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Dossier

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PART 2

Second and Third Generation Biofuels: Towards Sustainability and Competitiveness

Deuxième et troisième génération de biocarburants : développement durable et compétitivité

Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, Vol. 68 (2013), No. 5, pp. 789-946

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Dossier

Second and Third Generation Biofuels: Towards Sustainability and Competitiveness
Seconde et troisième génération de biocarburants : développement durable et compétitivité

Insight on Biomass Supply and Feedstock Definition for Fischer-Tropsch Based BTL Processes

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Résumé — **Aperçu sur l'approvisionnement en biomasse et la caractérisation des charges pour les procédés de synthèse de biocarburants par voie BTL** — Les procédés de conversion de la biomasse lignocellulosique par gazéification et synthèse Fischer-Tropsch (communément appelés BTL) représentent des alternatives prometteuses pour la production de biocarburants. La biomasse étant hétérogène en termes de qualité et de répartition au sein des territoires, l'un des enjeux technologiques majeurs réside dans le développement de chaînes de procédés flexibles, capables de traiter la plus large diversité de biomasses.

La présente publication s'attache à examiner la diversité des biomasses mondiales en termes de potentiels et disponibilité, composition et coûts économiques en liaison avec les spécifications des procédés de conversion thermochimiques. Cinquante biomasses, classées en quatre catégories (coproduits agricoles, cultures énergétiques, taillis à courte rotation et biomasses forestières) ont été considérées dans cette revue pour leur utilisation en bioénergies.

L'étude de la disponibilité et des potentiels en biomasse a été réalisée à l'aide d'une revue bibliographique (rapports de projets, par exemple le projet RENEW ou le projet *Biomass Energy Europe*, ainsi que des articles de recherche). La majorité des données collectées représente des potentiels techniques, c'est-à-dire qu'elles prennent en compte les limites géographiques et les conditions physiques (climat et sol) des surfaces agricoles et forestières, les progrès technologiques, la concurrence pour la terre et les autres usages de la biomasse, ainsi que les contraintes environnementales et écologiques. Les résultats montrent l'émergence de plusieurs marchés. L'Amérique du nord et du sud disposent de potentiels biomasse très élevés du fait de quantités considérables de coproduits agricoles, de résidus forestiers et de surfaces disponibles où pourraient être cultivées des cultures énergétiques et des taillis à courte rotation. L'Afrique présente des surfaces importantes pouvant être dédiées aux cultures énergétiques ou aux taillis à courte rotation. La Russie possède de grandes quantités de coproduits agricoles et forestiers disponibles pour de nouveaux usages énergétiques. L'Asie dispose quant à elle de grandes quantités de coproduits agricoles, de même que de surfaces pouvant accueillir des cultures dédiées. Dans une moindre mesure, l'Europe possède d'importants potentiels de biomasse en coproduits agricoles et forestiers, nécessitant néanmoins une structuration des filières.

La composition minérale des biomasses est également une caractéristique importante pour la chaîne de procédés BTL, le catalyseur Fischer-Tropsch – avant dernière étape du procédé de conversion – étant très sensible à la plupart des éléments minéraux présents dans la biomasse. Cinq bases de données publiques ont été examinées. Les données de contenus en cendres, azote, chlore, phosphore, soufre ainsi que de pouvoirs calorifiques ont été collectées. En analysant ces informations, nous observons que les plantes à cycles courts (typiquement les cultures agricoles) ont des contenus minéraux bien plus élevés que celles à cycles longs (les essences forestières par exemple). Ceci est principalement dû aux fertilisants minéraux épandus sur les parcelles agricoles, permettant une augmentation de la productivité. En conséquence, les coproduits agricoles apparaissent comme les biomasses les plus contraignantes en termes de contenus minéraux.

L'étude du coût des biomasses a également été menée au moyen d'une étude bibliographique et a porté plus spécifiquement sur le cas français. La plupart des données disponibles proviennent du programme REGIX ou d'organismes français (FCBA, Association AILE, etc.). Les biomasses les moins onéreuses (coût estimé sortie champ) sont les coproduits agricoles (10 à 15 €/MWh, correspondant à 50 à 75 €/t de matière sèche), du fait qu'ils sont encore souvent considérés comme des sous-produits du grain. Leur coût est principalement conditionné par les opérations qui leur sont entièrement dédiées : typiquement le pressage, le conditionnement et le transport. Les taillis à (très) courte rotation ont un prix de revient légèrement plus élevé (13 à 17 €/MWh, correspondant à 70 à 90 €/t de matière sèche) car des matériels spécifiques sont nécessaires pour l'implantation et la récolte. Néanmoins, ce prix reste plus faible que celui des cultures énergétiques (20 à 22 €/MWh, correspondant à 95 à 110 €/t de matière sèche) dont les pratiques culturales et notamment le recours aux produits phytosanitaires et fertilisants augmentent le coût. Enfin, le coût des biomasses forestières est lui très variable (de 11 à 25 €/MWh, correspondant à 60 à 130 €/t de matière sèche), en fonction de la valeur initiale attribuée à la matière bois, aux techniques et technologies utilisées à la récolte, de la facilité d'accès aux parcelles forestières et de l'usage ou non de plateforme de stockage (type de séchage et broyage).

