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Biofuels in the nexus energy-environment-food

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Résumé

La production de biocarburants à partir de ressources biologiques a fait l'objet de nombreuses controverses. Leur opportunité mérite d'être revisitée pour la maturité technologique et évaluer leur pertinence en réponse aux préoccupations environnementales actuelles. Les innovations dans les procédés biotechnologiques et chimiques permettent une large gamme de biocarburants liquides et gazeux; leurs caractéristiques concernent le contenu énergétique, la compatibilité avec les carburants fossiles, l'ouverture vers des usages strictement chimiques. Les facteurs d'évolution de ce marché technologique sont l'implantation de politiques publiques foisonnantes, l'évolution des pratiques agronomiques, la préoccupation de séquestration du carbone dans les sols, les attentes du secteur aéronautique avec les biokérosènes, et les comportements des consommateurs. A partir des plantes de grande culture et des forêts, les matières premières mobilisables se sont élargies aux microalgues, aux déchets animaux et végétaux. Les biocarburants s'inscrivent alors dans la bioéconomie territoriale et l'économie circulaire. Les chaines de valeur sont plus complexes que celles anciennes centrées sur le biodiesel à base d'oléagineux et de saccharose de betterave, de canne ou d'amidon de blé ou de maïs. L'intégration des acteurs économiques et le dimensionnement des marchés ont fait l'objet de travaux de prospective aux échelles internationales et francaises. La durabilité environnementale est avérée globalement avec toutefois des réserves pour certaines sources (soja, palmier à huile). Les biocarburants s'insérent dans un nexus alimentation-énergie-environnement. Les politiques publiques, si elles se fondent sur la durabilité et l'acceptabilité sociale des biotechnologies, orienteront aussi les choix des seuls intérêts économiques. Cet article aborde les travaux de recherche et développement nécessaires pour inscrire durablement les biocarburants dans les politiques énergétiques.

Abstract

The production of biofuels from biological resources has been the subject of much controversy. Their opportunity update deserves to be revisited for technological maturity and assess their relevance in response to current environmental concerns.

Innovations in biotechnological and chemical processes allow a wide range of liquid and gaseous biofuels; their characteristics concern energy content, compatibility with fossil fuels and openness towards strictly chemical uses.

The factors driving this technological market's evolution are the implementation of abundant public policies, the evolution of agronomic practices, the concern for carbon sequestration in soils, the expectations of the aeronautical sector with biokerosenes, and consumer behaviours. From field crops and forests, the mobilizable raw materials have been extended to microalgae, animal, households and plant wastes. Biofuels are then part of the territorial bio-economy and the circular economy. Value chains are more complex than those traditionally focused on biodiesel based on oilseeds and sucrose from beet, cane or starch from wheat or maize. The integration of economic actors and the scaling of markets have been the subject of foresight work at international and French levels. Environmental sustainability is generally proven, with reservations for some sources (soya, oil palm). Biofuels are part of a food-energy-environment nexus. Public policies, if based on the sustainability and social acceptability of biotechnology, will also guide the choices of economic interests alone. This article discusses the research and development work needed to make biofuels a sustainable part of energy policy.

Mots clés

biocarburants, biomasse, technologie, réglements, durabilité

Keywords

biofuels, biomass, technology, regulation, sustainability

Introduction

The ongoing energy transition implies necessary structural modifications of production and consumption of energy. Bioenergy, encompassing all biomass and renewable wastes, is currently the main renewable energy source, accounting for 63.8 % of renewable energy consumption in the European Union (EU) and 66.1 % in France.

A particular feature of the bioenergy market in the EU28 (before the Brexit) is that it is based principally (96 %) on European resources. For import-export of wood fuels from non-EU-countries, EU28 is a net importer: these imports account for just around 4.2 % of the total wood fuel production (Eurostat, 2016). In contrast EU28 imports 8.1 % of liquid biofuels. France imports 22.9 % of liquids biofuels and 0.3 % of solid biofuels. This reflects the importation of oilseeds, driven by animal feed. Whereas EU28 is a net exporter of grains and sucrose, with both high exports and low imports, EU imports represent about half of the oilseed used in animal feed annually. Crushing the oilseeds provides vegetables oils and meal. Vegetable oil is generally used in the food industry or to produce biodiesel, while oilseed meals are an important component of animal feed.

Despite the rapid growth of other renewable resources like wind and photovoltaic, bioenergy is expected to remain the main renewable energy source for decades to come. Its outstanding

Table 1. Importance of petroleum products and biofuels for transportation. Liquid petroleum gas (LPG, butane and propane); Compressed natural gas (CNG) and Liquid natural gas (LNG, methane and ethane), the last two encompassing the former GNV (in French, "gas naturel pour vehicule").

Final Consumption	Gas and Petroleum products	Diesel	Gasoline	LPG and CNG	Biofuels	Biodiesel	Biogasoline	Biogas CNG and GNV
EU28	14,063	8 ,385	3,243	498	579-631	475	112	5.6 – 6.3
France	1,930	1,352	288	4	127-138	108	18.7	0.014

versatility (heat, electricity, fuel), far above other renewable energy sources, questions us about its use for fuel. In the near future 2030, four main sources (BioEnergy Europe, 2020; Kluts *et al.*, 2017) have to be considered: energy crops ranging from 3.3 to 15.8 exajoules (10^{18} J, EJ) agricultural residues from 1.9 to 2.8 EJ, forest biomass from 0.2 EJ to 7.3 EJ and wastes from 1.7 to 5 EJ. However, each country has its own energy policy and package of bioresources. Ensuring the viability of a sovereign energy supply then leads each country to focus on its specific national resources; they differ considerably from one country to another.

Fuel operators are facing radical breaks related to:

- the markets now subject to the pressure of externalities for the climate challenge and local pollutions (NOx and fine particle emissions from exhaust gas),
- a multiplicity of emerging technological solutions, some being biomass-based ;
- the need to integrate any biomass-based solution in local territorial policies integrating the different stages of the value chains,
- the regulatory status of CO_2 according to its origin biogenic or fossil-based processes.

In the future, biofuels should increase their contribution to transportation fuels. The World Energy Outlook (WEO) provides a way of exploring different possible futures, the levers that could bring them about, and the interactions that arise across a complex energy system. Using the World Energy Model, the International Energy Agency (World Energy Outlook, 2018) describes a sustainable development scenario (SDS), in which accelerated clean energy transitions put the world on track to achieve the long-term objectives of the Paris Agreement.

Meeting the SDS goals would require greater use of biofuels (from 3.45 EJ up to 10.51 EJ in 2030) in more countries and also for shipping and aviation (12 % share of biofuels). This will be driven by cost reductions of advanced biofuels, widespread sustainability governance and more adoption in aviation and marine transport. Most of the output growth is expected to come from Latin America and non-OECD Asian countries. The consequence is that any process must be able to cope with a large range of biomass.

Biofuels, diesel and gasoline represent an important topic of bioeconomy (Colonna and Valceschini, 2017). Biobased liquefied petroleum gas are neglictable at the european scale and in France. Data quoted in this article come from different sources (2016 and 2017) : ADEME ; Bioenergy Europe; Commissariat général au développement durable, Connaissance des énergies; International Energy Agency; International Renewable Energy Agency; DG Energy EU; Eurostat; USDA Foreign Agriculture Service, Global Agricultural Information Network)

The research domain of biofuels (gasoline,

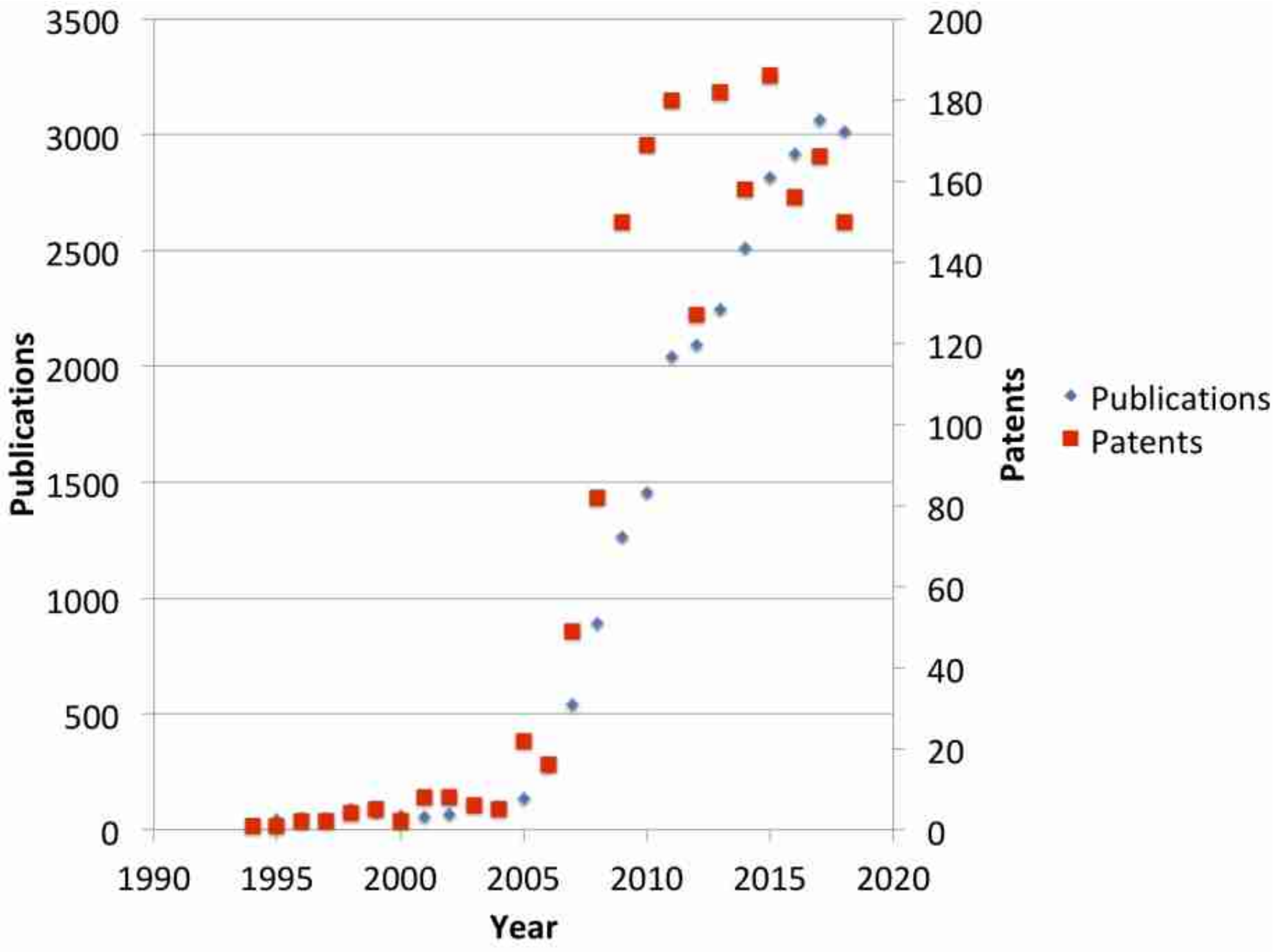


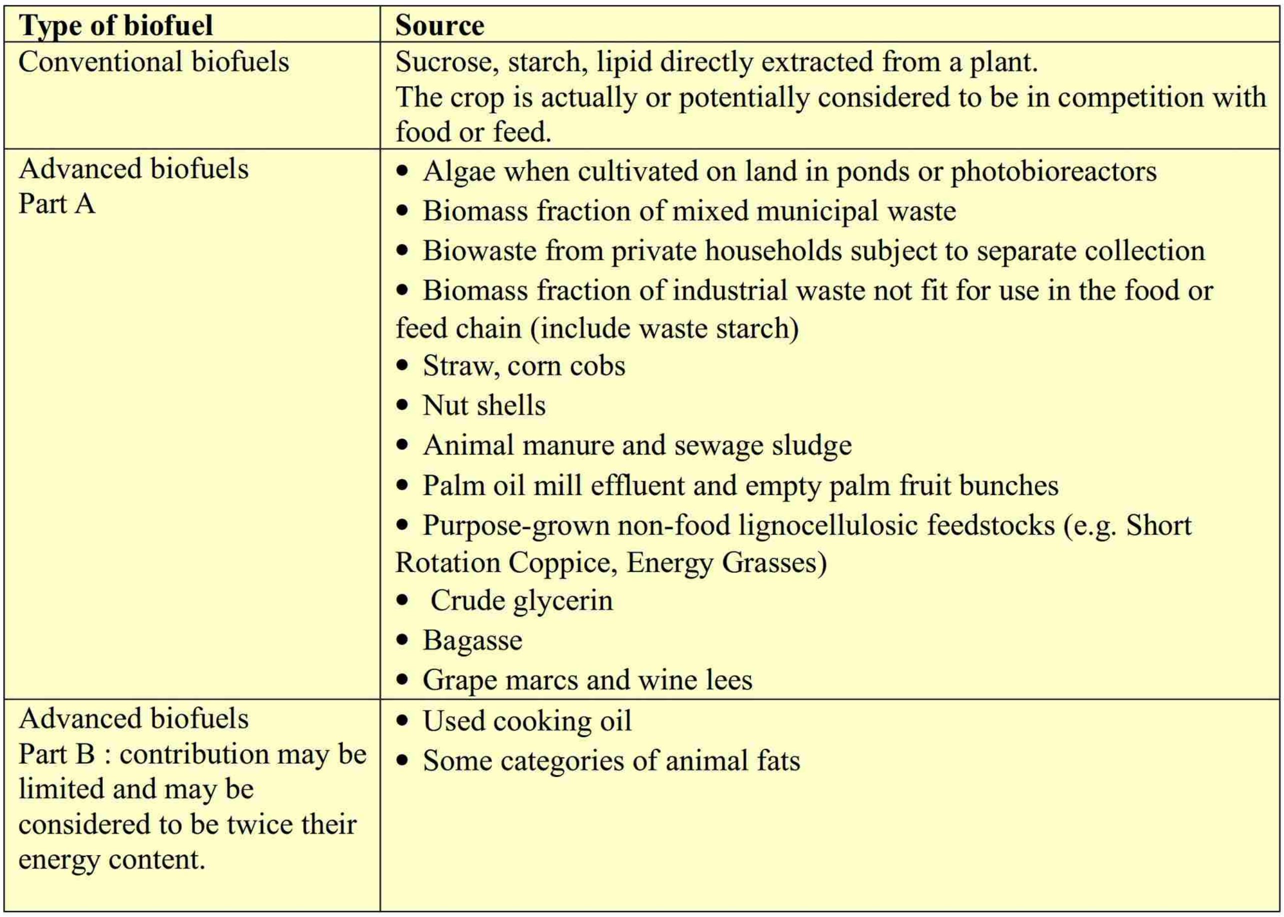
Figure 1. Evolution of publications, according to the Web of knowledge *(keyword "biofuel not cell"), and of patenting (European Patent Office, 2020) from 1994 to 2018.*

diesel and jet fuel) is very active. 672 patents and 25,912 publications can be retrieved from European Patent Office and WOS databases respectively from 1984 to 2018 (Figure 1). Six disciplines from the WOS are mobilized with decreasing contributions of science categories: Energy Fuels, Biotechnology applied microbiology, Chemical Engineering, Environmental Sciences Ecology, Agriculture Engineering and Agriculture and finally Environmental studies.

Any analysis on fuels must take into account the heat engines that will ultimately use biofuels: a co-optimization of fuels, engines and distribution infrastructure is necessary (Figure 2). The starting premise is that no revolution of heat engines requiring a new fuel type is expected before 2050. No foresight publication has been devoted to the future shares of diesel-powered vehicles and gazoline-powered vehicles in the transport sector. ADEME *et al.* (2019) project petrol and diesel consumption for 2030: petrol/diesel ratio (21.5 % - 25.1 % / 74.9 - 78.5 %) increases compared to the situation in 2018 (14.8 % / 85.2 %). So none of the two biofuel technology pathways, diesel or gazoline, has to be preferred.

With regard to fossil fuels, biofuels, either gasoline or diesel, are alternative fuels substituable and compatible with a particular conventional (typically petroleum-derived) fuel. A perfect drop-in fuel does not

Table 2. Definition of conventional and advanced biofuels (from Renewable Energy Directive II, 2018).



Type of biofuel	Source
Conventional biofuels	Sucrose, starch, lipid directly extracted from a plant. The crop is actually or potentially considered to be in competition with food or feed.
Advanced biofuels Part A	• Algae when cultivated on land in ponds or photobioreactors • Biomass fraction of mixed municipal waste • Biowaste from private households subject to separate collection • Biomass fraction of industrial waste not fit for use in the food or feed chain (include waste starch) • Straw, corn cobs • Nut shells • Animal manure and sewage sludge • Palm oil mill effluent and empty palm fruit bunches • Purpose-grown non-food lignocellulosic feedstocks (e.g. Short Rotation Coppice, Energy Grasses) • Crude glycerin • Bagasse • Grape marcs and wine lees
Advanced biofuels Part B : contribution may be limited and may be considered to be twice their energy content.	• Used cooking oil • Some categories of animal fats

require adaptation of the fuel distribution network or the vehicle or equipment engine fuel systems, and can be used “as is” in vehicles and engines that currently operate on that particular fuel. Biojets and other synthetic diesels fulfill these requirements. Some alternative fuels (ethanol, fatty acid methyl ester) have a limited incoporation rate in conventionnal engines (due to material compatibility issue) and need specific vehcile adpatation to be used at high content. The blending wall for ethanol has been upgraded from 15 % to 85 %. Butanol could also bring positive perspectives with high value of blending wall (Liu *et al*., 2019).

Three classes of biofuels are defined on the origin of biomass in the European regulation (Table 2). European governmental bodies use this typology, well detailed in the current Renewable Energy Directive, and is by now used at national level .

In the U.S.A., another classification prevails, bringing confusion when comparing USA and EU28 policies. The Renewable Fuel Standard (RFS) program was created under the Energy Policy Act of 2005 (EPAct), which amended the Clean Air Act (CAA). The Energy Independence and Security Act of 2007 (EISA) further amended the CAA by expanding the RFS program. EPA implements the program in consultation with U.S. Department of Agriculture and the Department of Energy.

