. The case for providing policy incentives for low-carbon energy has never been stronger. The latest assessment report of the Intergovernmental panel on Climate Change on the science of climate change (IPCC), released in late 2021, highlights the urgency of the need for action to avoid the worst consequences of climate change. And the Russian invasion of Ukraine in February 2022 demonstrates the need to reduce our reliance on imported oil and gas, including by boosting the production of domestic bioenergy resources.

The starting point for government policymaking specifically aimed at rLPG is to formally recognise it as a renewable fuel so that its production and use are supported within existing national policy and regulatory frameworks. The additional benefits of rLPG on top of those associated with renewable diesel need to be explicitly taken into account explicitly when designing overall biofuel incentive polices and measures. That is because the near- to medium-term prospects for rLPG are likely to hinge to a large degree on incentives to encourage the production and use of renewable diesel, since rLPG is at present a by-product of renewable diesel production. That is also the case for some emerging technologies, though dedicated rLPG production pathways could become viable in the longer term. Policy incentives that encourage rLPG as well as other co-produced fuels will further boost the attractiveness of investing in those technologies, as well as in rLPG separation and purification facilities.

Regardless of the production pathway, strong financial incentives for rLPG alongside those for co-produced fuels are essential. Experience in the five countries surveyed in this report, and in many other countries, shows that policies must involve making all types of renewable fuel competitive with other fuels in end uses, power and heat generation and non-energy uses. Incentives should be directed at both production and consumption. Demand-side incentives are critical to driving demand for rLPG and making investment financially viable. Much lower taxes – or an exemption – should be applied to rLPG (and conventional LPG) and other renewables than on oil, natural gas and coal to lower the running cost of rLPG relative to fossil fuels and make it more attractive to end users.

RLPG should also be included explicitly in regulatory schemes to promote renewable fuels, including blending mandates and targets, to effectively guarantee demand for the fuel. Extending such schemes to rLPG would increase the overall attractiveness of investments in production pathways that produce that fuel either as the main output or a by-product. Blending mandates need to distinguish between first-generation and advanced-generation rLPG-related technologies, which generally rely on more sustainable feedstocks. Depending on future availability, blending mandates could be used to increase demand for rLPG for end uses other than transport, such as cylinders for household heating and cooking, and bulk use in industry. National authorities and public agencies also have a role to play in raising awareness about rLPG and encouraging investors and end users to take advantage of incentives on offer.

Government support for innovation will be crucial to the development and commercialisation of dedicated rLPG technologies in the longer term. The urgency of the need to expand the supply of renewable fuels justifies a step increase in public funding of R&D in this area, either through direct public institutions or financial support for private sector research activities. The productivity of corporate research is increasingly dependent on ideas arising from publicly funded R&D, which tends to leverage more private sector spending.

Introduction

Objectives and scope of the study

The World LPG Association (WLPGA) engaged Menecon Consulting to conduct a study of government policies to incentivise the production, supply and use of renewable energy fuels. The aim of the report is to provide useful information and data on how governments around the world go about promoting the production, supply and use of renewable fuels, including renewable LPG, and why and how those policies that not currently applicable to renewable LPG can and should be applied to it.

Renewable fuels in both liquid and gaseous form are currently used mainly in the transport sector, for heating buildings and for generating power and heat (used locally in household, industry or farming). Limited volumes of renewable LPG (also known as bioLPG, biopropane or renewable propane) have started to come onto the market, mainly in Europe and the United States, in recent years, but supply is expected to grow significantly in the coming years and decades.

Renewable LPG, henceforth referred to as rLPG, represents an important opportunity for the LPG industry to contribute to and hasten the long-term transition to a sustainable global energy system. A clear understanding of how government policies can best encourage the development of rLPG is crucial to the success of efforts by the industry to persuade policy makers to make in place the required incentives to make that happen. This report is designed to assist in that endeavour.

The work involved a detailed survey of the market for renewable fuels and government policies aimed at promoting them in five countries: Brazil, France, Germany, Thailand and the United States. This involved gathering detailed information on the production and supply of renewable fuels, including the contribution of rLPG, and policies with respect to renewables, as well as identifying differences in the way rLPG is treated to other renewable fuels.

Structure of this report

Part A of this report presents the main findings of the study:

- Section 1 provides an overview of the global renewable fuels market, including data on global and regional trends by fuel and an assessment of the principal drivers of production and demand, including the policy rationale and technological and economic factors.

- Section 2 reviews the market status of and prospects for rLPG, including major projects in operation or in the pipeline, technological developments and long-term projections, as well as the rationale for promoting rLPG.

- Section 3 looks at overall policy approaches and specific measures at the disposal of policy makers (including financial and regulatory instruments) to promote renewable fuels and a comparison of current policies in place in surveyed countries.

- Section 4 presents a broad set of generic recommendations for policy makers with respect to incentives for rLPG, drawing on the policy toolkit and results of the country surveys.

Part B presents the detailed results of the five surveys of incentive policies for renewable fuels, country by country. References and a note on data sources are included in the annexes.

PART A: MAIN FINDINGS

1 The global renewable fuels market

Renewable fuels are a central pillar of the global energy transition. Today, they are made almost entirely by processing biomass, though new synthetic fuels are also expected to contribute to decarbonising sectors – notably long-distance transport and heavy industry – that are hard to electrify in the long term. The case for renewable fuels rests not just on the need to curb and eventually eradicate greenhouse emissions, and tackle air pollution; they can also enhance energy security and bring broader economic and social benefits. Government policies will remain pivotal to the development and deployment of new renewable fuel technologies.

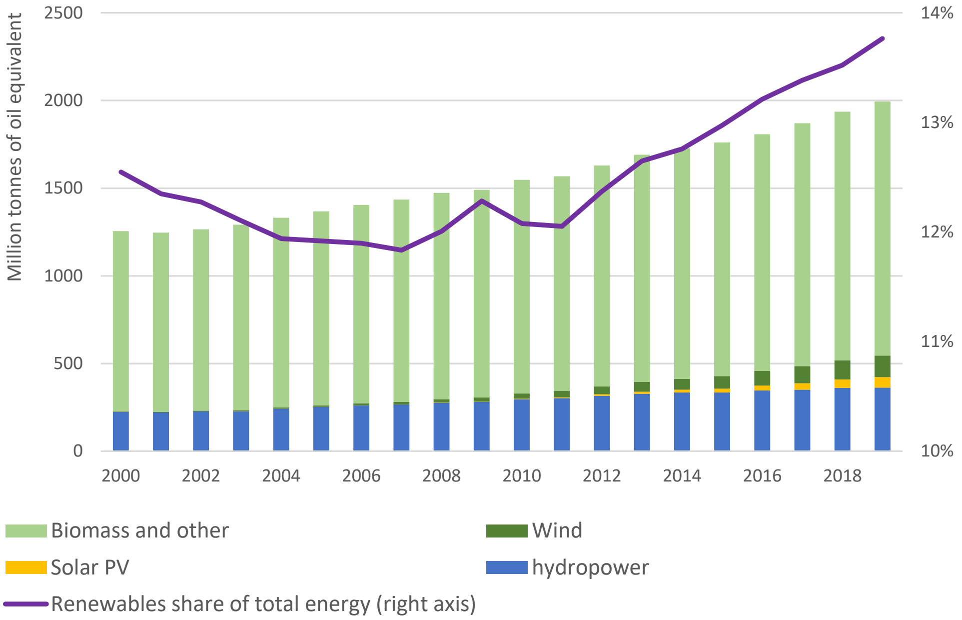
1.1 Market trends

Renewable sources of energy will need to play a leading role in the global transition to clean non-fossil energy. The primary consumption of renewables, including their transformation into electricity and heat and their direct use in end uses, has been growing steadily over the last two decades, with all types of renewables seeing significant increases (Figure A1.1). In total, the supply of renewables grew by 59% between 2000 and 2019.[1] Bioenergy, various forms of biomass used in traditional ways for cooking and heating, for generating electricity or for making modern fuels, remains by far the most important source of renewable energy, though solar photovoltaics (PV) and wind power have seen the fastest growth. Yet despite the impressive expansion of renewable energy, their share of world primary energy use remains small relative to that of fossil fuels, which continue to provide over 80% of total supply. Worldwide, the share of renewables in primary energy reached just 13.8% in 2019, compared with 12.1% in 2010 and 12.5% in 2000.

Only a small proportion of the total amount of bioenergy used around the world is transformed into renewable fuels – defined for the purposes of this report as modern, gaseous or liquid fuels obtained from renewable energy sources through some form of transformation or production process (Box A1.1). In 2019, renewable fuels made up almost 7% of total world renewable primary energy supply with biomass accounting for around 60% (Figure A1.2). Liquid biofuels – mainly biogasoline (anhydrous bioethanol)[2] and biodiesel – account for close to two-thirds of the total supply of renewable fuels and biogas/biomethane for most of the rest (the supply of synthetic hydrogen-based fuels derived from renewable electricity is tiny as yet). In total, renewable fuels meet less than 1% of the world's total primary energy needs.

[1] The latest year for which comprehensive world data are available. In any case, trends in 2020 were distorted by the impact of the Covid-19 pandemic.
[2] Anhydrous and hydrous ethanol differ according to their water content. The water content of anhydrous ethanol is approximately 0.5%, compared with 5% for hydrous ethanol. Anhydrous ethanol is used as an additive in gasoline, whereas hydrous ethanol is used in its pure form, in vehicles that have been adapted to use this fuel.

Figure A1.1: World primary renewable energy supply by source



Notes: PV = photovoltaic.
Source: IEA online databases (https://www.iea.org/data-and-statistics).

Box A1.1: What we mean by renewable fuels

The term renewable refers to energy that is obtained from renewable resources that are naturally replenished over a human lifetime. Renewable energy sources include sunlight, wind, rain, tides, waves, geothermal heat and biomass. By contrast, fossil fuels are non-renewable as their consumption far exceeds the rate at which they are being replenished. Not all biomass is genuinely renewable as some sources are being produced in an unsustainable way, i.e. they are not being replenished as quickly as they are being exploited.

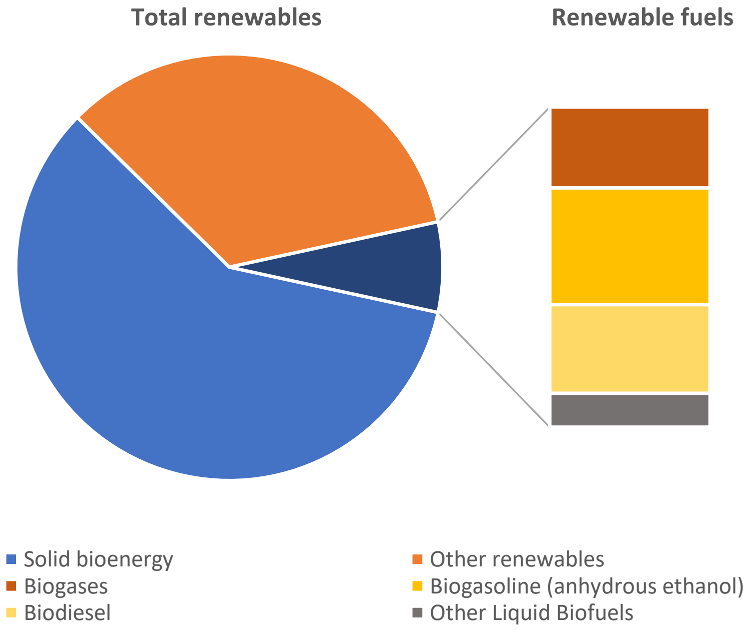
Renewable fuels are liquid and gaseous forms of energy obtained from renewable energy sources through some form of transformation or production process. They include biogas (including landfill gas) and biomethane derived from processes that use biomass as the primary feedstock, and biofuels used primarily for transport, as well as hydrogen derived from electrolysis using renewable electricity (such as wind or solar power). Biogas is a mixture of gases produced by anaerobic digestion of agricultural waste, manure, municipal solid waste (MSW), plant material, sewage, green waste and food waste, as well as dedicated energy crops such as corn. Raw biogas is roughly 60% methane, with carbon dioxide (CO_2) making up most of the rest. Biogas can be used for generating electricity in a combined heat and power (CHP) plant, in which the waste heat is generally used as a fuel input to the anaerobic digester, or in direct end-use applications, such as cooking, space and heating, and process heat. To be injected into a gas grid and for certain direct uses, it usually needs to be upgraded to pure biomethane (CH_4).

Biofuels are transport fuels, usually in liquid form, produced from dedicated energy crops and agricultural, commercial, domestic and/or industrial biological waste. The two most common types of biofuel are bioethanol and biodiesel. Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane or sweet sorghum. Cellulosic biomass, derived from non-food sources, such as trees and grasses, is also being developed as a feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form (E100), but it is usually blended into petroleum gasoline to increase octane and improve vehicle emissions. Bioethanol is widely used in the United States, Brazil, Europe and some other parts of the world. Biodiesel, used widely in Europe, is produced mainly from oils or fats using transesterification to produce fatty acid methyl esters

(FAME). Diesel can also be produced by hydrogenation of vegetable oils (HVO) or esters and fatty acids (HEFA), with the primary output normally referred to as renewable diesel to differentiate it from FAME biodiesel. Biodiesel and renewable diesel can be used in pure form (B100) or blended into non-renewable petroleum diesel.

For the purposes of this report, renewable fuels exclude other renewable sources or forms of primary energy used to produce electricity, such solar, wind, hydroelectric power, geothermal energy and unprocessed biomass used as feedstock or consumed directly for heating (in both modern and traditional ways).

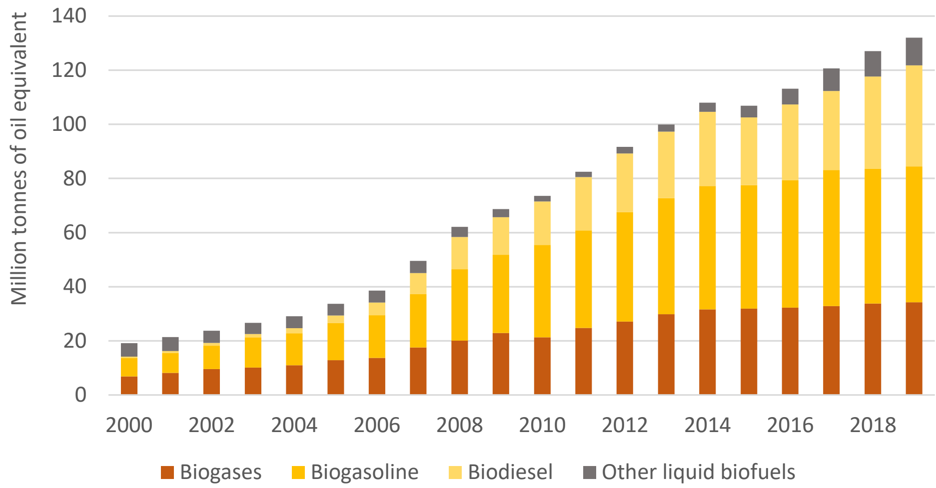
Figure A1.2: World primary supply of renewable energy by fuel, 2019



Notes: Solid bioenergy does not include renewable MSW, which is included in other renewables. Other liquid biofuels include hydrous ethanol, renewable (HVO/HEFA) diesel, rLPG, biomethanol and biobutanol.
Source: IEA online databases.

Although renewable fuels play a small role in the global energy system today, their importance has been growing rapidly in recent years in response to policy incentives. Production of biogasoline and biodiesel have grown most in absolute terms over the last two decades, their combined output expanding more than tenfold since 2000 (Figure A1.3). Biodiesel has seen particularly spectacular growth in output since the mid-2000s, driven mainly by Europe. Most biofuels today use agricultural crops as feedstocks. These "first generation" biofuels use well-established conventional technologies to convert sugar or starch to ethanol (fermentation) and lipids to diesel fuel (transesterification). The main second-generation technology already in widespread use today is renewable diesel produced by hydrogenating vegetable oil (HVO). Globally, 102.8 billion litres of bioethanol, 43.2 billion litres of biodiesel and 7.1 billion litres of renewable diesel were produced in 2020. Together, these fuels accounted for about 5% of all liquid fuel used for transport (IEA, 2021). Global output of biogas grew steadily through to the early 2010s, but has since slowed, their share of total renewable fuels output dropping from over one-third in 2000 to around one-quarter at present. Biogas production reached 34 million tonnes of oil equivalent (Mtoe) in 2019, equal to just 1% of natural gas supply.

Figure A1.3: World production of renewable fuels by type

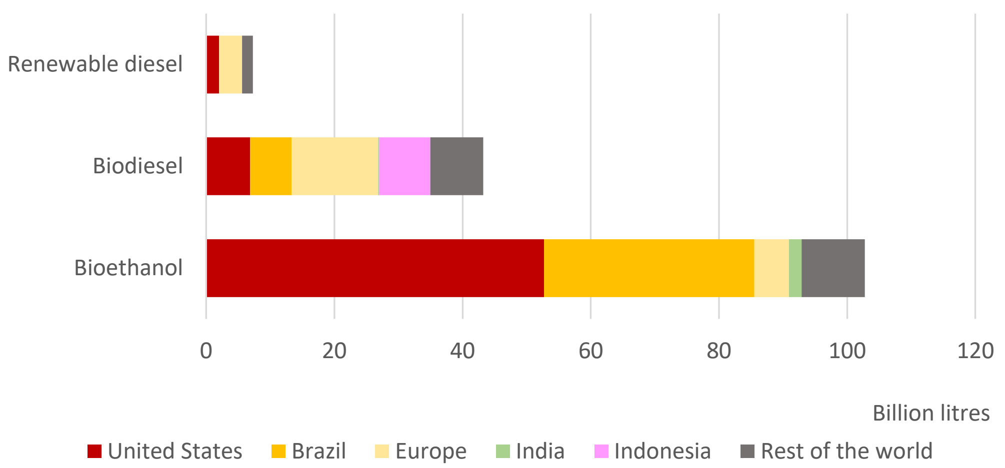


Notes: Other liquid biofuels include rLPG, hydrous ethanol, renewable (HVO/HEFA) diesel, biokerosene, biomethanol and biobutanol.
Source: IEA online databases.

The recent expansion in output of biofuels has been geographically highly concentrated. The United States and Brazil are the leading producers of bioethanol, together accounting for well over 80% of global output (see Part B); Europe accounts for much of the rest (Figure A1.4). Ethanol accounts for around 10% of the gasoline consumed in the United States, with most cars able to run on blends of up to 10% ethanol and some flexible-fuel vehicles able to use up to 100% ethanol. US ethanol is made mainly from corn (see Section B5). The shares are even higher in Brazil, where blending of ethanol – made by fermenting sugar cane – into gasoline has been mandatory since 1976 (see Section B1). Europe is the leading producer of biodiesel, though output has been growing rapidly in recent years in Asia, notably Indonesia.

The development of the biogas industry has also been very uneven across the world, due to differences in the availability of feedstocks and policies that encourage its production and use. Europe accounts for well over half of world biogas production, and China and the United States for most of the rest (Figure A1.5). Germany has by far the largest market with two-thirds of Europe's biogas plant capacity, based mainly on energy crops, though the use of crop residues, sequential crops, livestock waste and the capture of methane from landfill sites is growing. Denmark, France, Italy and the Netherlands are the other main producers in Europe. In China, policies have supported the installation of household-scale digesters in rural areas with the aim of increasing access to modern energy and clean cooking fuels, as well as – more recently – its use as an industrial fuel and upgrading to biomethane for use as a transport fuel. In the United States, the primary pathway for biogas has been through landfill gas collection, which today accounts for nearly 90% of its biogas production. Around half of the remaining production comes from developing countries in Asia, notably Thailand and India.