Abstract* — *Insight on Biomass Supply and Feedstock Definition for Fischer-Tropsch Based BTL Processes — *Process chains of thermo chemical conversion of lignocellulosic biomass through gasification and Fischer-Tropsch synthesis (known as BTL) represent promising alternatives for biofuels production. Since biomass is heterogeneous and not homogeneously spread over territories, one of the major technological stakes of the project is to develop a flexible industrial chain capable of co-treating the widest possible range of biomass and fossil fuel feedstock.*

The present study aims at characterizing biomass diversity (availability and potentials by area, cost and mineral composition) by carrying out a state of the art, as a preliminary step in order to define a series of biomasses to be tested in the demonstration plant and therefore define specifications for the process. Fifty different biomasses were considered for their bioenergy application potential and were finally classified into four categories: agricultural by-products, dedicated energy crops, (Very) Short Rotation Coppice ((V)SRC) and forestry biomasses.

*Biomass availability and potentials were investigated by the mean of a literature review of past and current projects (*e.g. *RENEW project, Biomass Energy Europe Project, etc.) and scientific articles. Most collected data are technical potentials, meaning that they take into account biophysical limits of crops and forests, technological possibilities, competition with other land uses and ecological constraints (*e.g. *natural reserves). Results show various emerging markets: North and South America have considerable amounts of agricultural by-products, forest residues, and large land areas which could be dedicated to energy crops; Africa shows relevant possibilities to grow Short Rotation Forestry (SRF) and energy crops; Russia has large available quantities of agricultural by-products and forest residues, as well as little valuable land where energy crops and SRC could be grown, and Asia shows relevant amounts of forest residues and possibilities of growing SRC, as well as relevant quantities of agricultural residues (notably from palm oil cropping systems). To a lesser extent, Europe also presents significant amounts of agricultural co-products and forestry residues which could be available for bio-energy.*

Nevertheless an improvement of biomass supply structure is necessary to be in the position to answer the demand for BtL (Biomass to Liquid) industry.

Mineral composition is also a relevant parameter to be considered for the thermochemical conversion process, since the Fischer-Tropsch catalysis – last step of the conversion process – is very sensitive to mineral elements of biomass. Concerning mineral composition of biomasses, five public databases were analysed to collect relevant characteristics and the information was aggregated in one large database dedicated to the project. Nitrogen, chlorine, phosphorus, sulphur, ash and energy contents are the major parameters collected. By analysing these data, we observe that fast-growing plants (typically agricultural co-products) contain much more minerals than low-growing crops (typically forest residues). This is mostly due to the fertilizers spread in the fields for the growth of agricultural crops. Consequently, agricultural by-products appear as the most constraining biomasses in terms of mineral contents.

*Regarding costs, a literature review was also carried out, with a special focus on the French case. Most data come from REGIX Programme and French organisms (FCBA, Association AILE, etc.). This allowed us to observe that agricultural by-products are the cheapest biomasses (10 to 15 €/MWh, equivalent to 50 to 75 €/TDM), as they are still considered as sub-products of grains. Their price is only driven by conditioning and transport costs. (Very) short rotation forestry biomasses are slightly more expensive (13 to 17 €/MWh, equivalent to 70 to 90 €/TDM), due to harvest costs, but they remain cheaper than energy crops (20 to 22 €/MWh, equivalent to 95 to 110 €/*TDM), *whose crop management practices (basically phytosanitary treatments and fertilization) increase costs. Finally, forestry wood chips show very variable prices (11 to 25 €/MWh, equivalent to 60 to 130 €/TDM), depending on the costs attributed to wood material, technology used, access to the plots, and the use of storage platform or not.*

SYMBOL LIST

(V)SRC	(Very) Short Rotation Coppice
BtL	Biomass to Liquid
EC	European Commission
SRF	Short Rotation Forestry
FT	Fischer-Tropsch
GCV	Gross Calorific Value
HHV	Higher Heating Value
LHV	Lower Heating Value
TDM	Ton of Dry Matter
ppm	Part Per Million

INTRODUCTION

BTL processes are attractive alternatives for future energy production. These processes aim at converting lignocellulosic biomass into synthetic biofuels. A gasification step converts the feed into a synthesis gas which undergoes the Fischer-Tropsch reaction.

For reasons relating to economics, 2nd generation BTL biofuels require large units and therefore relevant quantities of biomass.

One of the main characteristics of Fischer-Tropsch based BTL chains is its potential ability and flexibility to process and transform a wide diversity of biomass. The main consequence is to enable its operability in most places of the world with very different biomass supplies and also, for a dedicated area, to get the opportunity to use all types of feedstock available.

Resources can be crop residues, but also dedicated crops (energy or forestry crops), as well as forest and wood industry residues. However, biomass is a limited resource, heterogeneous in terms of nature and quality and also not homogeneously spread over territories.

The present review aims at identifying biomass opportunities in relation with process specifications and constraints in order to ensure that the widest possible range of biomass can be economically processed in BTL plants. It is worth noting that biomass characteristics can affect the whole process chain in different ways. Considering biomass pretreatment such as torrefaction for example, this process will mostly be sensitive to the physical properties of the biomasses, their initial moisture, physical aspect (straw, chip, etc.), handling conditions, etc. Considering the gasification and the Fischer-Tropsch synthesis steps elemental mineral composition (in particular sulphur, phosphorus, nitrogen, chlorine) and the overall ash content of biomasses are of concern.

