3 Data on Biofuels Production, Trade, and Demand

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3.1 INTRODUCTION
This chapter compiles information on biofuels with regard to the market, expectations on further development, and information on costs as well as greenhouse gas (GHG) emissions. As a basis, a classification of the different biofuels for transport (Section 3.2) and time series of statistical data on biofuels production, trade, and demand (Section 3.3) are given. The chapter also discusses data on projections of future trends in biofuel demand (Section 3.4) and the long-term biomass and biofuel potentials (Section 3.5). Additionally, the development of market prices and background production costs (Section 3.6), as well as the GHG mitigation potential (Section 3.6.3), are illustrated for different biofuels.

3.2 CLASSIFICATION OF BIOFUELS
Biofuels are fuels produced directly or indirectly from organic material. Biofuels are typically classified with regard to their physical properties into solid, liquid, and gaseous biofuels and with regard to their application into biofuels for transport, biofuels for stationary application, and so on. In this chapter, we focus on biofuels for transport, which are typically liquid biofuels but also include certain gaseous biofuels. An exemplary overview on the wide range of biofuels for transport currently discussed is given in Figure 3.1. Biofuels differ in feedstock, production route, and product quality. Additionally, they are in different stages of technical development, market implication, and application fields. It has to be mentioned that beside the biofuels, which are presented in the table, additional options are discussed, such as farnesane.

More generally, a differentiation is made between conventional biofuels, which are introduced into the market and include bioethanol from corn or sugarcane; further biofuels from oily biomass, such as fatty acid methyl ester (FAME) and hydroprocessed fats and oils (HVO) from rapeseed oil or palm oil; and advanced biofuels, which are in development and/or in the market introduction phase (e.g., lignocellulosic ethanol or biomethane). Because the term biodiesel is used in different ways in the existing literature (as a synonym for FAME or for fossil diesel substitutes including FAME and HVO), we do not use the term here, but apply always the specific terms FAME and HVO.

More in detail, there are different conversion routes and products to be considered (Figure 3.1). Today pure plant oil (PPO), FAME, HVO/hydroprocessed esters and fatty acids (HEFA), and bioethanol (EtOH) from sugar and starch are produced, traded, and used in larger amounts, while the other fuels are on a different stage on market introduction (methane from biogas, dimethylether [DME], methanol [MeOH]), while others are still under research and development (methane and ethanol from lignocellulosic materials, Fischer–Tropsch ((FT) carbohydrates) fuels or H2), some of those future renewable fuels options can be produced from other renewables as well (i.e., H2 or diesel from PtL), but this is not considered in the following. This variation in market implementation also causes different information availability and information quality on the available data on production, trade, and demand. For example, the range of future cost expectation is much higher for biofuels, which are still under research and development.

For access to market, biofuels need to fulfill certain quality criteria to be introduced in existing fuel infrastructures and application. So for many different biofuels, technical specifications are established. Therefore, different biofuels require different standards. Table 3.1 gives an overview of the most important standards. To satisfy current political and/or technical developments the standardizations are frequently adjusted. Additionally, new standards are going to be created, for example, CEN/TC 408 for a Europe-wide biomethane regulation. According to fuel and region, different
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Biochemical process

Physicochemical process

Thermochemical process

Supply of biogenic raw materials

Raw materials and residues from agriculture and forestry

Oil-/fat-containing biomass

Sugar biomass

Starch biomass

Lignocellulosic biomass

Conversion

Future route/technology

Established route/technology

Biofuel

PPO

FAME

EtOH

CH₄

HVO/HEFA

DME

MeOH

FT

Electrical power

H₂

Electrolysis

Distribution and use

Mobile (transport sector)

Stationary (CHP, use as intermediate)

Infrastructure

Notes: PPO, pure plant/vegetable oil; FAME, fatty acid methyl ester (biodiesel); HVO, hydrotreated vegetable oil; HEFA, hydroprocessed esters and fatty acids; EtOH, bioethanol; CH₄, biomethane; DME, dimethylether; MeOH, methanol; FT, Fischer–Tropsch fuels; H₂, hydrogen; CHP, combined heat and power. (Adapted from Naumann, K. et al., Monitoring Biokraftstoffsektor, DBFZ Report (No. 11, 3. überarbeitete und erweiterte Auflage), Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, Germany, 2016.)

FIGURE 3.1 Overview of biofuel options.

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## TABLE 3.1
Overview of Important Biofuels Specification Standards

<table>
<thead>
<tr>
<th>Committee + Standardization Number</th>
<th>Stage of Standard</th>
<th>Fuel, Product, Process, Service</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 590</td>
<td>In force</td>
<td>Diesel and biodiesel</td>
<td>Sets regulations for diesel and share of biodiesel</td>
</tr>
<tr>
<td>EN 14214</td>
<td>In force</td>
<td>Biodiesel</td>
<td>Sets regulations for biodiesel</td>
</tr>
<tr>
<td>EN 228</td>
<td>In force</td>
<td>Gasoline and bioethanol</td>
<td>Sets regulations for gasoline and share of bioethanol</td>
</tr>
<tr>
<td>EN 15376</td>
<td>In force</td>
<td>Bioethanol</td>
<td>Sets regulations for bioethanol</td>
</tr>
<tr>
<td>CEN/TC 019</td>
<td>In process</td>
<td>Petroleum products, lubricants, and related products</td>
<td>WG 41 for pyrolysis oil has just started</td>
</tr>
<tr>
<td>CEN/TC 383</td>
<td>In process</td>
<td>Sustainably produced biomass for energy applications</td>
<td>No mandate from the Commission, include only sustainability of liquid biofuels</td>
</tr>
<tr>
<td>ISO 13065</td>
<td>In force</td>
<td>Sustainability criteria for bioenergy</td>
<td>Sustainability criteria for production, supply chain, and application of bioenergy</td>
</tr>
<tr>
<td>ISO/TC 255</td>
<td>In process</td>
<td>Biogas</td>
<td>Standardization in the field of biogas (work is just starting)</td>
</tr>
<tr>
<td>CEN/TC 408</td>
<td>In process</td>
<td>Natural gas and biomethane</td>
<td>Specifications for natural gas and biomethane for injection in the natural gas network as well as for usages as automotive fuel</td>
</tr>
<tr>
<td>ASTM D6751</td>
<td>In force</td>
<td>Biodiesel</td>
<td>Standard specification for biodiesel fuel (FAME) (B100) blend stock for distillate fuels</td>
</tr>
<tr>
<td>ASTM D4806</td>
<td>In force</td>
<td>Bioethanol</td>
<td>Standard specification for denatured fuel ethanol for blending with gasoline for use as automotive spark-ignition engine fuel</td>
</tr>
<tr>
<td>ASTM D5798</td>
<td>In force</td>
<td>Bioethanol fuel blends</td>
<td>Standard specification for ethanol fuel blends for flexible-fuel automotive spark-ignition engines</td>
</tr>
<tr>
<td>DIN V 51605</td>
<td>In force</td>
<td>Rapeseed oil</td>
<td>Fuels for vegetable oil–compatible combustion engines; fuel from rapeseed oil requirements and test methods</td>
</tr>
<tr>
<td>SS 155438</td>
<td>In force</td>
<td>Biogas</td>
<td>Motor fuels—Biogas as fuel for high-speed otto/gasoline engines</td>
</tr>
<tr>
<td>SS 155437</td>
<td>In force</td>
<td>Bioethanol</td>
<td>Motor fuels—Fuel alcohol for high-speed diesel engines</td>
</tr>
</tbody>
</table>

Based on Thrän and Fritsche (2015) as well as respective standardization.
CEN, European Committee for Standardization; TC, technical committee; ISO, International Organization for Standardization; ASTM, American Society of the International Association for Testing and Materials; DIN, German Institute for Standardization; SS, Swedish Standard.
institutes are responsible for the standardization, for example, CEN in Europe. Further, there are national institutes like DIN in Germany or ASTM in the United States and ISO as a worldwide acting organization for standardization.