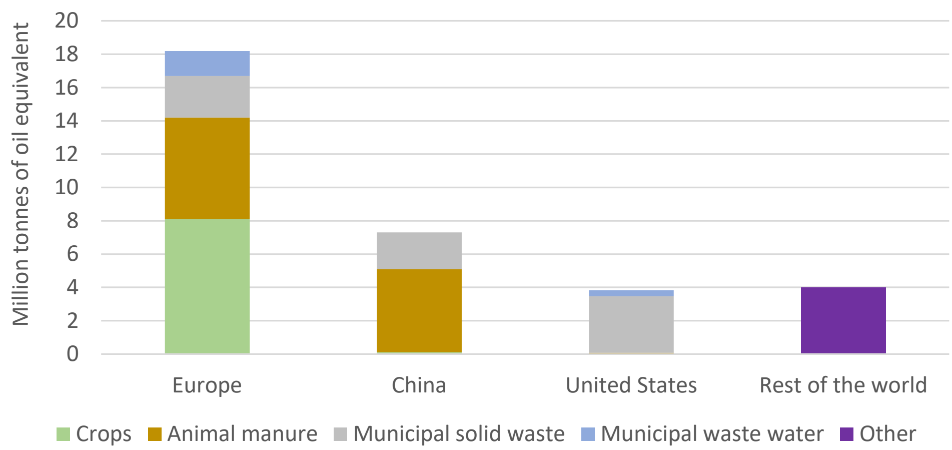
Figure A1.4: World production of biofuels by country/region, 2020



Source: IEA (2021a).

All biogas and the bulk of biofuels produced around the world are consumed domestically. Biofuels are generally produced in countries that rely on imports of oil to meet domestic needs, so it makes economic sense to consume them locally. Globally, trade in biofuels amounted to less than 17 million tonnes of oil equivalent (Mtoe) in 2019 – equal to less than one-fifth of total output. Most of this trade is local cross-border trade in Europe; inter-regional trade in biofuels is very small.

Figure A1.5: World production of biogas by country/region and feedstock type, 2018



Source: IEA (2020a).

1.2 Drivers of renewable fuels markets

The growth in the supply of renewable fuels over the last two decades has been driven by a combination of economic and policy factors. The cost of making renewable fuels varies considerably according to the type of fuel, local market factors and technologies. In some cases, such as bioethanol derived from sugar cane in Brazil, biofuels have been commercially competitive during periods of high oil prices without the need for policy support, though direct subsidies and other forms of policy support have been required at certain times when oil prices have fallen. But in other parts of the world, especially the United States and Europe, strong policy support has always been necessary to compensate for the higher cost of making biofuels compared with conventional petroleum-based alternatives.

The case for policy support to encourage the production and use of renewable fuels rests on several economic and environmental pillars. Reducing reliance on imports, thereby enhancing energy security, is an important rationale – highlighted by the war in Ukraine. Domestically produced biofuels can reduce the need to import oil products, rendering the country less vulnerable economically to the adverse impacts of supply disruptions. Similarly, developing a domestic biogas industry can reduce reliance on natural gas imports, as well as provide a way of expanding access to clean cooking and heating in remote areas in developing countries. Reducing domestic demand for oil products or natural gas can also reduce their prices on international markets, boosting economic growth in oil- and gas-importing countries. Developing a domestic biofuels or biogas industry, to the extent that it displaces imported energy, also adds economic value and creates jobs – the main rationale behind the Brazilian government's decision to develop a large-scale ethanol industry in the mid-1970s, and one still used to justify subsidies to biofuels worldwide.

The environmental benefits of renewable fuels provide an increasingly important rationale. Tailpipe emissions of nitrogen oxides (NOx), sulphur dioxide, carbon monoxide (CO) and particulate matter (soot) are generally low compared with conventional gasoline and diesel (Menecon Consulting and Atlantic Consulting, 2014). Ethanol, in particular, can ensure complete combustion, reducing CO emissions.

Renewable fuels may also reduce greenhouse-gas (GHG) emissions depending on their carbon footprint (or carbon intensity) and that of the fuel that the biofuel displaces. Bioenergy is by definition a renewable energy source, insofar as the carbon emissions (in the form of carbon-dioxide, or CO_2) that result from its combustion are fully offset by the CO_2 that is initially removed from the atmosphere by the biomass feedstock. But CO_2 is usually emitted during the process of transforming the biomass, as well as in producing any fertilizer used to grow the biomass and in irrigating the land and harvesting the biomass. Changes in land-use patterns, such as growing soybeans or oil palm trees in tropical forests, may also increase GHG emissions by releasing carbon stored in the land to the atmosphere. In addition, the use of fertilizer releases NOx – a potent GHG. Most biorefineries run on oil and gas, emitting CO_2 and other pollutants. Emissions from these activities offset at least part of the savings from using renewable feedstock.

The net GHG emissions reductions that can be achieved with different types of biofuels vary considerably by type of fuel, production route and location. The findings of the many life-cycle assessment studies of the potential of biofuels to achieve reductions in GHG emissions are often conflicting, with a wide variation in estimates. In general, first-generation biofuels on average emit less GHGs than fossil fuels when land-use changes are not taken into account, though the savings are not always very big. Second-generation biofuels have a greater potential than first generation to reduce GHG emissions (Jeswani et al., 2020). For example, a recent study found that renewable diesel performed better than first-generation bioethanol or biodiesel and waste biomass feedstock better than cellulosic biomass or bio-oils (Cabrera-Jimenez, 2022).

Assessing the benefits of renewable fuels also needs to take account of other factors, such as the impact of growing energy crops that would otherwise be used directly for human consumption directly or indirectly as animal feed. Diverting these crops to biofuels may lead to more land area devoted to agriculture, increased use of polluting inputs and higher food prices. Cellulosic feedstocks, such as forest or farm residues, can also compete for land and water that might otherwise be devoted to food production. Production of biofuel feedstocks, particularly food crops like corn and soybeans, can cause water pollution from nutrients, pesticides and sediment. These drawbacks are generally less problematic with second- and third-generation advanced biofuels (such as algae-based processes), which are not based on food crops and generally need less water and farm land.

The potential overall environmental benefits of renewable fuels need to be weighed against various disadvantages, foremost among which is production cost. In many cases, biofuels and biogas are significantly more expensive to produce than equivalent conventional forms of energy. This is particularly true for first-generation biofuels in the northern hemisphere, where climatic conditions are less well-suited than in countries with a tropical climate, like Brazil. As a result, large subsidies or financial incentives are often necessary to make some types of bioenergy commercially viable. The competitiveness of renewable fuels increases at times of high oil prices.

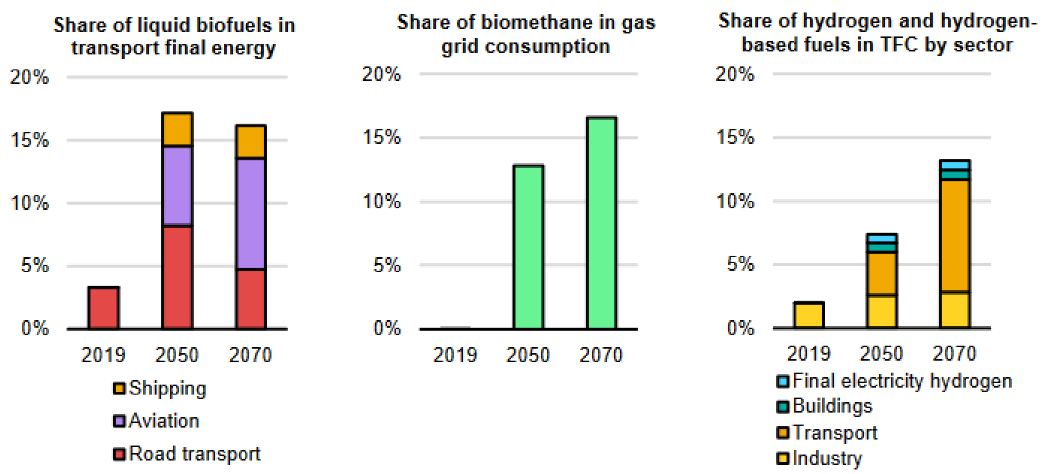
A major advantage of most renewable fuels is that they can usually be blended into conventional petroleum fuels, avoiding the need for dedicated supply infrastructure. In practice, the ease of blending varies by fuel and technology: biomethane derived from biogas is chemically identical to natural gas, so can be injected directly into gas grids as a genuine "drop-in" fuel without any technical modifications. The same is true of rLPG (see Section 2). Other renewable fuels, such as bioethanol, usually require some adjustments. Most cars are able to run on ethanol blends of up to 10%, though higher shares require some adjustments to the fuel system. Hydrogen produced from renewable sources is less easily blended into other gases such as natural gas.

1.3 Market prospects

Renewable fuels are expected to play an important role in the clean energy transition. In particular, sustainable biofuels, low-carbon hydrogen (derived from renewable electricity or from natural gas in steam reforming plants equipped with carbon capture and storage facilities) and hydrogen-based synthetic fuels will be needed to decarbonise certain transport modes, notably aviation, long-distance shipping and road freight, where switching to electricity is difficult. Hydrogen is also expected to make a growing contribution to energy needs in industry, especially in supplying high-temperature heat for the production of steel, cement and chemicals. Biogas could provide a bridge to decarbonising gas supplies through existing distribution networks, as well as power generation in some locations.

How quickly the production and use of these fuels grow hinges critically on policy action by governments around the world to accelerate the decarbonisation of the energy system. In the IEA's Sustainable Development Scenario, which describes an energy pathway to global net-zero emissions in 2070, renewable fuels in the form of liquid biofuels, biogas/biomethane, low-carbon hydrogen and other hydrogen-based fuels make a significant contribution to decarbonising energy use in transport, buildings and industry, driven by strong policies (Figure A1.6). Those fuels meet 20% of global final energy demand in 2070, with hydrogen fuels alone accounting for 13% and liquid biofuels for 5%. Biomethane and biogas are responsible for just 2% of total final energy use, but biomethane blended with natural gas in existing gas grids accounts on average for over 15% of global grid gas consumption in 2070. Both biomethane and biogas are used for cooking in emerging economies as well as for power generation.

Figure A1.6: Role of renewable fuels in the IEA Sustainable Development Scenario



Notes: TFC = total final energy consumption. Hydrogen-based fuels refer to the fuel use of synthetic hydrocarbon fuels produced from hydrogen and CO_2, and ammonia. Final energy demand of hydrogen includes in addition to the final energy demand of hydrogen, ammonia and synthetic hydrocarbon fuels, the onsite hydrogen production in the industry sector and the final electricity produced from hydrogen.

Source: IEA (2020b).

The amount of biomass feedstock supply needed in this scenario is well within the range of most estimates of the availability of sustainable biomass. But major technological advances will be needed to lower production costs, as well as far-reaching measures to mobilise these resources in a sustainable manner, including by improving crop yields, sequential cropping, reducing waste in food supply, utilising abandoned and degraded lands, and mobilising supply chains for dispersed wastes and residues; improving electrolysis technologies for converting renewables-based electricity into green hydrogen will also be required (IEA, 2020b). Governments will need to play the pivotal role in driving these market and technological changes, through comprehensive clean energy strategies involving measures that are tailored to local infrastructure and technology needs, notably in strengthening markets for technologies at an early stage of adoption, developing and upgrading infrastructure, boosting support for research and development (R&D) and demonstration, and expanding international technology collaboration.

2 Renewable LPG

Renewable LPG, or rLPG, is a cost-effective solution to decarbonising fuel use and reducing air pollution from off-grid heating and cooking, industry and transport. Today, almost all rLPG is a by-product of renewable diesel and jet kerosene production. In many cases today, that output is used in the production process itself, though some plants separate out and commercialise the rLPG as a premium product. Output based on existing technologies is set to continue to grow in the near term, but new production pathways will be needed to expand supply substantially in the longer term.

2.1 Global market status and trends

RLPG is the term commonly used to describe LPG derived from production processes that use biomass or other renewable energy sources as feedstock (Box A2.1). The main attraction of rLPG, beyond the economic benefits associated with the value added from production, is that it can bring about significant reductions in GHG emissions if it is substituted for fossil LPG (see below). As a genuine "drop-in" fuel, it can be used in all current LPG market applications, requiring no modifications to supply infrastructure or end-use equipment. Unlike other biofuels, it can be used for other uses than simply as a transport fuel.

Box A2.1: What is renewable LPG and where does it come from?

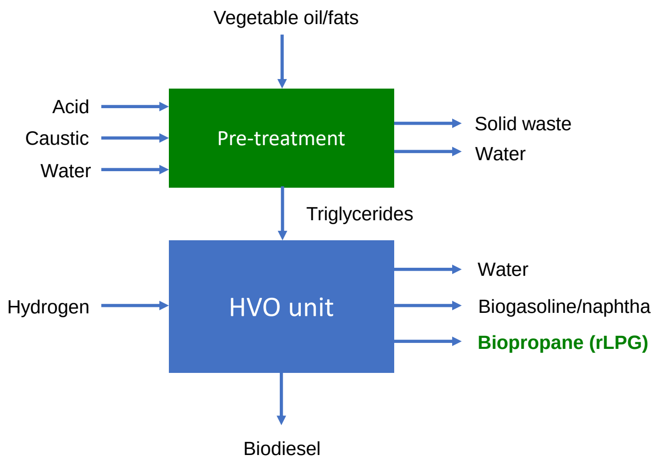
R (rLPG is LPG derived from production processes that use sustainable biomass or other renewable energy sources (such as low-carbon electricity and CO_2) as the feedstock. LPG is the generic name for mixtures of hydrocarbons that change from a gaseous to liquid state when compressed at moderate pressure or chilled. The chemical composition of LPG can vary, but is usually made up predominantly of propane (C_3H_8) and butane (C_4H_{10}). Propane and butane have a high energy content on a per-tonne basis (in a liquid state) compared with most other oil products and they burn readily in the presence of air, giving off a hot flame. These characteristics have made LPG a popular fuel for household and commercial heating and cooking, for industrial processes and as an alternative automotive fuel (where it is called Autogas). It is also used as a feedstock in the petrochemical industry.

Propane and butane are traditionally produced as a by-product of crude oil refining and natural gas processing, but new techniques already being commercialised can produce these gases from biomass feedstock – mainly as a co-product. In practice, rLPG may contain some butane (normal butane or isobutene, an isomer of butane) and other light hydrocarbons, though most existing and emerging production technologies yield primarily propane. The molecular structure of rLPG is identical to that of conventional pure propane or butane produced from hydrocarbons (in the same way that pure biomethane is identical chemically to fossil methane), so can either be blended or sold in a pure form. As a genuine "drop-in" fuel, it can be used in all current LPG market applications.

RLPG can, in principle, be produced in many different ways, using different types of thermal and chemical processes, either as a co-product in the production of other fuels or as the principal output (see main text). Only one technology – hydrotreated vegetable oil (HVO), which yields significant volumes of rLPG as a by-product – is in full commercial use today, though other advanced biofuel production processes that yield rLPG using a variety of renewable feedstocks are under development.

RLPG can, in principle, be produced in many different ways, using different types of thermal and chemical processes, but only one of these technologies – hydrotreated vegetable oil (HVO) – is in full commercial use today and is the source of almost all the rLPG currently available. The HVO process involves the hydrogenation of vegetable oil or animal fat to produce renewable diesel or jet kerosene, yielding small volumes of rLPG – typically 5-7% by weight of the renewable diesel. Chemically, it entails direct catalytic hydrogenation of vegetable oil (a triglyceride) into paraffins, while the glycerine chain of the triglyceride is hydrogenated to produce propane (rLPG) (Figure A2.1). Oxygen is removed from the oil so that the diesel is not an oxygenate, like traditional FAME biodiesel. The technology allows flexible use of any vegetable or waste oil and the diesel produced is of very high quality (better even than conventional diesel), requiring no modifications to diesel engines and can be blended in any proportion with petroleum diesel. The process can be carried out in a conventional refinery, potentially in combination with non-renewable feedstock (in which case the resulting diesel and LPG are only partially renewable), or in a dedicated biorefinery running exclusively on biomass feedstock.

Figure A2.1: HVO production process



Source: Menecon Consulting analysis.

There are 30 commercial HVO plants around the world currently producing rLPG as a by-product of renewable diesel production. Ten have a capacity of at least 20 thousand tonnes/year (kt/y) and four 40 kt/y or more (Table A2.1). We estimate current global rLPG capacity at around 450 kt/y. Neste Oy, a Finish oil company, was the first company to commercialise HVO rLPG on a significant scale, marketing since 2018 40 kt/y from its Rotterdam plant to various markets in Europe, including France, Scandinavia and the United Kingdom.[1] Its Singapore plant is the largest source, producing up to 60 kt/y. Around 54% of global capacity is in Europe, followed by the Americas (24%) and Asia (23%). Most of this capacity has come on stream in the last five years:

[1] https://www.neste.com/releases-and-news/renewable-solutions/neste-delivers-first-batch-100-renewable-propane-european-market

total output, including rLPG included in off-gases, was estimated at just 130 kt in 2014 (Menecon Consulting and Atlantic Consulting, 2014). A number of other projects are under construction or planned, notably in the United States (see below and Section B5.1). In many cases, the rLPG produced at these plants is consumed on site as fuel gas or used as feedstock for making the hydrogen needed for the HVO process, though some – including Neste' Rotterdam plant and Total's La Mede biorefinery – have installed separation and purification facilities in order to commercialise the rLPG as a premium "green" product.