More precisely, the objectives of the review are to assess worldwide biomass available for new energy usages in 2020 considering current biomass offer and new possibilities of development, to carry out an assessment of biomass cost and highlight its mineral diversity in relation with process specifications.

1 GENERAL METHODOLOGY

A literature review has been carried out on the basis of public data acquired within public projects [1] and scientific publications. This first task consisted in performing a state of the art regarding worldwide biomass characteristics in order to illustrate its diversity. All the data were aggregated in a database. The results of this work also enable to define the input specifications for a BTL process.

2 CONSIDERING WORLDWIDE BIOMASS DIVERSITY

The BioTfueL project considers a Biomass-to-Liquid thermo chemical conversion of lignocellulosic biomass. In this project, torrefaction is the first step of the biomass conversion, before gasification and Fisher-Tropsch synthesis. Some of the aims of torrefaction are to facilitate biomass grinding and homogenise heterogeneous biomass. Therefore, the following paragraphs give details about heterogeneity of worldwide biomass. A synthesis of biomass family type characteristics is given in Table 4 at the end of this section.

2.1 Biomass Physical Properties (Form and Moisture)

Physical properties of feedstock widely vary worldwide according to the type and the nature of biomass.

2.1.1 Moisture

Table 1 gives moisture in harvesting conditions of some of the investigated biomasses.

Moisture at harvesting conditions is quite variable: from 6-15 wt% for cereal straws to 65 wt% for forestry biomass and 75 wt% for oil crop by-products. This shows that some biomasses should require drying or pre-treatments before torrefaction.

2.1.2 Physical Aspect after Harvesting

The biomass physical aspect after harvesting is also very variable:

- cereal straws can be directly harvested in round or square bales, as their moisture is relatively low. This operation increases the low mass density of non-baled straw (80 kg/m^3) up to 200 kg/m^3;
- oilseed crop by-products, as well as hemp and flax straw can also be harvested in bales. However, their higher moisture content opens the door to the opportunity of a drying step in swathes on the field;
- energy crops can be directly harvested in square bales, in dry conditions occurring in winter;
- forestry products (VSRC/SRC, forestry residues) require drying before use, as their moisture is too high (25 to 50%). There are two possibilities: either woody biomasses are directly ground into wood chips on the

TABLE 1

Moisture in harvesting conditions of the investigated biomasses. Table are indicated in wt%

Agricultural by-products				Energy crops	(V)SRC	Forestry biomasses		Other representative biomasses
Cereal straws	Legume crops	Oil crop by-products	Others			Hardwoods	Softwoods	
Wheat straw 12-15	Alfalfa 60-75	Rapeseed straw 20-45	Hemp straw 14-18	Swithgrass 15-30	Poplar 50-55	Oak	Spruce	Rice straw 06
Barley straw 12-15		Sunflower straw 20-75	Flax straw 12	Miscanthus 18-25	Willow 50-58	Beech	Spruce bark	Rice husk
Triticale straw 12-15		Olive residues > 50		Fibre sorghum < 30	Eucalyptus 43-48	Beech bark	Pine	Bagasse 50
Maize cane 20-25				Bamboo 25-45	Black locust 45-55	Birch	Pine bark 25-65	Palm fiber husks 50-60
Sorghum straw 20-30						Birch bark 25-65		Palm kernels 10-12
								Coconut husks and shells < 10

roadside and then dried on storage platforms, or stems are dried on the roadside and then ground into wood chips for direct use;
- concerning the other sub-tropical biomasses, the common practice is a sun-dry step before transformation or use. Rice straw and bagasse can be conditioned in bales. In Asia, some companies use pressing methods adapted from other industries (tire industry) to reach densities of rice straw bales of about 600 kg/m^3. Palm fibre husks and kernels and coconut husks and shells are generally ground in small chips after sun-drying.

2.2 Biomass Potentials and Availability

2.2.1 Methodology

Various sources were used to obtain biomass potentials data for most regions of the world. The different data sources used, according to each partner, are listed in references.

Five types of potential can be found in the literature: theoretical, technical, environmental (or ecological), economic and implementation potentials [2]. Most studies have been focusing on the theoretical, technical and environmental potentials. Economic and implementation potentials are usually assessed at local scale, as part of market studies.

The *Theoretical potential* represents the overall maximum amount of terrestrial biomass which can be considered as theoretically available for bioenergy production within fundamental biophysical limits.

The *Technical potential* is the fraction of the theoretical potential which is available under the considered techno-structural framework conditions and with the current technological possibilities, also taking into account spatial confinements due to competition with other land uses (food, feed and fibre production) as well as ecological (*e.g.* nature reserves) and other non-technical constraints.

The *Environmental potential* designates the fraction of the technical potential which satisfies ecological criteria related to biodiversity as well as to soil erosion and water resource depletion.

The *Economic potential* represents the share of the environmental potential which satisfies criteria of economic profitability within the given framework conditions (purchase price of biomass must be higher than the cost of biomass, harvest, conditioning and logistics, etc., in order to ensure an income to the different stakeholders of the value chain).

The *Implementation potential* is the fraction of the economic potential which can be implemented within a certain time frame and under real socio-political framework conditions, including institutional and social constraints and policy incentives.