Biofuels, among others, are mixed with fossil petrol and diesel fuels in order to achieve European targets for renewable energy in the transportation sector. As a rule, the limits for FAME blending with fossil diesel as well as bioethanol with petrol/gasoline are at 5% (by volume). In some Member States, higher blendings or pure biofuels are used and are defined in appropriate standards. Figure 3.2 shows an overview of the blending limits (admixture) for biofuels into fuels in the European Union (EU).

3.3 STATISTICAL DATA ON BIOFUELS PRODUCTION, TRADE, AND DEMAND

3.3.1 DATA ON BIOFUEL PRODUCTION

3.3.1.1 Global Production

3.3.1.1.1 Conventional Biofuels

Global biofuel production has grown strongly over the last 25 years. In 1990, this comprised about 15 million m$^3$ of ethanol as fuel, of which 77% was produced in Brazil and 23% in the United States. These volumes grew by 2000 to between 15 and 20 million m$^3$ and has continued to grow to nearly 100 million m$^3$ in 2016, which is equivalent to 2086 PJ. FAME production increased from 3.4 million t in 2005 to 25 million t in 2016, which is equivalent to 926 PJ. In addition, HVO has become more important in recent years as a bio-based diesel substitute; production volumes increased from only 0.1 million t in 2008 to 4 million in 2016, which is equivalent to 177 PJ. (F.O. Licht 2016a)

The production volume of 3.2 EJ a$^{-1}$ of biofuels (F.O. Licht 2016a) corresponds to approximately 3% of the 107.5 EJ of fuels in the transportation sector in 2014 worldwide (IEA 2015).

Figure 3.3 shows growth of biofuel production for the past 10 years.

Areas of focus have formed in the geographic distribution of biofuel production (see Figure 3.4).

FIGURE 3.4 Global production and utilization of biofuels, 2015. Notes: Mt, 1,000,000 tonnes; Mm³, 1,000,000 m³; Bioethanol contains ethanol used as biofuel and others. (Illustration from Naumann, K. et al., Monitoring Biokraftstoffsektor, DBFZ Report (No. 11, 3. überarbeitete und erweiterte Auflage), Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, Germany, 2016; Based on F.O. Licht, World ethanol & biofuels report, Vol. 2008–2016, 2016a, Copyright DBFZ.)
3.3.1.1.2 Bioethanol

The majority of production and use of biofuels worldwide is in the form of bioethanol. Significant production volumes are realized in Brazil and the United States. Europe is the focal point for FAME and HVO production. **Figure 3.5** shows the total production volumes for bioethanol as fuel since 2000.

Global production of bioethanol grew strongly, especially up to 2010, to 80 million m$^3$ a$^{-1}$, where the greatest growth was in the United States. But Brazil also increased its production. The current production accounts to nearly 100 million m$^3$ a$^{-1}$.

In addition, about 20 million m$^3$ of ethanol was produced, which was not used as fuel but rather as industrial or drinking alcohol.

The largest bioethanol producers in the world are represented by five U.S. companies: POET, ADM, Valero, Green Plains, and Flint Hills (each from about 3–6 million m$^3$ a$^{-1}$), followed by Abengoa (Spain), Raizen (Brazil), COFCO (Canada), Tereos (France), and Odebrecht (Brazil). (F.O. Licht 2016a)

3.3.1.1.3 FAME and HVO

The largest production volumes for FAME as well as for HVO are in the EU. Production volumes have also increased in recent years in the United States, South America (especially Brazil and Argentina), and Southeast Asia. At present, global production volumes of FAME are about 25 million t a$^{-1}$. With regard to the largest national production volume for FAME, the United States at 4.2 million t (2015) has just overtaken Germany. Global production of HVO has grown 10-fold in the past 5 years to 4 million t in 2016 (see **Figure 3.6**). Neste, with a capacity of around 2 million t year$^{-1}$, is by far the largest producer of HVO. Other large global HVO producers are Avril, ADM, REG, Wilmar, Cargill, Louis Dreyfus, Glencore, Petrobras, and Bunge with each at least 0.5 million t a$^{-1}$ since 2014. (F.O. Licht 2016a)
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3.3.1.2 Global Production Capacity

The DBFZ database for biofuels production facilities last updated on the international level in 2013 and compared to the facilities was database of F.O. Licht (2013). As on December 13, 2013, the database included about 2250 bioethanol and 1280 FAME facilities (in operation and off-line, in planning, as well as those under construction). As on July 15, 2016, there were (F.O. Licht 2016b) about 1750 production facilities for bioethanol, 900 for FAME, and 24 for HVO, either online or off-line, as well as those under construction. The following pages give a short presentation of the databases for bioethanol, FAME, and biomethane in 2013. Current production capacities for advanced biofuels such as ethanol from lignocellulose are shown in the following.

3.3.1.2.1 Bioethanol Production Capacity

Bioethanol production capacity has grown very strongly in Brazil in the past 20 years, as well as in North America. This productive capacity development slowed down since 2010. The production in each new facility that produced bioethanol was at an above-average level in the United States up to 2011, with over 150,000 t a⁻¹ from 2000 to significantly over 200,000 t a⁻¹ in 2008. The few new facilities since 2010 nearly all have a production capacity of 100,000 t a⁻¹ or less. The current facility status (producing, bankrupt, etc.) is difficult to estimate for the approximately 2250 bioethanol production facilities.

Global production capacity for bioethanol in 2013 was over 100 million t a⁻¹, as compared to a produced volume of 70 million t a⁻¹ (corresponding to 98 million m³) in 2015 (F.O. Licht 2016a). Growth in installed production capacity up to 2013 is shown in Figure 3.7, whereby no capacities were included for about 100 facilities (unknown).
3.3.1.2.2 FAME Production Capacity

FAME production capacity was heavily expanded especially in Europe and the United States up to 2010. The few new facilities since 2010 were primarily installed in North and South America. The average production capacity per facility is about 50,000 t a⁻¹ and did not appear to change significantly over time, in contrast to bioethanol production. Facility sizes, particularly in Europe, tended to increase up to 2010/2011. New facilities in South America are significantly larger, on average, than those in North America.

Production capacities can be found for the majority of FAME facilities. The approximately 1200 facilities in 2013 that were in operation had a capacity of about 60 million t a⁻¹, as well as a capacity for off-line facilities and those with an unknown status of about 12 million t a⁻¹. With a production of 22 million t in 2015 (F.O. Licht 2016a), existing production capacities are, for the most part, not being used.

Figure 3.8 shows the growth of global production capacity (status: in operation, off-line, and unknown) in a summary form. It was over 70 million t a⁻¹ in 2013.

3.3.1.2.3 Biomethane Production Capacity

Production capacities for biomethane in 2013 were solely based on biochemical conversion. Large volumes of waste gas were made available in the United States, of which the majority was fed into the natural gas network. The product was used directly as fuel in only two facilities. The biogas produced and processed in Germany is nearly completely used for electricity provision, and also fed into the natural gas network. Biogas from sludge and organic waste is produced in Sweden and Switzerland—used as fuel in Sweden nearly exclusively, and is fed into the natural gas network in Switzerland. (IEA 2013)

Figure 3.9 shows a summary of global biomethane production capacity in 2013 (not including Germany). Current production capacities for German biomethane were about 870 million m³ in 2013; this has grown to about 1125 million m³ in 2015 (DBFZ 2016).

Biomethane as fuel is not a substitute for fossil petrol or diesel fuel, in contrast to all other relevant volumes of available biofuels; rather, it is used as natural gas. Thus, its use is connected to existing distribution infrastructures and the existing fleet of natural gas vehicles. This is at a comparatively low level worldwide, at about a 1.34% share. The share of natural gas vehicles in the main production countries for biogas and biomethane, the United States, Germany, Sweden, and Switzerland, is significantly under 1% (NGV A 2012).