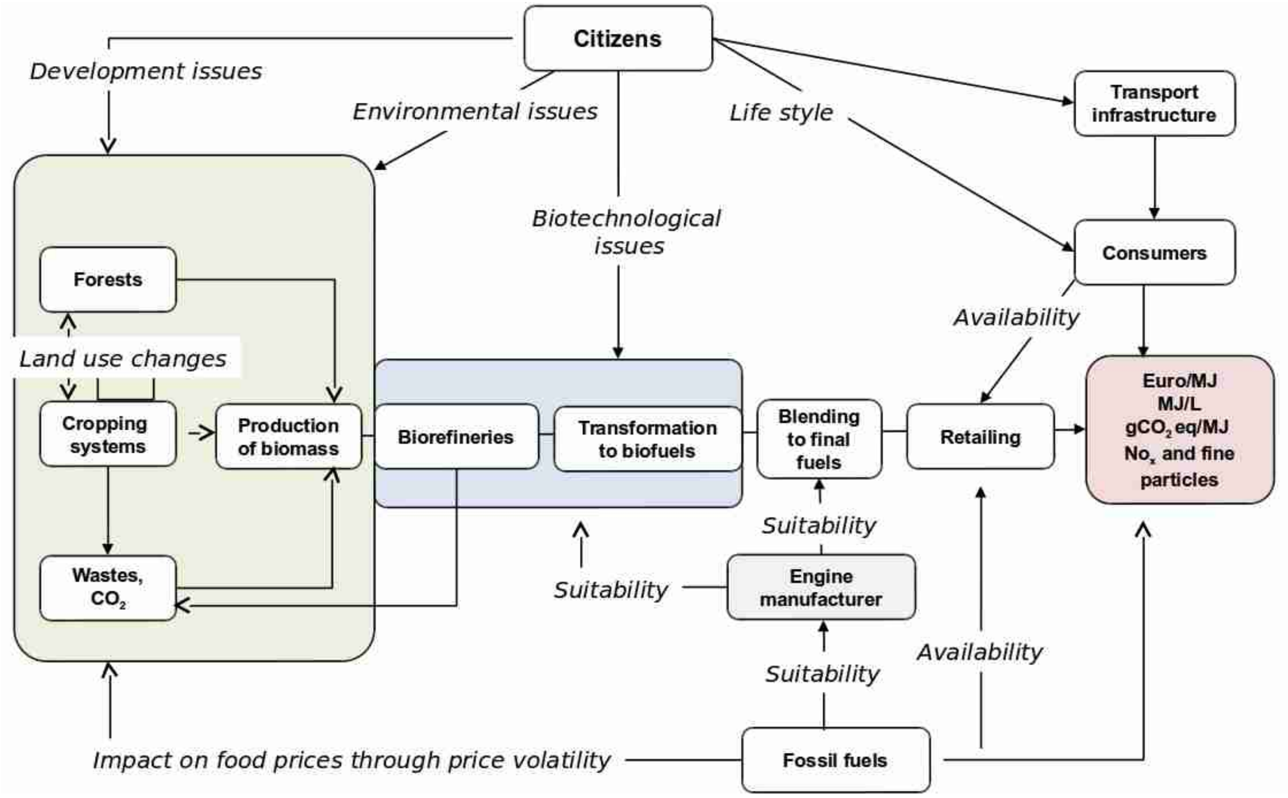


Figure 2. Stakeholders involved in the biofuel system.

The RFS program is a national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel. The four renewable fuel categories under the RFS are:

- biomass-based diesel must meet a 50 % lifecycle GHG (greenhouse gas) reduction,
- cellulosic biofuel must meet a 60 % lifecycle GHG reduction,
- advanced biofuel can be produced from qualifying renewable biomass (except corn starch) and must meet a 50 % GHG reduction,
- renewable (or conventional) fuel typically refers to ethanol derived from corn starch and must meet a 20 % lifecycle GHG reduction threshold.

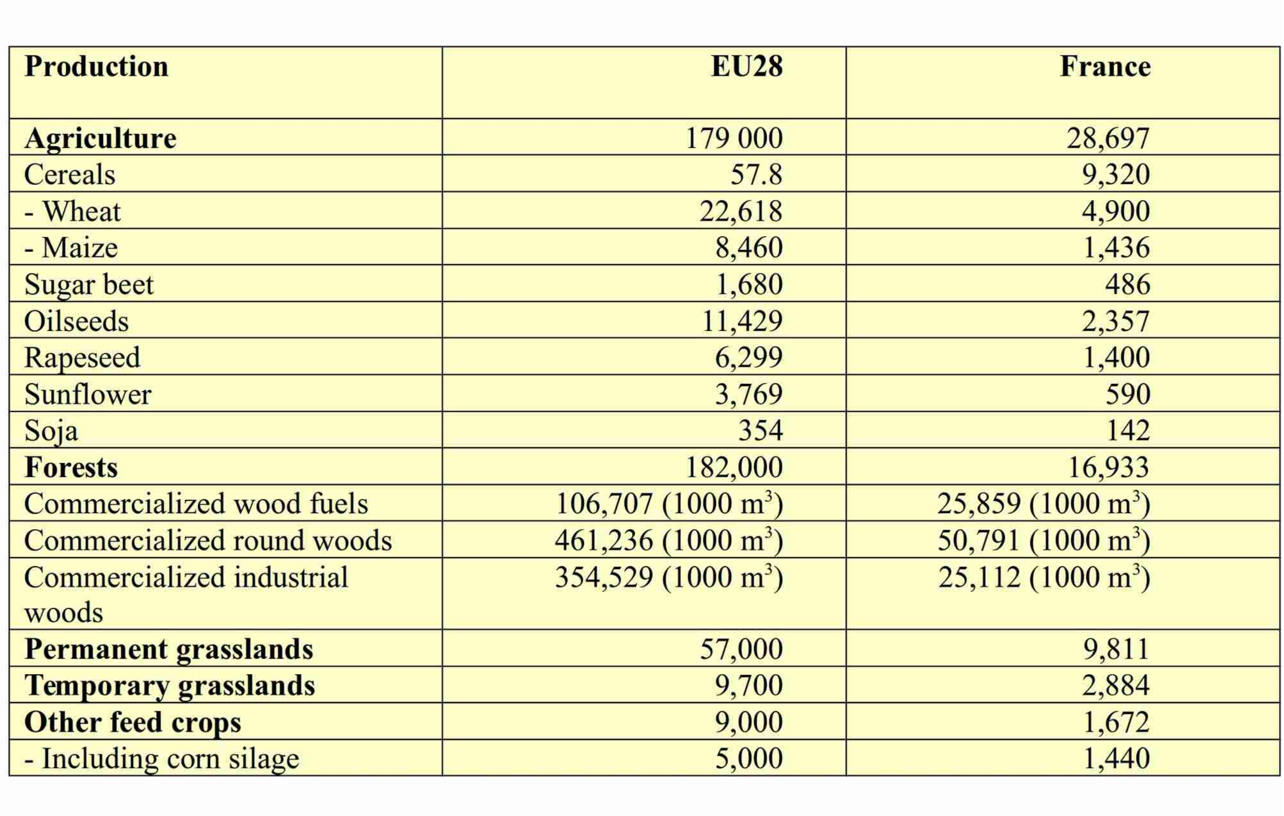
Biofuel facilities (domestic and foreign) that were producing fuel prior to enactment of EISA in 2007 are “grandfathered” under the statute, meaning these facilities are not required to meet the GHG reductions.

This article deals with the current situation and discuss the required contribution of research for biofuels and stakeholders involved (Figure 2). This article is restricted to EU28 and France when considering economics and regulations.

Whereas conventionnal biofuels are technologically mature (Colonna, 2006), most biofuels produced from lignocellulosic biomass have reached high levels (8-9) of technological readiness (TRL) whereas processess based upon microalgae are still matter of research and development (TRL 3-4). Their developments are framed in a bunch of policies and regulatory frameworks that raise questions. Four issues have to be considered in a market-oriented approach:

- technological feasability: what are the technological bottlenecks ?
- competitiveness: how to reduce production cost? And who is able to pay the extra cost ?
- environmental suitability: what are the environnemental issues to consider in order to have biofuels more environnementall friendly

Table 3. Surfaces (in units of 1000 ha) devoted to agricultural and forestry production in EU28 (DG Agriculture and Rural Development of the European Commission, 2016; 2018) and metropolitan France (Agreste 2017-2018).



Production	EU28	France
Agriculture	179 000	28,697
Cereals	57.8	9,320
- Wheat	22,618	4,900
- Maize	8,460	1,436
Sugar beet	1,680	486
Oilseeds	11,429	2,357
Rapeseed	6,299	1,400
Sunflower	3,769	590
Soja	354	142
Forests	182,000	16,933
Commercialized wood fuels	106,707 (1000 m^3)	25,859 (1000 m^3)
Commercialized round woods	461,236 (1000 m^3)	50,791 (1000 m^3)
Commercialized industrial woods	354,529 (1000 m^3)	25,112 (1000 m^3)
Permanent grasslands	57,000	9,811
Temporary grasslands	9,700	2,884
Other feed crops	9,000	1,672
- Including corn silage	5,000	1,440

than fossil ones? how to be in line with public policies?
- availability and scale: beyond the types of biomasses suited for these technologies, what could be the lands to mobilize (Table 3), the way for waste collection, and thereby the targets?

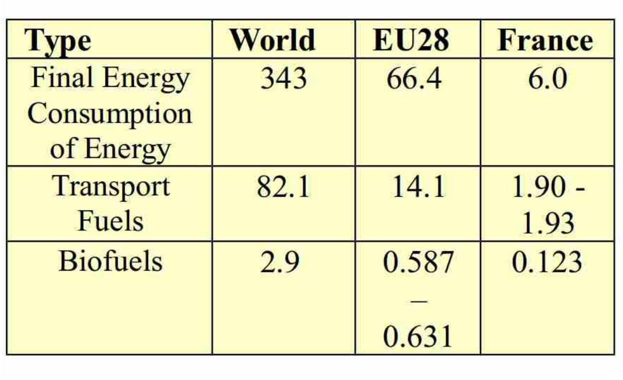
Biofuels from mature technologies

Among technologies currently used for the road transport market in the world, we mainly find conventionnal biofuels (Figure 3) made by combination of sugars, starch and vegetable oils from food crops using standard processing technologies (Colonna, 2006; Ballerini, 2011). For about last five years, these mature technologies used more and more industrial residues like used cooking oil, animal fats, raw alcohol, etc.

Current biofuels for diesel engine

Two biofuel technologies are currently used for diesel engine (Table 4). The first to be developped is fatty acid methyl ester (FAME; lower heating value LHV 37.1 MJ/kg), produced after transesterification of triglycerides. Today around 180 FAME plants are operating in EU28.
More recently a second technology is used to produced a diesel substitute called hydrotreated vegetable oil (HOV). It appeared commercially, with production (12 biorefineries) in Spain (run by the company *CEPSA*), Finland (*UPM*) and Netherlands (*Neste Oils*) and an ongoing starting plant in France. HVO, referred also as hydroprocessed esters and fatty acids (HEFA), are produced via hydroprocessing of oils and fats. HVO are linear chain paraffinic hydrocarbons that are free of aromatics, oxygen and sulfur, and have high cetane numbers.

Table 4. Final energy consumption of energy (EJ/year), transport fuels (EJ) and biofuels (EJ) for World, EU28 and France (Eurostat Energy Statistics, 2019).



Type	World	EU28	France
Final Energy Consumption of Energy	343	66.4	6.0
Transport Fuels	82.1	14.1	1.90 - 1.93
Biofuels	2.9	0.587 – 0.631	0.123

Synthetic diesel produced by HVO offers a number of benefits over FAME, such as reduced nitrogen oxides emission, better storage stability, and better cold flow properties. Hence HVO can typically be used in all diesel engines. Furthermore the technology co-produced synthetic kerosene or bio-jetfuel already approved to be used in aviation sector and, to a lesser extent, a synthetic gasoline

However this process is not stand-alone: it needs the availability of hydrogen, commonly produced by steam methane reforming in refinery but also by water electrolysis or either by biomass gasification.

Demand for HVO is expected to grow because of the “drop-in” properties of these fuels: they can potentially be used unblended without modifications to engines.

In Europe, rapeseed oil remains the predominant feedstock (6,145 kt) for biodiesel market, in 2017, far above palm oil (2.452 kt) and soybean (700 kt). Almost one third of biodiesel consumption came from non food-based biomass like used cooking oil (UCO, 2,843 kt), animal fats (795 kt), and others (558 kt; tall oils, pine oil, fatty acids) (USDA, 2018; EU Biofuels Annual, 2018).

Current biofuels for gasoline engine

All over the world the main biofuel used as gasoline substitute is bioethanol (29.7 MJ/kg) (Tables 1 and 4). In the European Union, bioethanol is blended in gasoline up to 5 % vol in all conventionnal gasoline fuels and up to 10 % vol. in the SP95-E10 fuel, suitable for a vast majority of gasoline vehicles. It can also be used as superethanol (up to 85 % vol. bioethanol blending) in specific flexfuel vehicles and in gasoline vehicles with E85 conversion switchbox. Main feedstock for bioethanol production in EU are cereals (wheat, corn) and sugarbeet. Raw alcohol is also used in wine-producing countries. Today around 55 ethanol plants are operating in EU28.

In France and a few other European countries, a little part of synthetic gasoline produced from HVO plants is also blended to conventionnal gasoline. This part is probably going to grow with the evolution of HVO market. An important feature of crop-based biofuels, except sugarcane based one, is the link with the production of feeds as by-products. Rapeseed contains 41.5 % of oil and 54.5 % of meal (de-oiled cake). 34 % of cereals are converted to distillers dried grains (DDG) in the production of ethanol. For starch plants, the co-products generated depend on the type of grinding used: dry grinding (dry milling) leads to gluten whereas or grinding with wet milling water leads to DDGS (distiller's dried grain with solubles). As EU is importing soja (~ 33 MT/year), the European sourcing of gluten, DDGS and oilcake reduce this trade deficit.

Current situation of market

In EU28, for 2016, the final consumption of (biodiesel + HVO) and ethanol represent respectively 475 PJ (petajoule, 1 PJ = 10^{15} J) and 112 PJ. 92.2 % of these biofuels are considered sustainable. So far to date, no significant incorporation of biofuels takes place in air or sea transport. The low share of ethanol comparatively to biodiesel differs from the nine main countries outside EU28 (USA, Canada, China, Russia, India, Turkey, Norway, India, Japan) where ethanol represents the major biofuel (609 EJ) comparatively to biodiesel (97 EJ).

Domestic production and consumption of ethanol are well-balanced. For the EU, four major sources of diesel are rapeseed oil (51 %), imported palm oil (20 %), used cooking oil (UCO, 20 %) and animal fats (9 %). Waste-based biodiesel reinforces the industry's efforts to use different raw materials and contribute to the circular economy.

In France, final consumption of biofuels represent 6.3 % of transport fuels (1 930 PJ), with biodiesel (124 PJ) and ethanol (18 PJ). 100 % of these biofuels are considered sustainable. Ethanol is produced from maize (27.1 %), sugar beet (25.9 %) and wheat (40.0 %), 95 % from France, the remaining from Europe.

Whereas ethanol is always obtained from European raw stocks, biodiesel relies on importations. In France, biodiesels come from rapeseed (82.9 %; 49.9 % is of French origin. 29 countries providing the rest) and palm oil (13.7 %).

For each feedstock, it is not possible to distinguish where and when land is dedicated to biofuel production vs food or other industrial purposes.

Assuming the business-as-usual yields, for 2016, European biofuels productions have required about 0.795 Mha and 3.704 Mha for ethanol and biodiesel respectively, in a total agricultural area of 186.6 Mha. But it is important to keep in mind the different EU28 land-use shares of EU arable land: 22.6, 1.68 and 11.4 Mha for wheat, sugar beet, oil seeds (rapeseed, sunflower and soja) respectively (Table 3).

In France, different incentives for the consumption of biofuels have been introduced. On the diesel side, the exemption of the internal tax on fuels has been extended to pure vegetable oils (HVP). It also promotes the use of diesel fuel B30, containing 30 % biodiesel, since 2007. On the gazoline side, the E85 superethanol, composed of at least 65 % of biofuel (ethanol) and at least 15 % of premium fuel, is suited for vehicles with "flex fuel". Since its launch, the superethanol is about 20 % cheaper than the SP95 unleaded super) and the purchase of the vehicle is easier (ease of payment, reduction or exemption of the tax additional amount related to the registration certificate). The introduction of the bonus-malus system to reward the buyers of new cars emitting the least CO_2 also favors the purchase of flexible fuel vehicles.

The bottleneck of food-based or conventionnal biofuels is the food vs fuel dilemma regarding the risk of diverting farmland or crops for biofuels production to the detriment of food supply. The biofuel and food price debate involves wide-ranging views, and is a long-standing, controversial one in the literature. The own price elasticities of supply equations in the long-term are the key variables to estimate the impact of an increase of biofuel production on agricultural commodity price adjustments (Koizumi, 2015). Nowadays the controversies are less important, conventionnal biofuels being considered as one of the ways to develop agriculture (Kuchler and Linnér, 2012). The impact of biofuel (bioethanol, biodiesel) prices on food prices is statistically significant but explains less than 2 % of the food price variance (Taghizadeh-Hesary *et al.*, 2019).

Lignocellulosic biofuels: technological foresight

If the previous parts describe mature biofuel technologies able to convert conventionnal (food-based) and advanced (industrial residues) biomass, this paragraph deals with technologies under-development able to convert a large range of advanced biomass like lignocellulose (Figure 3). The low LHV of lignocellulosic biomass prevent its direct use for transportation. In contrast heat engines are suited when located in fixed station inside or near a biorefinery (Priou *et al.*, 2014). So main processes aim to convert biomass into liquid and gaseous biofuels.

Methane (Natural Gas for Vehicule, NGV)

Anaerobic fermentation of biomass leads to the production of blends of CO_2 and methane (LHV 50 MJ/Kg). In addition, the overall carbon yield is low because the efficient uses of the digestates are not mature. Today methanisation biogas is more suitable for less demanding uses than drop'in biofuels (heating, in particular, or well-maintained captive fleets)).

The originality is to use energy crops (mainly in Germany) and wastes, which can be non-hazardous biowaste (from agriculture, industry, household waste, etc.), plant-based materials and mud from waste water treatment plants (WWTP). Methanisation of agricultural wastes is a proven strategy to reduce methane (CH_4) emissions from livestock manure while still allowing nutrients to be recovered and used as fertiliser. Methanization of microalgae is another solution proposed for the long-term.

In France, methanization has developed more recently, and has intentionally favored the use of biowastes, including manure. The use of agricultural residues such as manure is particularly important in countries such as Denmark, France and Italy. This underlying coupling between animal farming and biogas provide a profitable manure management solution and production of digestate, a fertilizing material that can be used instead of traditional fertilizers.

Other biomethane production processes are being tested or are in the demonstration phase, such as gasification of biomass from lignocellulosic resources. In this option, biomethane is produced by CO_2 methanation through reaction with hydrogen.

Another process is based upon the hydrogen methanation technology of CO_2. In this so called Power-To-Gas (PtG) route, electrolysis is used to produce hydrogen. CO_2 is converted either directly or inderectly (though a CO intermediate, produced by reversed water gas shift). The hidden trick is the need to have hydrogen. In contrast biomethanation with *in situ* production of hydrogen, has reached TRL 2-3.