Since all figures given in the literature do not always come with the indication of the type of biomass potential considered and given the high variability of worldwide biomass potentials, the first step of this work was, for each data considered, to assess the kind of potential definition it dealt with. A series of indicators have been defined in order to screen data sources and get more information about the parameters used to calculate biomass potentials. These indicators were the following:
- *techno-structural conditions and technological possibilities:* it refers to various technical factors, for example the conditions of accessibility of woody biomasses in the plots, as well as the available technologies in one location at a certain time;
- *renewable criterion:* it refers to scenarios of sustainable management of biomass resources (*e.g.* renewable forest management scenarios), consideration of protected areas, etc.. This criterion only refers to forest management and must be distinguished from the ecological criterion, which considers the potential benefits of forest on its environment;
- *competition with other biomass and land usages:* it refers to competitive uses of biomass, for other purposes than energy, *e.g.* other industries, soil requirements, cattle breeding, etc. and also to competitive uses of land, mostly regarding agriculture for food production and also wood for building, etc.;
- *ecological criteria (soil, water, biodiversity):* it refers to the consideration of biodiversity preservation, soil erosion risks, water resource depletion, etc.;
- *policy alternatives and levers (regulation, public policies, etc.) and impact on market demand:* it refers to the consideration of impacts of policies on biomass markets and biomass reserves evaluation, *e.g.* carbon credit prices, European Commission (EC) policies and incentives, etc.;
- *geographical scale:* this criterion refers to the geographical accuracy used in the models and assumptions in order to estimate biomass potentials. It corresponds to the level of details of the biomass potential estimation.

Table 2 gives an example of assessment of some of the data sources according to the previous criteria and gives details about the accuracy of these studies.

2.2.2 Results

Figure 1 presents a synthesis of the results from the critical analysis on worldwide technical biomass potentials based on the data found in literature [6-14].

TABLE 2
Methodology assessment of biomass potential data found in the literature

Literature reference	Type of potential			Qualitative assessment of the conservatism of the assumptions used				
	Theoretical	Technical	Environmental	Techno-structural conditions and technological possibilities	Renewable criterion	Competition with other biomass usages	Ecological criterion (soil, water, biodiversity)	Geographical scale
[2]		X		X	X	X		Regional
[3]		X		X				ND
[4]			X	X	X	X	X	National and regional
[5]		X		X	X	X		National

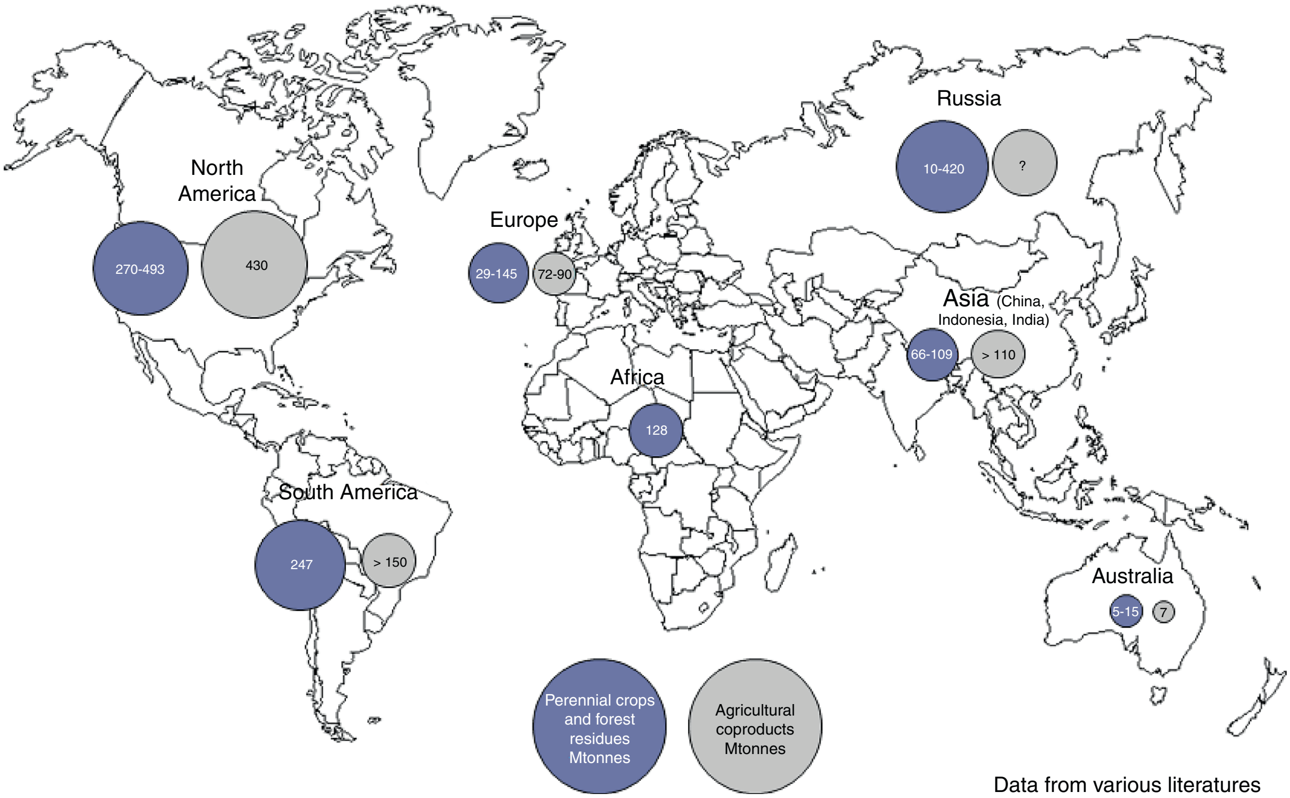

Figure 1

Synthesis of worldwide biomass potential [6-14].