3.3.1.2.4 HVO Production Capacity

Production capacities for HVO were initially mainly installed by Neste, which is by far the largest producer with more than half the worldwide production (facilities in Singapore, Finland, and the Netherlands). In recent years, an increasing number of such facilities have been built by other market participants. Current capacity in production is about 4.3 million t a⁻¹, shown in Figure 3.10. Global HVO production at 3.8 million t a⁻¹ in 2015 (F.O. Licht 2016a) shows that these facilities’ capacity use is very high.

3.3.1.2.5 Advanced Biofuels

Presently, the installed international production capacity for cellulosic ethanol is about 19 PJ, from which about 14 PJ is in operation (corresponds to about 650 million L). Many additional facilities are in the planning stages. Europe has about 20 sites with a total capacity of 19 PJ of ethanol, which corresponds to about 890 million L. Worldwide, there are about 100 facilities in the planning stage with a total capacity of >95 PJ. The numbers are estimated on the basis of F.O. Licht (2016b). International Energy Agency (IEA) task 39 bioenergy lists higher operational capacities for cellulosic ethanol.

The main international industries for the development and market introduction of advanced biofuels are in the United States, China, EU, and Brazil (see Figure 3.11). The U.S. Government and the U.S. Environmental Protection Agency (EPA) have set ambitious targets for the coming years in the context of their Renewable Fuel Standard (RFS) program. The United States intends to increase the share of renewable energy to 10.44% in 2017, of which 2.22% (F.O. Licht 2016a) is intended for advanced biofuels.
Technology to produce BTL fuels for transport continues to be within the pilot/demonstration stage despite significant research and progress and needs to perform better economic feasibility (Thrän and Pfeiffer 2015). Some projects are being pursued globally, but they do not promise meaningful volumes in the short term. In the United States, relevant political conditions have led to the planning of many facilities.

### 3.3.2 Data on Global Trade

#### 3.3.2.1 (Liquid) Biofuel Trade in the EU

Large volumes of biofuels were imported into the EU through 2013 (over 1 million t a⁻¹ of FAME/HVO, >1 million m³ of bioethanol) and significantly smaller volumes were exported. Net import volumes decreased sharply since 2014, to altogether less than 0.65 million t in 2015 (bioethanol and FAME). The origin and targets for EU imports and exports for 2015 are shown in Figure 3.12. (F.O. Licht 2016a)

The import of FAME into the EU was 0.46 t in 2015. The United States was the largest FAME supplier to the EU in 2008 with over 2.2 million t a⁻¹. Changes in the U.S. tax policies and EU customs policies led to a significant reduction to very low figures from 2012 onward. At the same time, import volumes from Argentina and Indonesia increased rapidly to 1.4 million t a⁻¹ (Arg.) and 1.1 million t a⁻¹ (Ind.) in 2012. In order to prevent double subsidies (in the land of origin and the EU through quotas in individual EU countries), the EU established antidumping tariffs for FAME/HVO from these lands of origin (EC 2013) on May 25, 2013. Thus, import volumes were greatly reduced in 2013. About 75% of the comparably low total volumes were imported from Malaysia in 2015, as shown in Figure 3.13. (F.O. Licht 2016a)

FAME export volumes from the EU have trended upward; they were altogether 202,000 t in 2015 (about 80,000 t in 2012) (Figure 3.14). These exports were primarily sent to Norway (64%) and Switzerland (17%), the rest to other non-European foreign countries. (F.O. Licht 2016a)

Next to FAME, HVO also plays an increasingly important role in exports due to increasing European and international production volumes. Due to this development, net imports of FAME and HVO in the past years also were at a low total level, as is shown in Figure 3.13. (F.O. Licht 2016a)
In 2012, about 570,000 m$^3$ of bioethanol was imported into the EU, and 202,000 m$^3$ exported (including industrial and drinking alcohol). A significant share of the import volume came from Brazil until 2010, while in 2011, the volumes imported from the United States increased sharply. Lately (2015), both countries play only a minor role. Next to Brazil (about 8%), significant shares also come from other countries in South and Central America, such as Peru and Bolivia.

![EU biodiesel (FAME) imports 2012](image1.png)

![EU biodiesel (FAME) imports 2015](image2.png)


![Biofuel external trade of the EU, 2008–2016](image3.png)

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This decreased by 2015 by about 74% in comparison to the imported volume of 2.2 million m³ in bioethanol in 2008. Exports also diminished during this period by 46%, and the resulting net imports by 80%. These amounts traded include technical alcohol and drinking alcohol in addition to bioethanol for fuel. In 2007, less than 50% of the bioethanol produced in the EU as well as imported bioethanol was used as fuel; this share was about 68% in 2015. (F.O. Licht 2016a)

3.3.2.2 Global (Liquid) Biofuel Trade
Market participants in the United States as exporters as well as importers play a significant role in the international trade in bioethanol. Brazil, one of the largest biofuel producers, traded nearly no biofuel in 2009, as its capacity was primarily used to satisfy domestic demand. Brazil became a significant land of origin for bioethanol exports, particularly in 2012 and 2013. Canada is an important net importer on the global market at 1.2 million m³. Europe’s role as a net importer has diminished in recent years and remains at a comparably low level at 370,000 m³ (extra trade, see Figure 3.16). Japan is the most significant importer in the Asian region with more than 1 million t a⁻¹ and Pakistan the most significant exporter with about 0.5 million t a⁻¹. (F.O. Licht 2016a)

International trade in FAME and HVO diminished in 2009 and 2010 to a total volume of about 2.5 million t a⁻¹, but then climbed again to about 5 million t a⁻¹ in 2013 and 2014, and then reduced to about 3.3 million t a⁻¹ in 2015 and 2016. The largest net importer is the United States. The EU’s share has been sharply reduced since 2013. Significant FAME and HVO exporting producers are Argentina and countries in Southeast Asia (primarily Indonesia, Malaysia, and Singapore). The development in global imports and exports of FAME and HVO since 2008 is shown in Figure 3.17. (F.O. Licht 2016a)

3.3.3 Data on Biofuels Demand
The share of biofuels used in the EU has not significantly changed in recent years, ranging between 500 and 600 PJ a⁻¹ since 2010. About 80% was used as FAME and HVO diesel substitute and about 20% bioethanol as a petrol substitute. The share of HVO used in biodiesel has grown about 20%
Data on Biofuels Production, Trade, and Demand

The remaining FAME share is about 40% (2015) produced from waste and residues (F.O. Licht 2016a).

About 3.7% of the EU’s total transportation energy needs are covered by biofuels at about 15 EJ (2015). This figure is about 4.4% for road and rail transport.

Global biofuel use roughly corresponds to global biofuel production of 3.14 EJ in 2014 and 2015 (F.O. Licht 2016a). There can be slight shifts between calendar years due to variations in stocks.
3.4 FUTURE TRENDS FOR BIOFUELS DEMAND

3.4.1 MARKET CONDITION DETERMINING THE TRENDS

3.4.1.1 European Union: 2009/30/EC Fuel Quality Directive

The 2009/30/EC Directive changed the 98/70/EC Directive of the European Parliament and Council of October 13, 1998, relating to the quality of diesel and petrol fuels and controls, among other specifications for petrol, diesel, and diesel fuels. It is also called the Fuel Quality Directive, or FQD. The 2009/30/EC Directive monitors and reduces the life-cycle GHGs from fuels. For this purpose, a system was introduced that obligates the fuel suppliers to communicate GHG emissions for the fuels they deliver and to reduce these emissions from 2011 onward (EC 2009 in the version of 2009).