In contrast to liquid petroleum gas (LPG, butane and propane), methane is the major component of compressed natural gas (CNG) and of liquid natural gas (LNG). Methane can be used as a vehicule fuel. It initially interested captive fleet users, ie fleets of vehicles attached to a site equipped with a compressor. Its two advantages are a 75 % reduction in CO_2 emissions and no more fine particle pollution.

At present, the primary energy production of biogas represented 695 PJ and 31.8 PJ for EU28 and France respectively. Among the three scenarios (ADEME *et al*., 2019), the consumption of methane gas as biofuel appears in scenarios Renewable Energy Directive (REDII) and MaxiG2; factors limiting a quick development of biogas are the supply of methanizers (and gasifiers), and the difficulty and externalities of collecting organic waste.

France ranks fifth among European countries with 20.9 PJ (0.3 % of final energy consumption). In Germany, who is the largest producer of biomethane (194 PJ) in EU28, only 1.6 PJ are used for transportation. The highest contribution of biomethane to transportation is observed in Sweden (4.6 PJ, 41.6 % of total biomethane).

Other gazeous and liquid biofuels

Lignocellulosic processes involve always a multistep process, starting with a pretreatment followed by either the biotechnological one (low-temperature) or the physical one (high-temperature). Nowdays the specific factors that prevent operators to invest in advanced biofuels are high production costs and regulations uncertainities (see part *Feedstock supplies: biomasses ressources*).

Biotechnological approach

It is based upon the enzymatic release of pentoses and hexoses issued from hemicellulose and cellulose, followed by the fermentation into ethanol or isopropanol (30.5 MJ/kg), farnesen, butanol (34.1 MJ/kg), isobutanol (33 MJ/kg), isobutene (45.1 MJ/kg), microbial paraffins (44-45 MJ/kg), or other molecules (Figure 3).

In the litterature, the major change has been the shift from successive hydrolysis and fermentation (SHF) to simultaneous hydrolyse-fermentation (simultaneous saccharification and

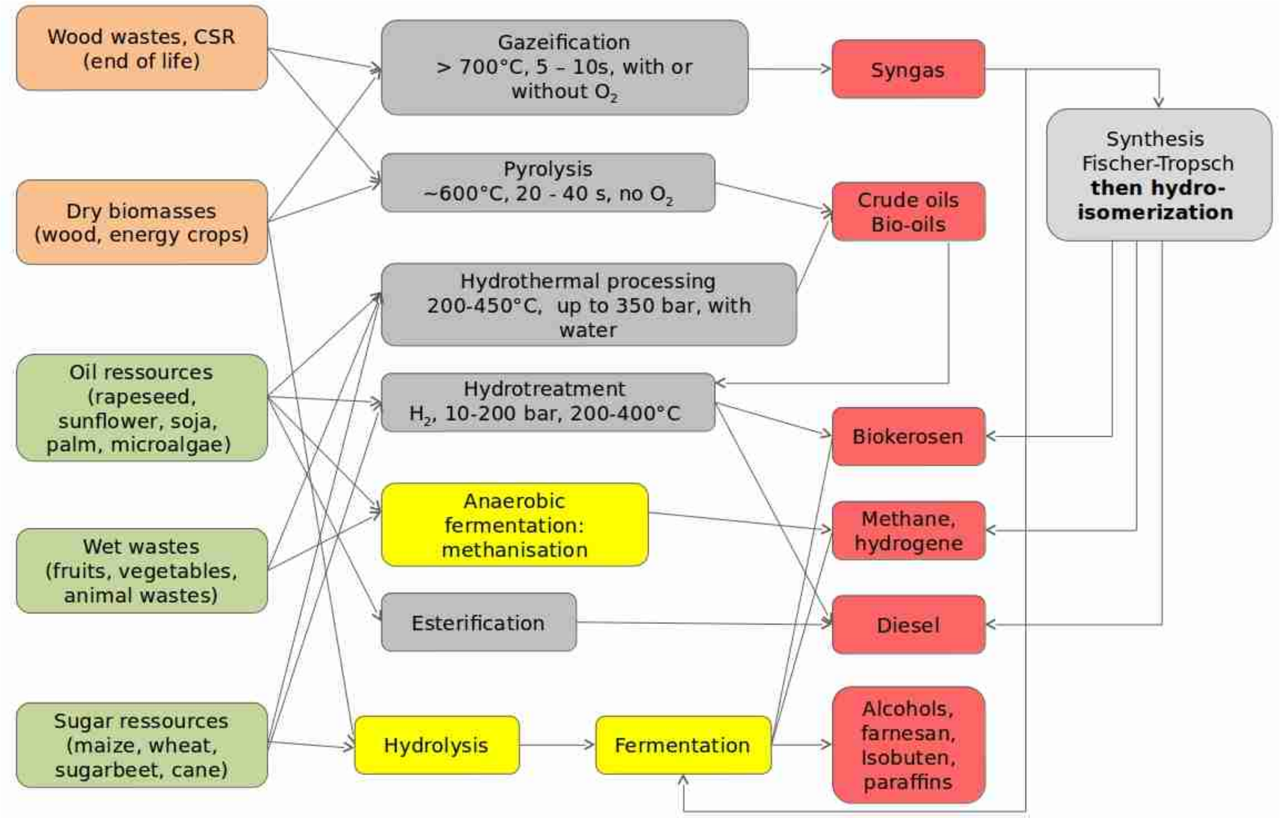


Figure 3. Overview of processes suitable for the production of biofuels.

fermentation, SSF), and finally simultaneous C5 / C6 hydrolysis-co-fermentation (simultaneous saccharification and co-fermentation, SSCF). This choice allows (a) the oligosides to be immediately consumed by the micro-organisms and thus to remove the enzymatic inhibitions induced by their accumulation and (b) reduces the risk of bacterial contaminations. One consequence has been the development of an GMO strain ensuring co-fermentation.

With biotechnological processes, the best operating conditions corresponds to a trade-off between increased susceptibilities of cellulose and hemicelluloses unfermented, and the formation of inhibitory factors (acetic acid, 5-hydroxymethylfurfural and furfural) during pretreatment).

Lignin, by-product of this process, can be burned to produce heat and electricity for the processing plant and possibly for surrounding homes and businesses. The key factors are the enzymes and the microorganism(s) for fermentation. Additional research works are needed to overcome different bottlenecks:

- the choice to use mixes of endo-, exocellulase and β-glucosidases excreted mainly from *Trichoderma* whereas in nature (soils, rumen), additional activities of peroxydases, specially Lytic polysaccharide mono-oxygenases (LPMO) (Villares *et al.*, 2017) are present;
- the high cost of production hydrolases (25 % of manufacturing cost) with cellulases in contrast to 1 % with amylases for conventional biofuels,
- the sensitivity of microbial strains to inhibitory compounds (furfural, 5-hydroxymethylfurfurl, acetic acid) produced during the pretreatment step, to high temperatures,
- the sensitivity of microbial strains to medium temperatures, limiting the simultaneous hydrolysis and fermentation, as enzymes could work at higher temperatures (45-55 °C),
- the paradigmal choice to use one strain instead

of mixed culture which could bring a larger number of enzymes (consolidated bioprocessing, CBP),

- the mass transfer limitations (gas solubility, gas-liquid and gas –solid) with the current stirred tank reactors (CSTR), which limit contacting and cell concentration.
- the energy-intensive distillation process while new emerging distillation technologies are appearing such as ohmic-assisted hydrodistillation, membrane assisted distillation, and heat integrated technologies.

A last point is the excessive focalisation on ethanol, whereas other molecules could be reachable by fermentation. It must be noticed that two molecules (farnesan, for Amyris; isobuten for Global Bioenergie) are already obtained after studies involving synthetic biology. These two products are notably aimed for aviation fuel market. Developments in synthetic biology and modern enzymology should help to overcome all bottlenecks previously described.

Thermochemical processes

The thermochemical conversion of lignocellulosic biomass involves a temperature gradient applied to biomass particles in order to "break" their chemical bonds by thermal cracking and to obtain liquid or gaseous products that can be used as biofuels after treatment. Depending on the temperature and residence time conditions, it is possible to obtain four main families of thermochemical conversion processes (Figure 3).

Liquefaction in hydrothermal media is performed under high pressure (around 100 bars) and moderate temperature (around 300 °C). It can produce liquid oily products (biocrudes) from a wide range of wet feedstocks. However, these liquid products fall short of diesel or biodiesel standards.

Gasification is performed under moderate pressure (1 to 40 bars) and high temperature (800 to 1500° C). It yields a mixture of gases, called synthesis gas (or syngas) including H_2, CO, CO_2, CH_4 (lower temperature) and other hydrocarbons, and water. The gas can either be fermented or chemically transformed into a range of fuels (biomass-to-liquid, BtL). Gasification is mainly aimed at ligno-cellulosic materials: wood and wood products, straw, and various wood by-products of agriculture. It can be carried out in equipments able to handle conventional feedstocks such as coal and crude oil as well as forest and agricultural residues. Purified syngas can be transformed via Fischer-Tropsch synthesis into a large range of products: diesel fuel, methanol, bio-DME (dimethylether), gasoline or methane. The key factor is the catalyst. One important advantage of thermochemical processing is the ability to generate a large range of molecules following Fischer-Tropsch step, whatever the future needs of gasoline, diesel and kerosene. Biomass gasification technology is still facing many cleaning issues of syngas. Tar and aromatics production in biomass gasification process is one of the biggest challenges for this technology.

Comparatively to coal, gasification of biomass is rather recent. Additional research works are needed to overcome different botlenecks:

- the low flexibility of biomass gasification due to some characteristics of biomass: moisture content, poor flow characteristics (linked to injection and flame issues), specific ash content (0.2 – 3 % on dry basis) and ash composition, presence of nitrogen, potassium and chloride;
- slagging, fouling and emissions during processing;
- gas cleaning mainly when lower-quality biomass is considered;
- specific catalysts suited for deoxygentation and denitrogenation.

Overall improvement of mechanistic understanding should lead to models useful for reactor design and optimisation of operating conditions.

Due to the increased processing and resource requirements (*e.g.*, hydrogen and catalysts) needed to make advanced biofuels as compared to conventional biofuels, large scale production of cost-competitive drop-in biofuels is not expected to occur in the near to midterm.

Pretreatments

Both biochemical and thermochemical routes require pretreatment of raw lignocellulose (Figure 3). A pre-treatment step is required in most of the cases for two purposes:
- it increases the amount of energy per volume or mass (up to 800 kg/m^3) related to the geographical dispersion of biomass,
- it adapts and optimizes feedstock type to primary conversion process. Additional research works are needed to overcome two bottlenecks : (a) the composition that may vary a lot depending on the type of resource, as well as on the harvest season (water), (b) the ordered structures of macromolecules in their native state often makes them largely inaccessible to enzymes.

For biochemical processes, physical pretreatments (grinding, steam explosion) help reduce particle size and cellulose crystallinity, alkali (and acid) pretreatments remove lignin and hemicelluloses and can lead to loss of cellulose, solvent fractionation leads to disruption of biomass components with lesser impact on lignin, while liquid hot water mainly removes hemicelluloses. Because of the variety of lignocellulosic composition found among feedstocks, not all feedstocks require the same pretreatment. The recovery of lignin represents a gap in current processes, after pretreatment. The difficulty lies in the recapture of products derived from oxygenated aromatic monomers monomers, dimers and trimers.

In thermochemical processes, some specificities of native lignocellulose (higher oxygen content and moisture content, lower calorific value, lower bulk density than coal, minerals) are shortcomings, determining unpredictable combustion process characteristics. The bottleneck is to obtain densification of biomass as (because) biomass pellets have the increased and fixed energetic and bulk density and the controllable moisture content. Biomass washing to decrease the minerals is considered.

An area that is especially important is the development of flexible and milder feedstock pre-treatment technologies in order to avoid the transportation of native biomasses. Torrefaction raises a lot of interest (Nhuchen *et al.*, 2014). Once treated at 200 - 300 °C in an inert environment at an atmospheric pressure, hydrophobicity, grindability and bulk energy density are increased from 1-3 GJ/m^3 to 14-18 GJ/m^3, enabling more efficient syngas production. This challenge is more demanding for the thermochemical route, because the transformation units are very capital-intensive (very high-temperature technologies and demanding catalysis) and therefore cannot be spread over the territory

Industrial actors in advanced biofuels

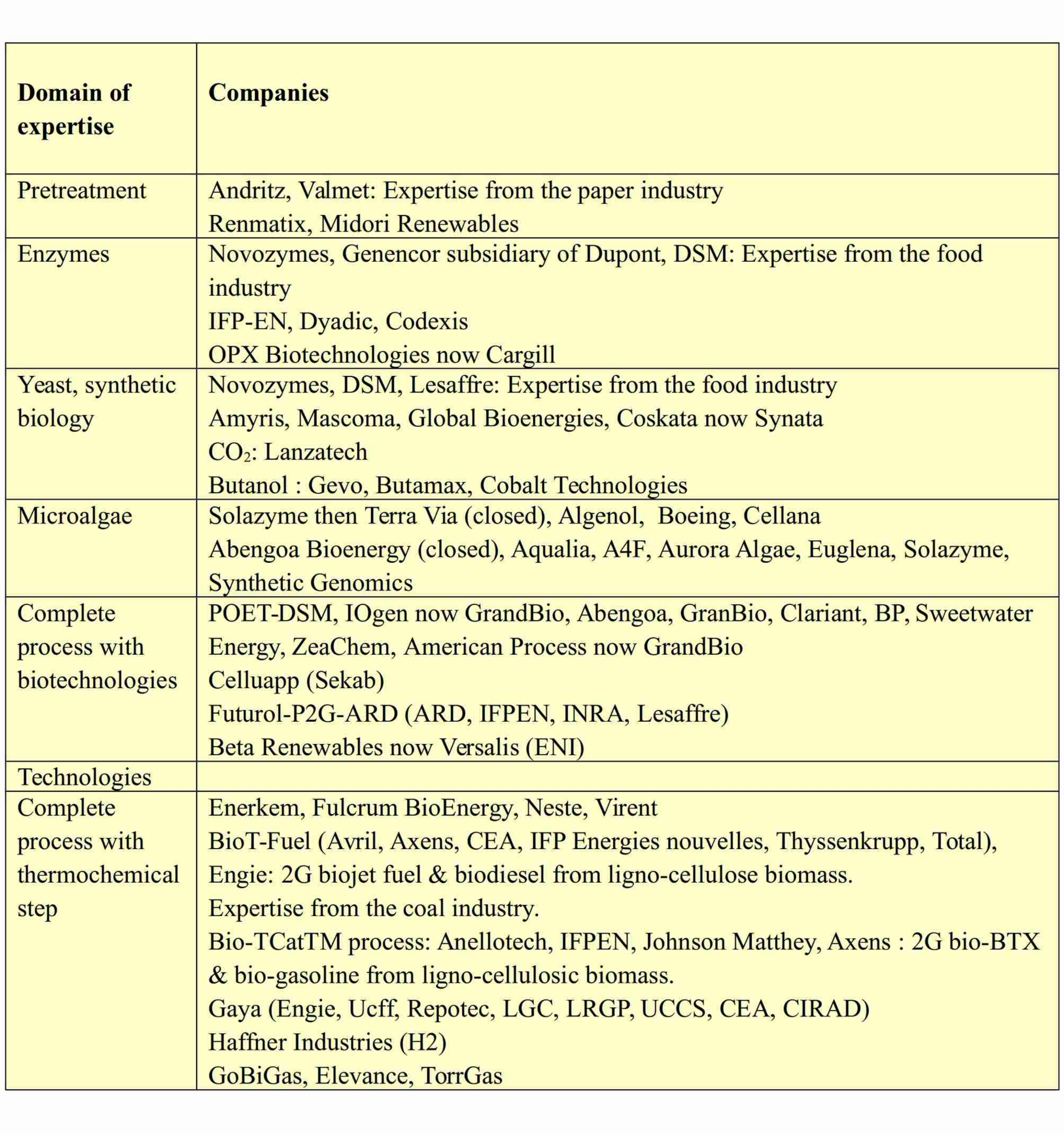
Different demonstration plants should bring results in the near future. Three types of actors (Table 5) are noticable: those coming from the paper industry, those from biotechnological tools and the last with complete process. There are many externalities: added value and job creation, trade balance, energy independence. The evaluation of externalities remains difficult due to the lack significant data for certain sectors, which required many assumptions to be made for the complete calculations.

Conclusions on lignocellulosic biofuels

All these processes open the possibility to get drop-in biofuels. While the biological transformation of lignocellulosic biomass leads presently to the production of ethanol and butanol, thermochemical conversion such as flash pyrolysis or gasification / synthesis is very oriented towards the production of biokerosene and biodiesel. Consequently, even if these processes are competing with the resource (lignocellulose), it should be noted here that they meet different objectives in terms of market.

Besides 2030 renewable energy targets for transport sector fixed in REDII, no policies measures (e.g., tax breaks, subsidies etc.) differentiate conventionnal from advanced bio-

Table 5. Main industrial actors in advanced biofuels.



Domain of expertise	**Companies**
Pretreatment	Andritz, Valmet: Expertise from the paper industry Renmatix, Midori Renewables
Enzymes	Novozymes, Genencor subsidiary of Dupont, DSM: Expertise from the food industry IFP-EN, Dyadic, Codexis OPX Biotechnologies now Cargill
Yeast, synthetic biology	Novozymes, DSM, Lesaffre: Expertise from the food industry Amyris, Mascoma, Global Bioenergies, Coskata now Synata CO_2: Lanzatech Butanol : Gevo, Butamax, Cobalt Technologies
Microalgae	Solazyme then Terra Via (closed), Algenol, Boeing, Cellana Abengoa Bioenergy (closed), Aqualia, A4F, Aurora Algae, Euglena, Solazyme, Synthetic Genomics
Complete process with biotechnologies	POET-DSM, IOgen now GrandBio, Abengoa, GranBio, Clariant, BP, Sweetwater Energy, ZeaChem, American Process now GrandBio Celluapp (Sekab) Futurol-P2G-ARD (ARD, IFPEN, INRA, Lesaffre) Beta Renewables now Versalis (ENI)
Technologies	
Complete process with thermochemical step	Enerkem, Fulcrum BioEnergy, Neste, Virent BioT-Fuel (Avril, Axens, CEA, IFP Energies nouvelles, Thyssenkrupp, Total), Engie: 2G biojet fuel & biodiesel from ligno-cellulose biomass. Expertise from the coal industry. Bio-TCatTM process: Anellotech, IFPEN, Johnson Matthey, Axens : 2G bio-BTX & bio-gasoline from ligno-cellulosic biomass. Gaya (Engie, Ucff, Repotec, LGC, LRGP, UCCS, CEA, CIRAD) Haffner Industries (H2) GoBiGas, Elevance, TorrGas

fuels. For the moment investors are not jostling because of the instability of the legislative and regulatory environment. It is a strong demand of the industrial actors, that a long term legislative and regulatory environment is implemented by the policy actors.