2.2.3 Biomass Potential Outlook

Whatever the biomass types, various relevant markets are expected to emerge:
– in North America (especially the United States), important amounts of agricultural by-products will be available, as well as forest residues and energy crops. The USA is one of the biggest agricultural producers in the world. Agricultural by-products are indeed a relevant source of ligno-cellulosic biomass [12]. Maize is already used for bio-ethanol production but maize cane could offer a relevant potential for BtL market, as long as the straw removing frequency does not lower soil fertility. Regarding forestry

biomass, the USA and Canada are important producers [12]. Some of the forests are essentially managed for energy production, which enables to standardize production, improve wood productivity and reduce biomass costs. Production area and harbours are judiciously located, in order to facilitate exportation in the form of high density wood chips or pellets. Mass densification allows reducing transportation costs;

- in South America (especially Brazil and Argentina), huge opportunities are expected for SRF, agricultural by-products and energy crops. Large areas where agriculture is abandoned due to drought conditions or difficult access to water could be cultivated with SRF and energy crops, which require few inputs and water (*e.g*. Eucalyptus). Besides, Brazil and Argentina are large producers and exporters of agricultural products. Large amounts of by-products are left in the field or not used. For example, large amounts of bagasse are not used by sugar distillery or refinery and are burnt without any valorisation;
- in Africa, there are relevant opportunities to develop SRF and/or energy crops, especially in areas suffering from drought conditions or to diversify cropping systems. Agricultural by-products are mostly used for cattle breeding and other uses;
- in Russia, significant amounts of agricultural by-products will be available, all the more so Russia is one of the biggest cereal exporters. In addition, given the very large forest areas in Russia, forest exploitation could result in relevant quantities of forest residues available for energy. However, uncertainty about potentials for both agricultural by-products and forestry biomass is high;
- in Asia and Pacific, there are interesting opportunities for SRF and forest residues. Agricultural by-products also seem to be an abundant resource, but no data was found in the literature. For example, relevant amounts of rice straw and husks are left in the field and burnt and could represent an interesting opportunity for bioenergy. More specifically in Malaysia and Indonesia, oil palm production offers relevant opportunities for biomass usages. Trunks, branches and residues from palm oil production could represent annually up to a hundred millions tons available for bioenergy uses;
- to a lesser extent in Europe, there are various biomass production opportunities [15], depending on country background. The great tradition of agriculture in European countries would result in high quantities of agricultural by-products. Several million tonnes of straw could be available for bioenergy [8] and especially for BtL industry, even considering preservation of soil organic matter levels [4] and traditional usages of straw. Most European countries are also major loggers which could result in large amounts of forestry and sawmill by-products available for energy [5]. In addition, large areas of forests remain unexploited [16] due to the lack of organisation of forest industry, reducing gradually their productivity. Energy crops and (V)SRC could also be cultivated in little valuable agricultural land.

It is worth noting that if agricultural straws (wheat, maize) and wood chips already represent relevant potentials and are economically interesting, energy crops (Miscanthus, Switchgrass, etc.) and (Very) Short Rotation Coppice (Poplar, Willow, Eucalyptus) have relevant potentials when cultivated in regions where soil and climate conditions impede from cultivating feed crop.

2.3 Biomass Quality

2.3.1 Methodology

The main objective of the work was to create a database of chemical composition of worldwide biomasses. Several characteristics were considered: Higher and Lower Heating Value (HHV or LHV), ash content, content of four selected mineral elements (nitrogen, chlorine, sulphur and phosphorus) particularly harmful to the FT cobalt catalyst, content and composition of ashes (when available) and fusion temperatures (when available). Various public databases electronically accessible were used. These are indicated in references.

More than fifty biomasses have been investigated such as cereal straws, legume crops, oilseed crops by-products, energy crops, (V)SRC, forestry residues, bagasse, palm tree co-products, other exotic green wastes, etc.

Various publications and database have been studied [17-22].

2.3.2 Results

All data have been compiled in a single database, according to the nature of biomasses and their geographical coverage. It is worth noting that most data are related to Europe and America. Few data are available for Asia and none in Africa. Figure 2 and Table 3 show an extract of the results compiled in the database, concerning Gross Calorific Value (GCV), ash and mineral contents.