Table A2.1: HVO rLPG production capacities, end-2021

Country	Owner/operator	Location	Capacity (thousand tonnes/year)
Brazil	Petrobras	Repar-Parana	<1
United States	BP	Cherry Point, WA	5
	NextChem-Saola Energy-East Kansas Agri-Energy	Garnett, KA	2
	Diamond Green Diesel	Norco, LA	45
	Holly Frontier Sinclair	Sinclair, WY	20
	Renewable Energy Group	Geismar, LA	14
	Tesoro/Marathon	Dickinson, ND	16
	World Energy	Paramount, CA	5
China	Beijing Sanju Environmental (BSE)	Rizhao	24
	BSE/Hebi Huashi	Henan	2
	BSE	Hainan	7
	Sinopec	NA	1
Indonesia	Pertamina	Dumai	2
	Pertamina	Paju Palembang	7
Japan	Hitachi Zosen	Kyoto	<1
Singapore	Neste Oy	Singapore	60
Finland	Neste Oy	Porvoo	30
France	Total	La Mede	30
Ireland	Irving Oil	Whitegate	3
Italy	ENI	Gela, Sicily	45
	ENI	Porto Maghera	30
Netherlands	Neste Oy	Rotterdam	40
Portugal	Galp	Sines	<2
Spain	BP	Castellon	4
	Cepsa	Huelva	7
	Repsol	Bilbao/Cartegna	20
Sweden	PREEM	Gothenburg	18
	Sunpine	Pitea	<5
United Kingdom	Phillips 66	Humberside	8
Total World			**c.450**

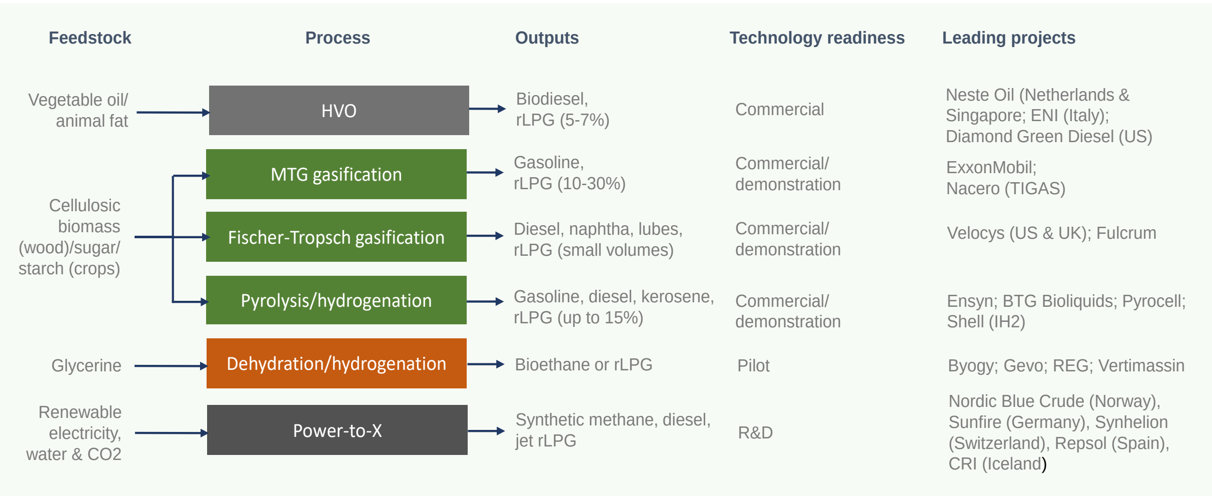
Sources: Menecon Consulting research and analysis; Malins and Sanderford (2022) for United States; information provided by Atlantic Consulting.

2.2 Emerging technologies

There are a number of processes other than HVO that can, in principle, produce rLPG either as the main target or as a co-product. These include gasification, dehydration and pyrolysis technologies. Fermentation to produce rLPG (lipid fermentation) has been proven at laboratory scale, but prospects for its large-scale commercialisation appear to have dimmed due to cost. Hydrothermal liquefaction of lignocellulosic biomass shows some promise, but is at a lower level of technological readiness than the other technologies. Similarly, aqueous phase reforming, involving catalytically transforming soluble plant sugars into gasoline and diesel, with rLPG produced as a by-product, has not progressed beyond the pilot phase as yet. Other technologies, such as power-to-x, involving the methanation of CO2 by electrolytically obtained hydrogen using renewable electricity and, after further synthesis, the processing of the syngas and synthetic methane into rLPG, are much further from technological maturity (Figure A2.2).

Converting biogas to rLPG is another option, but production costs are likely to be a stumbling block to commercialising such technologies.

Figure A2.2: Principal process technologies that can be used to produce rLPG



Source: Menecon Consulting analysis.

2.2.1 Gasification technologies

RLPG can be produced as a by-product of various gasification technologies. They involve the conversion of biomass into a synthetic gas (syngas) before being further processed into different products, including methanol, dimethyl ether (DME, Box A2.2), gasoline and diesel. The product yields depend on the makeup of the syngas, the type of process, the process temperature and the catalyst used. The two main gasification technologies that are under development for use with biomass feedstock are as follows:

- *Methanol-to-gasoline processes:* Methanol-to-gasoline (MTG) technology, an indirect liquefaction process, involves the gasification of any type of fossil fuel or biomass to produce synthetic gas (syngas), which is then converted to crude methanol and low-sulphur, low-benzene biogasoline or biodiesel in separate stages. Methanol has traditionally been produced from coal or natural gas, but research is underway to adapt the process to use different types of biomass or biomass/coal mixtures. Up to 90% of the hydrocarbons in the methanol are converted to gasoline, with propane and butane making up most of the remaining 10%. Depending on the configuration of the plant and the composition of the syngas, LPG output can be as high as 30%. ExxonMobil was the first company to develop a commercial MTG technology in the 1970s, initially using gas and later coal as feedstock. Haldor Topsoe, a Danish company, is also developing a competing process – the TIGAS, or Topsoe Integrated Gasoline Synthesis – to utilise natural gas, coal or biomass for the production of gasoline with LPG as a by-product. A 100 kb/d commercial plant is being built in Pennwell, Texas, by Nacero using the TIGAS process, though the feedstock will be natural gas; CO_2 emissions will be reduced by carbon capture and storage.[1]

- *Fischer-Tropsch gasification:* Biomass-based syngas can also be reformed to liquids using the well-established Fischer-Tropsch (FT) technology, which involves synthesising syngas into liquid hydrocarbons by passing it through a reactor containing catalysts. However, the output of LPG from this process is relatively small, at a few per cent of the total hydrocarbons output. The technology using biomass-based syngas is close to commercialisation. The key challenges are securing enough biomass feedstock at low cost and reducing the cost of syngas production and clean-up – high syngas purity is required to protect the catalyst in FT synthesis (NNFCC, 2019). Velocys, a British-American technology firm, is planning to build two integrated FT gasification units using MSW and woody biomass as feedstock, in partnership with Shell in Mississippi in the United States and British Airways in the United Kingdom.[2] In addition, Fulcrum, a US firm, recently brought on line its first FT gasification facility, the Sierra BioFuels Plant in Nevada, which processes 175 kt/y of MSW into various fuels, including small volumes of LPG.[3] In Japan, the New Energy and Industrial Technology Organization and the Japan Gas Synthesis Company have demonstrated FT processes that convert biosyngas directly to propane, but they have not yet been commercially deployed.

2.2.2 Dehydration of glycerine

Dehydrating glycerine (sometimes called glycerol) is another potential pathway for making significant volumes of rLPG. Glycerine, which is has a similar chemical structure to propane, is a residue of conventional first-generation biodiesel FAME production processes. The boom in biodiesel production worldwide, particularly in Europe, has led to a huge increase in the

[1] https://blog.topsoe.com/nacero-selects-topsoes-tigas-technology-significantly-reducing-lifecycle-carbon-footprint-of-gasoline-production
[2] https://www.velocys.com/projects/
[3] https://www.prnewswire.com/news-releases/fulcrum-bioenergy-completes-construction-of-the-sierra-biofuels-plant-301326178.html

supply of glycerine, which has depressed its price. As a result, efforts have been stepped to find alternatives uses for glycerine. In Europe, these efforts have been boosted by the EU Renewable Energy Directive (RED), which allows biofuels produced from glycerine to count double in meeting transport-fuel targets and to be subsidised by member states. Several companies, including Byogy, Gevo, the Renewable Energy Group (a subsidiary of Chevron) and Vertimass in the United States, are active in this area, although production has not yet been commercialised (LGE, 2021).

Box A2.2: Bio-dimethyl ether and rLPG

Bio-dimethyl ether (or rDME) is both another pathway to making rLPG as well as an alternative. It could be blended with rLPG or used as an intermediate feedstock for rLPG production. DME is chemically very close to propane and butane and displays similar characteristics in use. It is increasingly being used as a source of energy, mainly in China. DME (conventional or bio) can be used as an alternative to diesel (requiring some modifications to the diesel engine) or can be blended into LPG for use in all applications. However, there are limits on how much DME can be blended into LPG, as DME is a solvent so can cause corrosion.

Today, DME is primarily produced by converting natural gas or coal to syngas, which is then converted to DME in a two-step process via methanol. If the syngas were produced from biomass, the final output of this process would be rDME. One-step processes, such as that being developed by Haldor Topsoe, permit both methanol synthesis and dehydration in the same process unit, eliminating the intermediate methanol synthesis stage and promising gains in efficiency and cost. Another potential pathway is to process glycerine into rDME via hydrogenation (see above). It is also technically possible to convert rDME to rLPG using hydrogen and catalysts. In practice, the additional cost would have to be weighed against the benefits of producing rLPG rather than simply blending rDME into rLPG.

Production of rDME from lignocellulosic biomass has been demonstrated by a project undertaken by a consortium of Chemrec, Haldor Topsøe, Volvo, Preem, Total, Delphi and ETC, supported by the Swedish Energy Agency and the EU 7th Framework Programme. A new project, FLEDGED, funded by the EU Horizon 2020 research and innovation programme to demonstrate the technology at industrial scale is underway.[1] In addition, SHV Energy and UGI International have formed a joint venture to advance the production and use of rDME, with up to six plants planned within the next five years, targeting a total production capacity of 300 kt/y by 2027. Total investment could reach US$1 billion.[2] In the United States, Oberon Fuels started production of rDME using waste methanol as feedstock at a demonstration facility in Brawley, California. The US$6 million project was funded in part by a grant from the California Energy Commission.[3]

2.2.3 Pyrolysis

Pyrolysis involves the thermal decomposition of organic compounds, such as wood and agricultural waste products, to create pyrolysis bio-oil (or biocrude), which can then be hydro-processed into gasoline, diesel and/or kerosene. RLPG (propane and butane) is produced as a by-product in both steps, amounting to about 10-15 % by weight. Pyrolysis bio-oil is a kind of tar and normally contains high levels of oxygen, resulting in non-volatility,

[1] http://www.fledged.eu/
[2] https://www.businesswire.com/news/home/20211222005527/en/SHV-Energy-and-UGI-Receive-European-Union-Approval-to-Create-Joint-Venture-to-Advance-the-Production-and-Use-of-Renewable-Dimethyl-Ether
[3] https://advancedbiofuelsusa.info/oberon-fuels-starts-commercial-production-of-renewable-dimethyl-ether-rdme-a-pivotal-step-towards-a-net-zero-future/

corrosiveness, immiscibility with fossil fuels and thermal instability. It typically requires significant additional treatment to render it suitable as a refinery feedstock to replace crude oil.

The Canadian company, Ensyn, has developed a technology – Rapid Thermal Processing – that uses a fast pyrolysis process that involves the thermal cracking of woody biomass feedstock to gases and vapours. The yields from processing dry biomass (with 8% moisture) are approximately 65-80% liquid by weight, with 12-16% each of char and combustible gas, including small amounts of rLPG. Ensyn originally commercialised its RTP technology in the 1980s and currently operates a number of small commercial biomass-processing plants in the United States and Canada, producing numerous natural chemicals and energy products. It has designed and commissioned a three million gallon per year fast pyrolysis plant in Canada, but it is not upgraded at conventional oil refineries (it is used for the generation of heat and power). Expansion of biocrude production capacity is underway, led by a ten million gallons(g)/y (40 million litres(l)/y) licensed production facility in Port Cartier, Quebec, which has just been completed. Additional production capacity is under development in Aracruz, Brazil, in a joint venture between Ensyn and Suzano – a 20 million g/y (80 million l/y) plant to produce biocrude for refining in Europe and the United States.[1] It is believed that the rLPG contained in the flue gases produced in making the bio-oil is consumed for generating heat.

Several other companies have also built commercial pyrolysis bio-oil facilities. BTG Bioliquids, a Dutch company, opened its first commercial fast pyrolysis plant in Netherlands in 2015 with a capacity of 25 kt/y and has since brought two others on line in Sweden and Finland. There are plans to upgrade the bio-oil by using it as a co-feedstock alongside virgin gasoil in fluidised catalytic cracking units. Pyrocell, a joint venture of Setra and PREEM in Sweden, has also brought onstream a 25 kt/y plant in 2021, with the oil processed in PREEM's oil refinery.[2] Shell is also developing an integrated process called IH², originally developed by the US Gas Technology Institute, where pyrolysis oil is upgraded for the production of drop-in hydrocarbons at its own refineries. A 2 kt/y demonstration plant has been built at Bangalore in India, processing local forestry residues.[3]

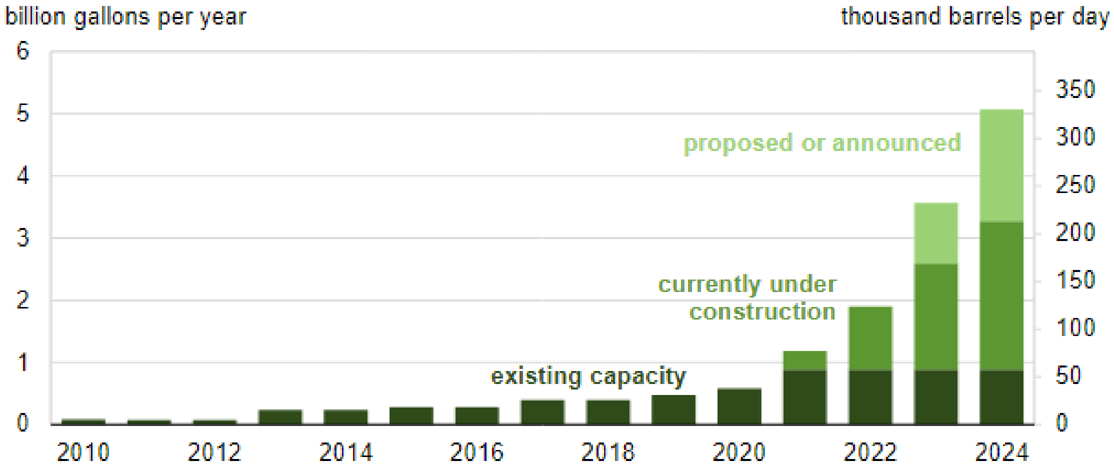
2.3 Outlook for rLPG supply

The supply of rLPG is expected to rise in line with that of renewable fuels generally, in response to rising demand in the face of tightening environmental constraints and technological advances. In the near to medium term, the vast bulk of the global increase in rLPG supply will come from new HVO plants. A number of plants are currently under construction, notably in the United States. According to one recent study, the global market is expected to register average annual growth of 47% from 2020-2025.[4] The

[1] http://www.ensyn.com/overview.html
[2] https://www.setragroup.com/en/pyrocell/about-pyrocell/
[3] https://www.shell.com/business-customers/catalysts-technologies/licensed-technologies/benefits-of-biofuels/ih2-technology/demonstration-facility.html
[4] https://www.fairfieldmarketresearch.com/report/bio-lpg-market

US Energy Information Administration estimates that current projects of major refiners, including Chevron, Love's, Marathon and Phillips 66, are set to boost renewable diesel production capacity in the United States fivefold by 2024, from around 1 billion g/year at present to more than 5 g/y, which could yield up to 500 kt/y of rLPG – more than doubling global capacity (Figure A2.3).[1] There are, however, doubts over whether all of those projects will proceed, given the need to raise soy oil production and imports of feedstocks and to divert feedstocks from biodiesel production.[2] Capacity additions are planned in other countries, including France (with the conversion of Total Grand Put plant to a 290 kt/y biorefinery), Italy (where ENI's Venice plant is due to add 240 kt/y of renewable diesel capacity) and Singapore (at Neste's biorefinery). FutureBridge, a consulting firm, has forecast that production of renewable diesel could reach 13 billion litres by 2024, implying rLPG output of 550-750 kt – a 20-60% increase on current levels.[3]

Figure A2.3: Existing and expected US renewable diesel production capacity



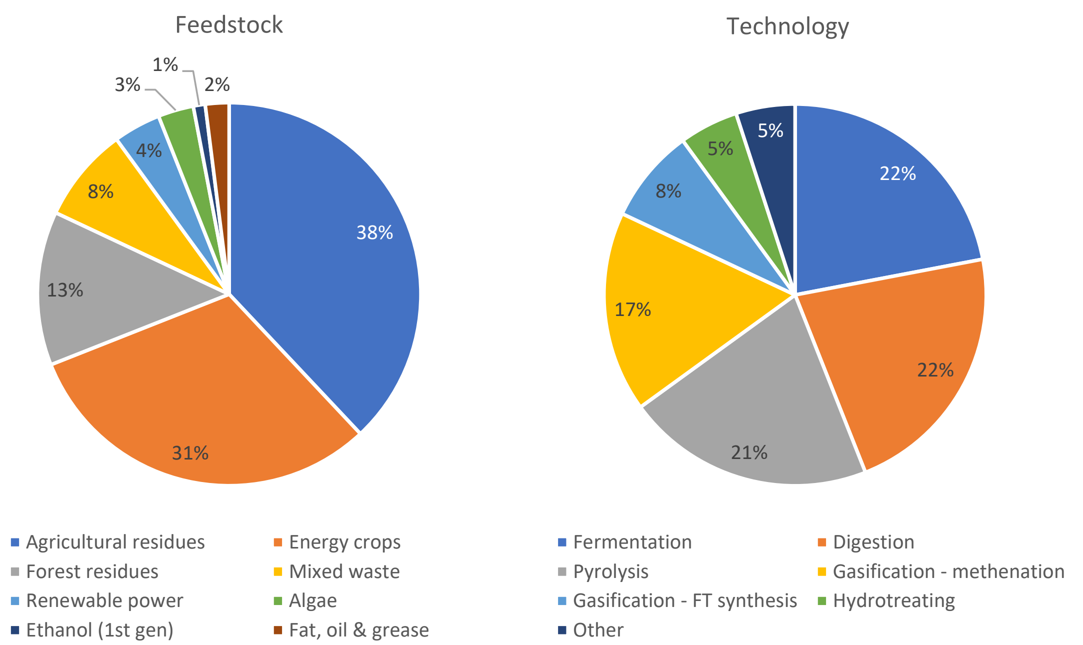
Source: US Energy Information Administration (EIA) based on data from company announcements in trade press (https://www.eia.gov/todayinenergy/detail.php?id=48916).

Other emerging technologies are expected to contribute increasingly to the growth in rLPG production in the longer term. This is because of limits to the supply of sustainable vegetable oil and animal fat feedstock, given that they compete to a large degree with food supply. There are few forecasts available of production of rLPG reflecting the enormous uncertainty over future policy and technological developments. Recent analysis by Atlantic Consulting on behalf of WLPGA finds that rLPG supply could, in principle, meet at least 50% of non-chemical LPG consumption by 2050. The precise fraction of rLPG in total LPG supply depends on government policy, mainly with respect to fossil fuels, as well as underlying trends in overall demand for LPG. In a base-case scenario, rLPG production and use reaches 226 Mt in 2050,

[1] https://www.eia.gov/todayinenergy/detail.php?id=48916
[2] https://www.reuters.com/business/energy/less-than-half-projected-us-renewable-diesel-output-likely-by-2025-study-2022-01-18/
[3] https://www.futurebridge.com/industry/perspectives-energy/renewable-diesel-the-fuel-of-the-future/

with supply coming from eight categories of feedstock and six types of technology (Figure A2.4).

Figure A2.4: Global rLPG base case supply scenario for 2050 by feedstock and technology



Source: Atlantic Consulting.

In another study prepared by Atlantic Consulting on behalf of Liquid Gas Europe covering European supply, future European demand for LPG, which drops by around one-third to 8-12 Mt in 2050 compared with current levels, is met entirely by domestically produced rLPG (Figure A2.5). Around 2.5 Mt comes from biorefining (fermentation), another 3.5 Mt from pyrolysis and gasification, and 3.2 Mt from power-to-x technologies. Another 3.5 Mt comes from the conversion of biogas. In the medium term, increased rLPG output comes mainly from the biorefining of lipids, biogas conversion and gasification of biomass. Power-to-x technology is expected to start penetrating the European market only after 2030. Sufficient feedstocks are expected to become available to meet this growth.