The central goal of the Directive in Article 7a is a reduction of life-cycle GHG emissions per energy unit from the fuel used in transportation by up to 10% by 2020. This reduction is planned in the following areas:

1. 6% through the use of relevant renewable energy
2. A further 2% (indicative value) through one or both of the following methods:
   a. Provision of energy for traffic that is used in all types of road vehicles, mobile machines and equipment (including inland shipping), agricultural and forestry tractors, as well as sports boats
   b. The use of procedures of all types (including the separation and storage of CO₂), which enables a reduction in life-cycle GHG emissions per energy unit of fuel or energy source
3. A further 2% (indicative) through the use of credits that have been bought in the context of a mechanism for environmentally friendly implementation of the Kyoto Protocol (EU ETS)
The Directive was last changed by the EU 2015/1513 Directive of the European Parliament and Council on September 9, 2015 (EU 2015). Significant points in changes to the FQD are as follows:

1. Make it possible to use biofuels in air transportation from the obligation to reduce life-cycle GHG emissions
2. Increase the requirements for specific reduction of GHG emissions to at least 60% (for biofuels from facilities that start operation after October 5, 2015)
3. Ability, using delegated legislation, to determine standard values for GHG emissions with regard to
   a. Renewable fuels of non-biogenic origin in the transport sector
   b. Separation and use of CO₂ for transportation purposes

### 3.4.1.2 European Union: Directive on the Promotion of the Use of Energy from Renewable Sources, 2009/28/EC (EU 2009)

The 2003/30/EC Directive was replaced in April 2009 by the 2009/28/EC Directive (EU 2009). In the current, valid 2009/28/EC Directive, the joint goal of the EU is defined as having 10% renewable energy in the transport sector by 2020. It is called the Renewable Energy Directive, or RED. Biofuels must, in order to reach the biofuel percentage, fulfill various criteria for sustainability. The relevant criteria are also contained in the 2009/28/EC Directive (Table 3.2).

Biofuel must, according to this, prove a GHG reduction potential of at least 35% as compared to fossil fuels. This minimum savings in GHG emissions as compared to fossil references increases to 50% from 2017 and 60% from 2018 for new facilities. Feedstock for biofuel production may not be derived from areas that had the status of moist areas, marshes, or permanent grassland up to 2008. In order to prove the potential to reduce GHGs for a biofuel, the Directive contains standard values for typical GHG emissions in grams of CO₂ equivalent/MJ for various biofuel options. System boundaries include the entire chain, from cultivation to use of the fuels. In addition, the European Commission must develop a concrete method in order to limit GHG emissions through indirect land use changes.

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<tbody>
<tr>
<td><strong>Sustainable Agriculture</strong></td>
<td><strong>Protection of Living Areas</strong></td>
</tr>
<tr>
<td>• Criteria to adhere to good professional practice (such as cross-compliance)</td>
<td>No raw material cultivation in areas that had the following status up to January 2008.</td>
</tr>
<tr>
<td>• No worsening of species variety and living space, soil function and soil fertility, water quality and water supply</td>
<td>Higher carbon storage:</td>
</tr>
<tr>
<td>• Correct environmental use of dung and plant protection materials</td>
<td>• Wet areas</td>
</tr>
<tr>
<td>• No significant increase in acidifying or toxic materials</td>
<td>• Continuously forested area</td>
</tr>
<tr>
<td></td>
<td>High biodiversity:</td>
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<tr>
<td></td>
<td>• Primary forest</td>
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<tr>
<td></td>
<td>• Nature protected areas</td>
</tr>
<tr>
<td></td>
<td>• Grassland</td>
</tr>
<tr>
<td></td>
<td>• Peat bog</td>
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</table>
The goal of 10% renewable energy in the transport sector in 2020 as well as in the associated framework areas, such as the sustainability requirements, is set forth in the Renewable Energy Directive 2009/28/EC (EU 2009).

The RED was last changed by the EU 2015/1513 Directive of the European Parliament and Council on September 9, 2015 (EU 2015). Significant points that have changed are the achievement of the 10% goal in 2020 (EU 2015):

- 7% biofuel (max.) from grains and other crops with high starch content, sugar plants and, oil plants, and from main crops primarily for energy harvesting using plants’ agricultural areas.
- 0.5% (min.) and 2x for renewable and biofuels from raw materials set forth in Appendix IX, Part A (waste and residues, algae and bacteria, power-to-X (PTX), and no old edible oils and animal fats)
- 2x for renewable and biofuels from raw materials set forth in Appendix IX (waste and residues, algae and bacteria, PTX, as well as old edible oils and animal fats)
- 2.5x (rail traffic) and 5x (road traffic) for electricity from renewable energy sources

In order to reach the RED goal (as well as the FQD goals), the Member States set forth suitable activities such as investment promotion, tax benefits, ratios, or penalties in national laws. A current overview of these individual country legal regulations within the EU can be seen in Figure 3.19.

The biofuel share that can be achieved in the context of these quotas can be through the use of pure biofuels as well as mixing them into fossil fuels.

3.4.1.3 European Union: Directives for the Development of Infrastructure for Alternative Fuels

The 2014/94/EU Directive of the European Parliament and the Council from October 22, 2014 (EU 2014a) on the development of infrastructure for alternative fuels is also called Alternative Fuel Infrastructure Directive. The goal is that each Member State develops the national strategic framework for market development for alternative fuels in transport and for the development of associated infrastructure. The relevant alternative fuels are as follows:

- Electrical supply for traffic (including a suitable number of publicly accessible charging stations for electric vehicles in urban areas by the end of 2020 as well as in the TEN-V core network by the end of 2025, and land electrical supplies for inland and ocean-going ships in the TEN-V core network by the end of 2025)
- Hydrogen supplies for road traffic (nonbinding: a suitable number of publicly accessible hydrogen service stations)
- Natural gas supplies for the transport sector:
  - Liquefied natural gas (LNG) (a suitable number of LNG service stations in ocean harbors by the end of 2025, in domestic harbors by the end of 2030, and in the TEN-V core network for heavy commercial vehicles by the end of 2025; a suitable LNG distribution network)
  - Compressed natural gas (CNG) (an appropriate number of publicly accessible CNG service stations in urban areas by the end of 2020 as well as in the TEN-V core network by the end of 2025)

In addition to requirements for infrastructure density and structure, the technical specifications and some further requirements are defined in the Directive.

3.4.1.4 Goal Setting and Perspective

As already presented, binding national and European goals have been set to prevent GHG emissions and increase the share of renewable energies to 2020.
Data on Biofuels Production, Trade, and Demand

The EU has committed to reduce its GHG emissions by 80%–95% as compared to 1990 by 2050 (EC 2011b). This also includes the transport sector, which means that its share of renewable energies must be substantially increased. Table 3.3 shows the stepwise legal projects and energy policy goals up to 2050 for the EU.

In addition to the quota-type obligations set forth in Table 3.3, legislators also have the opportunity, for example, to pass tax regulations or emissions trading in order to achieve the various targets.

The European Strategy for Low-Emissions Mobility, published on July 20, 2016 (EC 2016), addressed the conversion of the European traffic system, and the connected activities of actors, and includes the following main points.