2.3.3 Gross Calorific Value

Woody biomasses have generally a higher Gross Calorific Value (GCV, equivalent to HHV) than agricultural

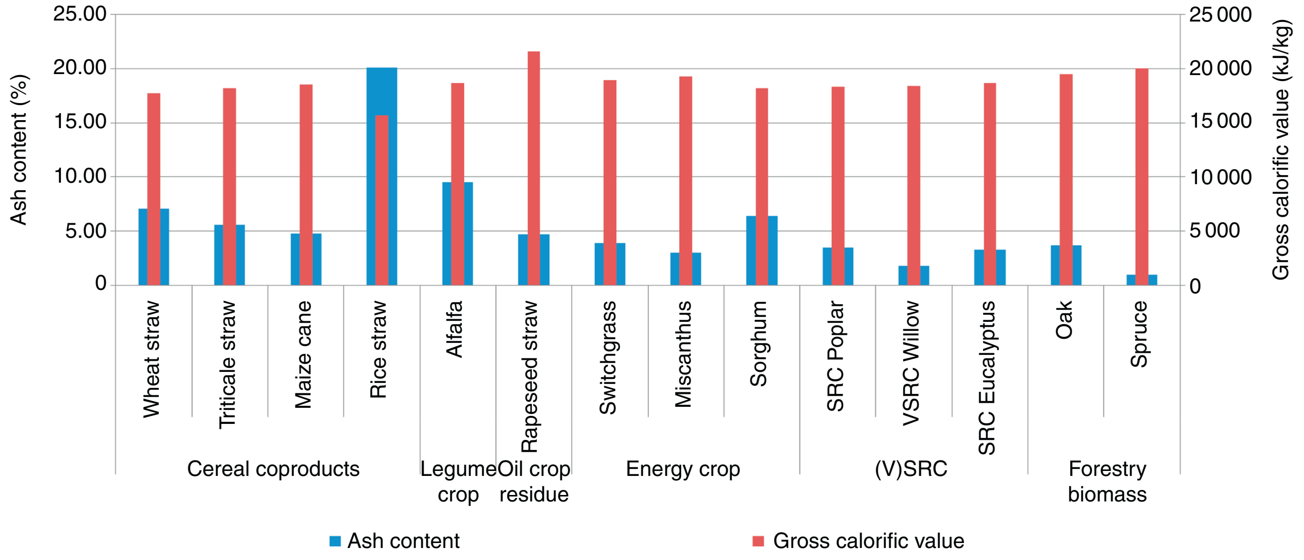

Figure 2

Variability of biomass Gross Calorific Value (GCV) and ash content.

TABLE 3

Range of nitrogen, chlorine, phosphorus and sulphur content in the panel of investigated biomass

Investigated mineral elements	Biomass with the lowest rate of related mineral element	Biomass with the highest rate of related mineral element
Nitrogen (N)	Spruce (N content of 1 000 ppm)	Rapeseed straw (N content of 54 000 ppm)
Chlorine (Cl)	Fir (Cl content of 100 ppm)	Wheat straw (Cl content of 23 000 ppm)
Phosphorus (P)	Spruce (P content of 100 ppm)	Hemp (P content of 3 107 ppm)
Sulphur (S)	Bamboo (S content of 400 ppm)	Alfalfa (S content of 22 000 ppm)

biomasses and (V)SRC, except in the case of rapeseed straw:

- woody biomass GCV ranges from 19 400 to 20 500 kJ/kg;
- agricultural biomass GCV ranges from 17 500 to 19 300 kJ/kg, except for rice straws (15 600 kJ/kg) and rapeseed straw (21 545 kJ/kg). It has to be noted that in addition to their very high productivity, switchgrass and miscanthus also have the highest energy contents of agricultural biomasses.

2.3.4 Ash Content

Woody biomasses ((V)SRC and forestry biomasses) have the lowest ash content. It is worth noting the remarkable high ash content of rice straw (greater than 20 wt%).

- woody biomass ash content ranges from 1 to 4 wt%,
- agricultural biomass ash content ranges from 3 to 8.3 wt%, except for alfalfa at 9.5 wt%.

2.3.5 Nitrogen, Chlorine, Phosphorus and Sulphur Content

The contents in sulphur, phosphorus, chlorine and nitrogen were compared by "family types", in order to identify if typical mineral contents could be distinguished depending on the family types or if some differences could be highlighted. Orders of magnitude of mineral (nitrogen, chlorine, phosphorus and sulphur) content are given in Table 3.

2.3.6 Synthesis

Fast growing plants, generally agricultural crops, energy crops and to a lesser extent (V)SRC, have high ash and mineral contents, because of mineral fertilizer applied on the plots for their growth.

From these results, it appears approximately that:

Mineral content of agricultural by-products > Mineral content of energy crops > Mineral content of (V)SRC > Mineral content of forestry biomasses

Within each one of the 3 families (V)SRC, energy crops and forestry biomasses, the mineral content is roughly the same for all the biomasses:

– forestry biomasses: very low content for the four investigated mineral elements. This is because of the absence of fertilization;
– (V)SRC: low sulphur, chlorine and nitrogen content. Phosphorus content is slightly higher. This can be explained by the low use of fertilizer (once every 3 years for VSRC and once every 7 years for SRC) and phytosanitary products (once every 3 years for VSRC and once every 7 years for SRC);
– energy crops: medium content for the four investigated mineral elements, also due to the low application of fertilizer (1 application of 30 to 40 units per year) and phytosanitary products (once per year). This is also due to the nature of the crops: nitrogen is going back to the roots at the end of the growth cycle (in winter) so that the harvested parts of the crops have low nitrogen content.