Main Drivers

Once the feasibility of suitable biofuels has been demonstrated in the three previous chapters, attention must be given to public policies which set the biofuels cap, adopted in a nexus energy-environment-food. The challenge inherent in the transition from fossil carbon sources to renewable sources is to decrease the impacts of human activity on ecosystems and not to displace the issues. This transition involves a wide range of stakes, making it necessary to carry it out in a clear, careful and methodical manner. Eliminating the ambiguities related to sustainability will make it possible to generate a non-economic value, to consolidate the integration of stakeholders into value chains and to justify public policies. These public policies have to be considered at european and french levels.

Driver 1: Climate change policies and european regulatory perspectives

Even though it has no common energy policy, the EU-28 expressed common objectives through several directives, the main one being the Climate and Energy Package (CCP) adopted in 2008 and revised in October 2014. This plan notably includes Directive 2009/29/EC on the promotion of renewable energies, and Directive 2009/28/EC on the improvement and extension of the Community greenhouse gas (GHG) emission allowance trading scheme.

Two starting premises are that:

- biofuels have to bring high GHG emission savingsTheir reference values are 93.3 g CO_2 eq/MJ for gasoline and 95.1 g CO_2 eq/MJ for diesel (EU Directive 2015/652 of the Council of April 20, 2015)
- biofuels have to mainly rely on European resources in order to reduce dependence on imports.

The Renewable Energy Directive (RED) 2009/28/EC of the European Parliament and Council of April 23, 2009, which is part of EU Energy and Climate Change Package (CCP), and revised in November 2018, established the following sustainability criteria:

- the GHG emission saving from the use of biofuels and bioliquids shall be at least 50 % compared to fossil fuels, 60 % for biofuels plants build after October 2015, and finally, 65 % for biofuels plants build after 2021.
- biofuels must not be produced from raw materials on land with high biodiversity value (primary forests, protected natural areas and natural grasslands).
- biofuels must not be produced from raw materials on land with large carbon stores (wetlands, forests and bogs).
- cultivated agricultural raw materials must be obtained in compliance with the minimum requirements for the maintenance of sound agricultural and environmental conditions.

The Directive (EU) 2015/1513 concerning the quality of gasoline and diesel fuels set the share food-based biofuels of the final energy consumed in transport in 2020 at a maximum of 7 %, and favored the development of “advanced biofuels” produced from agricultural and forest by-products, waste or microalgae in order to, in particular, restrict changes in the use of agricultural lands (forests, grasslands) for crops intended for the production of biofuels.

The choice of a cap of 7 % for food-based biofuels should be compared to the US policy based upon statutory requirements. This latter establishes new specific volume standards (Renewable Fuel Standard) in order to separate the issues of fuel quality and volume of fuel. This could be another way to ensure a long term energy diversity and to minimize the volume of fossil fuels, according to the needs.

Liquid and gaseous biofuels for all modes of transport are compliant with this Directive 2009/28/EC. A special attention must be given to biofuels produced from wastes, residues, non-food cellulosic materials and lignocellulosic materials, where a multiplier of 2 is applied to reach the targets.

Finally a last directive REDII (April 18, 2018) was adopted by the European Parliament on the circular economy. This directive aims to increase the efficiency of raw material use by decreasing the impact on the environment. The key is circular production and design, with industrial symbioses for recycling and cascading uses. The development of cascade uses will stimulate the biorefineries in a context where food wastage should decrease by a factor of 2 in relation to 2014. After a trilogue betweeen

European Council, Parliamant and Commission, the targets for incorporating biofuels are for 2030, a maximum threshold for food-based biofuels at the consumption level registered in 2020 in each Member State with a maximum of 7 % (which is the case in France). Moreover an increasing target for advanced biofuels from 1.5 % in 2021 to minimum 3.5 % in 2030.

Historical Eurostat transport fuel statistics and EU projections for transport fuel use (Capros *et al.*, 2016) combined with the 7 % cap for conventional biofuels in the RED II translate to a consumption maximum of conventional and advanced biofuels combined of about 879 PJ in 2030, including 418 PJ for advanced biofuels (Phillips *et al.*, 2019). This volume can be cut by the proposed multipliers for reaching the overall mandate of 14 % renewable energy in transport: electric transport (4 x for road, and 1.5 x for rail transport), the use of biofuels by the aviation and maritime sector (1.2 x), and advanced biofuels which count double to the mandate.

There is insufficient transparency in the Commission Impact Assessment on how the caps and cut multipliers have been determined.

The revised Energy Efficiency Directive (EU) 2018/2002 and the new Governance Regulation (EU) 2018/1999 also entered into force on 24 December 2018. Biofuels produced from High ILUC (Indirect Land Use Change) risk feedstocks will have to fall under graduate phase out by 2030 unless firms can certify sustainable production. At this stage only biofuels produced from palm oil are concerned by this specific phase-out measure.

In Europe biodiesel from UCO and animal fat provides already 95 PJ in 2016 (Eurostat, Bioenergy Europe, 2019). In the Renewable Energy Directive, biofuels from these two specific feedstock are limited up to 1.7 % of a country’s fuel production in 2030. This maximum target is established in order to prevent the advanced biofuels target being an incentive to generate or import disproportionate amount of waste vegetable oils. This emphasis on producing transport fuel from biomass waste may be seen as a forstering to the anaerobic fermentation sector, as biogas utilised as fuel is counted in the same manner. Furthermore many anaerobic digestion plants utilise waste feedstocks to qualify for advanced biofuel status (notably animal manures).

RED II also acknowledges that heating and cooling are decarbonising at a lesser rate than electricity, and so to prevent member states from putting all their eggs in one basket by focusing on renewable electricity, all member states should raise their levels of renewable heating and/or cooling by 1.3 % per year, including waste heat and cold.

Worth of anaerobic fermentation lies in its versatility and scalability. The Directive encourages decentralisation of energy grids, encouraging the establishment of local heat networks. As anaerobic fermentation can be set at relatively small scale when compared to the capacity of other technologies, this emphasis on local generation plays into anaerobic fermentation’s hands nicely, if member states choose to go down this route with their own renewable energy strategies.

For 2050, the former Reference Scenario (2013) has been updated into a new "EU Reference Scenario 2016" ("Reference Scenario", Capros *et al.*, 2016). It focuses on trend projections – not forecasts. It starts from the assumption that the legally binding GHG and RES targets for 2020 will be achieved and that the policies agreed at EU and Member State level until December 2014 will be implemented. In the EU Reference Scenario 2016, the activity of the transport sector shows minor growth up to 14,864 PJ energy demand including 2.3 % electricity in road transport. LNG enters the market, especially over the mid and long term horizon, for road freight and inland navigation transportation. The share of LNG in total consumption of heavy duty trucks would go up to 2.8 % and 8.2 % in 2030 and 2050, respectively. The share of biofuels in total fuels reach 6.6 % in 2050. Only after 2035 biofuels (biokerosene) slowly start penetrating the aviation fuel mix- driven by higher, compared to the medium term, European Union Emissions Trading System (EU ETS) prices.

Last point, the adopted European regulation

(2019) on emission standard for passenger car and light duty vehicles (LDV) sets targets of 37.5 % reduction in greenhouse gas emissions by 2030 for new passenger cars, 31 % for new LDV and possible 30 % reduction for heavy duty vehicles.

Driver 2: French climate change policies and regulatory perspectives

The French framework encompasses fuels, fuelwood and gas. The overall objectives for France are set out in the French Energy Transition Law for Green Growth (Loi transition énergétique pour la croissance verte, LTECV) enacted on August 17, 2015) with a dual dynamics: reduction of fossil fuel consumption, compensated by the progression in renewable energies. Without omitting qualitative objectives like the emergence of a competitive economy, supply security and the reduction of dependence on imports, the LTECV also sets out major quantified objectives concerning the bioenergies:

- reducing greenhouse gas emissions by 40 % between 1990 and 2030, and by 3/4 between 1990 and 2050;
- reducing the final energy consumption by 50 % in 2050 compared to the reference year 2012, aiming at an intermediate target of 20 % in 2030;
- increasing the share of renewable energies to 23 % of the final energy consumption in 2020 and to 32 % of this consumption in 2030 (14 % in 2012); in order to reach this target by that date, renewable energies must represent 40 % of electricity production, 38 % of final heat consumption, 15 % of final fuel consumption and 10 % of gas consumption in 2030. Thereby ADEME *et al.* (2019) project a level of 209 PJ for biofuels (petrol, diesel, gas) consumption for 2030.
- contributing to fulfilling the atmospheric pollution reduction objectives laid out in the national plan for the reduction of atmospheric pollutant emissions defined in Article L. 222-9 of the French Environment Code;
- achieving energy self-sufficiency in the French overseas departments by 2030, with the intermediate target of 50 % of renewable energies by 2020 and 100 % by 2030.

The LTECV also includes the circular economy with the reduction of waste by recycling carbon through cascading uses and closing the N, P and K cycles. The key measure concerning the bioenergies is the generalization of on-site sorting of biowastes between now and 2025, so that they can be recycled in the form of organic amendments.

In addition, the energy methanisation autonomy nitrogen plan (Plan Énergie Methanisation Autonomie Azote, EMAA), has a a target of installing 1000 methanisation units on farms by 2020, as compared to 90 at the end of 2012.

The French National Low-Carbon Strategy (SNBC) introduced by the LTECV in 2016 defines the course of action to reduce GHG emissions and to implement the transition towards a low-carbon and sustainable economy. The SNBC indicatively sets the evolution of GHG emissions associated with waste treatment to 18 Mt CO_2 eq for 2015-2018, 15 Mt CO_2 eq for 2019-2023, and 13 Mt CO_2 eq for 2024-2028.

The French Multiannual Energy Plan (PPE), pursuant to Article 176 of the LTECV, defines the short-term objectives for 2028 in relation to 2012:

- reduction of the consumption of petroleum products by 35 % in 2028 compared to 2012,
- advanced biofuels: gasoline sector from 1.2 % in 2023 to 3.8 % in 2028 and diesel sector from 0.4 % in 2023 to 2.8 % in 2028.

Finally two laws will complete the regulatory framework:

- the Mobility Orientation Law (LOM, adopted on November 18th, 2019) provides a framework for the objective of carbon neutrality in land transport by 2050, with a ban on the sale of fossil fuel vehicule by 2040. Meanwhile public support for biogas production units, opens opportunities to NGV.
- the energy and climate law will set decarbonization targets, including carbon neutrality by 2050.

Driver 3: Land-use changes on cropping systems

New production systems include agroforestry and agroecology. The first is based on the association of an annual plant (crop) and a perennial plant (tree) on the same agricultural plot, on the edge or in the field (Dupraz and Capillon, 2005). Agroecology (Francis *et al.*, 2003; Meynard, 2017) is a way of designing production systems that are based on the principles of ecology with the functionalities offered by ecosystems. It amplifies them while aiming to reduce pressures on the environment (greenhouse gases, synthetic fertilizers and phytosanitary products, etc.) and to preserve natural resources (water, energy, mineral elements, etc.) by placing them on the scale of the farm or even the production area.

In both cases, the necessary insertion of woody species leads to a diversification of production, including lignocellulose, which can be used for both energy and chemistry purposes.

For 2050, Ademe *et al.* (2018) has projected a potential harvest of Multi-Service Cover Crops (MSCC) reaching 50 Mt MS (million tonnes of dry material). By adding Multi-Service Cover Crop and crop residues (20 % of the crop residue production, 14 Mt MS), the potential of plant material usable in methanisation, excluding main crop, goes from 79 Mt MS currently to 110 Mt MS. The potential for producing biogas of agricultural origin is estimated at 443 PJ PCS, in a global gas consumption steadily decreasing to reach 984 PJ PCI or 1.098 PJ PCS, in 2050.

Sequestration of carbon in the soils

Dynamics of Soil Organic Carbon (SOC) extends the analytical framework beyond the fractions harvested. Direct and indirect land-use changes (LUCs) are critical points (Searchinger et al., 2008) that may increase (crops) or decrease (waste) contributions to the net balance of GHG emissions.

Indirect land-use changes are due to the planting of a crop, for energy or chemical application in this case, in the place of a food crop that will then be moved to another carbon-rich ecosystem. Without an attributional assessment for each parcel, this evaluation presents technical difficulties, particularly at the global level. Consequently, simulation on the basis of different models (US EPA, California Air Resources Board) is an essential tool to better grasp the consequences of indirect land uses when a forest or wetland is converted to intensive agriculture. For EU, this issue is covered by European Union's Directive (EU) 2015/1513 and the revised Directive 2009/28/EC (RES Directive).

In field crop soils in France, additional storage could exceed the 0.4 % target, which is largely due to the low inherited stocks (Pellerin and Bamière, 2019).

The forest resource warrants another particular attention for the export of mineral elements that could create an imbalance in the soil, risks in terms of public health, fire and storms and, finally, a threat to the stability of organic carbon in the ground.

French forest can be considered for example: it is at the intersection of the 3S: Sequestration of carbon in the forest (70 to 90 Mt eq CO_2/year, equivalent to 14 to 18 % of GHG emissions), Storage in wood products, and Substitution (27 to 42 Mt eq CO_2/year, or 5 to 9 % of GHG emissions) (Deleuze, 2017). Sequestration of carbon in the french forest could reach 100 Mt eq CO_2/year (EPE, 2019). When brought back to the wooded area, trees in French forests store an average of 79 t C/ha. However, there is a high degree of variability within the national territory.

The high amount of forest sequestration comes from the annual biological increase of forest biomass. It depends on the choice of silviculture scenario: high withdrawals reduce the sink but produce more wood material and energy, thus avoiding CO_2 emissions by substituting fossil fuels or materials, while reducing the risk of accidental destocking (fires, diseases, storms) and increasing the resilience of the forest (Roux *et al.*, 2017).

In French forests, no better storage practices than current practices have been identified

(Pellerin and Bamière, 2019). The challenge for forest ecosystems is to preserve existing stocks and silvicultural management methods that allow positive trend sequestration to be maintained. However the complete carbon balance of the forest-wood sector includes carry-over and offsetting phenomena (between different stocks, between stocks and substitution) that ensure a certain stability. This compensation mechanism between storage in forests and substitution in the sector underlines the importance of the most integrative modelling possible of the forest system.

However the pursuit of the accumulation of organic carbon remains a point of scientific controversy: Nabuurs *et al.* (2013) indicates a future saturation of soils in European forests. Orienting forests towards a preferential storage of carbon would lead to a smaller reduction (-199 Mt CO_2 eq/year over the period 2000-2030), compared to a business-as-usual scenario (1.118 Mt CO_2 eq/year) .

Generally speaking, the diversity of worldwide forest covers leads to highly heterogeneous values of the LUCs (Land Use Changes) (Bispo *et al.*, 2017). The main experimental difficulty is the inventory of emissions in the field linked to inputs (fertilizers, pesticides) that often play a major role in the impacts. The factors underlying land use in crop rotations are critical and poorly understood in meta-analyses that are not adapted to long transitions.

Transitions from forests to grasslands and grasslands to crops provide a margin that makes it possible to adjust biomass production areas to the type of biomasses expected. Consequently, Taylor *et al.* (2015) and McClean *et al.* (2015) showed that transitions to short rotation coppice (SRC) of miscanthus and willow are globally neutral in terms of organic carbon in the soil, whereas transitions from arable land to SRC lead to an increase in the level of organic carbon in the soil. Methodological progress is necessary in terms of LCA to improve both transparency and validation if stakeholders are to have confidence in complex bioenergetic systems linked to degrees of uncertainty (Finkbeiner, 2014; Searle and Giuntoli, 2017). Overall, there is a general lack of shared and tracable data to validate these models in terms of the content of organic carbon in the soil and GHG emissions. Emissions savings and carbone missions resulting from land-use changes, adoption of improved agricultural pratices, carbon capture and storage, processing, transport and distribution are included.

Valin *et al.* (2015) made a significant critical contribution by putting the environmental impacts of biofuels into perspective. Some crops even have net positive balances of atmospheric carbon fixation over their entire life cycle, consistent with the logic of carbon sequestration in the soil (Global Research Alliance, 2020). In RED II, the GHG emission threshold is fixed at 65 % compared to the reference fossil fuel. This threshold is respected for biofuels made from rapeseed and sunflower (63-65 g CO_2 eq/MJ), 1G ethanol made from sucrose (cane: 17 g CO_2 eq/MJ; beet: 15 g CO_2 eq/MJ) or starch (maize: 14 g CO_2 eq/MJ; wheat: 34 g CO_2 eq/MJ) and ethanol produced biotechnically from poplar, miscanthus (-29 to –12 g CO_2 eq/MJ) or straw (16 g CO_2 eq/MJ) or thermochemically (BtL) (17 g CO_2 eq/MJ). In contrast palm (231 g CO_2 eq/MJ) and soybean (150 g CO_2 eq/MJ) don't fulfill these requirements.

Conversely, fossil fuel emmissions (93.3 g CO_2 eq/MJ for gasoline; 95.1 g CO_2 eq/MJ for diesel) may widely differ from the reference value for non-conventional sources of fossil fuels. In Europe, current controversies revolve around the use of palm (Strapasson *et al.*, 2019) soy, corn and sugar cane in South America may also bring significant ILUC (Indirect Land Use Change) (Searle and Giuntoli, 2017).

Additional research works are needed to mitigate ILUC effects:

- develop process suited for the use of residues and by-products: residues from crops and forests, secondary residues from industry & waste;
- develop cropping systems involving abandoned, unused, marginal, fallow, under-utilised or polluted lands.

In the future, a major improvement is to adopt the same methodological rigour for these life cycle calculations wathever fossil fuels and those biobased. Deviations and potential inconsistencies should be reduced (Kavelkamp and Karbe, 2018) with better calculation and allocation rules. The other indicators of environmental impact (water, biodiversity) are rarely documented.

Finally, crop production on polluted ground and industrial wasteland makes it possible to consider dedicated crop production without any restrictions as to use. Two databases co-exist: BASOL (French Ministry of Ecology), with 6442 polluted or potentially polluted sites and soils, calling for a curative or preventive action on the part of the public authorities (2016); and BASIAS (BRGM), with some 300,000 abandoned and unabandoned industrial sites and services capable of causing environmental pollution (soil, water, air). Abandoned industrial wasteland represents 100,000 ha in France (16.2 % of the total land in Europe); efforts are required to remove obstacles linked to pollution risks depending on the projected use. Reconversion of agricultural plots targeted for energy production (potential of 17 GJ/year) provides a temporary solution while waiting for the progressive disappearance of pollution.