1. Optimization of the transport system, and increasing efficiency
   a. Digital solutions for mobility
   b. Fair and efficient transport prices
   c. Promoting multimodality
2. Increased use of low-emissions alternative fuels in the transport sector
   a. Effective framework for low-emissions alternative energy
   b. Construction of the infrastructure for alternative fuels
   c. Interoperability and standardization for electromobility
3. Transition to emissions-free vehicles
   a. Better vehicle testing to regain customer trust
   b. Strategy for passenger vehicles and light trucks after 2020
   c. Strategy for lorries, city buses, and road buses after 2020

**Table 3.3**

<table>
<thead>
<tr>
<th>Energy Policy Goals for the EU: An Overview</th>
<th>EU Goals</th>
</tr>
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<tbody>
<tr>
<td>Sector</td>
<td>2020</td>
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<tr>
<td>Energy in all sectors</td>
<td>Energy consumption</td>
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<tr>
<td></td>
<td>GHG emissions (as compared to 1990)</td>
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<tr>
<td></td>
<td>Share of renewable energies (RE) in energy consumption</td>
</tr>
<tr>
<td></td>
<td>20%</td>
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<tr>
<td>Energy in the transport sector</td>
<td>GHG emissions</td>
</tr>
<tr>
<td>Share of RE in energy consumption</td>
<td>10%</td>
</tr>
</tbody>
</table>

Data on Biofuels Production, Trade, and Demand

- Skills
- Investments
- City actions
- Global trade in international transport

In addition to presenting this strategy, the EC initiated public consultation on procedures to reduce road traffic emissions (passenger vehicles, light trucks, lorries, and city and road buses). The EC 2016 strategy made the following statements in regard to renewable, mainly bio-based fuels:

The already-started conversion to low-emissions alternative fuels in the transport sector must be further accelerated in the next 10 years. A key goal here is the reduction of import dependence on petroleum-based fuels. In addition, Europe has the opportunity to play a leadership role in the development of new products, such as advanced biofuels.

Following the revision of the RED, the EC is currently examining opportunities to implement strong incentives, such as in regard to an obligatory share of renewable alternative energies, including advanced biofuels and synthetic fuels.

The prior view of the EC that biofuels produced from nutritional feedstocks after 2020 should no longer be incentivized after 2020 (EC 2014) was adapted, so that these fuels are replaced by advanced biofuels on a step-by-step basis.

Advanced biofuels are viewed over the medium term as particularly important for air transport as well as for lorries and buses. In addition, natural gas will increase in significance as alternatives for ship fuels and diesel for lorries and buses. It explicitly names the significantly increased potential from the use of biomethane and synthetic methane (“power-to-gas” technologies).

The EU’s ambitious long-term goal to reduce (inter alia) transport-related GHG emissions by 80%–95% has not been translated into binding milestones after 2020. Figure 3.20 shows the current goals for the share of renewable energies in transport for 2020 and 2050.

Specific strategies and resulting actions as well as and trustworthy framework conditions are decisive with regard to reducing energy consumption and GHG emissions and increasing the share of renewable energy in the transport sector after 2020 (see Table 3.3).

3.4.1.5 Development in Energy Use in the Transport Sector

Energy consumption in the transport sector has grown to about 77 EU (Eurostat) to 2006, and has increased slightly since then. The EU expects transport energy consumption in 2050 at about 15.3 EJ, which is about equivalent to that of 2015. To what degree this 2013 reference scenario (EU 2014b) further reduces total proven energy demand as well as the share of 8% biofuels (see Figure 3.21) with regard to further options for regenerative energies in the transport sector can still be expanded primarily on the actions taken to reach the 2050 goals (80%–95% GHG reduction in all sectors as compared to 1990).

Global energy use in the transport sector has increased from 1990 to 2014 by more than 60% to 2568 million t (107 EJ). Continuing current policies will result in a similar increase of energy use in the transport sector. This will more than double from 1990 to 2030 and reach a level of 138 EJ, and 158 EJ by 2040. Changed political framework conditions can result in a less-steep growth and result in energy use of 143 EJ in 2040 (new policies) or 115 EJ (450 scenario) in the transport sector; see Figure 3.22. (IEA 2015)

About 3.1 PJ, or about 2.9% of global transport energy use was provided by biofuels in 2014 (F.O. Licht 2016a; see Figure 3.3).

3.4.2 Expected Trends for Biofuels for Different Countries

Global energy demand for the transport sector and therefore, in particular, demand for fuels has significantly increased in recent decades, and will continue to climb strongly in the future

Data on Biofuels Production, Trade, and Demand

Perhaps due to various motivations (including supply security, reduction in import dependence on fossil fuels, supporting local farming, climate protection, and therefore a reduction in anthropogenic GHG), many nations have set obligatory goals to increase biofuel share in the transport sector. Thus, at least a part of the additional energy needs should be covered in the coming years.

Figure 3.23 shows the biofuel goals of various selected countries. Many of these countries, such as Brazil and Argentina, already have significant biofuel production in relation to their national fuel demand.

At present, some quota increases are planned in the Member States of the EU, such as in Finland, Italy, and the Netherlands. After Spain reduced the quota from 6.5% (energy) in 2012 down to 4.1% in 2013, consumption has increased since then. In 2016, the quota increased again to 4.3%, and should increase stepwise to 2020 at 8.5% (energy) (F.O. Licht 2016a).

Internationally, such as in Argentina, an increase from B10 to B12 or B15 (15% volume share of FAME and HVO in diesel) is being discussed. Indonesia has increased the biofuel goal for the transport sector on a stepwise basis in recent years (B5 in 2010/2011, B10 in 2013/2014, B15 in 2015) to 20% volume share (B20) in 2016. Nevertheless, it remains well behind the set goals (such as at the latest 10% volume share in 2014 (F.O. Licht 2016a).

### Expected Trends for Biofuels for Different Modes

Biofuels will mainly be used in heavy-duty road transport and ship and air transport, as the potential of alternative renewable fuels in these sectors is limited. The estimation of expected trends for the use of biofuels in different sectors has been the subject of a series of studies. In particular, energy scenarios are used as a tool to assess and discuss the development of energy sectors. The results of these scenarios show a high uncertainty and may vary considerably concerning the potential development futures due to different goals, assumptions, methods, and data used. By 2050, total bioenergy demand for biofuels from "low-risk" feedstock sources is projected at 65 EJ in 2050 (IEA 2010, BLUE Map Scenario). The following presented trends until the year 2040 and 2050, respectively, are based on the studies of IEA (2008, 2010, 2015). The growth for biofuels in the transport sector mainly depends on a major increase in efficiency in all modes of transport and in general a favorable regulatory environment.
FIGURE 3.23 Selected biofuel quotas and goals worldwide, 2015/2016. Notes: ¹Projection based on the IEA final energy consumption; ²Only in New South Wales (NSW); ³In nine provinces; ⁴Only in the city: Kisumu; ⁵Since 2015: avoidance of GHG-emissions of all liquid fuels regarding to the fossil reference. Current and future mandates in shares volumetric (blend), energetic shares in %, E, ethanol; B, biodiesel (FAME). (Illustration from Naumann, K. et al., Monitoring Biokraftstoffsektor, DBFZ Report (No. 11, 3. überarbeitete und erweiterte Auflage), Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, Germany, 2016; Based on Biofuel Digest, Biofuels mandates around the World: The world’s most widely read biofuels daily, 2016, http://www.biofuelsdigest.com/bdigest/2016/01/03/biofuels-mandates-around-the-world-2016/, accessed August 19, 2016; USDA, Gain reports: Biofuels annual 2015/2016 of Argentina, Australia, Brazil, Canada, China, Colombia, India, Indonesia, Malaysia, Mexico, Paraguay, Philippines, Russian Federation, Thailand, U.S. Department of Agriculture, 2016, Copyright DBFZ (no claim to be exhaustive. status: 07/2016).)
3.4.3.1 Road Transport

Currently, most biofuels are used in the road transport sector (IEA 2015). In all studies, the use of biofuels in the transport sector is expected to increase by 2050, amounting to between 1 and 15 GJ per capita (Szarka et al. 2016). IEA further assumes that the share of biofuels in the road transport sector more than doubles, from 3% today to 8% in 2040. In general, the studies assume that policy efforts with regard to emission mitigation measures will continue and support the increase of biofuels in the future. Thus, second-generation biofuels (produced from nonfood biomass) are estimated to be produced on a larger scale and penetrate the market by 2050. However, if oil prices remain low, political support for biofuels may weaken and the biofuels consumption may decrease (IEA 2015).