2.4 Rationale for encouraging rLPG

As with other renewable fuels, the main attraction of rLPG is that, as it is derived from renewable biomass, it can potentially bring about significant reductions in greenhouse-gas emissions if it is substituted for fossil LPG. The current carbon footprint of HVO rLPG varies markedly in practice, mainly according to the type of feedstock used and how it is produced, the extent to which methane is captured at the mill producing the oil, land-use changes associated with feedstock production and whether the feedstock is classified as a residue. Emissions range from 5-102 g of CO_2 equivalent per megajoule (CO2eq/MJ), representing a saving of 43-88% relative to the benchmark petroleum-derived LPG it displaces, the 'fossil fuel comparator' (Johnson, 2019).[1] If the feedstock is treated as residue, which is normally the case, the emissions are at the low end of the range, implying emissions savings of 80-90%. In most cases, HVO rLPG qualifies for government support in the European Union, i.e. financial credits and biofuel mandates enacted by member states under the RED.

Figure A2.5: European production of rLPG, 2050

Source: Atlantic Consulting/LGE (2021).

The carbon footprint of rLPG is likely to decline significantly in the long run. The emissions intensity of HVO production should decline with the increased use or low-carbon energy in processing and a move towards the use of waste or cellulosic materials as feedstocks. In addition, new technologies could result in even lower CO2 emissions depending on the feedstock and energy inputs.

A major advantage of rLPG over some other renewable fuels is that is a direct renewable replacement for conventional LPG, making it a drop-in gaseous, liquified fuel. As such, it can be used in pure form or blended into conventional LPG in all applications ranging from vehicles to boilers without any need to change or modify end-use appliances and equipment. Existing

[1] Under the EU Renewable Energy Directive (RED), the fossil-fuel comparator has a footprint of 87 g CO2eq/MJ.

LPG supply chains and distribution infrastructure are also able to function with rLPG without any need for modifications or additional investment.

RLPG offers all the other benefits that conventional petroleum-based LPG already provides. Because LPG is made up of chemically simple and pure hydrocarbons, it mixes easily with air allowing almost complete combustion. As a result, it emits roughly 84% less NOx – the principal precursors of ozone, which produces smog – than oil products and emits almost no particulate matter, or soot – the leading causes of poor air quality in most towns and cities around the world. LPG also emits much less unburned hydrocarbons, CO, toxics and heavy metals than heating oil and coal. LPG gives rise to negligible emissions of toxic gases that can cause serious health problems if breathed in close to the point of combustion. LPG is also non-toxic, so it cannot contaminate soils or aquifers.

LPG/rLPG – like natural gas – has several practical as well as environmental advantages over liquid and solid fuels that can also be used for cooking, heating and as a transport. LPG has been used for more than a century around the world, so suppliers and consumers are well-educated in how to handle the fuel safely and effectively. The physical properties of LP Gas enable significant amounts of energy to be transported easily as a liquid under moderate pressure in specially designed bottles or in tanker cars and trucks. This portability makes it particularly suitable for applications in remote locations that cannot economically be supplied with natural gas via a pipeline network. LPG is also a widely available and secure fuel. It is traded freely on international markets and widely distributed throughout the world through well-established supply chains.

3. Government policies to promote renewable fuels

There are several ways in which governments can and do encourage the production and use of renewable fuels. Financial incentives are the most common, involving subsidies to producers and/or consumers, including tax rebates or exemptions and feed-in tariffs to make them competitive with other fuels. Regulatory measures, notably blending mandates or targets and renewable portfolio standards, have also proved extremely effective. Public support for innovation, including funding of R&D, has also been an essential foundation of the renewable fuel industry.

3.1 Policy approaches

Government policies are a critical driver of the development and deployment of renewable fuel technologies. Policy support across a growing number of countries has spurred innovation, increased competition and driven down costs, leading to the rapid market take-up of a range of different fuels and processes for making them, especially since the turn of the century. In most countries, renewable energy policies have focused on electricity-based technologies, especially solar PV, wind and hydropower, but there is growing support for biofuels, biogas and other renewable fuels across the world, spurred by the need to accelerate the clean energy transition and drive down GHG emissions (IRENA/IEA/REN21, 2018).

As in other energy sectors, there is a range of different policy strategies and approaches at the disposal of governments to encourage the production and supply of renewable fuels alongside other renewable and clean forms of energy. In practice, the overall approach adopted and the chosen mix of instruments reflects both ideological and practical considerations. Given that main justification for governments to promote renewable fuels is environmental, intervention should in principle be aimed at correcting the market failure that gives rise to environmental damage in the form of climate-destabilising greenhouse gases and air pollution.

Environmental damage caused by the use of fossil energy is a type of market failure, since the market fails to put a financial value or penalty on the cost of emissions generated by individuals or organisations. Air quality and the climate are, in economists' parlance, public or common goods, from which everyone benefits. Damage done to the environment is known as an external cost or externality. It follows that governments have a responsibility to correct these failures, to discourage activities that emit noxious or greenhouse gases and to make sure that each polluter pays for the harm he causes to public goods (WLPGA, 2020). Levying charges on polluting activities is effectively a way of internalising these environmental externalities. However, placing an exact financial value on them is extremely difficult and inevitably involves a large degree of judgment.

Other barriers to the uptake of renewable fuels provide additional justification for policy intervention. They include:

- *Awareness and capacity barriers*, such as a lack of sufficient information and knowledge about renewable fuels and their performance, as well as a lack of skilled personnel in that sector.
- *Financial barriers*, including a lack of adequate funding opportunities and financing products tailored for renewable fuels.
- *Administrative barriers*, such as a lack of effective institutions and agencies focused on renewables, an absence of clearly defined responsibilities, complicated licensing procedures, planning restrictions and complex, slow or opaque permitting processes.
- *Market barriers*, including inconsistent pricing structures that disadvantage renewable fuels, distortions in market power and subsidies to fossil fuel and nuclear power.
- *Public acceptance* of renewable fuel projects at specific locations, leading to higher costs, delays and even cancellation of projects.

In principle, the most economically efficient approach to internalising external costs is one that relies mainly on financial incentives, i.e., a market-based approach. In other words, the effective market price of the activity that gives rise to an environmental externality should be adjusted through the application of taxes and/or subsidies large enough to reflect the value or cost of that externality. That can involve taxing or subsidising fuels or the equipment used to heat buildings in such a way that the financial costs to end users of the different fuel and technology options reflect their associated environmental costs. In practice, however, it is very is complex to apply taxes and subsidies exactly according to the actual emissions produced during use even if reliable quantitative estimates of external costs can be obtained. Emission-trading schemes are similarly impractical for certain end uses, like for transport or heating buildings, given the large number of users. Social considerations also complicate matters: raising the price of fossil fuels tends to hurt the poor most, as they are least able to afford to pay more and the cost of fuel for heating usually represents a large share of household spending. Vested interests and broader social impacts can also play a role: for example, discouraging coal use can undermine employment in local mines.

In practice, governments usually deploy a mix of complementary approaches to address all these market failures and barriers. By influencing the choice of fuel and technology, those policies effectively seek to internalise in an implicit manner the external environmental costs of fuel use while taking account of social costs and benefits and addressing specific barriers to the deployment of renewable fuels. Policies focused on renewable fuels often include specific targets for deployment, such as a share of total energy use, which can provide a clear direction of travel for all stakeholders, but need to be supported by specific measures to ensure that the targets are achieved.

3.2 Typology of policy instruments

The main types of policy tools at the disposal of governments to promote the development and deployment of renewable fuels across all sectors are financial and regulatory instruments. As discussed above, financial measures seek to internalise the external environmental costs associated with the use or other, more polluting fuels. Regulatory measures, including mandates regarding the share of renewable fuels in particular sectors, are the other main category. Other measures include support for technology development and public awareness programmes. These are summarised in Table A3.1 and are discussed below.

Table A3.1: Typology of government policies and measures to promote renewable fuels

Fiscal/financial	Regulatory	Other
Excise-duty exemption or rebate on purchases of renewable fuels *vis-à-vis* other fuels Carbon taxation, which favours renewable fuels over more carbon-intensive fossil fuels Grant/tax credit or sales/value-added tax exemption for acquisition of equipment and vehicles that use renewable fuels Feed-in tariffs for power and heat generated at biogas-fired plants Capital grants for renewable fuel supply projects Soft loans and rapid depreciation for owners of renewable fuel distribution infrastructure	Mandates on the use of renewable fuels, such as minimum blending requirements for biofuels and portfolio standards for biofuels and renewable fuels for power generation Tradeable certificate schemes Restrictions on use of fossil fuels for heating and other end uses Emissions and other standards and certification for power and heat plants, end-use equipment and vehicles	Public procurement of renewable fuel related equipment and vehicles Technical capacity building Information dissemination and public awareness campaigns Direct funding for research, development, demonstration and deployment of renewable fuels

Source: Menecon Consulting analysis.

3.2.1 Financial incentives

As for other forms of clean energy, financial incentives are essential for kick-starting the development of renewable fuel markets. Such incentives can be directed at the fuels themselves or at the technologies that use them. Supply-side incentives can take the form of capital grants, soft loans or rapid for investment in production facilities, such as biogas, biomethane and biofuel plants, or in fuel distribution infrastructure. Demand-side incentives can take the form of a lower rate of excise duty and/or sales or value-added tax (VAT), or a complete exemption. In some cases, businesses may enjoy a rebate on fuel taxes. Excise taxes may include a carbon tax, which is levied on each fuel at a rate that varies according to the carbon intensity of the fuel. Carbon taxation favours renewable fuels over fossil fuels, as well as electricity in countries with a highly carbon-intensive fuel mix in power generation (see Section 3). Excise taxes can also be used to internalise the broader external air quality benefits of renewable fuels *vis-à-vis* other fuels.

Since differences in excise duty or carbon taxes show up in retail prices, the measure is highly visible, raising public awareness of the potential cost savings from switching to those fuels (Table A3.2). The lower the rates of duty and tax relative to other fuels, the bigger the financial incentive to switch. The case for differential fuel taxes and subsidies to achieve environmental objectives is well-established (see above), but in practice effective tax rates – and, therefore, final energy prices – are rarely consistent with stated policy goals (Coady et al., 2019).

Financial incentives can also be directed at end-use equipment, such as boilers, heaters and cookstoves, vehicles and power or heat plants that use renewable fuels. They can take the form of a tax credit, direct grant or a sale-tax exemption for consumer purchases, or subsidies to investment by businesses in heating equipment and vehicles. They can also take the form of a cost-based feed-in tariff guaranteed under a long-term contract for power and heat generated at plants fuelled with biogas (or biomethane). Feed-in tariffs have proved extremely successful in stimulating investment is different renewables-based generating technologies, notably wind and solar PV (IRENA/IEA/REN21, 2018).

3.2.2 Regulatory measures

Governments can strongly influence both investment in renewable fuel supply and fuel choices by energy consumers through the design of the regulatory framework. The most direct type of regulatory intervention, and one used in a growing number of countries, is formal mandates on the use of renewable fuels, such as minimum blending requirements for biofuels and portfolio standards for renewables, including biogas and biomethane for power generation. Such mandates may be accompanied by tradeable certificate schemes, whereby the obligation to meet a blending requirement or portfolio standard can be met by buying a certificate for a given volume in an organised marketplace, with certificate supplies by companies that exceed their mandate.

A less direct type of regulatory measure is restrictions that limit the sale or installation of technologies that use fossil fuels. These can be indirect, such as energy performance or emission standards, and health and safety regulations, which can effectively prevent some dirty technologies from being commercialised, favouring those based on renewable fuels. Building codes like the EU Energy Performance of Buildings Directive can be used to favour non-fossil fuels and technologies, including heat pumps and biogas. For example, a new building energy law in Germany recognises rLPG as a low-carbon renewable source of energy for heating in new buildings when used with conventional condensing boiler technology, making it easier for efficiency standards to be met with rLPG (see Part B, Section 3.2). They can also be direct, such as explicit bans on the sale of conventional cars or oil- and gas-fired boilers (due to be introduced in a growing number of countries). These restrictions effectively expand opportunities for renewable-fuel technologies, such as biomethane-fired boilers or low-carbon hydrogen fuel cell cars, to take their place.

Table A3.2: Strengths and weaknesses of primary policy instruments used to promote renewable fuels

Type of instrument	Instrument	Strength	Weakness
Financial	Carbon/energy taxes	Strong, highly visible price signals; can be ratcheted up over time	Politically difficult to implement; exemptions can mitigate their effectiveness
	Subsidies (e.g. grants, tax credits)	Improves the competitiveness of renewables compared with fossil fuels; can lower or offset high capital costs	Support levels can be subject to frequent changes due to shifting political priorities; difficult to determine appropriate levels
	Feed-in tariffs for biogas-fired power or biomethane plants	Limit risks for project developers by providing a hedge against electricity or gas price volatility; suitable for small-scale projects	Tariff setting and adjustment mechanisms can be complex and administratively burdensome
Regulatory	Portfolio standards and mandates	Provides certainty over future deployment, giving confidence to investors and consumers	Require good governance for effective monitoring and compliance (including systems for penalising shortfalls); in most cases, must be tied to a system of tradable certificates and other mechanisms.
	Restrictions on fossil fuel options	Mandatory so guarantees success	Cost-effective alternatives must be available
	Tradeable certificates	Economically efficient market-based mechanism	Require an effective compliance and enforcement mechanism for the market to operate efficiently
	Energy performance and emissions standards and certification	Important for supply chains and increasing consumer confidence	Requires transparent and representative performance testing; can increase capital costs; requires liaising with equipment manufacturers
Other	Technical capacity building	Important for developing supply chains	Unlikely to result in much deployment without other measures
	Public procurement of equipment/vehicles	Can help build critical market mass for increasing deployment more generally	Only accounts for a certain share of demand and must be complemented with measures to aid broader penetration
	Information (e.g. awareness campaigns and labelling)	Educates stakeholders about options, costs and benefits	Most effective when done as part of tailored energy advice which can be expensive to deliver
	R&D and demonstration	Important for building capacity and testing local suitability	Unlikely to result in much deployment without other measures

Source: Menecon Consulting analysis based on IRENA/IEA/REN21 (2018).

3.2.3 Other measures

Governments can also support the research and development (R&D) and demonstration of renewable fuel technology either through voluntary agreements with manufacturers and fuel providers or through direct funding of such activities. Voluntary agreements or collaborative partnerships with industry are usually seen as an alternative to stringent, mandatory regulations and punitive fiscal measures. Information dissemination and education can also form a key element of government-incentive programmes for clean technologies, including renewable fuels. They may take the form of regular communications, such as websites, newsletters or social media, to inform the public and investors of market and technology developments and to indicate how to apply for subsidies if available.

The deployment of renewable fuel related equipment and vehicles by the government itself in can also expand the market for renewable fuels and set an example to other end users. Public procurement can be a powerful tool to build critical market mass for increasing the deployment of renewables more generally, though it needs to be complemented with other measures to promote private sector investment given the typically small demand public sector purchases represent. Publicly funded programmes to develop technical capacity in producing on using renewable fuels can also be effective in developing supply chains, though their impact is likely to be limited without other supportive measures.

3.3 Comparison of policies in surveyed countries

There is a large degree of convergence in the types of policies and policy instruments used to incentivise the production and use of renewable fuels across the countries surveyed in this report (Brazil, France, Germany, Thailand and the United States). This reflects to a large extent the policy lessons learned in countries that were early movers in promoting biofuels countries and the transfer of that experience to other countries. Their effectiveness in those countries, as in the rest of the world, nonetheless varies, largely according to the strength of the policies deployed and local market factors, notably production costs and the cost and availability of competing fuels and energy technologies. Incentive policies for renewable fuels, including rLPG, in those countries are summarised in Table A3.3; details can be found in Part B.

Financial incentives, in the form of grants, other direct subsidies, loans and tax incentives (rebates, exemptions or credits), are the most commonly used and effective instrument:

- In *Brazil*, the government has long used lower taxes on biofuels relative to gasoline and diesel to stimulate demand and has recently provided financial support to the sugarcane sector in response to the slump in demand for sugar-based ethanol due to the COVID-19 pandemic.
- *France* uses a tax to penalise fuel suppliers that fail to meet annual blending targets for biofuels, which effectively ensures that those targets

(for each type of fuel) are met, while feed-in tariffs are the main instrument used to encourage biogas projects.

- *Germany* also uses a penalty system to ensure that biofuel blending targets are met, while biogas production is promoted through competitive auctions and feed-in tariffs for small-scale biogas-fired generating plant; policies to encourage CHP generally also favour investment in biogas plants.

- The prices of biofuels in *Thailand* are kept artificially low through favourable taxes and subsidies (through the state oil fund), while a tax rebate is applied to sales of ethanol-compatible vehicles. Thailand also offers capital subsidies for biogas plants and feed-in tariffs for community biogas projects.

- In the *United States*, there is a large array of federal and state financial incentives, including tax credits and subsidised loan programmes for biofuels, biogas and biomethane projects. There are feed-in tariffs for biogas power projects in three states.

Most countries combine financial incentives with mandates or standards such as biofuel blending obligations and RPSs for biogas/biomethane. France, Germany and the United States have blending mandates for bioethanol and biodiesel, while mandates are limited to biodiesel in Brazil and Thailand. In France and Germany, blending mandates are driven by the requirement of the EU RED, which was updated in 2018 (Box A3.1) Auctions and competitive-bidding schemes for biogas power projects are used in Germany and Thailand as an alternative to feed-in tariffs. Fuel/technology-neutral RPSs, which cover biogas/biomethane alongside other options, are used in a number of US states.

The other main type of policy support for renewable fuels in the surveyed countries is public funding of R&D and demonstrations of emerging technologies. All countries, with the exception of Thailand, provide significant funding of such programmes covering renewable fuels. Their focus varies across countries. For example, Germany is a leader in research in the field of power-to-x fuels and the production of biogas, while France is prioritising innovation in low-carbon hydrogen. The United States spends by far the most on renewable fuels R&D.

Box A3.1: The revised EU renewable energy directive (RED-II)

In 2018, the European Commission issued a new directive, the Renewable Energy Directive-II (RED-II), which mandates fuel suppliers to supply a minimum 14% of renewable energy in road and rail transport by 2030. In addition, the directive sets a dedicated sub-target of 3.5% for advanced biofuels produced from biomass and waste base feedstock (including 20 biomass and waste-based feedstock, but excluding used cooking oil and certain animal fats). The 14% target cannot be achieved solely by FAME biodiesel, providing an opportunity for renewable diesel to fill the gap on condition that the feedstocks are able to meet sustainability criteria.