On the contrary, regarding agricultural by-products, it was not possible to define a typical mineral content. However, it was possible to identify one specific biomass with a very high content of each one of the four investigated mineral elements, enabling to set specifications for the BtL process.

2.4 Biomass Costs

2.4.1 Current Biomass Costs

Currently, it does not exist any specific biomass market for each of the four investigated biomass categories and quantities of biomass already traded are definitely low in comparison to biomass potentials. In addition, the development of the BTL industry is likely to create a sharp biomass demand in the coming years that will considerably modify these markets and therefore

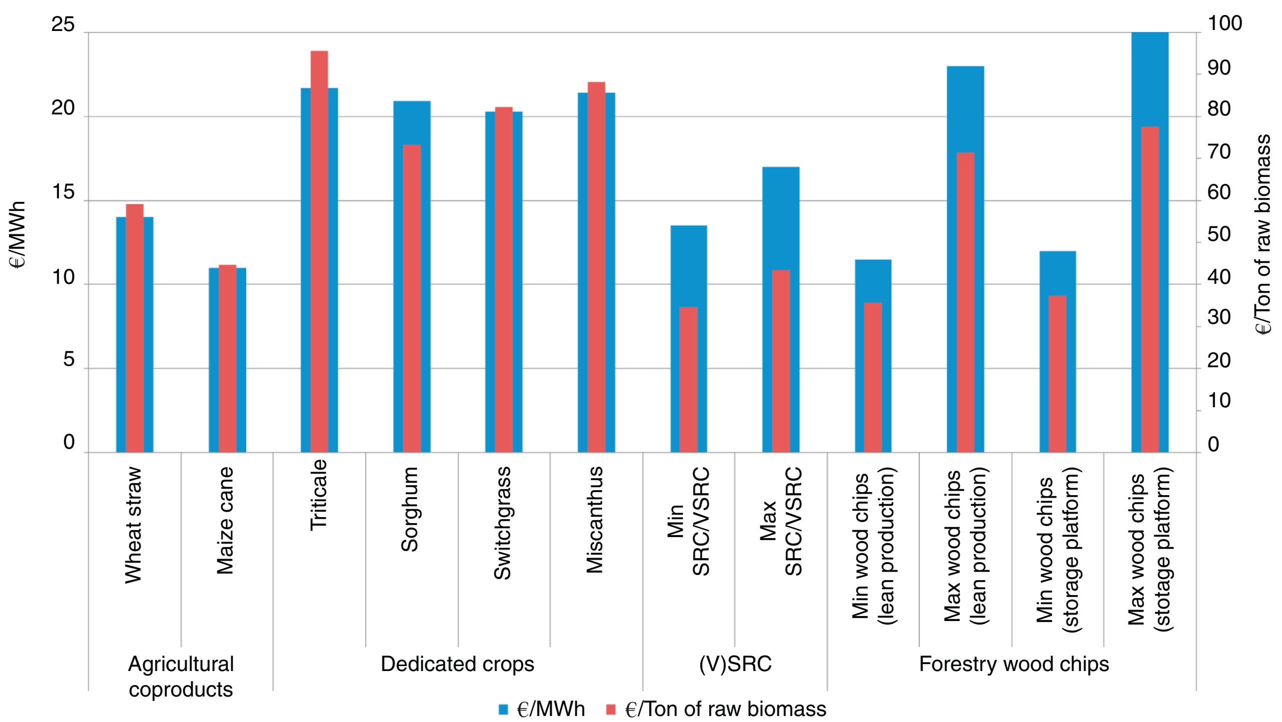

Figure 3

Cost of considered biomasses. Source: adapted from REGIX and Sofiprotéol.

TABLE 4
Synthesis of worldwide biomass characteristics studied

	Physical properties			
	Agricultural by-products	Energy crops	(V)SRC	Forestry biomass
Biomass potential and availability	Relevant potentials in rural zones, especially: – USA (maize cane, wheat straw, etc.), – EU (wheat straw, oil seed crop by-products), – South America (bagasse).	Potential in: – Africa, – South America.	Potential in: – Africa, – South America.	Relevant offer and potentials in: – USA, – Canada, – EU, – Russia.
Biomass cost	Current biomass costs are not representative of those if biomass demand increases. Costs are mostly based on traditional usages. Implementing agricultural by-product supply for energy usages	The early stage of development and the lack of standardized and organized market enabling to set price make these current crop cost not representative of what it will be when biomass demand will increase sharply		Wood chip and pellet prices are set on international market
Biomass quality	Agricultural by-products have the highest mineral content among all the categories of biomass	According to the quantities of fertilizers applied, energy crops, (V)SRC and forestry biomass have different mineral content profiles: medium to low		
	All mineral content profiles are represented: low, medium and high for the following elements: nitrogen, chlorine, Sulphur and phosphorus			

structure the prices (by modifying the breakdown of biomass costs).

French biomass cost data were first investigated because they were the most easily accessible. Besides, it could give a relevant picture of the cost differences between biomasses.

Figure 3 gives indications of cost for the four main investigated biomass categories in France for the current period:
– wheat straw, maize cane and part of wood chips costs come from internal *Sofiprotéol* sources;
– other data are adapted from the REGIX programme [12].