Furthermore, concerning individual transport, it is expected that the biofuels will increasingly compete with other alternative renewable systems such as fuel cells and e-mobility cars. By the year 2050, around one billion fuel cell or e-mobility cars are forecasted to be on the road (IEA 2008).

Anyway, the unit production costs for biofuels in the transport sector are expected to drop as the biofuels in the road sector become more competitive with conventional fossil fuels’ price rise.

In the EU, the share of biofuels in road transport energy consumption will increase significantly (currently 16%), as the RED has set a target of 10% renewable energy in the transport sector by 2020.

In this context, food-based biofuels are limited in this context to a maximum of 7% out of the 10% target. For advanced biofuels, an indicative target of 0.5% (counting double toward the 10% target) is set.

In Brazil, the country with by far the highest share in the world of almost 20% of road transport, an increase to 31% in 2040 is expected. Further, recent policy decisions have improved the expectations for ethanol consumption in the future (IEA 2015).

3.4.3.2 Ship Transport

The increase of biofuels use in the shipping transport sector is supported by international regulations. For example, the EU set the goal to reduce the CO2 emissions from maritime transport by 40% (if feasible 50%) by 2050 compared to 2005 levels.

Also, so-called Emission Control Areas (ECAs) support the use of biofuel in shipping. ECAs are sea areas in which airborne emissions (SOx, NOx, ODS, VOC) from ships should be minimized as defined by Annex VI of the 1997 MARPOL Protocol.

Both, technology and fuels and operations must be improved to achieve these goals (EC 2011b).

There are few scenarios that take into account the availability of bioenergy for the international shipping sector. The results of three different scenarios with a low (Anandarajah et al. 2013), medium, and high availability (IEA 2011) of biofuels for the shipping sector are presented in the following.

In the low bioenergy availability scenario, 1 EJ of bioenergy is assumed to be used in the shipping sector by 2050. The high bioenergy availability scenario estimates 11.5 EJ for the bioenergy will be used in the shipping sector by 2050. In all scenarios, the energy share of biofuels for the shipping sector is 2.42% (Anandarajah et al. 2013, IEA 2011, LR and UCL 2014).

3.4.3.3 Aviation

A strong increase in the air transport sector with rapidly increasing rates in transport loads and fuel demand is expected for the future (Thrän and Ponitka 2016). Alternative renewable-based fuels will most likely play an increasing role in aviation as it is driven by international ambitions and national regulations (Rosillo-Calle et al. 2012, Shell 2011). As an example, the International Air Transport Association (IATA) is committed to achieve 50% emission reduction in the international aviation by 2050, relative to 2005 levels (IATA 2015). Furthermore, the EU FQD aims at reducing GHG emissions by 6% until 2020, compared to 2010 for all energy used in the transport sector (Toop et al. 2014).

Biofuels could significantly contribute to zero-emissions biojet fuels in the future.
In the last year, the following preconditions for the market implementation of biojet fuels have been achieved:

- **Demonstration**: A wide range of biojet fuels have been tested successfully.
- **Technical standards/certification**: Technical standards for five biojet fuels have successfully been established during the last several years (HVO, FT-diesel, SIP fuels [renewable synthesized iso-paraffinic fuel; renewable farnesane hydrocarbon], alcohol-to-jet fuels, and hydrogenated pyrolysis oils). They can be applied as drop-in fuels without major changes in infrastructure or aircraft engines.
- **Sustainability assessment**: Biojet fuels are recognized by the European Union’s Emission Trading System (EU ETS) (Thrän and Ponitka 2016).

The fuel certification as a drop-in fuel is a precondition for using the biojet fuel commercially.

Few available scenarios on biofuel use for aviation vary significantly, from 100% to 10% of the aviation fuel could be supplied in 2050 (Rosillo-Calle et al. 2012).

The scenarios consider various factors, such as overall fuel demand, biojet fuel availability, and environmental, social, political, legislative, and market development. According to the IEA (2008), the share of bio-based jet fuels is assumed to be 27% or 6.5 EJ a⁻¹ by 2050. Other studies estimate even 25 EJ a⁻¹ (Rosillo-Calle et al. 2012).

It is expected that the aviation industry will foster the use of biojet fuel blends that will subsequently also be part of the EU ETS system. After 2025, biofuels use in aviation is expected to account for 1% of total aviation fuels in 2040 (IEA 2015).

Due to the long life of aircraft products (e.g., engines last 30–40 years), the implementation of other improvements (i.e., energy efficiency) in the total fleet is quite slow (Blakey et al. 2011), so the importance of biojet fuels for aviation is expected to be quite high also in the longer term.

Nevertheless, there are still major challenges to solve for the broad implementation of biojet fuels in the future:

- **Mandatory international targets, standards, and certification schemes** (Toop et al. 2014, Alberici et al. 2014): The development of an appropriate international support mechanism is necessary.
- **Production costs**: A stable, long-term favorable policy framework (e.g., blending mandates, higher carbon taxes or penalties, taxation of fossil jet fuel) is necessary to achieve economic security and cost reduction for biojet fuel provision.
- **Achievable environmental effects of biojet fuel**: The provision of sustainable biojet fuels is essential. Therefore, the harmonization of certification schemes regarding their applicability in the aviation sector is necessary. Aspects of biomass availability and restrictions have to be considered (biofuels for land transport, heat production, etc.). Monitoring systems for biojet fuels, including GHG effects and land use change, need to be implemented internationally for early detection of possible adverse impacts.
- **Research and development**: Stable support for research and development in the biojet fuels field should be provided long term (e.g., cost and efficiency improvements of biojet fuel production, logistics, and use; further development of sustainability criteria and certification approaches; and integration of biojet fuels in overall sustainable and efficient future energy strategy based on renewable energies) (Thrän and Ponitka 2016).

### 3.5 RESOURCES FOR BIOFUELS

#### 3.5.1 Biomass Availability for Biofuels Production

Biomass contributes to the heat and power (including combined heat and power), as well as the transport market (REN21 2013).
At present, some 76 EJ of the total primary energy (equivalent) are used globally. Around 24.5 EJ of heat are used from solid biomass (including solid waste) and biogas in 2014, that is, 61 EJ biomass primary energy equivalents. In addition, 406–480 PJ of power is generated from solid biomass (including solid organic waste) and biogas in 2014, that is, 6.9–8.2 EJ biomass primary energy equivalents. Further, approximately 2.9 EJ of biofuels with a primary energy equivalent of about 7.5 EJ are used in 2014. Thus, about 80% of the globally used biomass is used in the heat market, around 10% in the electricity market and transport sector, respectively (Kaltschmitt et al. 2016a).

For a future increased production, there is a need for appropriate resources. Many studies have been performed to answer the future biomass availability, but the results vary in a wide range.

Typically assessed in those studies is the “technical biomass potential,” which describes the amount of biomass that might be used for energy purposes under the technical framework conditions (e.g., average yields, recovery rates, conversion, and storage losses). Further restrictions include limitations that are regarded as exclusion criteria as given structural, legal, environmental, or societal issues. As the technical potential is less subject to temporal fluctuations—such as yield differences between two years or price effects on the markets—it is often used in representing the biomass potential (Thrän 2015).

An overview on recent studies is given in the following figures (Figures 3.24 and 3.25). Compared with the today’s biomass use for energy provision the studies highly agree on a small increase in the future, but differences can be seen especially in the expected energy crop potentials. This is

![Figure 3.24](image-url)
especially crucial for biofuels, because the conventional biofuels used today are mainly made from energy crops (sugarcane, wheat, corn, palm oil, rapeseed oil). The additional potential from forests and many of the residues are lignocellulosic biomass, for which appropriate biofuel processing technologies are still under development.