Driver 4: Biokerosene

Out of all of the energy users, the aeronautics sector is of particular concern in terms of environmental impacts because of its exclusive dependence on fossil kerosene. The aeronautics sector is growing worldwide, from 5 to 6 % per year, which should continue at a rhythm of 4.7 % per year, at least until 2025, even if this figure varies depending on the region.

In 2016, the ATAG (Air Transport Action Group), representing all of the manufacturers in the sector, reached a single global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) agreement that included three objectives:

- an objective to improve energy efficiency from 1.5 % per year until 2020, and 2 % per year until 2040 (International Civil Aviation Organization);
- an objective “Carbon Neutral Growth 2020” to cap CO_2 emissions from air transport as of 2020;
- a global reduction of CO_2 emissions of 50 % in 2050 compared to their 2005 level.

In the absence of major changes expected in the engine technologies, and considering the lifespan of aircraft (approximately 25 years), biokerosenes represent a solution to reach these ambitious objectives. The lack of robust data on the “GHG content” of biokerosenes does not allow us today to estimate the potential contribution of the latter to reach the emission reduction targets to 2050 (in relation to a business-as-usual scenario).

On the basis of six worldwide certified alternative kerosene production processes (2 obtained by hydrotreatment of lipids – HEFA-SPK, 2 by Fischer-Tropsch synthesis – FT-SPK, 2 by fermentation- farnesane and Alcohol-to-Jet), more than 2000 demonstration commercial flights with fuels known as experimental “drop-ins” have taken place as of this time. The specificities of biokerosene can currently be obtained by the generation of synthetic kerosene from BtL (Biomass-to-Liquid) technology or by hydrotreating lipids and fatty acids (HVO) process. Regarding the certification rules, these two products can be blended up to 50 % vol. into traditional petroleum-based kerosenes. Alcohol-to-jet is certified up to 30 % vol. blending and farnesane up to 10 %.

Moreover, political ambitions reveal a preference for incorporation. In 2011, the European Commission launched the project European Advanced Biofuel FlightPath that aimed at a level of incorporation of 2 Mt of biojet for 2020, or 4 % of European consumption. In its White Paper on Transport (2011), the European Commission foresaw an incorporation of 40 % of low-emission engine fuel for aviation by 2050.

In 2015, European kerosene consumption (UE-28) was 1.74 EJ. These two biokerosene markets with 50 % incorporation and biofuels for ground transport have comparable volumes, leading to competition of biomass uses depending on market opportunities. Among the 3 scenarios (ADEME *et al.*, 2019), the consumption of biokerosene in France appears in scenarios REDII and MaxiG2 for 10.5 and 17.2 PJ respectively in 2030.

Today, the major obstacle is the high production cost of alternative fuels compared to that of fossil fuel, and the absence of political incentives to counterbalance this extra cost (Académie des technologies, Académie de l'air et de l'espace, 2015; Banoun *et al.*, 2015).

Driver 5 : Social drivers

The biofuels development responds to the 4 challenges described in the introduction and more generally to the 12 principles that form the core of green chemistry (Anastas and Warner, 1998). However, the transition from technological invention to innovation involves the adoption of these biofuels by consumers.

The conventionnal biofuels was introduced in drop-in, hiding the innovation step. Controversies over the food vs. fuel dilemma led to a debate (Rulli *et al.*, 2016). Biofuels rely on about 2-3 % of the global water and land used for agriculture, corresponding the needs of about 30 % of the malnourished population. However no one has demonstrated that biomass diverted to biofuels could have been available at low price for foods. Nevertheless this controversy anticipates the introduction of advanced fuels.

The second difficulty is the industrial price difference between sources. On the assumption of a unit of 100,000 t bioethanol / year, the cellulosic ethanol production price varies from 0.75 to 0.80 € / L (motor fuel taxes not inluded) depending on the incoming biomass listed from 55 € / t poplar to 59 € / t miscanthus. For the record, the selling price of food-based ethanol was around 0.65 € / L in Rotterdam, and 0.56 € / L in Brazil in 2017. When expressed on MJ basis, fossile fuels (gasoline 0.008 € /MJ; diesel 0.010 €/MJ) are less expensive than bioethanol (0.019 € /MJ). The same ranking between fossil and biobased fuels was observed in 2018: 0.019, 0.016, 0.021, 0.023, 0.025-0.033 and 0.022-33 € /MJ for gasoline SP95, diesel, food-based ethanol, biodiesel, methane (PCS) and Syngas (PCS) respectively (US Grains Council, 2018).

The development of these biofuels, provided they are sustainable, must be based on criteria other than economic ones and justify the implementation of public policies. Directive 2003/96 / EC provides for the possibility for Member States to apply a reduced rate of taxes on biofuels.

Once consumers' awareness of issues is risen, the presentation of biofuels to consumers must be based on key-determinants of consumer acceptance and drivers' willingness (WTP) to pay for advanced biofuels.

Willingness-to-pay is defined as someone's economic value for such a good, usually stated as the highest amount he/she is prepared to pay more for this good than for its conventional counterpart (i.e. the so-called price premium).

In different countries (Table 6), part of the population is ready to use cellulosic-based biofuels, provided that reasonable information is provided and that the premium price is limited.

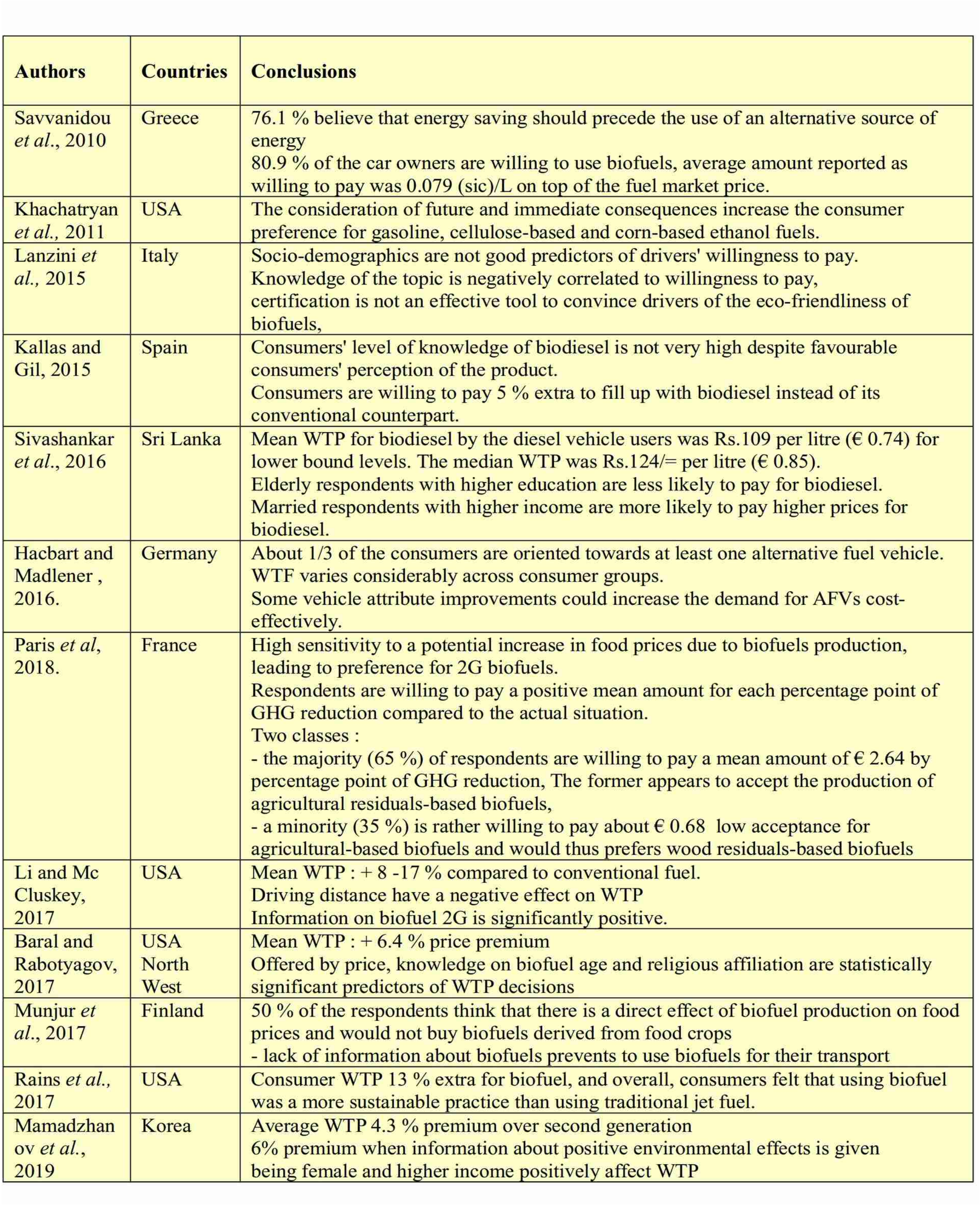
Feedstock supplies: biomasses ressources

The main issue is the maximisation of biomass ressources (Table 7) for biorefineries with the security and flexibility of supply, guarantee of biomass quality, environmental sustainability and low cost of biomass feedstock. The rationale is both to increase the carbon stock in agricultural and forestry ecosystems (soils, vegetation) and at the same time to substitute biomass for fossil fuels, if possible without competition between these two functions, if not proposing a balanced equilibrium on the basis of a global greenhouse gas balance.

Another assumption is to ensure that the overall demand of biomass does not significantly increase the EU's or national global land footprint.

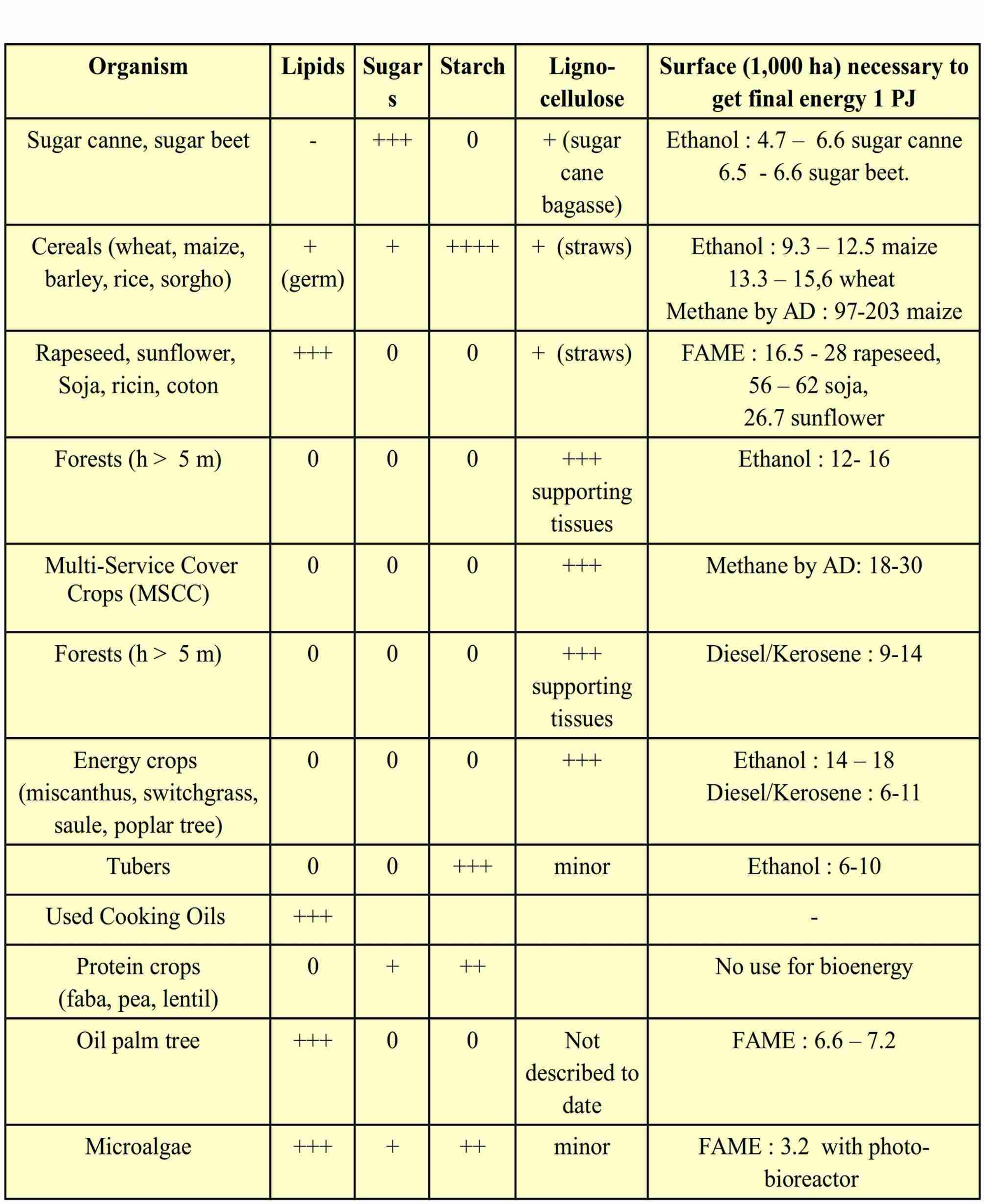
Faced with a simplistic view of optimization,

Table 6. Key determinants of consumer acceptance and willingness (WTP) to pay for advanced biofuels.



Authors	**Countries**	**Conclusions**
Savvanidou *et al.*, 2010	Greece	76.1 % believe that energy saving should precede the use of an alternative source of energy 80.9 % of the car owners are willing to use biofuels, average amount reported as willing to pay was 0.079 (sic)/L on top of the fuel market price.
Khachatryan *et al.*, 2011	USA	The consideration of future and immediate consequences increase the consumer preference for gasoline, cellulose-based and corn-based ethanol fuels.
Lanzini *et al.*, 2015	Italy	Socio-demographics are not good predictors of drivers' willingness to pay. Knowledge of the topic is negatively correlated to willingness to pay, certification is not an effective tool to convince drivers of the eco-friendliness of biofuels,
Kallas and Gil, 2015	Spain	Consumers' level of knowledge of biodiesel is not very high despite favourable consumers' perception of the product. Consumers are willing to pay 5 % extra to fill up with biodiesel instead of its conventional counterpart.
Sivashankar *et al.*, 2016	Sri Lanka	Mean WTP for biodiesel by the diesel vehicle users was Rs.109 per litre (€ 0.74) for lower bound levels. The median WTP was Rs.124/= per litre (€ 0.85). Elderly respondents with higher education are less likely to pay for biodiesel. Married respondents with higher income are more likely to pay higher prices for biodiesel.
Hacbart and Madlener , 2016.	Germany	About 1/3 of the consumers are oriented towards at least one alternative fuel vehicle. WTF varies considerably across consumer groups. Some vehicle attribute improvements could increase the demand for AFVs cost-effectively.
Paris *et al*, 2018.	France	High sensitivity to a potential increase in food prices due to biofuels production, leading to preference for 2G biofuels. Respondents are willing to pay a positive mean amount for each percentage point of GHG reduction compared to the actual situation. Two classes : - the majority (65 %) of respondents are willing to pay a mean amount of € 2.64 by percentage point of GHG reduction, The former appears to accept the production of agricultural residuals-based biofuels, - a minority (35 %) is rather willing to pay about € 0.68 low acceptance for agricultural-based biofuels and would thus prefers wood residuals-based biofuels
Li and Mc Cluskey, 2017	USA	Mean WTP : + 8 -17 % compared to conventional fuel. Driving distance have a negative effect on WTP Information on biofuel 2G is significantly positive.
Baral and Rabotyagov, 2017	USA North West	Mean WTP : + 6.4 % price premium Offered by price, knowledge on biofuel age and religious affiliation are statistically significant predictors of WTP decisions
Munjur *et al.*, 2017	Finland	50 % of the respondents think that there is a direct effect of biofuel production on food prices and would not buy biofuels derived from food crops - lack of information about biofuels prevents to use biofuels for their transport
Rains *et al.*, 2017	USA	Consumer WTP 13 % extra for biofuel, and overall, consumers felt that using biofuel was a more sustainable practice than using traditional jet fuel.
Mamadzhanov *et al.*, 2019	Korea	Average WTP 4.3 % premium over second generation 6% premium when information about positive environmental effects is given being female and higher income positively affect WTP

Table 7. Main sources of biomasses for biofuels.



Organism	Lipids	Sugars	Starch	Ligno-cellulose	Surface (1,000 ha) necessary to get final energy 1 PJ
Sugar canne, sugar beet	-	+++	0	+ (sugar cane bagasse)	Ethanol : 4.7 – 6.6 sugar canne 6.5 - 6.6 sugar beet.
Cereals (wheat, maize, barley, rice, sorgho)	+ (germ)	+	++++	+ (straws)	Ethanol : 9.3 – 12.5 maize 13.3 – 15,6 wheat Methane by AD : 97-203 maize
Rapeseed, sunflower, Soja, ricin, coton	+++	0	0	+ (straws)	FAME : 16.5 - 28 rapeseed, 56 – 62 soja, 26.7 sunflower
Forests (h > 5 m)	0	0	0	+++ supporting tissues	Ethanol : 12- 16
Multi-Service Cover Crops (MSCC)	0	0	0	+++	Methane by AD: 18-30
Forests (h > 5 m)	0	0	0	+++ supporting tissues	Diesel/Kerosene : 9-14
Energy crops (miscanthus, switchgrass, saule, poplar tree)	0	0	0	+++	Ethanol : 14 – 18 Diesel/Kerosene : 6-11
Tubers	0	0	+++	minor	Ethanol : 6-10
Used Cooking Oils	+++				-
Protein crops (faba, pea, lentil)	0	+	++		No use for bioenergy
Oil palm tree	+++	0	0	Not described to date	FAME : 6.6 – 7.2
Microalgae	+++	+	++	minor	FAME : 3.2 with photo-bioreactor

some countries also aim at supply sovereignty in order to secure their consumer markets and industrial sectors.

Regional pedoclimatic conditions lead to contrasting biomass availabilities. In Northern European countries or Canada, forest is the leading resource. In contrast UK has orientated to other main potential resources as are household waste (414 PJ in 2050), energy crops (360 PJ in 2050) and agricultural by-products (288 EJ in 2050) (Welfe *et al.*, 2014).

Biomass availability is a necessary condition to ensure supply over long periods. It is an important critical structural point for all value chains, especially in the case of biofuels, to avoid dependence on market conditions. A major advantage of plant production, with the exception of sugar beet and sugar cane, is the stability of agricultural and forestry materials once harvested: it is thereby possible to desynchronize production, storage, imports, processing and consumption.

Data come from various data sources not harmonised among each other. Evaluation methods are very different depending on the country, making comparisons between European countries difficult. Overall, the EU-28 exports agricultural products derived from field crops. Therefore, mismatches are hard to solve (Camia *et al.*, 2018).