Table A3.3: Summary of main incentive policies for renewable fuels in surveyed countries, 2021

	Financial	Regulatory	Other
Brazil	Lower federal and state taxes on biofuels Tax incentives (PNPB) Low-cost loan programme for renewable fuels (BNDES) Support for the sugarcane industry	Blending mandate for biodiesel Decarbonisation credit scheme (CBIO)	Public funding of R&D and demonstration projects for advanced biofuels (PAISS programme) and SAFs (Future Fuels programme)
France	Penalties for non-respect of biofuel blending targets (TIRUERT) Financial incentives for investment in SAF projects (4th Future Investment programme, PIA4) Feed-in tariffs for biogas power and biomethane projects	Blending targets for ethanol, biodiesel and qualifying renewable diesel, and SAFs Biomethane purchase obligation on grid operators	Public funding for R&D (National Strategy for Energy Research) Increased funding for renewable fuels under PIA4, notably for low-carbon hydrogen
Germany	Penalties for non-respect of climate protection quotas (CPQs) for biofuels Loan guarantees for renewable fuel projects Subsidised rates and feed-in tariffs for biomethane and biogas power projects Subsidies for biogas CHP projects	CPQs for biofuels (1st generation and advanced) Auctions for biogas power projects	Federal and some state funding of renewable fuel R&D and demonstrations, notably power-to-X and biogenic waste
Thailand	Favourable taxes and subsidies (from state oil fund) for biofuel blends Lower taxes on sales of gasohol (ethanol/gasoline blends) compatible vehicles Capital subsidies for biogas plants Feed-in tariffs for community biogas projects	Blending mandate for biodiesel Obligation on service stations to sell lowest mandatory biodiesel blend Competitive-bidding for community biogas projects	
United States	Large array of federal and state financial incentives for biofuels, including tax credits and subsidised loans (e.g. federal Alternative Fuel Excise Tax Credit) Federal tax credits, grants, and loan programs for biogas or biomethane projects (e.g. Renewable Electricity Production Tax Credit and Energy Investment Tax Credit) Feed-in tariffs for biogas power projects in 3 states	Federal Renewable Fuel Standards (RFSs) for biofuels with trading of credits Similar programmes in California (Low Carbon Fuel Standard) and Oregon (Clean Fuels Program) RPSs covering biogas/biomethane in 33 states and jurisdictions Alternative fuel vehicle mandates (federal and state)	Several large federal R&D programmes on biofuels and bioenergy. Funding includes US$ 400 million for a new Office of Clean Energy Demonstrations for innovative technologies and US$ 61 million for technologies to produce low-cost, low-carbon biofuels, particularly for heavy road freight, aviation and shipping

4. Incentivising renewable LPG

Reaping the benefits of rLPG calls for supportive, clear and predictable policy, regulatory and legal frameworks. RLPG needs to be formally recognised as a genuine renewable fuel so as to profit from existing incentive programmes directed at those fuels. To the extent that rLPG remains a co-product of other biofuel production processes, the prospects for rLPG are likely to hinge to a large degree on incentives to encourage the production and use of biofuels generally. Government support for innovation will be crucial to the development and commercialisation of dedicated rLPG technologies in the longer term.

Government policies are critical to encouraging investment in developing and producing rLPG and other bioenergy technologies that yield rLPG as a co-product. Energy and climate policies everywhere need to be strengthened to promote all types of renewable fuel to meet global climate goals and enhance energy security. The case for providing policy incentives for low-carbon energy has never been stronger. The working group I report on the science of the climate system of the sixth assessment report of the Intergovernmental panel on Climate Change on the science of climate change, released in late 2021, highlights the urgency of the need for action to avoid the worst consequences of climate change (IPCC, 2022). And the Russian invasion of Ukraine in February 2022 demonstrates the need to reduce our reliance on imported oil and gas, including through encouraging the production of domestic bioenergy resources.

The development of policies to encourage rLPG needs to take place within the broader strategic framework for sustainable transport, buildings, industry and power generation. This includes urban planning and low-carbon energy infrastructure development plans. In designing incentives for rLPG and co-produced fuels, policy makers need to take account of the critical success factors behind the development of a sustainable market, notably the need for those fuels to be price-competitive. In many cases, bioenergy technologies involve higher production costs than conventional fossil-fuel-based ones, so the policy and regulatory framework must be designed in a way that favours the supply and use of renewable fuels, including rLPG, by lowering their relative cost.

The starting point for government policy making specifically aimed at rLPG is to formally recognise it as a renewable fuel so that its production and use are supported within existing national policy and regulatory frameworks. Evaluating the environmental advantages of rLPG, such as default GHG emissions settings for rLPG production pathways, needs to be based, as for other renewable fuels, on full-fuel cycle – or "well-to-wheels" – assessments that take account of their much lower GHG and pollutants emissions *vis-à-vis* conventional petroleum-based fuels. That would ensure that rLPG competes on a level playing field by benefiting from the same incentives applied to other renewable fuels and other low-carbon technologies, including electric heat pumps, whether for use in transport (as a biofuel), heating and cooking (both in cylinders and blended into biomethane for distribution through gas grids), industry, power generation or petrochemicals production (as a feedstock).

The additional benefits of rLPG on top of those associated with renewable diesel need to be explicitly taken into account explicitly when designing overall biofuel incentive polices and measures. That is because the near- to medium-term prospects for rLPG are likely to hinge to a large degree on incentives to encourage the production and use of renewable diesel, since rLPG is at present essentially a by-product of HVO renewable diesel production (in the same way that conventional LPG is a by-product of crude oil refining). That is also the case for some emerging technologies, though dedicated rLPG production pathways could become viable in the longer term (see Section 2). Policy incentives that encourage rLPG as well as other co-produced fuels will further boost the attractiveness of investing in those technologies, as well as in rLPG separation and purification facilities (at a plant that is already built or a planned plant that is economically viable on its own). For the latter to be financially viable, the marginal price at which the rLPG can be sold at the plant gate, over and above the price of off-gases, would need to be high enough to cover the incremental capital and operating costs (Menecon Consulting and Atlantic Consulting, 2014).

Regardless of the production pathway, strong financial incentives for rLPG alongside those for co-produced fuels are essential. Experience in the five countries surveyed in this report and in many other countries shows that policies must involve making all types of renewable fuel competitive with other fuels in end uses, power and heat generation and non-energy uses. Incentives should be directed at both production – such as through capital subsidies, subsided loans or accelerated depreciation for pilot projects – and consumption, through favourable pricing.

Demand-side incentives are critical to driving demand for rLPG and making investment financially viable. Fuel-pricing strategies, including taxes and subsidies, need to ensure market equality for all technologies taking account for their broader environmental, social and economic impacts. Removing subsidies on fossil fuels, which often benefit oil over rLPG, as well as conventional LPG and natural gas, is critical in this regard. The goal should be to tax all fuels in all sectors according to their comparative environmental attributes – CO2 and air pollutant emissions. That implies that much lower taxes – or an exemption – should be applied to rLPG (and conventional LPG) and other renewables than on oil, natural gas and coal. Taxes on final and intermediate fuels should, in principle, include an explicit carbon tax to reflect differences in carbon intensity to discourage the dirtiest fuels (rLPG, as a low-carbon fuel, should be largely exempt from this tax). This would lower the running cost of rLPG relative to fossil fuels and make it more attractive to end users.

RLPG should also be included explicitly in regulatory schemes to promote renewable fuels. These include blending mandates and targets, RPSs and auctions and competitive-bidding programmes for new decentralised power generation or gas supply for grid injection, effectively guaranteeing demand for the fuel. Extending such schemes to rLPG would increase the overall attractiveness of investments in production pathways that produce that fuel either as the main output or a by-product, bolstering supply. As in Europe and the United States, blending mandates need to distinguish between first-generation and advanced generation rLPG technologies, which generally rely on more sustainable feedstocks. Depending on future availability, blending mandates could be used to increase demand for rLPG for end uses other than transport, such as cylinders for household heating and cooking, and bulk use in industry. Consumers also need to be informed about the opportunities and benefits of using rLPG. National authorities and public agencies have a role to play in raising awareness about rLPG and encouraging end users, as well as investors, to take advantage of incentives on offer.

Governments need to actively support innovation in rLPG production technologies alongside other renewable fuels. Limits on sustainable supplies of vegetable oil and animal fat feedstocks will constrain the expansion of HVO renewable diesel and rLPG production in the medium term, so most of the expansion in rLPG supply in the longer term will have to come from emerging technologies such as gasification, dehydration/hydrogenation and pyrolysis. Power-to-X technologies may also emerge as a major source of rLPG depending on the cost of renewable energy. None of these new technologies are yet commercially viable, but could become so with strong public support for innovation.

Increased public funding, either through direct public institutions or financial support for private sector research activities, is just one aspect of this support. It must also encompasses educating people, providing network infrastructure, protecting intellectual property, supporting exporters, buying the fuels, helping enterprises, shaping public opinion and setting the overall regulatory framework for markets and finance (IEA, 2020b). Evidence suggests that the productivity of corporate research is increasingly dependent on ideas arising from publicly funded R&D, which tends to leverage more private sector spending. The urgency of the need to expand the supply of renewable fuels justifies a step increase in public funding of R&D in this area, including specifically focused on rLPG. For example, in Europe, national and EU R&D funding should be made available for processes at an early stage of technology readiness to obtain rLPG through the EU Horizon Europe and LIFE programmes (LGE, 2021).

Policy stability and a strong, long-term commitment to boosting the role of rLPG and other renewable fuels are crucial to their success. Stakeholders need to be given clear advance warning of any major shift in policy. Without policy stability, coherence and consistency, fuel and equipment suppliers will not be confident that they can ensure a return on their upfront investment. For example, recent changes in biofuels policy, involving a move away from blending mandates, have discouraged investment in new biofuels production capacity in some countries, such as France. The economics of biofuels and biogas are sensitive to the international prices of crude oil and natural gas, so it is important that policy makers provide assurances to investors about future demand for renewable fuels given the uncertainty about their competitiveness with hydrocarbon fuels, for example through feed-in tariffs and blending mandates.

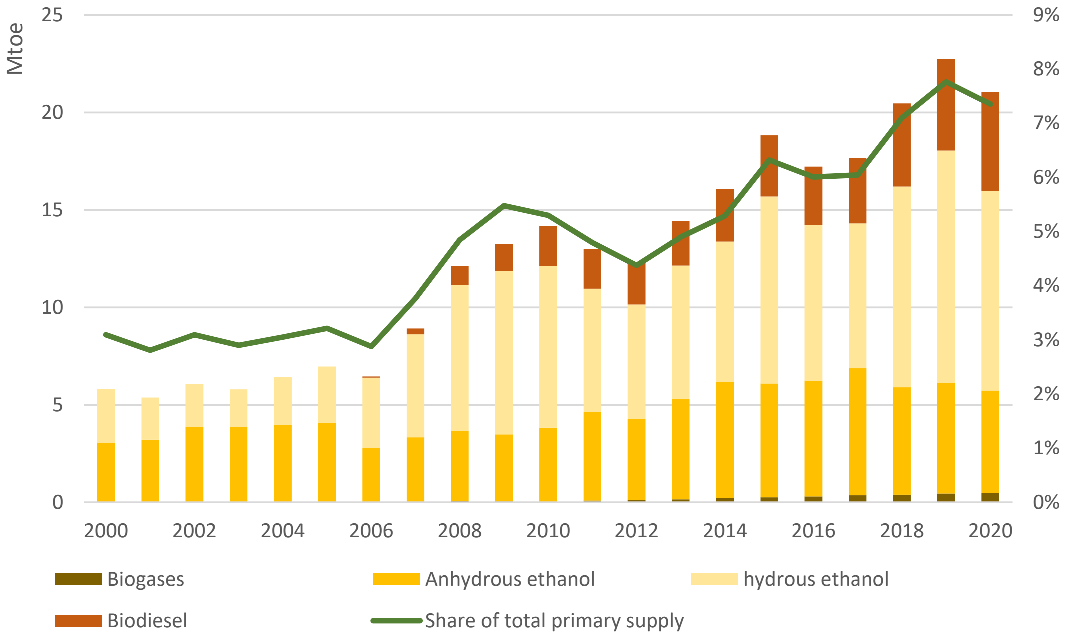
PART B: COUNTRY SURVEYS

1 Brazil

1.1 Market overview

Liquid biofuels – mainly ethanol – account for almost all the renewable fuels produced and consumed in Brazil. The country was a leader in encouraging the development of a bioethanol industry in the wake of the first oil price shock in the 1970s as a way of reducing its dependence on imported oil, and is today the second-biggest producer after the United States. Biofuels meet around one-quarter of Brazil's transport fuel needs – the highest share of any major country – and around 7-8% of its total primary energy use. Biofuel output and their share of energy use have continued to grow in recent years (Figure B1.1). Biogas use is tiny compared with biofuels, reaching 445 ktoe in 2020 (2% of total renewable fuels consumption), though it has been growing in recent years.

Figure B1.1: Primary supply of renewable fuels by type – Brazil



Source: IEA databases; Menecon Consulting analysis.

Bioethanol, derived from sugarcane, remains by far the most important biofuel, accounting for over three-quarters of total renewable fuel supply. Hydrous ethanol, which must be used in pure form as its water content precludes blending it into petroleum gasoline, is the leading vehicle fuel in Brazil, having surpassed the use of anhydrous ethanol, which can be blended, in the mid-2000s. Most cars on the country's roads are flex-fuel vehicles, which are capable of using either ethanol or gasoline. The use of biodiesel has also been growing steadily, replacing petroleum diesel in heavy-duty vehicles, making up around 10% of total diesel use today. Almost all of the biofuels produced in Brazil are consumed domestically, with small volumes of ethanol exported on a net basis.

1.2 Incentive policies

The importance of Brazil's biofuels industry today is the result of decades of supportive policy action, complementing the country's inherent propensity to produce low-cost sugarcane and other energy crops thanks to its climate, soil and relatively cheap labour. Policies introduced in the 1970s creating the conditions for large-scale development of the sugar and ethanol industries were initially driven by concerns about energy security and the social and economic developmental benefits, but climate change is now a major driver. Brazil's nationally determined contribution (NDC) under the UN Framework Convention on Climate Change (UNFCCC), which was updated in 2020, sets economy-wide GHG emissions reduction targets of 37% by 2025 and 43% by 2030 relative to 2005, as well as an indicative objective of achieving carbon neutrality in 2060. Federal decision-making on energy policy is guided by the ten-year energy expansion plan (PDE-2030) which is updated by the Ministry of Mines and Energy each year, and the 2050 National Energy Plan (PNE), launched in December 2020.[1] The latest PDE-2030 sets an overall target of 328 Mtoe of renewables use, or 46% of total final consumption, by 2030 (EPE, 2021).

Brazil has adopted a broad framework of regulations and legislation to support biofuels, providing long-term policy stability (IRENA/IEA/REN21, 2018). Mandatory anhydrous ethanol blending in gasoline has been in place since 1976. The mandated blend was initially set at 11% and reached 27% in 2015. It has not changed since. In addition, a national alcohol programme, *Proálcool*, was launched in 1975 aimed at encouraging the production of hydrous ethanol for use in dedicated vehicles through a range of incentives; the first commercial neat ethanol (E100) car was launched in 1979. The Brazilian government guaranteed purchases by the state-owned oil company, Petrobras, provided low-interest loans for agro-industrial ethanol firms and fixed gasoline and ethanol prices to ensure that hydrous ethanol sold for 59% of the government-set gasoline price at the pump. Incentives were reinforced after the second major oil shock in 1979. Many of the incentives, including direct price subsidies to ethanol, were dismantled after oil prices fell back in 1986 as part of a broader programme of economic deregulation, including fuel pricing.[2] With the end of the subsidies, the use of hydrous ethanol initially fell sharply but anhydrous ethanol use grew with higher mandated blends.

Hydrous ethanol prices at the pump have generally been very competitive with gasoline (known as gasoline C, currently with a 27% anhydrous ethanol blend) – especially when international prices have been above US$30 per barrel – without direct subsidies in recent years, largely thanks to lower federal and

[1] https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/plano-decenal-de-expansao-de-energia-2030

[2] Fuel prices were deregulated in 2002, but the government continues to indirectly control oil product prices through its ownership of the Petrobras, which dominates the market to cushion the impact of international fuel prices volatility on domestic prices.

state taxes than on petroleum gasoline and diesel. Because owners of flex-fuel vehicles, which make up the vast majority of cars in use in Brazil, can chose between gasoline C and pure hydrous ethanol, the prices of the fuels at the pump tend to remain closely aligned. For example, in the first nine months of 2021, the price of hydrous ethanol averaged around R$ 4.10 per litre, or R$ 5.45/litre of gasoline C equivalent (which has higher energy content), compared with R$ 5.30/litre for gasoline C.[1]

Policies to promote biodiesel were introduced more recently. The biodiesel law of 2005 established a minimum blending requirement of 2% by 2008 and 5% by 2013. The blend was increased further, reaching 13% in March 2021, but was reduced to 10% in September 2021 as a result of a surge in the international price of soybean oil, the principal feedstock for Brazilian biodiesel production.[2] Various tax incentives were also introduced in 2005 under the federal biodiesel production and use programme (PNPB) aimed at the sustainable implementation of biodiesel production and use, focusing on social and regional development, via job and income generation. Renewable diesel has not yet been included in the blending mandate for biodiesel.

In 2017, Brazil established a new biofuels programme, known as *Renovabio*, which creates a regulatory framework to revitalise the biofuels sector by encouraging energy efficiency gains in biofuels production and use. The policy, which sets national emission-reduction targets for fuel supply, aims to reduce the carbon intensity of the transport fuel matrix by 10% and avoid 620 million tonnes of CO2-equivalent (eq) emissions from 2018 until 2030 (IEA Bioenergy, 2021a). Fuel distributors can meet these targets by increasing sales of all biofuels (ethanol, biodiesel, and biomethane). Under Renavabio, a decarbonisation credit (CBIO) scheme was launched in 2020, with credits traded on the Brazilian stock exchange. A CBIO corresponds to 1 tonne of CO2-eq avoided. Despite the Covid-19 pandemic, fuel distributors achieved 98% of the established goal of 14.9 million CBIOs traded (EPE, 2021). The national development bank, BNDES, has also created a loan programme with a R$1 billion budget to support the development of carbon reduction projects, including renewable fuels, under Renovabio.[3] Companies that reach the CO2 emission reduction targets stipulated by the programme during the loan repayment period benefit from a reduction in their interest rate. Loans are capped at R$100 million per production unit and R$200 million per company.

As a result of the drop in fuel demand caused by COVID-19 pandemic, BNDES set up a special funding line to support the sugarcane industry. The programme provided emergency financial support to cash-strapped producers through working capital loans for ethanol storage in coordination

[1] https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/boletins-anp/btpvc-1/2021/boletim-trimestral-sdc-11-3t21_vf.pdf
[2] https://www.reuters.com/business/energy/brazil-reduces-minimum-biofuel-content-diesel-10-2021-09-06/
[3] https://www.iea.org/policies/13015-bndes-renovabio?country=Brazil&qs=brazil&source=IEA%2FIRENA%20Renewables%20Policies%20Database&technology=Bioenergy%20supply%20and%20transformation%20technologies%2CTechnologies%20for%20production%20of%20liquid%20biofuels%2CBiogas%2CBiomass%20and%20renewable%20waste

with other banks. A R$3 billion budget was established with loans ranging from R$10 million to R$200 million per company.[1]

The Brazilian government recently launched the Future Fuels' Programme, which aims to increase the supply of sustainable and low-carbon fuels, including aviation biojet fuel and sustainable alternatives in maritime shipping. Measures for carbon capture in biofuel production and hydrogen will also be proposed by this programme. In April 2021, the government established guidelines for the preparation of the National Hydrogen Programme aimed at the development of production and supply chains in several key sectors, notably transport, steel and fertilizers (EPE, 2021).

Brazilian government has a number of government-backed mechanisms providing support for biofuels R&D and demonstration plants. Public support totalled over R$200 million (US$38 million) in 2018 in the form of loans, equity participation and grants via the PAISS programme for ethanol and other biofuel production including cellulosic ethanol, and drop-in biofuels including aviation fuels (IEA Bioenergy, 2021a).