Demographics: The development of the world’s population and average wealth influence, among others, significantly the food and land use and the consumption of renewable resources for material use. Thus, the area available for biomass cultivation is affected. The expected population growth varies considerably and is estimated from today’s perspective for 2050 around 9.7 billion people (approximately, 7.3 billion in 2015) (UN 2015).
Per capita food consumption: The per capita food consumption is growing only slowly (FAOSTAT 2015). However, the composition of the average food consumed (food energy) has a significantly higher impact on the future land use compared with the per capita consumption of food. Livestock is the world’s largest user of land resources (Westhoek et al. 2014). The present livestock occupies around 80% of all agricultural land worldwide (FAO 2014). It is assumed that the global per capita consumption of animal products will rise by 2050 to 85%, which consequently will result in increasing land use (Bruinsma 2009) and therefore in decreasing biomass potential. An increasing population together with a change in food consumption patterns and an increasing urbanization will lead to an additional demand for arable land for food production.

Development of crop yields: Increasing yields might reduce the specific area demand for food production significantly. Thus, land and, therefore, energy crop potential will increase (Thrän 2015).

Land availability: The availability of land for energy crops production or the potential of energy crops, respectively, depend on the overall amount of available arable land and the demand of land for food and fodder production. The land availability is also determined by changes in cultivation management (conservation of land development) and other land losses (Thrän 2015).

Loss of land reduces the land availability too. It can result from land degradation (erosion, salinization, desertification, etc.), urban expansion (impervious surfaces), inappropriate agricultural practice, and conversion of agricultural land or conservation of land development. Totally, an area loss from 8% today to 20% in 2050 is estimated, added by about 0.2% land loss due to unsustainable cultivation (UNEP 2014).

An additional option to expand the future resource basis for biofuels is to shift from heat and/or power production to biofuels. So far, many countries intend to increase their bioenergy provision, but with still varying priorities (see Figure 3.27) (Thrän et al. 2014b). In conclusion, also the additional biomass availability from other bioenergy provision pathways is limited.

3.5.2 Trade Perspectives

There are a lot of studies on the estimation of future bioenergy potentials. But usually the trade of bioenergy between the countries is not explicitly investigated (especially not including liquid biofuels). Subsequently, until now there is little knowledge regarding long-term implications on bioenergy trade (Kranzl et al. 2014).

In the few studies available (e.g., IEA 2012), obviously the trade balances used for various countries differ significantly in the different regions. Nevertheless, some generally robust trends can be stated for 2050. In general, with the increase of the biomass potential, demand, and supply, as forecasted by a lot of studies, the trading systems will change in a lot of regions, subsequently. Most of the model scenarios show a huge increase of potential bioenergy trade.

The major factors for the development of bioenergy trade are the impacts from energy markets, technology development, and energy and climate protection policies.

In ambitious scenarios, liquid biomass is traded in the range of 65 million t to more than 360 million t in 2030 and from 40 to 520 million t in 2050, respectively. In moderate scenarios, the range of traded liquid amounts to 1–360 and 12–820 million t in 2030 and 2050, respectively. Compared to 2011, the trade volumes of liquid fuels (ethanol, FAME, and HVO) did not exceed 5 million t (Lamers et al. 2014).

Nevertheless, for the interpretation of trends it should be taken into account that trading streams between regions, no individual countries were investigated, and only net trade balances are considered. Consequently, the stated forecasts most likely underestimate the actual international trade (Figure 3.28).
3.6 ECONOMIC ASPECTS OF BIOFUELS

3.6.1 PRICE DEVELOPMENT OF AVAILABLE FUELS

3.6.1.1 Price Development of Biofuels, Resources, and Coproducts

Since the provision costs of biofuels are strongly dependent on raw material costs, and can account for 80%–90% of costs in large technical facilities, one can only make a precise calculation for a defined period or point in time. The development of selected raw material and product prices is discussed in the following.

The prices for agricultural raw materials are highly volatile. Changes in time and regions result, inter alia, from variable supply (e.g., caused by strong or weak yearly yields), and on the other hand, from variations in demand intensity in consumption sectors (primarily foodstuffs, animal feed, and energy).

3.6.1.2 FAME and HVO

Plant oils as a main raw material for FAME and HVO production have been subject to high price variations in recent years. Price changes for the plant oils used for biofuel production, rapeseed, soya, and palm oils as well as used cooking oil (UCO) in comparison to fossil petroleum are summarized in Figure 3.29. According to this, all prices approached one another in the summer of 2014 (volume-related in € t⁻¹); since then, the difference between rapeseed and soya oil to fossil petroleum has grown due to the heavy reduction in the latter’s price. UCO is not
FIGURE 3.28  Range of trade balances of liquid biomass (Unit: million t) in the median of ambitious model scenarios, 2030 and 2050. (From Kranzl, L. et al., Chapter 8: Medium and long-term perspectives of international bioenergy trade, in M. Junginger et al. (eds.), International Bioenergy Trade: History, Status & Outlook on Securing Sustainable Bioenergy Supply, Demand and Markets, Lecture Notes in Energy 17, Springer Science+Business Media, Dordrecht, the Netherlands, 2014.)

traded as a commodity on raw material markets, in contrast to plant oils, and cannot therefore be presented in a comparable fashion. Its price was somewhat equivalent to that of raw palm oil in the past.

Figure 3.30 shows the wholesale prices for FAME/HVO and its possible associated product rapeseed meal as well as a comparison to fossil diesel fuel. While the difference between fossil and FAME/HVO was about €10 GJ⁻¹ in the summer of 2010, it increased to nearly €28 GJ⁻¹ in January 2016. This difference has declined somewhat since then due to increasing diesel fuel prices.

American FAME/HVO prices have significantly decreased in recent years. Soya-based fuels from Argentina sank from June 2013 to October 2015 from about $1150 t⁻¹ by 43% to $650 t⁻¹; U.S. FAME/HVO sank from about $1500 t⁻¹ in July 2013 by 55% to less than $700 t⁻¹ in October 2015 (fob) (F.O. Licht 2016a).

3.6.1.3 Bioethanol

Figure 3.31 shows summarized price changes for selected raw materials and main and coproducts in bioethanol production, compared to the price of fossil petrol or gasoline. One can clearly see that the U.S. price is above the Euro price for ethanol. This delta was less than €4 GJ⁻¹ in 2014 and increased in 2015 to an average of €9 GJ⁻¹, which is about €ct20 L⁻¹. Changes in wheat and DDGS prices were roughly parallel to this trend, in which the price of DDGS (distiller’s dried grains with solubles) animal feed was about €50 t⁻¹ over the wheat price (January 2014–June 2016).

3.6.1.4 Biomethane

The targeted revenues for biomethane are similar to that of natural gas in the fuel market. Additional revenues are achieved in Germany due to the application of biomethane to the biofuels quota, so that
this so-called quota trading usually shows a delta between the FAME/HVO price and diesel price, which is the limit price. As a consequence of very low diesel prices and quota trading, the targeted revenues for biomethane waste and (primarily from waste and residues) is comparatively high since 2015 (see Figure 3.30).

3.6.1.5 Provision Costs of Selected Biofuels

Figure 3.32 shows the fuel provision costs for selected biofuel concepts as well as the prices for fossil references at the plant gate. While biogenic fuels’ provision costs were between €14 and €32 GJ⁻¹, those for fossil references were between €616 GJ⁻¹. A better comparison of biogenic fuels can be provided by the lower heating value (HV) as compared to the usual processes in the gas business. Under these selected assumptions, FAME from rapeseed as an established biofuel, as well as HVO on the basis of palm oil at €19 GJ⁻¹ is significantly less expensive than bioethanol, with provision costs of €27–€32 GJ⁻¹ (at the plant gate). Bioethanol from the residue wheat straw has slight cost advantages due to high revenues from the sale of lignin pellets as a coproduct. These roughly balance the comparatively high capital and operating costs (especially for raw materials, energy, and enzymes). Biomethane from the fermentation of organic waste with provision costs of € GJ⁻¹ is particularly advantageous from an economic point of view, as the high revenues from organic waste recycling significantly reduce costs.

