To be or not to be a biobased commodity

Assessing requirements and candidates for lignocellulosic based commodities

IEA Bioenergy: Task 43

March 2022

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Authors: Wolter Elbersen[1], Iris Vural Gursel[1], Juliën Voogt[1], Koen Meesters[1], and Biljana Kulisic[2]
[1]Wageningen Food & Biobased Research, Wageningen, The Netherlands [2]Energy Institute Hrvoje Pozar, Zagreb, Croatia

This study was carried out by Wageningen Food & Biobased Research with financial support by IEA Bioenergy Task 43 and funding from the Wageningen University & Research Knowledge Base program: Towards a Circular and Climate Positive Society (Project KB-34-012-002).

Wageningen Food & Biobased Research
Wageningen, March 2022

Report 2242
DOI 10.18174/562461

WFBR project number: 6224088700
Version: Final
Reviewer: Edwin Hamoen
Approved by: Jan Jetten
Subsidised by: the Dutch Ministry of Agriculture, Nature and Food Quality
Commissioned by: the Dutch Ministry of Agriculture, Nature and Food Quality
This report is: public

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PO box 17, 6700 AA Wageningen, The Netherlands, T + 31 (0)317 48 00 84, E info.wfbr@wur.nl, www.wur.eu/wfbr.

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Summary

Lignocellulosic biomass is an underutilised renewable resource. Using this biomass for biobased applications is hampered by a lack of possibilities to efficiently link the biomass to markets which include both energy applications such as heat and electricity production, conversion to transport fuels and chemicals and materials. Siting conversion facilities near abundant biomass has the benefit of availability of low cost biomass, but the locations generally lack security of supply, availability of qualified personnel, and do not benefit from existing infrastructure and possibilities to add value to residues. Furthermore, the scale of conversion systems is limited by local cost of biomass supply.

The development of real lignocellulosic commodities can connect biomass to markets and lower the opportunity costs of the commodities. The characteristics of real commodities are defined as follows: a commodity has to be easy to store, have a high (energy) density and be nutrient depleted. The commodity has to be uniform enough to be fungible. This will allow standardization of transport, contracting, insurance, conversion systems and development of functioning markets which includes high tradability and availability of financial instruments. Finally sustainability also has to be standardized.

Several candidates as real commodities exist including wood pellets and pyrolysis oil. It is argued that only a few biomass commodities have to be defined that cover all lignocellulosic biomass types (wood, grass, straw, bagasse, processing residues, etc.) and also all applications such as heat, electricity, fuels, chemicals and materials. The standards have to be as wide as possible and avoid frivolous or unnecessary demands. To achieve this all stakeholders in the production chain (biomass producers, machine builders, regulators, insurers, bankers, transport, final users) have to be involved. This will require international collaboration else the potential lignocellulosic biomass will not materialize. The development of real lignocellulosic commodities can connect biomass to markets and lower the cost of biomass supply by lowering transaction costs. Commodities can contribute to efficient and circular use of biomass by giving biomass that would not have an efficient use (stranded biomass) a market.

Keywords: lignocellulosic biomass, commodity, biobased economy, pellet, pyrolysis, hydrothermal upgrading, torrefaction, standards, trade.

1 Introduction

Lignocellulosic biomass is the most abundantly available biomass resource. It is mainly composed of lignin, cellulose and hemicellulose. It includes a wide variety of biomass types such as wood, energy crops, forest residues, agricultural residues, and industry (forestry, agri-food) residues and wastes. Lignocellulosic biomass is expected to become an important source of renewable carbon to produce materials, chemicals and advanced fuels thereby reducing reliance on fossil feedstocks.

Worldwide, lignocellulosic biomass is currently highly underutilized. A large proportion of the unused residues are essential for soil health[1] and, when they are removed, alternative sources of minerals and organic matter are essential. Yet, Krausmann et al. (2008)[2] estimate that of agricultural residues 2.5 Gton is burned and 1.5 Gton is left on the field and there are 0.7 Gton of dry biomass per year felling losses in the forest. Agricultural residues are often burned in the field as a practice for clearing land for replanting that leads to pollution problems. And although generally forbidden, it is still in practice in many countries (see Figure 1). When not burned the residues are left on the field. Some residues are so abundant that they form large layers, which compose slowly. Under anaerobic conditions methane is formed, a powerful greenhouse gas contributing to climate change. An example of this happens is sugarcane trash where trash accumulates due to phasing out of trash burning before harvesting (Figure 1 D). The harvesting of this trash for alternative uses can have beneficial effects as the trash layers can result in releasing of methane and cause hygiene and pest problems. The agricultural residues do have some local applications such as animal feed or bedding. However, the supply often far exceeds local demand for these purposes. Furthermore, many industrial residues currently don’t find good use and are often wasted (such as empty fruit bunch from palm oil mills). Biomass that could have, but nonetheless has not, been released for use in the biobased economy, makes no contribution to the replacement of fossil fuels.