Concerning the USA, the different sources have been well-identified in the 2016 Billion-Ton Report (Langholtz *et al.*, 2016; Rogers *et al.*, 2017). It makes possible to address growth prospects for green chemistry and bioenergy for 2030 by particularly focusing on agricultural residues, woody and herbaceous energy crops, as well as on organic municipal waste, which are in high demand if we are to go from 365 Mt of biomass in 2014 to 1042 Mt biomasse in 2030, without impacting food crops (Rogers *et al.*, 2017).

The potential of available biomasses can be evaluated on the basis of agricultural and forest land, competition between uses and certifications of sustainability at the production stage (RSPO: Roundtable on Sustainable Palm Oil; ISCC: International Sustainability and Carbon Certification, FSC: Forest Stewardship Council; PEFC: Program for the Endorsement of Forest Certification Schemes).

Crops

Annual and perennial plants (not including forests) constitute a resource, the amount of which depends on local pedoclimatic conditions and market conditions. Studies undertaken by the U.S. Department of Energy (Perlack *et al.*, 2005; Downing *et al.,* 2011; Langholtz *et al.*, 2016) are impressive and remain the reference. The methodological difficulties linked to the interconnexions between the sectors food, feed, bioenergy and biobased chemicals make the descriptions difficult. Green chemistry applications represent traditional optimization channels and are often very attractive for small volumes. Biodiesel is representative of systemic effect. One important driving force is the increasing global demand for soybean meal for animal feed and with it the increasing price of soybean meal. Soya oil production is increasing much faster than the food market (edible oil) can absorb. The only other outlet is the biodiesel market (Bockey, 2019). In addition oilseed processing in a one step process gives FAME and at the same time high-grade pharma glycerol, which gradually forced other sources of glycerine out of the market (Bockey, 2019)

Field crops are also a source of lignocellulose when the straws, stems, cobs are harvested. The average rate of sustainable straw harvesting determines the extent to which residues can be extracted in a sustainable way. Current straw harvesting efficiencies are near 50 %. It is highly variable at the regional and sub-regional level and depends on the choice of varieties. Numerous crop rotation and soil tillage factors influence how harvesting crop residues will affect soil conservation and other agrosystem services. Monteleone *et al.* (2015) examined some management strategies of wheat cultivation system and its sustainability in using wheat straw as an energy feedstock. Straw use for energy generation in parallel with the optimization of the cropping system are key factors in long-term environmental sustainability. So straw harvesting must be rationalized on the scale of the cultivation system. Many studies that claim to take all factors into consideration conclude 25 to 35 % of the straw may be available for energy uses.

Additional research works are needed to overcome uncertainties concerning crop residues: crop models of agricultural residue production taking into account the interrelationships between genetic factors (varietal differences), agro-climatic conditions, and cropping management practices

The use of life cycle assessment (LCA) as a comprehensive tool to assess environmental impacts of bioenergies is an essential tool. Godard *et al.* (2013) demonstrated the large influence of allocation method (economic or mass-based). Simulation models using local data in agricultural LCAs, especially for dynamics of Soil Organic Carbon (SOC) and pesticide from fields are recommended and need additional research works.

For EU28, cereals, oils seeds, other arable crops, fodder (green maize, temp. grassland), set-aside + fallow lands and permanent grassland represent 57.8, 11.5, 9.7, 21.7, 6.6 and 58.3 Mha respectively. One advantage of crops is that annual biomass collection is inherent to the cropping systems. Thereby commercial activities on large volume are easy to forecast.

Dedicated energy crops have very low fertilizer requirements and provide ecosystem services including organic carbon storage. These attractive characteristics cause perennial biomass crops (PBC) to be seen a source of bioenergy with significant potential for growth. Transportation and fertilization were the main contributors of field emissions during feedstock production (Godard *et al.*, 2013). In Germany, biogas from energy crops has played a major role in the Energiewende (2010) to date. In the years 2000 to 2012, the silage maize cultivation area grew from 1.154 Mha to 2.038 Mha (total agricultural area of Germany : 17 Mha) and since has remained constant at ca. 2.1 Mha since 2014.

However, current land use in the EU for the production of dedicated energy crops is marginal (63,907 ha for short rotation coppice, 53,494 ha for grassy energy plants, mainly Miscanthus). To allow the EU to benefit from the promise of dedicated energy crops, political incentives included in the CAP reform should be applied to encourage more widespread plantation of energy crops, like short rotation coppice and miscanthus.

Additional research works are needed to understand the functioning of plants and their adaptation of the raw materials, for boosting of yields by enhanced photosynthesis, integrate new breeding targets (composition and ultrastructure) and increase diversity of varieties and crops.

Forests

Solid biomass coming from forests represents today the main source of bioenergies in EU28 and France, 3,950 – 5,630 PJ and 464 - 661 PJ respectively. This resource is the one likely to have the greatest versatility of uses (electricity, heating, fuel). Of course the choice biofuel vs heatwood is an issue with different stakeholders to take into account. The difficulty is to understand the positions and underlying motivations of stakeholders groups relative to their perception of energy and inform misconceptions about bioenergy.

Additional research works are needed to overcome different bottlenecks of lignocellulose disruption. More reactive lignin (Le Bris *et al.*, 2019) leads to better saccharification yieds.

The issue is to determine whether wood biomass could be available for biofuels, either directly in 2G biorefinery, or in a cascade scheme. Forestry biomass is generally considered to have the potential to deliver substantial amounts of biomass for the bioeconomy.

Evaluation of the available biomass from forests combines different steps (Figure 4):

- total theoretical available resource defined as the maximum amount of terrestrial biomass theoretically available over bark,
- environmentally sustainable resources; available resources taking account of eventual constaints (competitive uses,

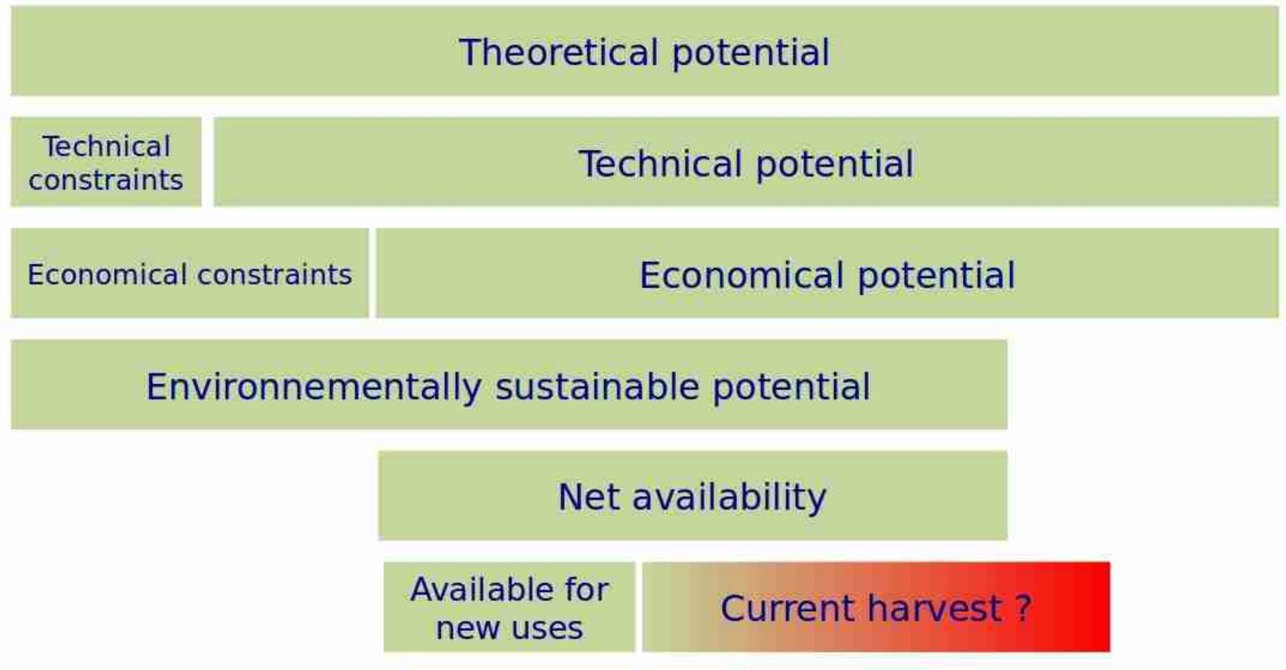


Figure 4. Different types of biomass from forestry.

soil/water/biodiversity preservation, negative impacts linked to its extraction, etc.) and based upon the net annual increment.;

- technically available resources, available under current technologies, with accessibility based on eventual logistical constraints: access, level of dispersion over the territory, ease of transport/storage, etc.;
- economically available resources, share of the technical potential which meets economic criteria within given conditions, covering the cost of production and the price of the biomass feedstock, with the existence of an international market able to supply a domestic market through imports. Biomass collection remains a bottleneck.

The combination of the last three fractions determines the net availability for use in timber, industry and energy. However current harvests might extend beyond this limit, making forest certification necessary.

Local framework conditions across Europe and in France of course are complex and diverse. They are defined by many factors such as forest ecosystem types (hard- and softwood), ownership structures, infrastructure, available harvesting technologies, transportation, logistics and transforming industries. Augmenting sustainable mobilisation consequently requires a multi-actor and multi-factor approach.

A European agrement has been reached for the methodologies devoted to the evaluation of total theoretical available resource In contrast the methodologies implemented for the other types of resources are rarely described, leading to significant disagreements. So the mismatched gaps can reach 15-20 % that is not surprising. Additional research works are needed to overcome these different uncertainties: modern methodologies (satellite data) to estimate harvest levels and removals of woody biomass, with a challenge on household use of fuelwood when non-marketed.

Generally, roundwood production is driven by demand from the wood products industry rather than by demand for bioenergy. This reflects the substantial price difference between industrial roundwood, pulpwood and wood residues from sawmills, which ensures that high quality timber is used for high-value products such as furniture and construction.

The particular difficulty of forest resources is the interweaving of sectors (timber, pulp and particle board, energy), reinforced by cascade uses, paper recycling and new biorefineries. In France, wood energy comes from three sources, wood energy sensu stricto, losses in the processing of timber and industrial wood. For example, Colin and Thivolle-Cazat (2016) have adopted the following assumptions for the French forests:

- timber: sawing mass yield of 50 % for sawn timber, 38 % for energy and 12 % for sawmill related products (SRP).
- industrial (paper, particle board): technical yield of 70 % for pulp and particle boards, 18 % for energy and 8 % for secondary processing industries,

In addition, the distinction between timber and industrial wood plantations does not result in volumes proportional to the area planted. In France, current withdrawals of potential timber are twice as high as actual timber uses, showing use for crushing or energy (Guinard *et al.*, 2016).

On the basis of an annual worldwide harvest (source: FAOSTAT) of 3,737 Mm^3, 1,863 Mm^3 are used for fuelwood (a considerably underestimated figure), 468 Mm^3 for lumber, 416 Mm^3 for panels and 180 Mt for pulp. At the global level, the report, Forests and agriculture: land-use challenges and opportunities (FAO, 2016), claims that deforestation is not necessary to meet food challenges in tropical regions in the case of 35 countries, to the benefit of ecosystemic services.

At the same time, the increased production capacity of forests under sustainable management remains an option for three products: lumber, construction and fuelwood. In developed countries, the forest area is slowly increasing, leaving way for an increase in uses. At the global level, fuelwood within the framework of sustainable harvesting (Kraxner *et al.*, 2013) is estimated at 115 EJ/year.

EU28 has 182 Mha of forests and other wooded lands, with an average increase of 0.2 % per year (322,000 ha). It represents a stock of 26.3 billion m^3 over bark. The value is of interest only to determine the sequestration of carbon in wood.

In contrast to the trend elsewhere in the world, the area covered by forests and other wooded lands in the EU28 is currently increasing. In the period from 1990 to 2015, the area of forest cover and other wooded land in the EU28 increased by 5.2 %, equivalent to an average increase of 0.2 % per year.

On average 63 % of the annual forest increment is felled and 38 % remain in forest. 53 % of EU28 forest area is certified PEFC and 26 % certified FSC (some forests may be certified both). This perspective is based upon the rationale that the net annual harvest in Europe's forests corresponds to roughly 60 % of the net annual increment, giving a potential to sustainably increase the mobilisation of forest biomass for a variety of uses.

There is no market incentive for bioenergy producers to buy high-quality wood (*i.e.,* sawlogs). Only low-value residues and other unmarketable wood are affordable for the energy sector. However Cyprus, The Netherlands, Denmark, Greece, France, and Italy were the only Member States where more than half of the total roundwood produced in 2016 was destined for fuelwood.

Socioeconomically, EU28 forests are divided into small family holdings, state-owned forests, and large estates owned by companies, which are often exploited by the forest and wood products industry. In total, around 60 % of the EU28´s forests were privately owned in 2010. This percentage is highest (98.4 %) in Portugal and lowest in Bulgaria (13.2 %). The high share of privately owned forests, which are often small and dispersed among many forest owners, makes forest management a challenging proposition.

Economic incentives play a major role to sustainable forest management. Bioenergy provides such an incentive by permitting the valorisation of low-quality wood such as tops, branches and early thinnings.

In EU28, net annual increment is about 720 Mm^3 (over bark). The roundwood production is 425 Mm^3, including 98 Mm^3 of fuelwood. Wood and agglomerated wood products such as pellets and briquettes provided the highest share of energy from organic, non-fossil materials of biological origin, accounting for almost half (45 %) of the EU-28's gross inland energy consumption of renewables in 2014. However measures of actual fuelwood consumption by households are not realized with the same rigour all over the different european countries.

EU28 market for biomass intended for the household and industrial production of heat or power represents 22.7 Mt of pellets (2017), 8.1 Mt being imported.

In addressing the complexity of sustainable mobilisation of forest biomass, EIP-AGRI Focus Group (2018) has identified three major bottlenecks:

- the importance of incentives in public policies and no study of their impact and effectiveness,
- the low diffusion of user-friendly information systems,
- the lack of cross-regional value-chains and production systems.

In France, net annual increment is about 83 Mm^3 (over bark). The roundwood production is 52 Mm^3, including 27 Mm^3 of fuelwood.

French forests (Kurtek *et al.*, 2018) represent 17.4 Mha, up by 6 % since the period 2006-2014. In France, the harvesting rate is only 55 % of the annual organic production, well below that of other European countries (72 %). In France, in 2014, the volume of standing timber was more than 2.9 billion m^3. Of the 92.3 Mm^3 of the net annual organic production, 40 Mm^3 were harvested and marketed in 2013, including 21 Mm^3 for fuelwood, 12 Mm^3 for industrial wood (pulpwood, pickets) and 22 Mm^3 for lumber (sawlogs, veneer). A large part of the production (25 Mm^3) was directly harvested and self-consumed by the owners. The rest was simply not harvested, allowing the forest biomass to increase year after year. The sector's lack of efficiency is well known compared to other European countries with timber harvesting rates on the order of 72 %.

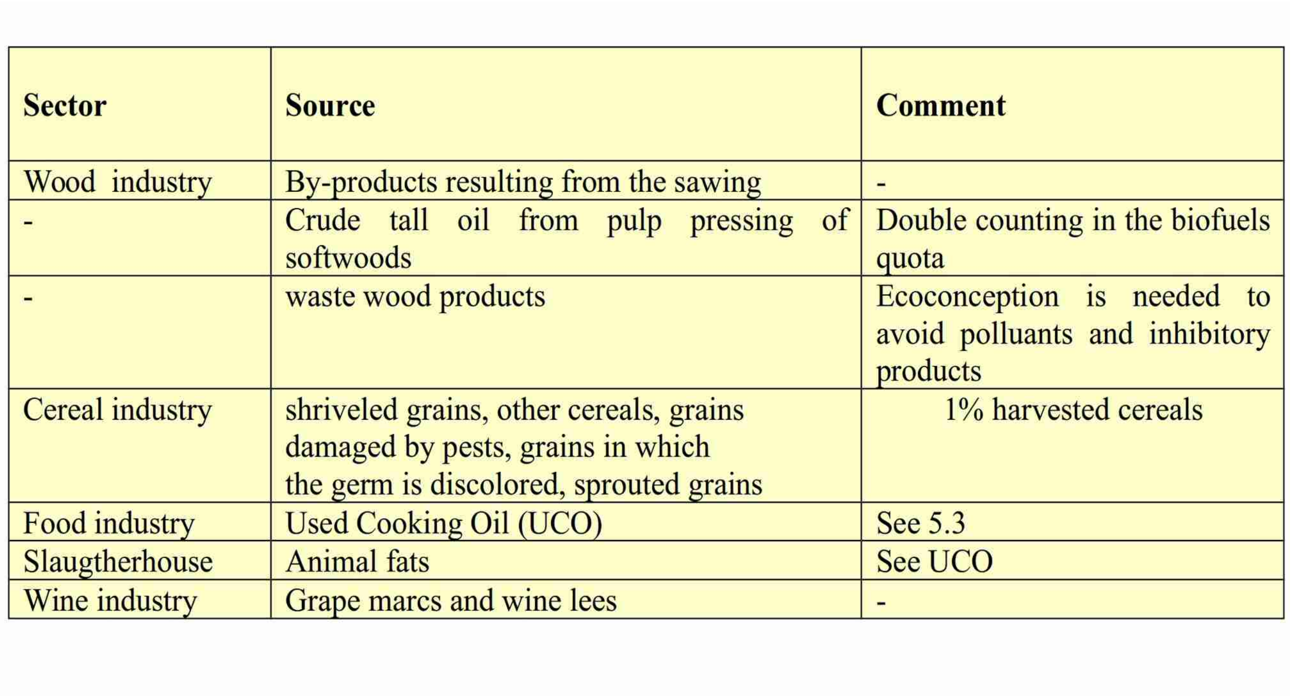
Fuelwood, not including direct harvesting, includes 6.6 Mm^3 of trees outside forests, 11.6 Mm^3 of by-produits and waste from the wood industry (half of which are linked to sawmills), 3.6 Mm^3 of black liquors and 2.2 Mm^3 of recovered wood. This represents a potential of 120 - 290 PJ/year.

On the basis of a productive area of 16.8 Mha, the volumes of timber that can be harvested between now and 2035 (Kurtek *et al.*, 2018) in quantity and in quality, in order to contribute to the development of national and regional forest-wood policies (FCBA-IGN, 2016) were considered according to two scenarii: continuous silviculture and progressive dynamic management. The demand for industrial and fuelwood estimated between 54 and 64 Mm^3 (or 1 m^3 – 750 kg – 5.940 GJ) per year in both less ambitious scenarios can be satisfied provided that round wood and products linked to the wood industries are made available and that the potential hardwood lumber not currently used is used as lumber.