1.3 Renewable LPG

Brazil does not produce any commercial volumes of rLPG at present, though small amounts (thought to be less than 1 kt/year) are currently being produced at a pilot renewable diesel project run by Petrobras at the Repar refinery in Parana. The diesel is being tested in local bus fleets. Much larger volumes of rLPG could become available in the medium term. In its 2022-2026 strategic plan, Petrobras is planning to invest US$600 million in large-scale production of HVO renewable diesel at two of its refineries – Replan and RPBC, both of which are located in São Paulo. They would have a combined capacity to produce a total of 505 kt/y of renewable diesel per year, implying rLPG output of at least 25 kt/y.[2]

The prospects for rLPG production in Brazil depend, therefore, on these projects going ahead. That would hinge on regulatory approval of the inclusion of renewable diesel in blending mandates, though there is no obvious reason why the authorities would not do so. There are no specific policy incentives covering rLPG in Brazil at present. For Petrobras to have an incentive to separate out the rLPG from the flue gas streams at any future HVO plant, it would probably need financial incentives or a mandate from the government, unless Petrobras were able to sell the rLPG at a significant premium to the replacement fuel needed to run the plant (see section A4). Such incentives would also improve the financial attractiveness of investing in the HVO processing facilities. Brazil is a major consumer of LPG, especially for

[1] https://www.iea.org/policies/13016-bndes-support-for-sugarcane-industry?country=Brazil&qs=brazil&sector=Biofuel%20production%2CFuel%20processing%20and%20transformation&source=IEA%2FIRENA%20Renewables%20Policies%20Database

[2] https://clickpetroleoegas.com.br/en/diesel-renewable-petrobras-does-tests-and-finds-higher-value-in-refining-the-fuel-will-be-produced-at-the-refinery-president-getulio-vargas-repair-no-pr/

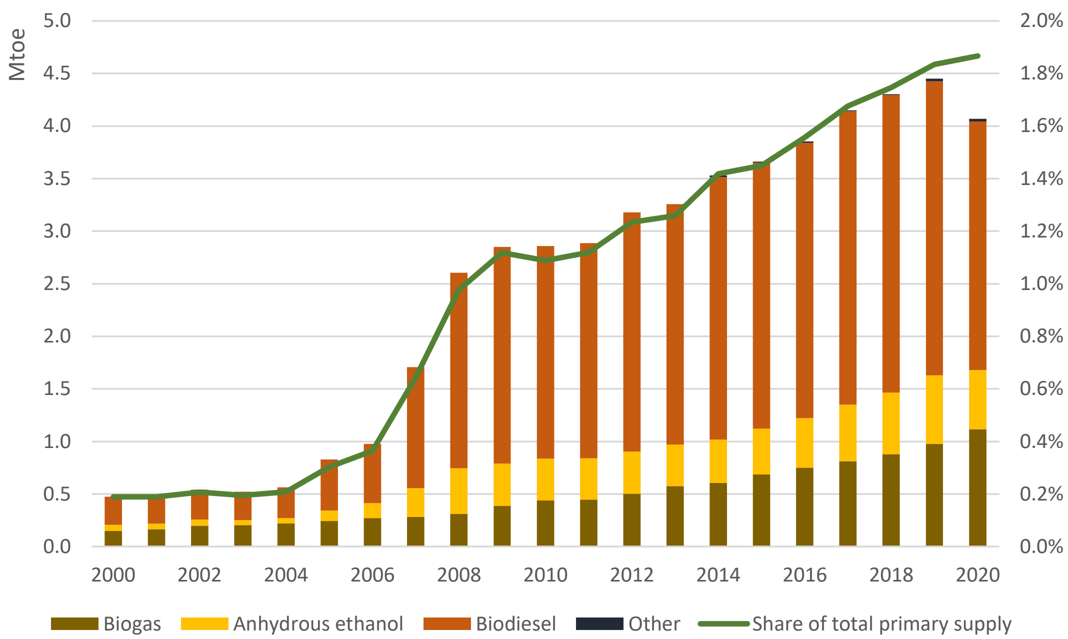
household cooking, so there may be potential for distributors to sell rLPG as a "green" fuel at a significant price premium to conventional LPG.

2 France

2.1 Market overview

Renewable fuels are playing an increasingly significant role in decarbonising France's energy system. Their use surged in the late 2000s and continued to grow steadily through the 2010s before dipping by almost 10% in 2020 due to the effects of the COVID-19 pandemic (Figure B2.1). Renewable fuels now make up almost 2% of total primary energy use and 16% of all use of renewables. Around half of the surface area in France – the largest country in the European Union – is agricultural land and one third forest. Favourable geography and climatic growth conditions mean that there is a large potential for supplying agricultural and forestry biomass (IEA Bioenergy, 2021b).

Figure B2.1: Primary supply of renewable fuels by type – France



Source: IEA databases; Menecon Consulting analysis.

Liquid biofuels remain the main type of renewable fuel used in France, though the consumption of biogas has been growing faster in recent years, accounting for just under one-third of the total renewable fuel market in 2020. Biodiesel is the main biofuel, in part due to the large share of diesel cars in the total French car fleet. France was one of the first European countries to adopt biodiesel. Most biodiesel is produced using FAME processing of mainly rapeseed and sunflower oil feedstock. Total commissioned a 500 kt/year HVO renewable diesel facility at the site of a former oil refinery at La Mède in 2019, but most of the output is exported as it runs primarily on palm oil, which is not considered sustainable by the French government and so the output does not benefit from tax exemptions like biodiesel (see below). The use of ethanol, most of which is produced from sugar beet and cereal crops, has also continued to rise in recent years. France imported around 4% of its anhydrous ethanol needs and a quarter of its biodiesel needs on a net basis in 2020. Biogas output, all of which is consumed domestically, has tripled since 2010. The overwhelming bulk of biogas output is used to generate electricity, with the rest converted to biomethane and injected into the gas grid.

2.2 Incentive policies

Renewable fuel policies are formulated within the overall policy framework set by the Energy Transition for Green Growth Act of 2015 and the Energy and Climate Law of 2019, which set objectives for the different energy sub-sectors. The overall objectives for 2030, which are in line with or exceed those under the EU RED II (see Section A3), are to reduce GHG emissions by 40% and to raise the share of renewable energy in the primary energy mix to 33%, in electricity production to 40%, in heat consumption to 38% and fuel consumption in transport to 15%. To meet these targets, the government established the multiannual energy plan (*programmations pluriannuelles de l'énergie*, or PPE),[1] which sets out strategic policy priorities for the next ten years (updated every five years). The two overriding priorities are to reduce energy consumption, particularly fossil fuel consumption, and develop renewable energy sources. Energy and climate policy is also guided by a "bioeconomy" strategy introduced in 2017, which sets out a framework for sustainable economic development consistent with national resources and needs while avoiding excessive exploitation and ensuring protection of the environment.

Significant public funding is available for R&D in the field of renewable fuels in France, guided by the National Strategy for Energy Research (*stratégie nationale de recherche énergétique*), which was last updated in 2016. Public institutions carry out much of France's R&D activities in the early stages of technology development, leaving private companies to demonstrate and commercialise new technologies. Total spending on renewables R&D, managed by French Agency for Ecological Transition (Agence de la transition écologique, or ADEME), has been declining in recent years, offset partially by rising funding of clean hydrogen (IEA, 2021c). A major increase in funding of R&D of renewable fuel and other clean technologies as part of the national economic recovery plan (the 4th Future Investment Programme, or PIA4) was announced in 2021 (IEA, 2021b). Priority is to be given to low-carbon hydrogen, with a budget of €7 billion, including €2 billion in 2021-22 alone, focused on electrolysis, hydrogen heavy vehicles and research in systems integration.

2.2.1 Liquid biofuels

The impressive development of the biofuels sector in France – one of the largest in the world – is largely due to strong policy support, compensating for the relatively high cost of producing them compared with petroleum-based fuels and biofuels in other parts of the world. The main policy instrument that is used to encourage blending of bioethanol and biodiesel is a tax incentive,

[1] https://www.ecologie.gouv.fr/programmations-pluriannuelles-lenergie-ppe

known as the *taxe incitative relative à l'utilisation d'énergie renouvelable dans les transports*, or TIRUERT, which replaced the *taxe incitative relative à l'incorporation de biocarburants*, or TIRIB, at the start of 2022 (which in turn replaced the taxe générale sur les activités polluantes, or TGAP, in 2019). The TIRUERT, which is applied to gasoline and diesel at a rate of €104/hectolitre, acts as a penalty for non-blending and is proportional to the quantity of biofuels incorporated, i.e., the tax is lower for blends with a higher proportion of biofuels. Every year, the government sets a target blending rate for each type of fuel (currently 8.4% for diesel and 9.2% for gasoline, Table B2.1). In the case of fuel that fully meets the targeted blend, the tax is fully exempted. In reality, most distributors meet these targets, so they pay very little tax: revenues were a mere €620,000 in 2020.[1]

Table B2.1: Historic evolution of biofuel blending targets since 2009 – France

Fuel	2009-13	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Gasoline	7.0	7.0	7.0	7.0	7.5	7.5	7.9	8.2	8.6	9.2	9.5
Diesel	7.0	7.7	7.7	7.7	7.7	7.7	7.9	8.0	8.0	8.4	8.6

Notes : Theese targest are used to calculate the applicability of a biofuels incentive tax, known as the TIRUERT since 2022.
Source: https://www.ecologie.gouv.fr/biocarburants#scroll-nav__4

In response to the EU RED II, which came into effect in July 2021, the government adjusted the incentive tax to exclude high indirect land-use change feedstock, such as palm oil and soy. France met its 2020 target for first-generation biofuels, but biofuels from second-generation sources are still at a very low level of market penetration. The PPE sets second-generation blending targets for advanced biofuels in gasoline and diesel/kerosene of 1.2% and 0.4% in 2023 and 3.8% and 2.8% in 2028, respectively. ADEME recently launched a call for tender for advanced biofuels, focusing on biochemical processes to convert lignocellulosic biomass into ethanol and biomass gasification technologies to produce a range of biofuels.

The French government has established an ambitious roadmap for the incorporation of sustainable aviation fuels (SAF), accompanied by a call for expressions of interest launched in January 2020. The roadmap builds on the "Green Growth Engagement" initiative launched in 2017 by the government alongside Air France, Airbus, Safran, Total and Suez Environnement, and is linked to the recovery funding provided to the airline industry in the wake of the COVID-19 pandemic. The roadmap sets a goal for the incorporation of 2% of SAF in aviation fuel by 2025, 5% in 2030 and 50% in 2050. In addition, the TIRUERT tax system was extended to air transport from 2022 with a target of 1% incorporation of advanced biofuels. A call for tender for projects to develop SAF supply chains with a budget of up to €200 million was launched in 2021

[1] https://www.ecologie.gouv.fr/fiscalite-des-energies

under PIA4 and the national strategy "Biobased products and industrial biotechnologies - Sustainable fuels".

2.2.2 Biogas

The latest PPE sets a biogas target of 7% of gas consumption in 2030 and up to 10%, depending on the decline in costs. It also sets targets for increasing the capacity of biogas/biomethane-fired electricity generating capacity (270 MW for 2023 and 340-410 MW for 2028) and total biogas production (14 TWh, or 1.2 Mtoe, in 2023 and 24-32 TWh, or 1.1-2.8 Mtoe, in 2028). Priority is to be given to projects that feed biomethane in the gas grid.

Feed-in tariffs are the main instrument used to encourage biogas projects. The production cost of biogas has generally been much higher than the price of natural gas on the wholesale market (at least, until prices surged to record levels in 2022), so a guaranteed tariff well above the wholesale market price has been needed to make investments financially attractive. Biomethane producers benefit from an obligation on the gas grid operator to buy their output (*obligation d'achat*) under a 15-year contract at a tariff determined by the regulator according to estimated costs and the size of the project, ranging from 4.5 et 9.5 cents/kWh.[1] An additional amount of 2-3 cents/kWh is due if the biogas is produced exclusively from agricultural waste, 0.5 cents in the case of MSW and 0.1-3.9 for sewerage. The cost of these subsidies amounted to €544 million in 2021 (IEA, 2021b). The minister responsible for energy is empowered to request that CRE, the national regulator, organise an open tender for biogas production if capacity additions fall short of PPE targets. Since 2018, gas network adaptation costs are no longer solely borne by biogas producers, but have been shared between all gas network users. In 2018, the Agriculture and Food Law (EGAlim Act) established a support scheme for adapting the infrastructure necessary for more biomethane injection (IEA, 2021b).

Feed-in tariffs under 20-year contracts are also available for biogas-fired power projects on mainland France with capacity up to 500 kW. Projects with capacity in excess of 500 kW can bid for feed in tariffs under regular tenders organised by CRE.[2] They can be adjusted downwards if the contracted biogas production capacity is higher than the annual target of 800 GWh/y (IEA, 2021b). Since 2021, the cost of this subsidy is charged to the state budget. Tenders for biogas co-generation installations have been less successful than for simple generating plants due to difficulties in finding a suitable outlet for the heat due to the rural locations of most of the biogas plants: only two projects were accepted in 2016, two in 2017 and just one in 2019 under the three-year programme.

Additional financial support is also available from ADEME, the national energy efficiency agency, for the construction of biogas and biomethane production

[1] https://www.ecologie.gouv.fr/biogaz#scroll-nav__3

[2] Biogas plants with capacity of 300 MW or more located in an area served by a natural gas network are requested to inject their biogas production into the network rather than generate electricity.

facilities for supplying generating plant or injection into the gas grid. ADEME also finances R&D in biogas under the PIA.

2.3 Renewable LPG

The only rLPG produced in France comes from Total's 500 kt/y biorefinery at La Mède, commissioned in 2019, which produces HVO renewable diesel and biokerosene. Up to 25 kt/y of rLPG is produced as a by-product (volumes vary according to the feedstocks used). The rLPG is separated from other off-gases and purified for commercial sale.[1] Total is also converting its Grand Puits refinery into biorefinery to produce renewable diesel, aviation fuel and rLPG, as well as naphtha for making bioplastics.[2] RLPG output could amount to about 15 kt/y once production starts up, as expected, in 2024.

RLPG is marketed in France by Primagaz, a subsidiary of SHV, sourced from Neste's HVO plant in Rotterdam, and Butagaz, which obtains small volumes of isobutene from Global Bioenergies (which runs a pilot fermentation plant in Germany) and larger volumes from, it is believed, La Mède. Primagaz markets its rLPG separately in small cylinders as pure biobutane or biopropane (under the brand name, Bio Twiny), as blended biopropane (51%) in larger cylinders, in bulk as biopropane to various household and business customers, and blended into petroleum propane sold throughout Primagaz' sales network and through Avia's service station network for use as Autogas (with an 8% blend).[3] Butagaz markets biobutane in cylinders in a minimum 20% blend.[4]

At present, rLPG is not treated any differently from petroleum LPG with respect to fuel taxation. Thus, the Autogas sold by Avia, which contains up to 8% rLPG, is subject to the same rate of excise duty as conventional Autogas. Similarly, rLPG sold by Primagaz and Butagaz in cylinders or in bulk to household and commercial customers is subject to the same rate of excise tax (*taxe Intérieure de Consommation sur les Produits Energétiques*, or TICPE) and VAT as for conventional propane and butane.[5]

The explicit recognition of rLPG as a liquid biofuel for transport and as a biogas for heating would, by virtue of financial incentives, increase its value to distributors and provide an incentive for them to seek out and market it in France. That would, in turn, improve the overall financial viability of new HVO projects and, in the longer term, other types of project that could yield rLPG. That would require suppliers of rLPG to prove that the production process meets sustainability criteria under RED II, i.e., that the feedstocks used to produce the fuel are compatible with current regulations (Total's HVO plant, which currently runs predominantly on palm oil, does not comply, though Total plans to stop using that feedstock from 2023).

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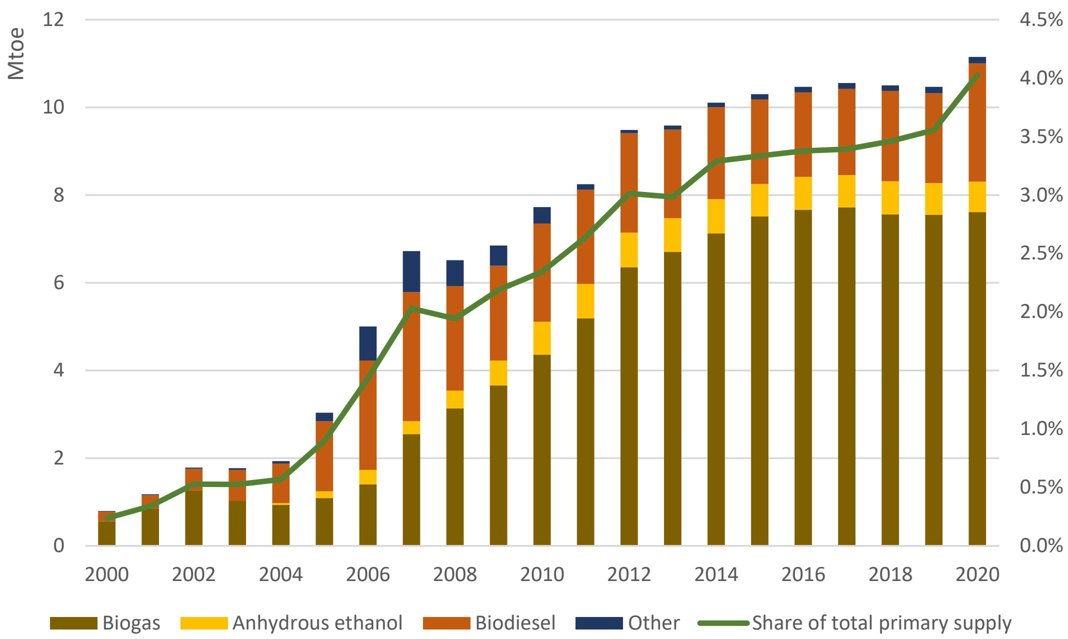
[1] http://documents.projets-environnement.gouv.fr/2022/01/14/6928108/6928108_FEI.pdf
[2] https://totalenergies.com/media/news/news/energy-transition-total-investing-more-eu500-million-convert-its-grandpuits
[3] https://www.primagaz.fr/a-propos/biopropane
[4] https://www.butagaz.fr/bouteilles-de-gaz/nos-produits/viseo
[5] https://lepropane.com/citernes/prix/taxes-ticpe

3 Germany

3.1 Market overview

Germany is a major producer and consumer of renewable fuels, mainly biogas/biomethane. It is the world's second-largest producer of biogas after China, all of which is consumed domestically. Biogas use surged between the mid-2000s and mid-2010s in response to the introduction of generous feed-in tariffs (see below), levelling off at around 7.5 Mtoe since 2015 (Figure B3.1). Close to three-quarters are used for power generation, mostly in CHP plants, of which there are close to 9 500 in operation.[1] Biogas accounts for around 5% of total power generation and over a quarter of all gas-fired power generation in Germany. The rest is injected into the gas grid and sold mainly to residential and commercial end users. The development of Germany's biogas industry was largely based on the use of agricultural feedstocks, with a significant contribution from energy crops, though policies are now shifting to smaller plants using manure feedstocks that offer higher levels of emissions reduction, deliver waste management benefits and avoid competition with food production.

Figure B3.1: Primary supply of renewable fuels by type – Germany



Source: IEA databases; Menecon Consulting analysis.