The cost of agricultural by-products (harvested biomass) ranges from 10 to 15 €/MWh (equivalent to 50 to 75 €/TDM). This cost is slightly lower than those of SRC and VSRC, 13 to 17 €/MWh (equivalent to 70 to 90 €/TDM), and the cost of dedicated energy crops is still higher, between 20 and 22 €/MWh (equivalent to 95 to 110 €/TDM). This is mainly due to the higher number of crop management operations in the field (preparation of the field, phytosanitary treatments and fertilization) in the case of energy crops than (V)SRC. Moreover, (V)SRC only require operations in the field during the first year of implementation. Then there are 2 years without any operation for (V)SRC and 8 to 9 years for SRC. The fact that the cost of agricultural by-products remains low is due to the low value given to these materials by farmers and users, which are already used for competing usages (animal feed, animal breeding). Their costs are currently driven by conditioning, transport and storage costs.

Regarding forestry biomass, a wide range of cost (more than a factor of two) can be noticed and is attributed to biomass origin: sometimes, forestry biomass is considered as a logging by-product with a very low cost, whereas in some cases, areas are dedicated to commercial forest for energy and biomass cost is therefore higher. Harvesting and conditioning steps are also of variable cost (between 9 and 16 €/MWh), due to many factors: level of equipment, accessibility of the plots/fields, etc. Finally, logistics and storage increase costs of woody biomass. Woody biomass that has been ground and stored in specific platform is considered to be of better quality (biomass is screened and impurities are removed) than biomass ground on the roadside. Moreover, storage requires large space and equipments (silos, warehouses), whose costs increase biomass price.

Finally, storage in platforms ensures supply guarantees for industrial users and reduces risks of supply disruptions, which are also costly.

2.4.2 Biomass Cost Outlook

Energy crops and (V)SRC are at an early stage of development. There is therefore no standardized and organized market enabling to set prices. Up to now, available data are only those from research programmes, which tried to carry out cost assessments [1] and evaluate what will be the best management practices. However, there are few actual data relying on a market base and it is likely that the costs presented above are not representative of the future costs in a few years. Current studies do not integrate the impact of a sharp demand increase, as in particular, the one foreseen from the BtL industry.

Although relevant quantities of agricultural by-products are sold in France, the market of agricultural by-products is still not well-organized. First reason is that historically, agricultural by-products were considered as sub-products since crops were originally harvested for the grain [23]. In addition, the agricultural by-products are also used for other purposes (soil fertilization, forage, cattle breeding, etc.), though, prices are neither linked with their energy content nor with the required work for their production. Prices presented above are "usual prices" in France.

Since wood chips are now traded on an international market, international prices are known (Free On Board prices – FOB). However, these prices do not always reflect the real value in local contexts. It is also likely that the biomass demand to supply the BtL industry will lead to significant changes in the organisation of the production and supply chains of wood products and finally will impact the price.

In general, whatever the type of feedstock, demand for biomass in the coming years will increase for energy uses – and not only for the BtL industry. This will modify production ways, stakeholder's organization, supply structure and consequently biomass costs. Certain types of biomass have been considered for other uses during hundred years and new definition of price should be made according to traditional and new energy uses (considering of course biomass availability and environmental footprint of biomass removing). We forecast that a sharp demand increase would lead to increase production means investments in the fields of biomass production, harvest, transport and transformation. Consequently, it is likely that biomass price increases during this biomass supply market structuration as a first step. That is also why other biomass-consuming technologies and processes play relevant role before and during the implementation of the BtL industry, in order to accompany and support gradually biomass demand and biomass-supply investments. This would enable to reduce risks of biomass shortage in case of sudden and disproportionate demand for biomass in comparison to biomass real offer and risks of excessive biomass price rise.

As yet announced at the beginning of this communication, a synthesis of biomass family type characteristics is given in Table 4.

CONCLUSION

All the four biomass categories identified are of substantial interest for the development of BTL chains. On the one hand, residues from agriculture and forestry management are already used for bioenergy uses but still have important development potentials. Specialization, improvement of harvest operations and of stakeholders' organization driven by the growing demand should increase biomass availability for BTL. On the other hand, dedicated crops (energy crops and short rotation forestry) are interesting opportunities due to their high yield and their ability to grow with low fertilization inputs. In addition, although biomass cost broadly differs, the sharp demand forecasted in the coming years for bioenergy should modify the level of cost and their main drivers, especially for those based on historical usages (for *e.g.* straw).

Regarding biomass composition, the flexibility towards biomass represents one of the main objectives of any BTL chain. The composition of the four biomass categories varies indeed widely. It has been demonstrated that fast-growing plants (*e.g.* agricultural residues) contain higher levels of minerals than slow-growing biomass (*e.g.* forestry biomass).

These considerations also raise the issue of production practices. Since quantities of biomass collected will considerably rise in the future, as well as their impact over soil carbon content, it is necessary to sep up efforts dedicated to research on sustainable practices, re-examine fundamental production ways and promote environmentally friendly operations. It is particularly the case for cereal straw. It has been proved that in general, it is possible to remove straw once every three years without harming soils. Thus, straw removing frequency could be increased in case new practices are operated to balance organic carbon losses. For example concerning agricultural by-products, intermediate cover crop between winter and spring crops enable to reduce soil erosion, retain mineral elements for the following crop, and increase soil organic matter level. These practices could be generalized in case of increasing biomass collection.

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