The Conseil général de l'alimentation, de l'agriculture et des espaces ruraux (CGAAER) reports, first Demolis *et al.* (2015), and then Galbert *et al.* (2015), project a theoretical volume of 40 Mm^3 of wood available for the processing industries, compared to the 35.2 Mm^3 of wood marketed in 2012. By considering the cascading uses of wood, excluding energy, the energy potential is increased compared to when fuelwood alone is considered (Mantau, 2015). Consequently, 42 to 55 % of the lumber used in sawmills consists of related products such as bark, sawdust, chips and non-compliant logs. ADEME supplemented this analysis for 2030 with an estimate of potentials of 50 Mm^3 of wood from forests, 3.6 Mm^3 from hedges, and 27 Mm^3 from waste and urban trees.

Longer-term foresight work conducted by ECOFOR is aimed at the horizon of 2100. Finally, Roux *et al.* (2017) brings a Dynamic Silviculture scenario, the gross availability in 2035 is 97 Mm^3 of wood, the technical and economic availability 74 Mm^3. These are the volumes of timber, industrial and energy wood and wood losses, after operating losses. For 2050, Roux *et al.* (2017) projected the trends of this scenario, which leads to a sampling assumption of 82 Mm^3. The 91 Mm^3 sampled in the forest in 2050 breaks down into 9 Mm^3 losses, 26 Mm^3 in timber, 24 9 Mm^3 in industrial wood (12 current + 12 future), and 33 Mm^3 for energy. In total, wood energy represents a potential of 824 PJ in 2050.

Table 8. Biomass sources to include in a cascade approach.



Sector	Source	Comment
Wood industry	By-products resulting from the sawing	-
-	Crude tall oil from pulp pressing of softwoods	Double counting in the biofuels quota
-	waste wood products	Ecoconception is needed to avoid polluants and inhibitory products
Cereal industry	shriveled grains, other cereals, grains damaged by pests, grains in which the germ is discolored, sprouted grains	1% harvested cereals
Food industry	Used Cooking Oil (UCO)	See 5.3
Slaugtherhouse	Animal fats	See UCO
Wine industry	Grape marcs and wine lees	-

Cascade uses

The cascading use principle applied to biomass gives priority to higher value uses (materials, foods) that allow the reuse and recycling of products and raw materials and promotes energy use only when previous options are starting to run out. It concretely prioritizes material uses of biomass before energy use since burning implies the molecules being lost (table 8).

Cascade uses of wood have already been described previously. When the remaining physical and chemical properties are no longer satisfactory for industrial wood and lumber, the opportunities of re-using and recycling have disappeared. Regulation either hinders (Poland, Spain) or promotes (Germany, UK) cascading uses of wood (Dammer *et al.*, 2016). The main idea is to reject the use of wood straight from the forest to produce energy. The consequence is that more wood ressources would be considered in these conditions. The bottleneck is to better integrate and implement existing bio-energy and waste policies.

Biodiesel (FAME and HVO) can be obtained from Used Cooking Oil (UCO) or animal fats and thereby fits with the concept of cascade use in bioeconomy. For the EU-27, Ecofys (2019) estimated in 2017 a total UCO potential of 3.55 106 t/year, including the catering sector, food processors and households (1.75 106 t/year). Green gas emissions from the production and consumtion of biodiesel from UCO are betweeen 60-90 % lower than the emissions from conventional diesel. However the bottleneck is the logistics involved in collecting small amounts of UCO from a very large number of individual households.

Algae biofuels: technological foresight

Cultivation of such feedstock types as algae is only at the early stages of development and the supply is currently marginal for biofuels.

Microalgae still attract (Moody *et al.*, 2014; Afzal *et al.*, 2017) a great deal of interest. Algae are expected to have several advantages by comparison with agricultural crops: possible settlement on non farmlands; better photosynthetic efficiency; higher oil productivity and possible growth by using CO_2

from gaseous effluent. Algae cultivation can also be coupled with wastewater treatment for biofuels production. Moreover, the biorefinery concept can be applied because different types of co-products (chemicals, pigments, agrochemicals, feed, food) can be obtained from algae together with the production of biofuels, within a biorefinery concept. In outside conditions close to those of a commercial operation, the production of eukaryotic and prokaryotic microalgae (50-70 t dry matter/ha.year) is greater than that of rapeseed, maize and switchgrass (10 to 30 t/ha.year), and may even exceed that of sugar cane (plants in C4). The main steps of the biofuels production are the biomass cultivation, the harvesting, the lipids extraction and the conversion to biofuels and the co-products valorisation. Hydrothermal conversion are possible with algae, in order to convert 100 % of the algae. However, the nitrogen content, the ash content and sulfur content can be problematic. The major technological obstacle today is the large scale production and the harvest stage (sedimentation, flocculation, filtering and drying). Moreover, the incorporation of microalgae (*Spirulina* and *Chlorella* at this time) in the energy system will surpass current applications (proteins, omega-3 acid, carotenoids, phycobiliproteins) provided that major progress is made in the laboratory/pilot/industry transition.

The algae cultivation and harvest is similar to agriculture, in a certain way. The main bottleneck to cope with are as follows:

- the water use is of great concern, as algaes grow in a 90 % water solution. The water management, inside the process must be treated with attention.
- the marine algaes contain up to 50 % of inorganics (ashes) in mass. The non-marine algae contain up to 20 % of inorganics in mass.
- K and P nutrients are necessary for the growth of algaes.

Industrial CO_2 constitutes the last available resource. This inert molecule must first be broken down using energy to obtain platform molecules depending on the chemical or biotechnological catalyzer implemented. Urea synthesis is the most frequent use of carbon dioxide in organic synthesis at this time. Industrial CO_2 presents two advantages:

- its abundance in industrial smoke (7 to 9 %) and fermentations, compared to its content in the atmosphere (403 ppm of CO_2 in the atmosphere in 2016).
- the possible link with industrial biotechnologies with bacteria, archaea and microalgae that use light, heat or electrical energy. The major advantage of the biotechnologies is that they can use CO_2 from power plants or industry without purification. LanzaTech (New Zealand) has developed fermentation systems to produce ethanol, butane and other products from non-purified gas emissions from the steel industry.

An important feature of microalgae is the co-production of protein-rich residues useful as feeds. However, in terms of biofuel production, it is a drawback, since it contains much more nitrogen (up to 10 %) than the tolerate amount in biofuels.

Nowdays industrial production is restricted to a small numer of species *Arthrospira* (*Spirulina*) *platensis* (~ 7000 t dry matter / year), *Chlorella* sp. (~ 4000 t dry matter/year) and *Dunadiella salina* (~ 2000 t/year) essentially for cosmetics, foods and feeds.

The transition to photo-bioreactor for cultivation of microalagae allows to increase production potential to 79.2 PJPCI on 250,000 ha.

Additional research works are needed to overcome different bottlenecks. The development of synthetic biology for photosynthetic strain optimisation is nowadays a real challenge. The implementation and the operating large scale production system is also an important issue, together with largely positive energy production processes, including innovating downstream processing for very wet biomass.

Wastes

Biogas, containing CH_4, can be obtained from all kinds of feedstock (ADEME, 2016a). However the different kinds of feedstock used, often very diffuse and difficult to transport, have a large influence on how plants operate, and the associated costs (collection, transportation and handling).

Any whole plant has to be considered around the main feedstock it intends to use. The use of biogas technology as part of integrated waste management and ressource management relies on large scales. 1 PJ can be obtained from biowaste from housholds (800,000 - 1,200,000 habitants) or 40,000 - 60,000 cattle.

Kampman *et al.* (2016) estimated European potential biogas production from waste at between 1.25 - 1.67 EJ by 2030, around 3 % of European energy consumption and approximately 10 % of gas consumption within that timeframe. Transport & Environment (2017) estimated lower values 264-327 PJ for advanced biofuels from wastes and residues (Annex IX part A) in 2030.

For France, Solagro and Inddigo (2013) estimated the potential at 167 PJ in 2030, a value equal to that produced by the United Kingdom and Italy. It was based upon methanization at 180 PJ in 2030, *i.e.*, a volume similar to that established in the European study. Some analyses by Negawatt (2011) predict a potential in excess of 335 PJ by 2040.

The more recent scenario Gas mix 100 % renewable in 2050 ? (ADEME, 2018) relies on the mobilisation of 10 MtMS of livestock manure, *i.e.*, 67 % of the mass produced. The potential for producing biogas of agricultural origin is estimated at 442.8 PJ PCS. of which 27 PJ are from livestock and 51 PJ from intermediate crops.

Additional research works are needed to overcome different botlenecks:

- designing technical solutions that allow the use of heterogeneous feedstock and/or with high dry matter content.
- reliability of supply of feedstock (in terms of both quantity and quality) for the entire duration of projects.
- digestate represents another value of this process, with the advantage to close the loops of nitrogen, potassium and phosphorus. The large areas of land required to spread the digestate are not always available in close proximity to anaerobic digestion units.

The sector’s complexity comes from he variety of stakeholders (from agriculture, industry, local authorities, etc.). Ways to integrate these different stakeholders needs to be investigated.

Conclusions on resources

The current consumption of biofuels represents 127 PJ/year , 23 % of bioenergies in France with mainly conventional biofuels (Dussud *et al.,* 2018). The roadmap advanced fuels for France (ADEME, 2011) has to be updated with five main sources : forest products (chips, related products and end-of-life wood products), wastes, agricultural residues, MSCC and energy crops. All these figures given in this chapter highlight that there is still the possibility for a large increase of bioenergy usage and a real need to promote biofuel as one of the reliable solutions for a low-carbon energy transition in France.

At the european scale, existing studies have calculated the domestically available potential for biomass for energy to be from 7,076 PJ up to 30,857 PJ each year in Europe from 2050 onwards. A literature review concludes that the middle range potential of 16,998 PJ, which is around 24 % of the total energy consumption in EU-28 in 2017, can be achieved by 2050 – considering different constraints (*e.g.,* costs). This means that, compared to the actual 6,028 PJ used in 2017, the potential gives enough room to almost triple the amount of bioenergy in the EU-28 energy mix.

Integration

Biofuels have to be considered in a system integrating production – transformation – distribution - use with three core dimensions:

- environmental sustainability, which covers preservation of biodiversity, water resources, carbon sink (cropping and forestry systems) and reduction of ghg emissions;
- land use competition to fulfil food security including the ongoing transformation to healthy

diets by 2050 will require substantial dietary shifts (Willett *et al.*, 2019). with generational evolutions (lower consumption of animal products),

- quantitative relevance of biofuels present either as a goal and an agricultural input (fertilizer….) in the energy system.

Balancing these three critical but sometimes conflicting goals is what we define as the nexus energy-environment-food. This nexus can be assessed from life cycle analysis to integrated assessment models.

Foresights

Energy has been the topic of many foresights, at world (Table 9) and national scales. Different scenarios have been published: they are not predictions of what is likely to happen. They explore the possible implications of different assumptions. They all include a share of biofuels. The most important uncertainity about the future of energy is the interaction with national policies: biomass use could evolve in a “sustainable” or “unsustainable” way depending on the governance context.

Biomass in 2013 contributed ~ 60 EJ (10 %) to global primary energy (2011). More than half was traditional biomass, predominately used for cooking and heating in developing regions, bioelectricity accounted for ~1.7 EJ, and transport biofuels for 3.19 EJ. The Special Report on Renewable Energy Sources (Smith *et al.,* 2014; Creutzig *et al.*, 2015) concluded that biomass supply for energy could reach 100-300 EJ/yr by 2050 with the caveat that the technical potential cannot be determined precisely while societal preferences are unclear. If limited by water and land availability, bioenergy is a somewhat lower range of 80-190 EJ/year (17 EJ for Europe).

Sustainability and emergence of new technologies (wind, solar, biotechnology) and ressources (gas) are the game changers involved of these exercices. Some factors should need deeper investigation:

- the development of agroecological practices, with the evolution of species-variety-cropping system to longer rotations, including nonfood crops,
- the potential role of carbon sequestration (0.4 %),
- the evolution of human diets towards less animal products.

Those which are considered here (Table 9) have expressed special attention to biofuels. These prospects are unquestionably the most developed, even though they face several difficulties, including the multiplicity of sources (primary energy including nuclear source), uses (heat, transport) and the cost of infrastructures, to be amortized over long periods.

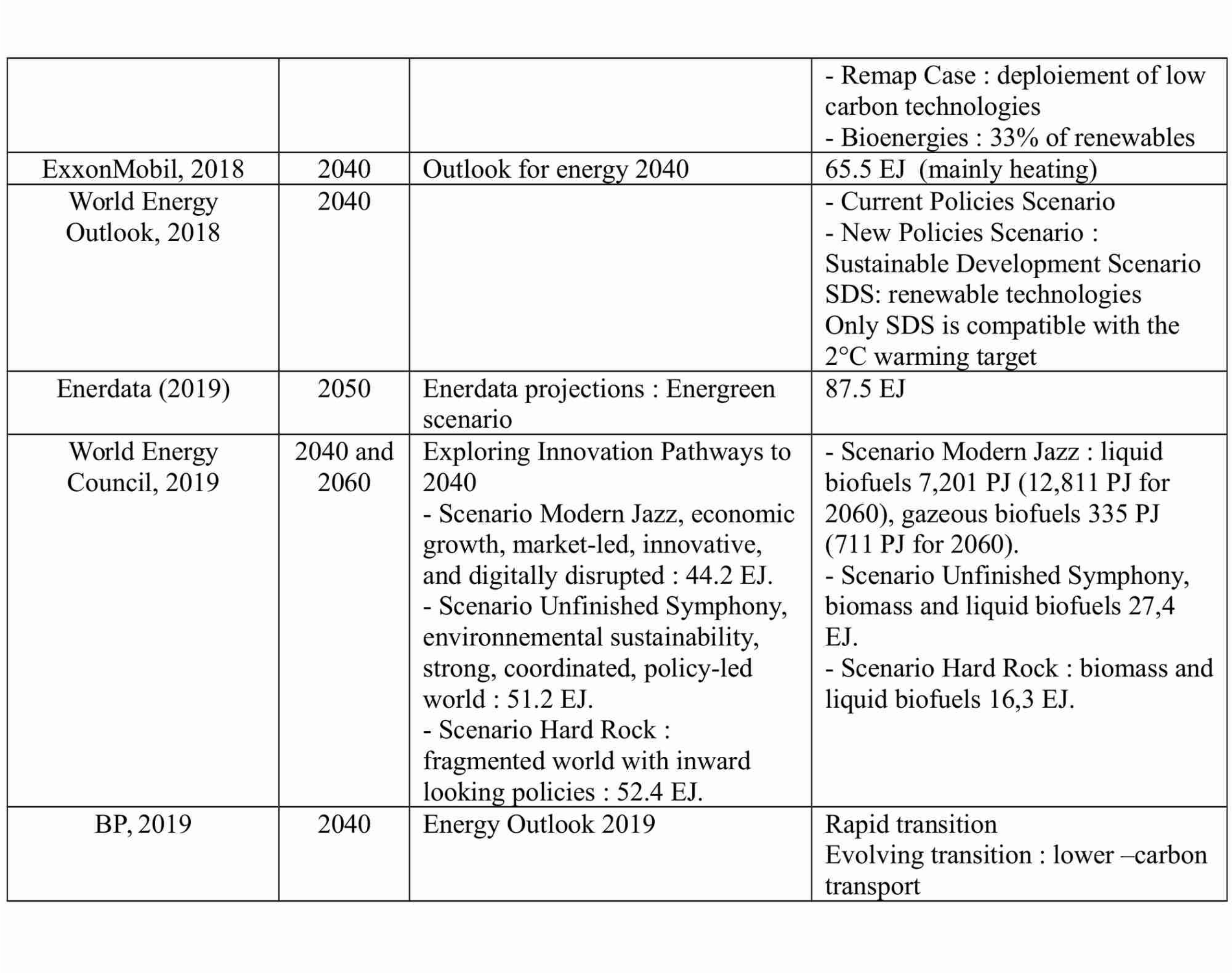
Growth of bioenergies, at all scales is present in all scenarios. Microalgae are appearing in 2040. Enough agricultural and forest lands are available to produce biofuels sustainably (see Ecofys and Solagro). The weakness of some exercises is the lack of explanation of the biomass ressources that will be mobilized.

A very interesting work has been published by IPCC (2019) where three Shared Socioeconomic Pathways (SSP) scenarii (Table 10) are considered to obtain the net emission reductions necessary to limit global warming in 2050 and 2100. It clearly points out that there is just limited land for food, feed and limited water while population is growing. SSP1 is focused on sustainability including human development, technological development, nature conservation, globalised economy, economic convergence and early international cooperation including moderate levels of trade. The scenario assumes a low population growth, relatively high agricultural yields and a move towards less-meat intensive diets. Dietary change and reductions in food waste reduce agricultural demands and well-managed land systems enable reforestation and/or afforestation. SSP2 is a scenario in which societal as well as technological development follows historical patterns (middle of the road). Land-based Carbon Dioxyde Removal is achieved through bioenergy and (Bio-Energy with Carbon Capture and Storage). (BECCS), and to a lesser degree by afforestation and reforestation. SSP3 is a scenario with limited technological progress and land-use regulation.

Table 9. World foresigths (energy on year basis; 100 Mtep = 4,2 EJ) (to be continued on next page).