In contrast to neighbouring France, the German biofuels sector remains relatively modest, having seen little expansion since the mid-2000s. They

[1] https://www.fnr.de/fileadmin/allgemein/pdf/broschueren/broschuere_basisdaten_bioenergie_2020_engl_web.pdf

make up less than a third of total renewable fuel use in the country. Biodiesel is the leading fuel, making up four-fifths of total biofuel consumption. The use of biodiesel has been broadly flat since 2006. Bioethanol use took off in 2005 and grew rapidly to 2010, before levelling off at around 700-750 ktoe/y. Biofuels in total accounted for just 5% of transport energy use in 2000 – well short of the 10% EU target (even taking into account renewable electricity). Overall, renewable fuels made up around one-quarter of total primary supply of renewables but just 4% of total energy supply in Germany.

3.2 Incentive policies

The main policy measures and frameworks relevant to the deployment of renewable fuels in Germany are specific policies supporting renewables deployment in the electricity, heat and transport sectors, as well as policies for energy efficiency – in particular in the buildings sector – and the more general energy and climate change policy framework (IEA, 2021c). Germany has a national target of 30% renewable energy in the gross final energy consumption by 2030 under its national energy and climate plan, which is in line with the results of the formula under the Governance Regulation on which the European Commission bases its assessment of Member States' renewable energy contributions. In May 2021, the German government amended its Climate Protection Act, setting a goal of climate neutrality in 2045, instead of 2050 (the binding target of the European Union). It has also agreed on a higher GHG emissions reduction target of 65% (previously 55%) by 2030 and a new reduction target of 88 % for 2040, in line with stricter levels of annual emissions for individual end-use sectors.

The principal instrument to support biofuels is a blending mandate. The 2006 Biofuel Quota Act (*BioKraftQuG*) and the act to introduce a biofuel quota by amending the Federal Emission Control Act (*BImSchV*) defined and prescribed for the first time a minimum share of biofuels amounting to 6.25% on an energy basis in total transportation fuel sales in Germany. This was supported by tax incentives. In 2015, Germany switched to a climate protection quota (*Treibhausgasminderungs-Quote*, or CPQ) policy, which places annual GHG emissions reduction targets on transport fuel suppliers. CPQs were reduced by 3.5% in 2015 and 2016, 4% in 2017 and 6% from 2020. In the event that a supplier fails to respect its quota, the biofuel quota office levies a penalty amounting to €0.47 per kilogramme of CO_2-eq of GHG reduction not achieved.[1] Biofuels, electricity and upstream efficiency savings can be used for compliance under the policy. Quotas can be traded. Tax incentives for biofuels expired on 1 January 2016, leaving the CPQ as the sole means of biofuel policy support. However, the CPQ target has failed to stimulate an increase in ethanol or biodiesel consumption volumes.

The national implementation of EU RED II and thus the adjustment of the GHG quota by 2030 was completed in June 2021, involving a cap on biofuels

[1] https://www.ufop.de/files/6214/2314/3390/UFOP_1262_Info-Erweiterung_THG_RL_031.pdf

production from cultivated biomass at 4.4% of total production from 2026.[1] RED II for the 2021-30 period requires a 14% share of renewable energy in transport, comprising a maximum share of conventional crop-based biofuels of 7%. The CPQ is to be the key policy mechanism used to meet this target. Germany's draft NECP outlines that it will comply with the 14% target but will limit consumption of conventional biofuels to current levels, with the increase coming from battery-powered vehicles (powered with renewable electricity), hydrogen and power-to-x synthetic fuels. Germany is at the forefront of global research efforts to the development of power-to-x fuels (IEA, 2021c).

Germany's national energy and climate plan (NECP) submitted to the European Commission in 2018 for the period 2021-2030 commits to meeting the 3.5% sub-target for advanced biofuels (including double-counting, corresponding to 1.75% in energy terms)[2] required by 2030. This is to be achieved through measures to facilitate innovation, technology learning and a scale- up of advanced biofuels production in order to reduce unit costs and increase consumption. These include advanced biofuel quotas and financial de-risking measures, such as loan guarantees from development banks. Technically mature biofuels produced from used cooking oil and animal fats, such as HVO renewable diesel, are expected to contribute up to 3.4% (1.7% in energy terms).[3]

Biogas production has historically been incentivised primarily through feed-in tariffs for biogas-fired power generation, which effectively guarantee a return on investment in new digester and generating plants by setting a cost-based electricity tariff under a long-term supply contract. The scheme was originally set up in 2000 under the Renewable Energy Sources Act (*Erneuerbare Energien Gesetz*, or EEG) to support the production of electricity from renewable energy sources and mine gas. Special tariffs are set for small manure-based plants with an installed generating capacity of 75 kW and using more than 80% manure as feedstock to restrict the use of crops as feedstock for energy.[4] In 2017, feed-in tariffs were replaced with auctions organised by the Federal Network Agency (*Bundesnetzagentur*) to determine the level of remuneration. Small-scale biogas installations involving electricity output of up to 150 kW are still eligible to receive feed-in tariffs. The EEG also provides a premium payment for bioenergy installations that provide flexibility measures for balancing fluctuating renewable energy sources (flexibility premium). These changes have resulted in less generous subsidies to biogas production, leading to a sharp reduction in new investment (see above). Biomethane is also covered by the CPQ scheme (described above).

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[1] https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Glaeserne_Gesetze/19._Lp/thg_quote/Entwur f/thg_quote_refe_bf.pdf

[2] Under the EU RED methodology, renewable electricity and certain biofuels from waste and residues are eligible for double-counting against the EU target given their potential to achieve bigger emissions reductions.

[3] https://energy.ec.europa.eu/system/files/2020-07/de_final_necp_main_en_0.pdf

[4] https://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-Germany-4ppa4_.pdf

Biogas-fired CHP plants also benefit from policies that support co-generation. Since 2002, the Combined Heat and Power (CHP) Act has provided support for co-generation through a bonus payment on sold electricity. The Act was revised in 2016, with funding extended up to 2022. Revisions also included targeted support to gas-fired co-generation facilities, including biogas, to reduce emissions as well as focused funding for boosting flexibility to accommodate rising shares of renewables on power grids. Since the end of 2017, support for investment in co-generation plants with capacity of 1-50 MW has been determined by auction. For highly innovative co-generation systems, the government holds separate auctions to provide stronger incentives to more flexible, lower-emissions co-generation plants deriving heat from biogas and other renewable sources.

The federal German government provides substantial funding for R&D of renewable fuels through several research programmes at the national level managed by the German Federal Ministry of Research and Education (BMBF), the Ministry for Economy Affairs and Energy (BMWi) and the Ministry of Food and Agriculture (BMEL), which has the lead for bioenergy R&D. The Agency for Renewable Resources (*Fachagentur Nachwachsende Rohstoffe*, or FNR) coordinates and administers BMEL's R&D budget, which amounted to around €150 million in 2021 (IEA Bioenergy, 2021c). The main funding areas are biomass from agriculture, forestry and aquatic sources, the utilisation of biogenic waste from agriculture and forestry, aquaculture, the processing industry, commerce and households, and the generation, handling, processing and use of renewable resources, as well as cross-cutting issues in the area of bioenergy. BMBF, BMWi and BMEL coordinate their R&D funding activities in the 7th Energy Research Programme. In addition, the Ministry of Environment (BMU) and the Ministry of Transport (BMVI) pursue activities relevant for bioenergy research, including a large programme on renewable fuels for transport run by the BMVI. Some states (Länder) are also involved in renewable fuel R&D.

3.3 Renewable LPG

There is no significant rLPG production in Germany (bar some small volumes of biobutane produced by Global Bioenergies) , though Primagas Germany, a subsidiary of SHV, does import some volumes from Neste's Rotterdam refinery under a long-term contract. This rLPG is marketed as a premium, green product alongside conventional LPG to household and commercial customers.

The current fiscal framework does not differentiate rLPG from conventional LPG, so both are taxed in the same way in each end-use application (see WLPGA, 2020 and 2021). Nonetheless, the new building energy law (*Gebäudeenergiegesetz*, or GEG), which came into force on 1 November 2020, recognises rLPG as a low-carbon renewable source of energy for heating in new buildings when used with conventional condensing boiler technology, making it easier for efficiency standards to meet with rLPG.[1] The GEG, which

[1] https://www.combifuel.ch/en/geg-biogenic-liquid-gas-legally-recognised-in-germany-since-1-november/

implements the EU Energy Performance of Buildings Directive, imposes requirements for the energy performance of buildings, the creation and use of energy performance certificates and the use of renewable energy in buildings.[1] The law makes it compulsory to disclose the CO_2 emissions of a building, based on the calculated primary energy demand or measured primary energy consumption, and comply with determined limits. It establishes a primary energy factor (PEF) of 0.7 for rLPG blends of 50% used in condensing boilers. For use in a CHP plant to supply new housing estates, the PEF for rLPG with a 30% blend is set at 0.5. RLPG was formally recognised as a renewable biofuel for transport under 38th Ordinance on the Implementation of the BImSchV in 2017.[2]

[1] https://qualdeepc.eu/new-german-buildings-energy-act

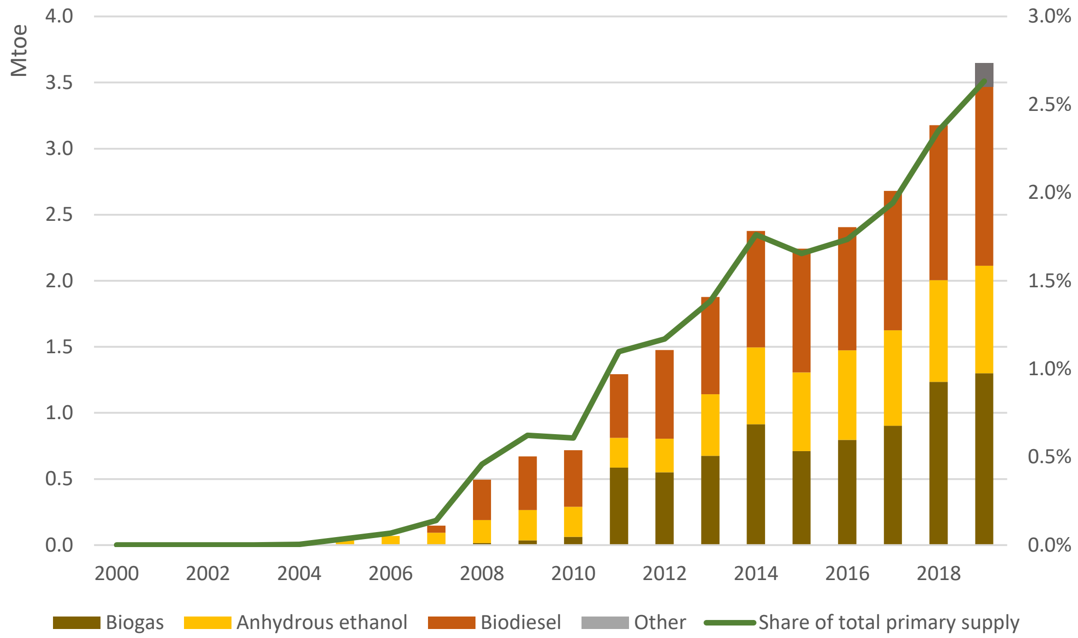
[22] https://auto-gas.net/mediaroom/german-regulation-underlines-sustainable-contribution-autogas/

4 Thailand

4.1 Market overview

The use of renewable fuels in Thailand has soared in recent years, reaching over 3.6 Mtoe in 2019, on the back of strong policy support (Figure B4.1). Demand is thought to have fallen in 2020 as a result of the Covid-19 pandemic, which severely curbed economic activity, notably tourism, in the country. Liquid biofuels, mainly biodiesel, make up almost two-thirds of total renewable fuel use and biogas for most of the rest. All those fuels are produced domestically and none are traded internationally. In total, they accounted for 2.5% of total primary energy supply and close to 13% of total renewable energy sources in 2019.

Figure B4.1: Primary supply of renewable fuels by type – Thailand



Source: IEA databases; Menecon Consulting analysis.

Thailand has become one of the leading producers of renewable fuels in Asia. The production of anhydrous ethanol and biodiesel took off in the mid-2000s, with the latter quickly becoming the leading biofuel. Ethanol is produced in Thailand mainly by the fermentation of molasses, a by-product of sugar manufacturing, and cassava (tapioca), while biodiesel is produced by transesterification of vegetable oil, mainly palm oil. Biogas production started on a significantly scale in 2011, quickly growing to over 1 Mtoe by 2018.

4.2 Incentive policies

The rapid growth of renewable fuels production and use in recent years in Thailand has been largely policy-driven. Thailand committed to reducing its GHG emissions by 20-25% of 2015 emissions by 2030 under the Paris Climate Agreement in 2015 and its first NDC committed to large emissions reductions in the energy and transport sectors, including by promoting biofuels. The goals of the 2015 NDC were confirmed in an updated NDC submitted to the UNFCCC in 2020. The initial NDC was translated into Thailand's National Energy Plan for 2015-2036, known as Thailand Integrated Energy Blueprint (TIEB 2015). That plan includes the Alternative Energy Development Plan (AEDP), which incorporates both overall climate goals, as well as those for national energy security and domestic economic development.

The AEDP was updated in 2018 and extended to 2037. Under the latest AEDP, ethanol consumption is targeted to reach 2.7 billion litres by 2037 (up from an estimated 1.5 billion litres in 2020) and biodiesel consumption 2.9 billion litres (up from 1.9 billion litres) (USDA, 2021).[1] These targets were reduced substantially compared with the previous AEDP, reflecting mainly the brighter prospects for electric vehicles[2] and downgraded projections of future feedstock availability. Actual biofuel use is currently well below the AEDP target of 1.985 billion litres for ethanol and 2.19 billion litres for biodiesel due to the effects of the pandemic. The government expects demand for biofuels to decelerate after 2025 as the take-up of electric vehicles slows demand for conventional cars.

The principal instruments used by the Thai government are blending mandates and financial incentives for the fuels themselves and cars able to use them. In the case of ethanol, there is no ethanol blend mandate for the entire fuel pool, but the authorities seek to encourage a shift to higher ethanol blends through fuel taxation (which takes account of the lower energy content of ethanol *vis-à-vis* gasoline). Four blends of ethanol (known as gasohol) are marketed in Thailand, in addition to premium (95 octane) gasoline: E10 (regular and premium), E20 and E85. The government is aiming to phase out the production of regular E10 by 2022 and premium E10 and E85 between 2023 and 2027, with the intention of making E20 the primary gasohol, though there are doubts about whether molasses and cassava feedstocks will be sufficient to meet the higher demand for ethanol that this would entail. All passenger cars manufactured in Thailand since 2008 are compatible with E20.

Current price subsidies typically make gasohol 20-40% cheaper than premium gasoline, not allowing for the lower energy content of ethanol (Table B4.1). All price subsidies for gasohol were due to be terminated in 2022 under the State

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1 https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Bangkok_Thailand_05-31-2021.pdf

2 The Thai government is encouraging the automotive industry to make Thailand a regional hub for electric vehicles. An excise tax exemption was introduced on January 1, 2020 to December 31, 2022 to encourage them to set up production facilities in Thailand. In addition, the excise tax rates will only be 2 percent after 2022 whereas the usual tax rate is 8 percent (USDA, 2021).

Oil Fund Act of 2020, but have been kept in place as a result of the surge in international oil prices since late 2020. The fund is used to balance differences in ex-refinery prices (which are deregulated) and wholesale prices, which are controlled by the government. In April 2021, the state oil fund levy on premium gasoline was 6.5 baht/litre compared with 0.6 baht on E10 and a subsidy of 2.3 baht on E20 and 7.2 baht on E85.

Table B4.1: Transport fuel pump prices, 2021 (bhat per litre)– Thailand

Fuel	Gasoline	Gasohol 95			Gasohol 91	Diesel				Autogas (LPG)
	Premium	E10	E20	E85	E10	HSD	B7	B20	Premium	
Minimum	35.69	28.40	26.86	22.06	28.15	25.62	27.95	25.38	32.77	10.19
Maximum	36.23	28.75	27.24	22.06	28.47	25.89	28.21	25.79	34.84	10.19
Average	35.94	28.52	26.90	22.06	28.21	25.70	28.02	25.51	33.72	10.19

Notes : HSD = high-speed diesel.
Source: Energy Policy and Planning Ofiice of the Thai Ministry of Energy (http://www.eppo.go.th/index.php/en/en-energystatistics/petroleumprice-statistic).

The government also incentivises the manufacturing and sale of vehicles that are compatible with E20 and E85 gasohol. The excise tax rate for E20 "eco-cars", with engines less than 1 300 cubic centimetres and fuel consumption not exceeding 5 litres per 100 kilometres, is 17%, compared with 30% for E10 vehicles, while an additional three percentage point reduction in the excise tax rate is applied to eco-cars that can use E85 gasohol.

In contrast to gasohol, the government imposes mandatory blending of biodiesel for on-road use, in addition to price subsidies on high biodiesel blends. All service stations are required to sell the lowest mandatory biodiesel blend. In 2020, the government increased the mandatory blend rate to B10 to help absorb excess supplies of oil palm, but still allowed B7 and B20 for older vehicles that are not compatible with B10. However, this move was recently reversed in the face of rising oil prices, which has increased the burden on the state oil fund. In early 2021, the government announced that only 7% biodiesel blends (B7) would be allowed to be sold, while the maximum blend was reduced further to 5% in February 2022, removing B7 from the market, at least until the end of March.[1] Plans to reintroduce B10 and B20 have been put on hold indefinitely in light of high prices. The government had previously set the price for B10 slightly lower than B7 to drive demand for the higher blended fuel: in April 2021, the state oil fund levy on B7 diesel was 1 baht/litre, compared with a subsidy of 2.5 baht for B10 and 4.16 baht for B20.

The development of the biogas industry in Thailand was initially assisted by collaboration with the German Corporation for International Cooperation (GIZ), which helped disseminate knowledge about production technology and

[1] https://www.biofuelsdigest.com/bdigest/2022/02/03/thailand-limits-biodiesel-blending-to-5-through-at-least-march/

build technical capacity in local universities and companies.[1] Early projects using the gas to produce electricity, based mainly on fermentation of waste cassava starch, were supported by a feed-in tariff system and capital subsidies, including from the energy conservation promotion fund. Capital subsidies, which averaged around 50% for the first pilot projects in the late 1990s, have fallen steadily as the technology has developed and deployment has grown.[2] The first AEDP, introduced in 2012, led to a sharp increase in public funding of biogas projects. Tighter regulations on the treatment of wastewater also helped to boost investment in biogas plants. Policy has shifted recently towards projects based on MSW.

In 2021, the Thai government announced a community power plant policy to support biogas and biomass based decentralised power generation. The purpose is to help remote communities in Thailand generate their own electricity and procure local economic benefits. For the first round of projects, a feed-in tariff of 4.73 baht per kWh was offered, with projects selected using a competitive-bidding process.[3] The Energy Regulatory Commission announced a list of selected bidders in September 2021; 27 of the 43 selected bids were for biogas projects, involving 74 MW of capacity.[4] A second round of bidding for a total of 1 000 MW is due to be launched in 2022.

4.3 Renewable LPG

There is no production or consumption of rLPG in Thailand at present. As a result, there is no policy specifically relating to rLPG.