3.6.2 Competition and Cost Expectations of Advanced Fuels

The cost development for advanced fuels is relatively difficult to estimate. On the one hand, there are higher uncertainties in the investment costs. This is especially relevant for cost-intensive technologies. In Figure 3.33, an overview on estimated capital expenditure (CAPEX) and production costs for FT-fuels is given as an example.

![Graph showing biofuel provision costs in comparison to fossil references. (Calculations and illustration based on Zeymer, M. and Zech, K., Gestehungskosten von Biokraftstoffen, in Monitoring Biokraftstoffsektor, 3rd edn., DBFZ Report, Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, Germany, 2016.)](image-url)
Additionally, the cost structures between advanced biofuels differ by a wide range. Different learning effects also need to be considered. This is especially relevant for biogenic natural gas subsidies, which can be produced by anaerobic digestion and biogas upgrading (biomethane) or thermochemical conversion (Bio-SNG).

Chemical biomethane and Bio-SNG are identical; both consist of mainly CH₄ (up to 99%) and CO₂ (remaining fraction) plus some other minor components (e.g., vapor) (Billig 2016, FNR 2014, Knoef 2012).

Whereas the biochemical conversion is already state of the art with over 250 plants in Europe (Thrän et al. 2014a), the thermochemical conversion is still in research and development, with only one commercial plant so far, which is located in Gothenburg (Sweden) with 20 MW_bio-SNG capacity (Billig 2016, Kopyscinski et al. 2010, Thrän et al. 2014). Methane via the power-to-gas process is in the research and development stage with no commercial plant running so far.

The costs for biomethane, respective bio-SNG, are depend on various factors. Several studies were conducted dealing with the costs for biomethane and bio-SNG (e.g., Billig 2016, Carbo et al. 2011, FNR 2014, Heyne and Harvey 2014, Müller-Langer 2011). Although dealing with different technologies respective concepts and substrates, the studies agree on the cost drivers for the biomethane resp. bio-SNG. It was found out that the cost for biomethane and bio-SNG are mainly driven by the substrate and capital costs. Operational costs play only a minor role.

The cost expectation in the longer term is given in Figure 3.34. The development was calculated by consideration of (1) the usage of the available, so far unused, biomass resources in Europe, (2) a theoretical plant expansion, and (3) a learning curve approach (Billig 2016).

It is shown that biomethane via biochemical conversion has a comparably low cost reduction potential because of the already well-advanced technology level. Bio-SNG via thermochemical conversion, on the other hand, has a large cost reduction potential, mainly because of the early development stage. This leads to the effect (with regard to plant capacity expansion and learning rate) that by 2030 the cost of bio-SNG could be lower than biomethane costs. It has to be kept in mind that the result is built on a high plant expansion basis.
Finally, future costs are highly subject to feedstock price developments, which are likely to overshadow the effect of investment cost reductions through technological learning. Thus, high yields combined with high conversion efficiencies become increasingly relevant. Figure 3.35 shows cost developments for certain conventional and advanced biofuels for 2015, 2030, and 2050 (Millinger and Thrän 2016).

As an example, assuming increasing biomass prices yet decreasing investment, operation and management costs, biomethane and bio-SNG may become the lowest-cost options in the long term. These are followed by bioethanol (based on sugar beet), which is the least-cost option at the beginning. The costs for FAME and BTL increase rapidly, despite being rather competitive at the start. FAME increases due to low yields of rapeseed and BTL due to low conversion efficiencies. For the full set of assumptions and method, please consult Millinger and Thrän (2016).

### 3.6.3 Sustainability Certification as a Market Factor

Bioenergy is often considered as one of the most promising components of the European decarbonization strategy for the energy and transport sector. Despite the expected GHG mitigation effects, energy security, independence from fossil fuel, and job creation in rural areas are the strongest incentives for the promotion of bioenergy at the European level. But over the last few years, there has been an intense debate about the sustainability of bioenergy, in particular about the sustainability of biofuels on a large scale.

At the heart of the debate are arguments that inefficient biomass conversion processes, an intensified agricultural production, monocultures, and direct as well as indirect land use change, as results of an increasing biomass production, can negate the positive environmental performance of bioenergy carriers. This discussion illustrates the importance and need for the implementation of additional legal requirements for the biomass sector and bioenergy production. As a direct consequence of this ongoing debate, the European Commission has introduced a set of mandatory sustainability criteria with regard to liquid biofuels as part of the EU RED 2009/28/EC Directive (EU RED).

![FIGURE 3.34 Cost development for renewable methane (according to calorific value, standard state). (From Billig, E., Bewertung technischer und wirtschaftlicher Entwicklungspotenziale künftiger und bestehender Biomasse-zu-Methan-Konversionsprozesse: Dissertationsschrift, DBFZ-Report, 26, Leipzig: DBFZ, 2016.)](image-url)
The fulfillment of these criteria is usually verified with a certification process executed under the standard of a certification scheme recognized by the European Commission. The introduction of precise GHG mitigation thresholds for biofuel systems is, among other criteria (e.g., requirements regarding good agricultural practice and the definition of no-go areas), one key element of this directive. The proof of fulfillment of these criteria shall be conducted in the context of certification that covers the entire value chain. The certification and thereby issued sustainability certificates have become a precondition of any promotion mechanism related to national quota system and thus the certification has become a market factor.

And this fact is gaining in importance if, as in the case of Germany, the basis for the fulfillment of the biofuel quota has changed from the energy content of fuels to an obligation to GHG emissions mitigation (BImSchG). Accordingly, biofuels with a high GHG mitigation potential have within the sustainability certification a market advantage, and this GHG mitigation potential is therefore an essential competitive factor (Oehmichen et al. 2015). To prove that the GHG mitigation potential of their biofuel meets the defined requirements and thresholds, there are three possibilities according to Annex V of the EU RED: (1) the use of default values for the biofuels included in Annex V of the EU RED, (2) an individual calculation based on actual values, and (3) a combination of actual values and disaggregated default values from EU RED Annex V. As a result, the number of individual calculations based on actual values (often for processing and transport) is increasing.
A look at the development of average GHG mitigation potentials of the sustainability certificates of each biofuel options from 2012 to 2015 shows that there are significant increases in GHG mitigation potential (Figure 3.36). This supports the expectation that the use of the default values from the EU RED Annex V decreases, and mainly individually calculated GHG balances are conducted as part of the certification, due to the fact that the GHG emission saving of biofuels has become an important factor for their market acceptance and competitiveness.

The sustainability certification has been established for the biofuel sector since its introduction in 2009, and the corresponding system will continuously be developed.

3.7 CONCLUSION

During the last decades, bioethanol, FAME, and HVO have been introduced in the market successfully. Production capacities and demand have been implemented all over the world; in 2016, the production capacity was 3.2 EJ. While at the beginning of the century a high increase in production and demand could be seen, the market development during the last five years has been stabilized. In parallel, biofuels trade has been increasing continuously. With about 100 million m³, bioethanol is the most important biofuel. The prices for conventional biofuels range between €ct15 and €ct40 GJ⁻¹ biofuels.

Biofuels quotas are the main instrument for market implementation. Advanced fuels are strongly supported by policy instruments in different countries. Limited resources, on the one hand, and increasing demand for transport fuels, on the other hand, will drive the further development of the
biofuels production. Decreasing costs and increasing GHG emission reduction provide promising frame conditions for the further development. Provision and trade of biofuels are supported by technical standards for different biofuels as well as dedicated certification systems, which have been introduced and/or are in progress.

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