Author and year	**Time frame**	**Title**	**Bioenergies**
Fischer and Schrattenholzer, 2001	2050		Potential : 370 - 450 EJ/year
Smeets *et al.*, 2007	2050	A bottom-up assessment and review of global bio-energy potentials to 2050.	Potential : 215 - 1272 EJ, depending upon technologies involved
Beringer *et al.* , 2011			Potential of 130 to 270 EJ/year, including 20 to 60 % from energy crops
WWF-ECOFYS, 2011	2050	100% Renewable Energy Future	
Turner, 2013	2030	Bloomberg, Energy Finance Global renewable energy market outlook	Bioenergies : 4,7 à 6,4 EJ
Creuzig *et al.,* 2014			100 to 300 EJ/year in a sustainable scenario
International Renewable Energy Agency, IRENA, 2014	2030	Global Bioenergy REmap 2030	In 2030 : agricultural residues and waste (37-66 EJ), energy crops (33-39 EJ) and forest products, (24-43 EJ). Increse of land for crop production from 1.5 bln ha (2010) to 2.7 bln ha (2030)
Reilly *et al*.,, 2015	2050	Energy and climate Outlook. Perspectives from 2015	Renewables Land use for biofuels 2010 : 38.6 Mha to 41.2 Mha in 2050
Greenpeace et al., 2015	2050	Energy (r)evolution 100% renewables -Reference scenario (REF) (~ Current Policies Scenarios IEA) - Energy [r]evolution scenario (e[r]) - Advanced energy [r]evolution scenario (adv e[r])	- Reference scenario (REF) : 86.7 EJ - Energy [r]evolution scenario (e[r]) : 76.3 EJ - Advanced energy [r]evolution scenario (adv e[r]) : 77.5 EJ Mainly for cogeneration in the 3 scenarios
World Energy Council, 2016	2060		- Scénario Jazz, economic growth. - Scenario Symphony, environnemental sustainability ; - Scenario Hard rock : no governance
International Renewable Energy Agency, 2016	2050	Energy technology prospective	
IEA, 2016	2040	Energy technology perspectives :towards sustainable urban energy systems	Primary Demand - Current Policy : 76.8 EJ - New policies scenario : 78.8 EJ - 450 scenario (2°C) : 96.8 EJ
OECD-FAO, 2018	2027	Agricultural Outlook 2018-2027	-
IRENA, 2018	2050	Global energy transformation : a roadmap to 2050	Two scenarios : - Ref Case : planned and current policies

Table 9. (continuation of previous page)



			- Remap Case : deploiement of low carbon technologies - Bioenergies : 33% of renewables
ExxonMobil, 2018	2040	Outlook for energy 2040	65.5 EJ (mainly heating)
World Energy Outlook, 2018	2040		- Current Policies Scenario - New Policies Scenario : Sustainable Development Scenario SDS: renewable technologies Only SDS is compatible with the 2°C warming target
Enerdata (2019)	2050	Enerdata projections : Energreen scenario	87.5 EJ
World Energy Council, 2019	2040 and 2060	Exploring Innovation Pathways to 2040 - Scenario Modern Jazz, economic growth, market-led, innovative, and digitally disrupted : 44.2 EJ. - Scenario Unfinished Symphony, environnemental sustainability, strong, coordinated, policy-led world : 51.2 EJ. - Scenario Hard Rock : fragmented world with inward looking policies : 52.4 EJ.	- Scenario Modern Jazz : liquid biofuels 7,201 PJ (12,811 PJ for 2060), gazeous biofuels 335 PJ (711 PJ for 2060). - Scenario Unfinished Symphony, biomass and liquid biofuels 27,4 EJ. - Scenario Hard Rock : biomass and liquid biofuels 16,3 EJ.
BP, 2019	2040	Energy Outlook 2019	Rapid transition Evolving transition : lower –carbon transport

Agricultural demands are high due to resource-intensive consumption and a regionalised world leads to reduced flows for agricultural goods. In SSP3, forest mitigation activities and abatement of agricultural GHG emissions are limited due to major implementation barriers such as low institutional capacities in developing countries and delayed as a consequence of low international cooperation. Emissions reductions are achieved primarily through the energy sector, including the use of bioenergy and BECCS. IPCC(2019) highlights the need for bioenergy and BECCS as part of an overall strategy to limit global warming to 1.5 °C or well below 2 °C.

Commercial biomass conversions present cost reduction: 30-50 % with high technology improvements in SSP1, 20-40 % with medium assuptions in SSP2 and 10-30 % with low technology improvements and SSP3.

The current trajectories of the different countries are insufficient. All pathways use CO_2 capture (CDS Carbon capture and storage) with contributions from bioenergy at the expense of fossil fuels, carbon capture and sequestration (BECCS) and uptake by soils (agriculture, forestry, AFOLU) and deep geological layers. The BECCS solution negative emissions. But this technology has not been experimented on a large scale, which can lead to competition over land use, with negative effects on agricultural production. Its potential for sequestration in soils is controversial (Harper *et*

Table 10. Breakdown of contributions to global net CO_2 emissions in three illustrative Shared Socioeconomic Pathways (IPCC, 2018) : SSP 1 low challenges to mitigation and adaptation, SSP2 medium challenges to mitigation and high challenges and SSP3 high challenges to mitigation and high challenges to adaptation (AFOLU Agriculture, forestry and other Land Use).

Scenario	**Target**	**SSP1**	**SSP1**	**SSP2**	**SSP2**	**SSP3**
Radiative forcing		1.9 W.m^{-2} mean (min, max)	4.5 W.m^{-2} mean (min, max)	1.9 W.m^{-2} mean (min, max)	4.5 W.m^{-2} mean (min, max)	4.5 W.m^{-2} mean (min, max)
Change in forest cover (Mkm^2)	2050	3.4 (9.4, –0.1)	0.6 (4.2, –0.7)	3.4 (7.0, –0.9)	0.9 (2.9, –2.5)	2.4 (1.0, -4.0)
-	2100	7.5 (15.8, 0.4)	3.9 (8.8, 0.2)	6.4 (9.5, -0.8)	-0.5 (5.9 ; -3.1)	-3.1 (-0.3, 5.5)
Change in cropland (Mkm^2)	2050	- 1.2 (0.3, –4.6)	0.1 (1.5, -3.2)	- 1.2 (0.3, -2.0)	1.2 (2.7, -0.9)	2.3 (3.0, -1.2)
-	2100	5.2 (-1.8, -7.6)	-2.3 (-1.6, -6.4)	-2.9 (0.1, -4.0)	0.7 (3.1, -2.6)	3.4 (4.5, 1.9)
Change in energy cropland (Mkm^2)	2050	2.1 (5.0, 0.9)	0.8 (1.3, 0.5)	4.5 (7.0, 2.1)	1.5 (2.1, 0.1)	1.3 (2.0, 1.3)
-	2100	4.3 (7.2, 1.5)	1.9 (3.7, 1.4)	6.6 (11.0, 3.6)	4.1 (6.3, 0.4)	4.6 (7.1, 1.5)
Food price (index 2010=1)	2050	1.2 (1.8, 0.8)	0. 9 (1.1, 0.7)	1.6 (2.0, -1.4)	1.1 (1.2, 1.0)	1.2 (1.7, 1.1)
-	2100	1.9 (7.0), 0.4)	0.8 (1.2, 0.4)	6.5 (13.1, 1.8)	1.1 (2.5, 0.9)	1.7 (3.4, 1.3)
Increase in warming above pre-industrial (°C)	2050	1.5 (1.7, 1.5)	1.9 (2.1, 1.8)	1.6 (1.7, 1.5)	2.0 (2.0 , 1.9)	2.0 (2.1, 2.0
-	2100	1.3 (1.3, 1.3)	2.6 (2.7, 2.4)	1.3 (1.3, 1.3)	2.6 (2.7, 2.4)	2.6 (2.6, 2.6)
Cumulative Energy CO_2 emissions until 2100 (Gt CO_2)	2100	482.2 (1009.9, 307.6)	2787.6 (3213.3, 2594.0)	380.8 (552.8, -9.4)	2642.3 (2928.3, 2515.8)	2994.5 (2447.4, 2084.6)
Cumulative AFOLU CO_2 emissions until 2100 (Gt CO_2)	2100	-127.3 (5.9, -683.0)	-54.9 (52.1, -545.2)	-126.8 (153.0, -400.7)	40.8 (277.0, -372.9)	188.8 (426.6, 77.9)

Table 11. Foresigths for France (annual basis) (to be continued on next page).

Source , year of publication	**Time frame**	**Energy frame**	**Bioenergies**	**Biofuels**
ANCRE , 2014	2050	Scenarios for the energy transition	3 scenarios: - SOB reinforced sobriety: 226 PJ - ELE decarbonization by electricity : 341 PJ - DIV diversified vectors: 703 PJ	12.6 (SOB) to 60.1 PJ (DIV with 51,000 km^2)
ADEME , 2013 and 2017	2030-2050	Visions 2030-2050 Visions 2035-2050 GES reduction 70-72%	Primary demand : 1,214 PJ with 699 PJ from forest, 239 PJ from agriculture Final demand : 925 PJ with 264 PJ from methanisation, 63 PJ from gazeification and 615 PJ from heating 5,15 EJ 2 scénarios : 6,3 EJ and 3,4 EJ	Biofuels 126 PJ (only 2G) Share of methane used in transport is not given Energy wood 16,670 PJ; biogas 242 PJ ; biofuel, 3,330 PJ ; wastes 58 PJ ; Energy wood 0.7 EJ ; biogas 0.4 EJ ; biofuel 0.23 EJ ; wastes 54 PJ
SOLAGRO, 2014	2050	Afterres Crop with energy co-production : 1.3 Mha Forests : 45-50 Mm^3	In 2050: 1.5 EJ including 856 PJ from forest, 612 PJ from biogas	46 PJ from 1G and 57.6 PJ 16 from 2G
Capros *et al.*, 2016	2050	EU reference scenario 2016. Energy, transport and ghg emissions trends to 2050	Bioenergies 845 PJ	Biofuels 144 PJ
ADEME , 2016b	2050	Mix électrique 100 % renouvelable à 2050 ?	1/3 of the remaining demand for fossil fuels from industry (544 PJ) and transport (586 PJ) in 2050 is met by biofuels or biogas (293 PJ).	293 PJ from biofuels and biogas for industries and transport
■ NegaWatt, 2017	2050	- Négawatt and 100% ENR en 2050 et Afterres. - Baisse consommation 50 % - Food diet	3 main pillars: sobriety and energy efficiency on the demand side and, on the supply side, massive use of renewable energies. Implicit output nuclear energy and reducing the share of fossil fuels.	Liquid biofuels 0.5 EJ

Table 11 (continuation of the previous page).

		change - No nuclear, no fossil Release of 5-8 Mha from food to energy 1	- 1.50 EJ from biomass : 0.90 EJ from solid biomass, 0.12 EJ of biofuels, 0.48 EJ biogas, 19.8 PJ wastes	
Acket *et al.*, 2017	2050	Negatep Divide by 4 CO_2 emissions due to energy Maintenance of nuclear. Reducing consumptions by 20 %	Ranging from 1256 to 1465 PJ	470 PJ from biomass. A share of electricity is needed. F
ADEME , 2018	2050	Gas mix 100%■ renewable in 2050?	Primary demand : 1,440 PJ , including 828 PJ from wood and by-products, 468 PJ PCS from agriculture , 54 PJ PCS from wastes and 50 PJ PCS from algae	No information 381 PJ PCS for transport
EPE Entreprises pour l'Environnement , 2019	2050	ZEN Exploring a carbon neutral France ZEN (zero emission) - forests also active as carbon sinks: 100 Mt eq CO_2/year	- 1210 PJ (673 PJ from wood, 50 PJ from MSCC and 31 PJ from wastes,	- No information - Replacement of thermal vehicles by zero-emission vehicles (GNV, electricty plug-in hybrid electric vehicle (PHEV))
ADEME et al., 2019	2030	Evaluation of the impacts of 3 biofuels development scenarios for LTECV	No information	no palm oil imports 3 scenarios, established at 213 PJ /year, to meet the objective of 15% renewable energy in transport by 2030,.They differ in the development of advanced fuels: 3 % in: scenario 1 : RED II trend, 7 % in scenario 2 Maxi G2, 1 % in scenario 3: no G2 and other fuels 5 % scenario 1, 7 % scenario 2 and 7 % scenario 3.

al., 2018, Lugato *et al*., 2018, Schipper and Smith, 2018).

The originality of this IPCC (2019) report is to look at systems rather than targeted technology streams or innovations. The key points are:

- the limitation of energy demand, while developing carbon sequestration solutions by forest sinks in a limited scale,
- the drastic reduction of fossil fuels, in particular for the production of electricity,
- a transport revolution with the efficiency of vehicles, the change of fuel; with the electrification of the park, the use of biofuels, according to the specificities of the countries. By 2020, low-emission fuels account for only about 5 % of all fuels. However, the scenarii propose to increase from 35 % to 65 % the share of low-emission fuels by 2050,
- the structural and organizational changes in the evolution of urban infrastructure food systems, land use,
- the absence of a generic solution, each country having to react in a specific way in its context, depending on the constraints. The question of equity is at the heart of national and international policies according to the social realities of each country. For France, whatever the scenario (table 11), the major problem is the current lack of integration between the different activities, whether it is the shift or the integration of crop production and initial transformation.

It would be necessary to go from a sector approach to a (Figure 2) systemic approach capable of formulating the different uses of the biomass in terms of human needs. The bioeconomy concept offers this possibility of integrated strategies (Directorate-General for Research and Innovation, 2019). Only the Solagro's foresight study is based on this integrated vision (Table 11).

This could offer the opportunity to develop the cascading use. This is a strategy to use raw materials such as wood, or other biomass, in chronologically sequential steps as long, often and efficiently as possible for materials and only to recover energy from them at the end of the product life cycle. Increased cascading use of wood will contribute to more resource efficiency and consequently reduce pressure on the environment.

Value chain

In a market oriented approach, the classical approach is to combine the design of the supply chain with the most appropriate feedstocks for a specific conversion route and the choice of best technology options (equipments, chemicals, enzymes, etc.), with biofuels to the energy sector.

A wide range of feedstocks can be used to produce advanced biofuels. The crucial factor for the economics of using biomass for energy is the cost of the feedstock, which today ranges from a negative for waste wood (based on credit for waste disposal costs avoided) through inexpensive residual materials to the more expensive energy crops. Taking into consideration the current costs of wood and agriculture residue, the feedstock cost share is 40 % - 70 % of total production costs. Establishing practical, efficient feedstock supply chains at scale, therefore, is crucial for the success of advanced biofuels.

However the low energy content (15-20 MJ/kg.ms) comparatively to fossil fuel (35-40 MJ/kg.ms) gives a direct emission highly dependent on the transport distance of initial biomass. For SRC Poplar fertilized (JRC 2014), the typical GHG emissions (g CO_2 eq/MJ) increase from 8 g CO_2 eq/MJ for a transport distance 1-500 km, then 10 g CO_2 eq/MJ for 500-2,500 km, then 15 g g CO_2 eq/MJ for 2,500-10,000 km and finally 24 g CO_2 eq/MJ above10,000 km.

Biofuels have led to the large development of biorefineries. This concept is analogous to today's petroleum refinery, which produces multiple fuels and products from petroleum. Comparatively to chemicals, biofuels need to be produced with the same quality all over the world as motors are designed for world markets. The consequence is that biofuels factories must guarantee specifications. Economy of scales is another feature based upon the large volume of biofuel market.

In this approach, the location of the biorefinerie is crucial. It leads to the potential development of a hundred cellulosic bioethanol plants, each with a capacity of 200 million L, in agreement with the expected EU28 volume of biofuels.

In order to overcome the collecting cost, another consequence for 2G biofuel is the need to increase the flexibility of biorefineries in order to transform broad range of feestocks. Nordic forests in EU28 present a small number of species whereas in middle and southern Europe, more species are present. For cellulosic ethanol, an industrial unit producing 40 to 160 kt ethanol / year will need 160 to 640 kt of biomass /year. As biomass availability is limited, a decrease of transport cost and related CO_2 emission looks a good compromise with a radius from 50 to 200 km. For thermochemical routes an order of magnitude is about 500 - 1000 kt/year biomass (dry basis) or about 100 - 200 kt/year biofuel production This gives finally the optimal system size and location.

Different bottlenecks are still requiring research: - the identification of market opportunities for farmers,the identification of suitable and available biomass feedstock available for biofuels production from forests. With annual crops, collection by cooperatives simplifies contracts between biomasse producers and biorefineries.

- the logistics chain to biomass pre-treatment to reduce the specific logistics costs by pretreatment at the field.,

The complexity of sustainable mobilisation of forest biomass is a matter of research since long time (EIP-AGRI Focus Group, 2018). Public incentives has not led to efficient regional forest ownership organisations. The development of user-friendly information system is lagging behind other industrial sectors. The weight of administrative structures and the local differences regarding incentives prevent the development of cross-regional value-chains and production systems.

Sustainability

The food versus fuel conflict has generated a lot of work. The determination of the influence of development of biofuels market on food prices relies on economic models. The choice of model type (partial equilibrium or general equilibrium) and data influences the results: estimates of price increases can range from a few percentage points to a few dozen percentage points. Furthermore, the different types of agrofuels have different impacts on food prices. The development of methods, including typologies, to assess the national potential for agrofuel production taking into account available land and water, population density, food and energy needs, agricultural production, per capita income is needed globally (High-Level Expert Group, 2013).

The pilar of environmental sustainability has now shown that main feedstocks realize significant reductions of GHG for conventionnal and advanced biofuels. More research is needed for algae biofuels. In the perspective of "carbon neutrality", mobilization of agricultural biomass and forestry must also be balance with carbon storage in the grounds. The net carbon footprint of the scenarios agriculture and forestry will have to be estimated in order to to consider the consequences of the choices of silvicultural, agricultural practices, harvesting biomass and return to soil (by degradation, burial, spreading, etc.).

The search for alternative fuels to reduce emission of pollutants into the atmosphere has stimulated few scientific studies. A majority have found positive effects for biofuels (Moore *et al.*, 2017) despite some discrepeancies.

The pilar economy is still a matter of research. Depending on the level considered in the value chain, different choices may be preferable depending on the added value criteria/ha or the added value/mass of matter treated or the reduction of greenhouse gasses emitted/J or the cost €/J. The difficulty is that biofuel quality results from a tradeoff between variables such as cost, efficiency, carbon storage, availability in order to ensure a stable supply all year round.

So multiple-criteria decision analysis should be more present to solve these conflicting criteria. Information and Communications Technologies (ICT) have become an important tool in promoting agricultural value chain efficiency. Further along the chain, technologies offer considerable possibilities to enhance traceability, which is particularly relevant as certification grows in importance.

This difference fossile vs biobased has to be relativised when offset against the abatment costs. However these comparaisons have to carried out on products at the same level ot technological readiness.

Beyond the technico-economic feasibility (cost : raw material, transport, availability of infrastructures), non-market factors are sometimes critical: conformity with the system of values (the conservation of forest environments without harvesting) and the ability to secure the exchange. In the case of private forests in France, the main obstacle is consent in terms of conditions of price and quantities and workload. When a supply plan is drawn up, particularly for projects > 1 MW, corresponding to the consumption of 1,250 t wood/year, this factor is recognized as a major obstacle in France, in constrast with other European countries.

General Conclusions

One of the biggest challenges for fuels is a dual one: the need to meet rising energy demand while at the same time reducing carbon emissions. The use of biofuels is limited by the availability of sustainable grown biomass.

The complete analysis of biofuels throughout this publication demonstrates that biofuels should be part of a transition strategy toward a sustainable energy system as long as they respect sustainability criteria as any energy sources. Reduced consumption and improved energy efficiency are also leading to changes in transport impacts.

Biofuels complete the technological offer for planes (kerosene) and road transportation on long-distance journeys which, by definition, require more autonomy and the shortest filling times possible. The big strength of biofuels is that they are ready to allow a GHG reduction in transportation without major infrastructure investments.

As regional priorities and resources differ, there is no one-size-fits-all solution to this nexus, as.flexibility and adaptability vary across contexts and scales .

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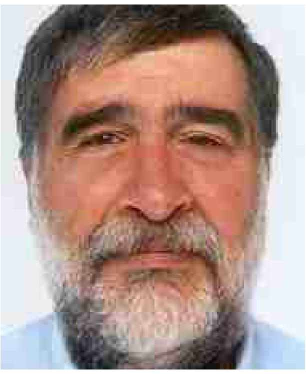

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