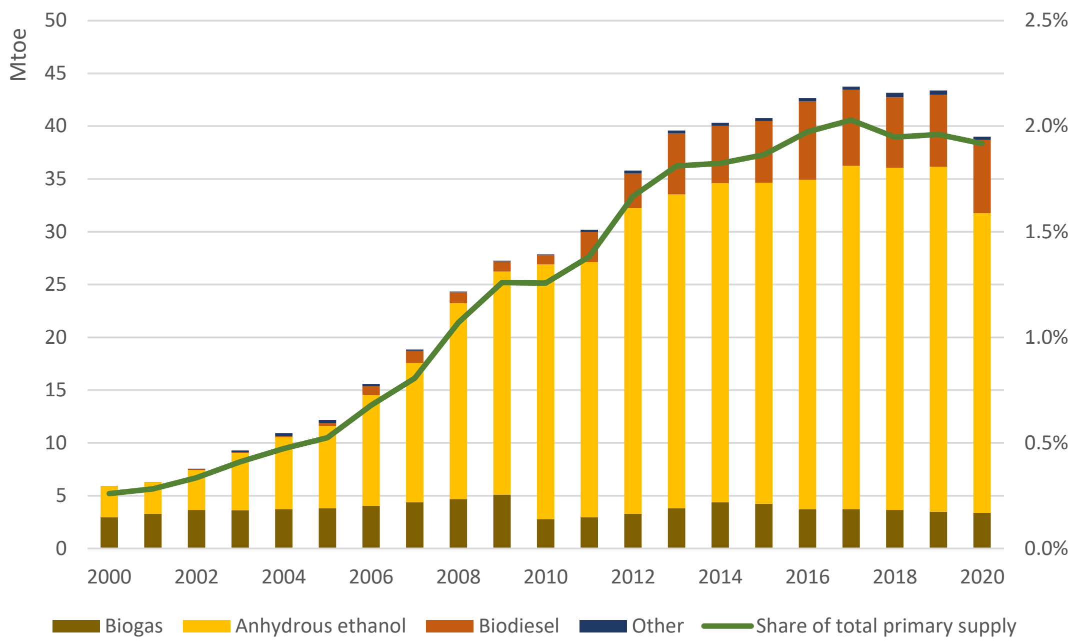
[1] https://ap.fftc.org.tw/article/2867
[2] https://iea.blob.core.windows.net/assets/cf8a0924-7255-4216-92f6-8e01cf0b9e22/1.5_Aggarangsi_Pruk_13Jul2021.pdf
[3] https://www.tilleke.com/insights/deadline-for-participation-in-thailands-vspp-and-community-power-plant-projects-draws-near/
[4] https://www.lexology.com/library/detail.aspx?g=d3136346-1c27-480d-8ca6-a26e259ba2c1

5 United States

5.1 Market overview

The United States is the biggest producer and consumer of renewable energy in the world. Liquid biofuels account for the bulk of the market, making up 92% of total demand in 2019 (91% in 2020, when transport activity was reduced by the COVID-19 pandemic) (Figure B5.1). Supply of biofuels surged during the 2000s and the first half of the 2010s, thanks to strong policy support. Renewable fuels contribute around 2% of US primary energy supply – a share that has been broadly constant since the mid-2010s – and about one-quarter of total renewables supply.

Figure B5.1: Primary supply of renewable fuels by type – United States



Source: IEA databases; Menecon Consulting analysis.

Anhydrous ethanol, produced mainly from corn (maize), is the leading biofuel, ordinarily making up over 80% of total biofuel supply. The United States is the world's largest producer of ethanol, with output reaching almost 60 billion litres in 2019, dropping to 53 billion in 2020 and, according to preliminary data, bouncing back to around 57 billion litres in 2021. Archer-Daniels-Midland Company (ADM) which has built over 100 corn-ethanol production plants, supplies about one-fifth of the market. The drop in domestic demand pushed up exports of ethanol in 2020, accounting for almost a tenth of total production. Most cars on the road today across the United States are able to run on blends of up to 10% ethanol (E10) and some are designed to run on much higher ethanol blends. Though E10 is mandatory only in ten states, ethanol blends in the US are available in other states.

Biodiesel is produced and consumed on a much smaller scale, with output reaching 6.9 billion litres in 2020, supplemented by around 1.3 billion litres of imports (net of some exports). Output is thought to have fallen further to around 6,2 billion litres in 2021. Biodiesel is commercially available in most oilseed-producing states, usually blended into conventional diesel. Output of renewable diesel, which can be blended into conventional diesel at higher rates than biodiesel, is growing rapidly, reaching over two billion litres in 2020 and an estimated 3.1 billion litres in 2021. Capacity could reach 12 billion l/y in 2024 if all the plants currently under construction are completed.[1]

There are over 400 biogas plants across the United States, mostly based on MSW at landfill sites, producing a total of around 280 billion cubic feet (bcf) of gas in 2020. Almost all of this gas is used to generate electricity on site, with output amounting to 11.2 TWh, or about 0.3% of total power generation.[2] Capacity and output have been broadly stable for several years.

5.2 Incentive policies

US renewable energy policies are formulated within the overall energy and climate policy framework, taking account of broader economic considerations. Historically, the United States has demonstrated varying approaches and intent with regard to addressing climate change generally and to participating in GHG abatement under the UNFCCC. The United States once again became a party to the 2015 Paris Agreement in February 2020, when President Biden reversed the 2017 decision by former President Trump to withdraw from it. President Biden subsequently announced a new GHG target for the United States to reduce net GHG emissions by 50%-52% below 2005 (Table B5.1). Various federal energy and renewable energy-related sectoral targets have also in place, including 100% clean power generation by 2035, half of all light-duty vehicles sales to be net-zero emissions vehicles by 2030 and the capacity to produce 3 billion gallons (11 billion litres) per year of SAF by 2030. State-level energy and climate policies also impact the renewable fuels sector.

5.2.1 Biofuels

There are several federal programmes to incentivise the production and use of biofuels and other alternative transport fuels, foremost among which are renewable energy standards and blending mandates, as well as financial incentives. The Renewable Fuel Standard (RFS) is the primary instrument to promote the use of biofuels. The RFS was originally established under the Energy Policy Act of 2005 and was updated under the Energy Independence and Security Act of 2007 as the RFS2, which is still in effect. The RFS works by awarding renewable identification numbers (RINs) for the production or import of biofuels, with different types of RIN awarded to different types of biofuel.[3] The targets established under the programme were defined under statute to gradually increase to 36 billion gallons by 2022, divided between 15

[1] https://www.eia.gov/todayinenergy/detail.php?id=48916
[2] https://www.eia.gov/energyexplained/biomass/landfill-gas-and-biogas.php
[3] https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard

billion gallons of conventional (corn-based) ethanol and 21 billion gallons of advanced biofuels, of which 16 billion is supposed to be cellulosic biofuel (IEA, 2019). The Environmental Protection Agency (EPA), which runs the programme, was tasked with defining specific blending targets for refiners based on the volumetric targets (known as Renewable Volume Obligations, or RVOs) for several categories of renewable fuels through annual rule-making.

Table B5.1: Renewable energy and GHG reduction targets by sector – United States

Sector	Renewable energy targets	GHG reduction targets
Overall		Reduce net GHG emissions by 50-52% below 2005 levels by 2030 and to net-zero by 2050
Buildings	Heat pumps and electric heaters to make up 60% of heating installations by 2030 and 100% by 2050 Cut HFC production and import by 85% by 2036	Phase-out of hydrofluorocarbons (HFCs) by 2050 (reducing emissions by 4.5 gigatonnes of CO2eq)
Transport	Half of all new light-duty cars sold in 2030 to be zero-emission vehicles Production of three billion gallons (11.3 billion litres) per year of sustainable aviation fuel (SAF) by 2030	Aviation emissions to drop 20% by 2030 compared with business as usual through use of SAF. Put the aviation industry on track to achieve net-zero emissions by 2050
Power generation	100% clean electricity by 2035	Net-zero emissions by 2035

Sources: IEA Bioenergy (2021d); US CRS (2021).

Cellulosic biofuels have not achieved the level of commercial success that the RFS2 law envisioned, so the EPA has had to cut the overall volumetric requirements in recent years. Other factors, including the technical capacity of the car fleet to use gasoline with higher ethanol blends, have also limited to ability to supply rising volumes of biofuels. Most gasoline used in the United States is blended to E10, which is known as the "blend wall" as few cars on the road are able to use higher blends without technical modifications. As a result, actual supply is well below overall statutory volumes under the RFS2, requiring the EPA to draw upon its waiver authority to reduce volumes in annual rule-making. There is uncertainty about the programme after 2022, as the statute defines volumes only until that date. After 2022, the law grants the EPA the authority to set volumes, unless Congress makes legislative changes to the programme for application in the post-2022 period. It has not yet set volumes for 2023.

The main state biofuels mandate programme is California's Low Carbon Fuel Standard (LCFS), which was originally established as part of a 2006 law to address transportation sector emissions. The programme, which started in 2011, is designed to encourage the use of cleaner low-carbon transportation fuels – including biofuels, clean hydrogen and electricity – in California, encourage the production of those fuels, and therefore, reduce GHG emissions and decrease petroleum dependence in the transportation sector.[1] It originally targeted a 10% reduction in the carbon intensity of transportation fuels by 2020, with the target declining annually. In 2018, the California Air Resources Board (CARB) voted to extend the LCFS, to achieve a carbon intensity reduction of 20% by 2030. Alternative or renewable aviation fuels will also be able to qualify for LCFS credits for the first time.

Oregon also has had a Clean Fuels Program in place since 2016, which requires a 10% reduction in the average carbon intensity of transportation fuels from 2015-2025.[2] Several other states are planning similar programmes, including Washington, where fuel suppliers have to gradually reduce the carbon intensity of transportation fuels to 20 percent below 2017 levels by 2038 under a scheme due to start in 2023.[3] In addition, the governors of Massachusetts, Connecticut and Rhode Island, along with the mayor of the District of Columbia announced in December 2021 the Transportation and Climate Initiative Program, which will cut GHG emissions from motor vehicles in the region by an estimated 26% from 2022 to 2032. Delaware, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Vermont and Virginia have the opportunity to join the programme in the future.

There is a vast array of federal and state financial incentives, including tax credits and subsidised loan programmes (IEA Bioenergy, 2021d). The federal Alternative Fuel Excise Tax Credit provides a 50 cents per gallon tax credit for taxpayers who sell or qualifying fuel, including biofuels. There are several tax credits in place to incentivise production and use of biodiesel, including the Alternative Fuel Refuelling Property Credit established by the Energy Policy Act of 2005, which provides consumers and businesses that install refuelling equipment with a 30% tax credit of up to US$30 000 for properties subject to an allowance for depreciation and $1 000 for all other properties. Under the Energy Improvement and Extension Act of 2008, producers of diesel/biodiesel or diesel/renewable diesel blends can claim a US$1 per gallon tax credit through the end of 2022. A Second-Generation Biofuel Producer Credit was established in 2009 under the Food, Conservation and Energy Act, allowing qualifying producers of cellulosic biofuels can claim a tax credit of up to US$1.01 per gallon.

There are a number of other types of federal programmes that promote the use of biofuels within the transport section, most of which are run by the Department of Agriculture (USDA) and others by the Department of Energy and the Department of Transportation (IEA Bioenergy, 2021d). The USDA has several programmes aimed at supporting the expansion of agricultural production of biofuels feedstocks, R&D on biofuels and bioenergy, and to establish and expand facilities to produce biofuels, bioenergy, and bio products primarily through the Rural Business-Cooperative Service. Other programmes include the following:

[1] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/about
[2] https://www.oregon.gov/deq/ghgp/cfp/Pages/default.aspx
[3] https://ecology.wa.gov/Air-Climate/Climate-change/Reducing-greenhouse-gases/Clean-Fuel-Standard

- The Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program facilitates the development of new and emerging technologies through loan guarantees for development, construction or retrofitting of commercial scale biorefineries for advanced biofuels, renewable chemicals and biobased product manufacturing.

- The Bioenergy Program for Advanced Biofuels (or Advanced Biofuel Payment Program) provides payments to fuel producers to support and expand production of advanced biofuels based on the quantity produced and the amount of production increase.

- The Biodiesel Fuel Education Program allocates grants to non-profit organisations and institutions of higher education that educate people on the benefits of biodiesel. The Biomass Research and Development Program, in cooperation with USDA and US DOE, provides competitive funding through grants, contracts, and financial assistance for research, development, and demonstration of biofuels and biobased products.

- The Higher Blends Infrastructure Incentive Program, which was announced in May 2020, is designed to expand the availability and sale of renewable fuels. The programme applies to vehicle refuelling and fuel distribution facilities converting to support fuel ethanol blends above 10% (US$86 million) and biodiesel blends above 5% (US$14 million).

The Sustainable Aviation Grand Challenge, a new federal programme announced in September 2021, sets a goal for the airline industry to produce three billion gallons (11 billion litres) of SAF by 2030, equivalent to about 15% of current jet fuel demand, and 35 billion gallons (132 billion litres), or 100% of jet fuel needs, by 2050. SAFs must achieve a 50% reduction in life-cycle GHG emissions compared with conventional fuel.[1] To support this goal, the government is working on a SAF tax credit linked to GHG intensity. SAFs qualify for credits under the RFS.

The US federal government spends large sums on renewable fuels R&D with a focus on critical energy technologies to address climate change. The FY 2022 budget, which complements the American Jobs Plan launched in 2021, allocates US$4.7 billion for the Office of Energy Efficiency and Renewable Energy, including more than US$1 billion in new funding to deploy clean energy technologies, including US$400 million for a new Office of Clean Energy Demonstrations to keep bringing innovative technologies to market.[2] In April 2021, the DOE announced US$61.4 million in funding for technologies to produce low-cost, low-carbon biofuels, particularly for heavy road freight, aviation and shipping.[3] In May 2021, the DOE announced US$35 million in funding for 15 R&D projects in technologies to decarbonisebiorefining

[1] https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge
[2] https://www.energy.gov/articles/statement-energy-secretary-granholm-presidents-us-department-energy-fiscal-year-2022
[3] https://www.energy.gov/articles/doe-announces-614-million-biofuels-research-reduce-transportation-emissions

processes. The projects will be carried out at colleges, universities and laboratories across nine states, supported by the Advanced Research Projects Agency-Energy (ARPA-E).[1]

5.2.2 Biogas

The federal government provides tax credits, grants, and loans for qualifying renewable energy technologies and projects, including those based on biogas or biomethane. There are no federal incentives explicitly directed at heating with those fuels. The Renewable Electricity Production Tax Credit (PTC) provides a per kilowatt-hour federal tax credit to the owner or operator of a power plant for the electricity generated by qualified renewable energy resources, amounting to 1.3 cents/kWh for electricity generated from landfill gas, open-loop biomass or MSW. The Energy Investment Tax Credit is also available for certain biogas-based generating plants. In addition, under the Modified Accelerate Cost-Recovery System (MACRS), owners of such plant may be eligible for a special depreciation allowance to recover part of the cost of construction for the first year it is in service, amounting to 50% for qualifying second-generation biofuel plants. Several federal agencies also have grants and loan programmes to support electricity generation from bioenergy sources, including under the Rural Energy for American Program (REAP).[2]

The other main policy instrument for biogas is Renewable Portfolio Standards (RPSs), which require a certain percentage of electric power generated within a state to come from renewable energy sources. The federal government does not have an RPS policy in place, though several proposals have been introduced in Congress at various times. However, a number of US states have adopted RPS policies, which have been very successful in driving investment in biogas- and other renewables-based capacity. At present, 30 states, Washington DC and two territories have active RPS programmes or clean energy requirements, while an additional three states and one territory have set voluntary renewable energy goals.[3]

The specific rules of each RPS plan can vary widely from state to state, including the targets themselves, carve-outs for specific technologies, cost caps and rules governing the trading of renewable energy credits (IEA, 2021d). Most states administer their RPS targets on the basis of a percentage of retail electricity sales, though Iowa and Texas measure them based on explicit quantities of renewable capacity and Kansas as a share of peak demand. Renewable Energy Certificates or Credits (RECs) have played a central role in the success of RPS. RECs increase compliance in states that mandate RPS by allowing utilities that generate more renewable electricity than the RPS requirement to sell or trade RECs to other electricity suppliers who struggle to meet their requirements. Biogas projects have proved less attractive to investors in recent years as the cost of alternative renewables technologies, notably solar PV and wind power, have plunged.

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[1] https://www.energy.gov/articles/doe-invests-35-million-dramatically-reduce-carbon-footprint-biofuel-production
[2] https://www.ruralhealthinfo.org/funding/3169
[3] https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

Some states have also introduced feed-in tariffs for purchasing electricity from certain types of renewable energy systems to encourage new projects for renewable energy technologies. At present, six states have such tariffs, half of which recognise electricity generated from some form of bio-based source as a qualifying renewable energy system (IEA Bioenergy, 2021d).

5.3 Renewable LPG

Significant volumes of rLPG were produced at the six renewable diesel plants operating across the United States in 2021 (see Section 1). Most of these plants do not separate out the rLPG produced from other flue gases. The Renewable Energy Group (REG), which runs a 280 kt (75 million gallons)/y renewable diesel plant at Geismar in Louisiana, is, to the best of our knowledge, the largest source of rLPG that is commercialized as such.[1] In October 2020, U-Haul, the largest LPG retailer in the United States, announced that it had acquired an initial one million gallons (3.7 kt) of rLPG from REG that it would sell as Autogas at its service stations in Southern California. It claims to have paid a premium to procure the fuel, but would not charge more for it at the pump.[2] In February 2022, AmeriGas Propane, a subsidiary of UGI Corporation, another large LPG retailer, entered into an exclusive agreement to purchase and distribute rLPG from Global Clean Energy Holdings (GCEH), primarily in California. The rLPG will be supplied from GCEH's new Bakersfield biorefinery, which is expected to begin operations in the first half of 2022.

As a byproduct of renewable diesel production, rLPG is indirectly promoted by the range of policies in place to promote renewable diesel, notably the RFS programme, the biodiesel blenders tax credit and state level policies such as the California Low Carbon Fuel Standard and Oregon Clean Fuels Program. In addition, the rLPG produced in this way, in principle, qualifies as an advanced biofuel (D5) under the RFS, on condition it can be proved that lifecycle GHG emissions reductions are at least 50% (based on a 2005 petroleum baseline).[3] One gallon of rLPG generates 1.1 RINs. The EPA is due to rule in July 2022 on whether canola oil qualifies as a feedstock for renewable fuels production.[4]

In California, a bill to adopt the Innovative Renewable Energy Buildings Act was introduced in February 2022. If enacted, it would establish and implement a programme to provide financial incentives to any producer for the production of rLPG, rDME or renewable hydrogen for use in buildings in the state. The incentive amounts to US$1.50 per gallon for the first 25 million gallons produced and US$1.25 per gallon for any additional volumes.

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[1] https://www.regi.com/products/transportation-fuels/reg-renewable-propane
[2] https://advancedbiofuelsusa.info/u-haul-purchases-first-million-gallons-of-renewable-propane/
[3] https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.
[4] https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202110&RIN=2060-AV55

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Annex 2: Note on data sources

Data on renewable fuels, including rLPG, were compiled from a range of sources. For the countries surveyed and for the world as a whole, basic volume data on production, consumption and trade were obtained from the online energy balance and statistics databases of the International Energy Agency (IEA).[1] Comprehensive global data are available only to 2019. For the surveyed countries, these data (which, in most cases, are available to 2020) were supplemented by data from national sources, including official statistics.

Information on policies were obtained from national sources, as well as from the IEA/IRENA policies database (https://www.iea.org/policies/about). In some cases, information was obtained from industry contacts, who cannot be cited for reasons of confidentiality.

[1] https://www.iea.org/data-subscriber-login