Table 1 shows the agricultural and processing residue production by the 10 largest crops on earth covering about 60% of agricultural land. This shows the potential of using these residues as feedstock for biobased economy. Besides combatting climate change, this will also be supportive of circular economy objectives of reducing input of additional primary raw materials to meet the energy and material demands.
A range of estimates is available for major sources of lignocellulosic biomass in EU that could support further growth of the biobased industries as compared to the current status. Estimates for agricultural residues range from 106 Million tonnes to 252 Million tonnes per year in the 2030 timeframe which are currently highly underutilized.[3,4] It is also estimated that EU forests could sustainably supply above 85 Million tonnes of additional woody biomass. Furthermore, there is high potential for industrial crops production estimated to rise above 100 Million tonnes (in the EU) especially also considering their growth on marginal lands.[5]

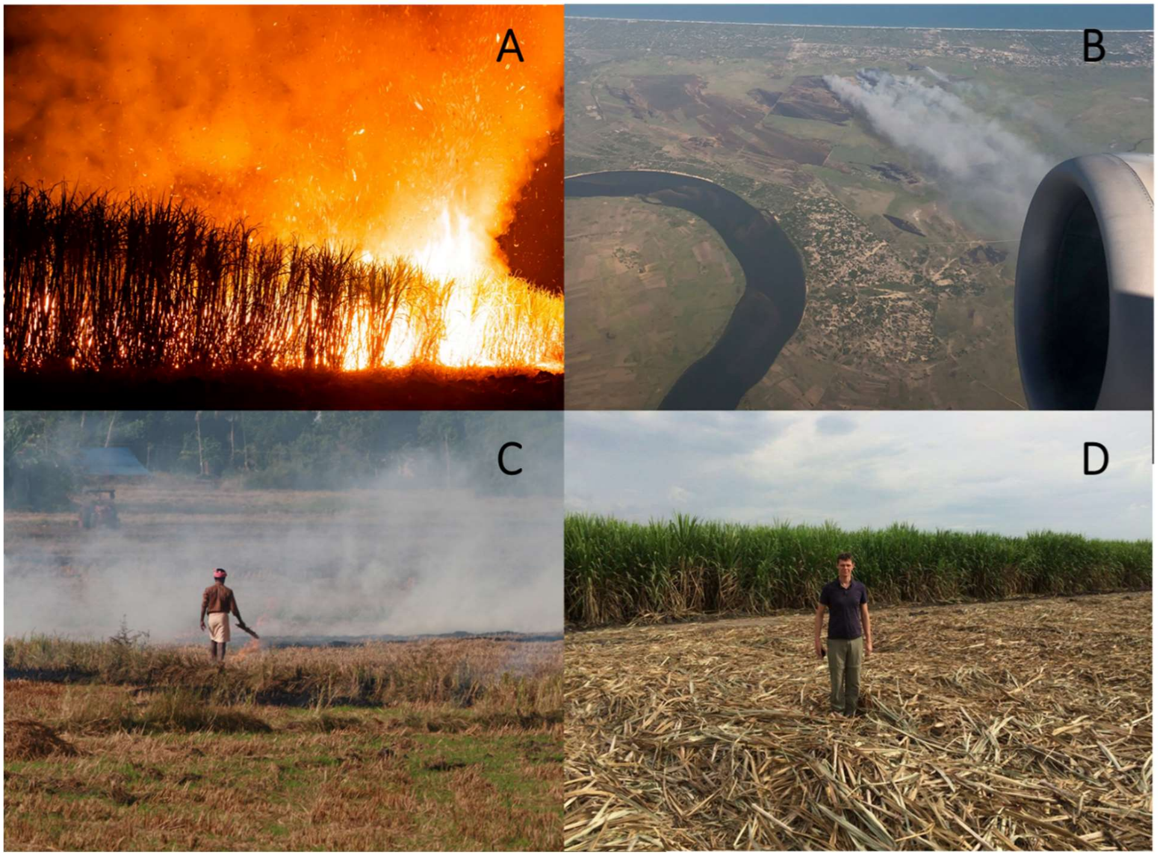

Figure 1 ***Examples of agricultural residues that are burned or pile up in the field. A) sugarcane burned before harvest to remove leaves in Thailand from Shutterstock.com; B) burning of field residues in Mozambique; C) burning of rice straw in India from AJP / Shutterstock.com; D) sugarcane trash left in the field in Colombia covering soil which prevents cane regrowth***

The demand for lignocellulosic biomass as a feedstock is growing and it is expected to contribute significantly in meeting international energy and climate goals.[7,8] The revised renewable energy directive (RED II)[9] strengthened the position of lignocellulosic biomass by supporting advanced biofuels and capping biofuels produced from food and feed crops. In the IPCC report that assessed mitigation pathways, consistent with limiting global warming to 1.5°C above pre-industrial levels, considered that renewables will supply a share of 52–67% of primary energy by 2050.[8] In this projection biomass will cover about half of this demand with about 155 EJ energy supply per year (from current about 60 EJ) and the study considers this bioenergy will be supplied mostly from second generation/lignocellulosic biomass feedstocks such as dedicated cellulosic crops (e.g. Miscanthus, poplar) as well as agricultural and forest residues.[8] To achieve the projected targets, access to more than 8,000 Mtonnes of dry biomass per year would be required. A very ambitious target.

A major challenge is to secure the supply and the logistics of the required lignocellulosic biomass feedstocks in a sustainable way. Food and feed commodities have been traded internationally for centuries. This also needs to be established for lignocellulosic feedstocks for the production of energy, chemicals and materials. Current lignocellulosic biomass trade volumes for these applications is still far below the volumes to meet the projected needs. This is mainly because there are currently no *real* commodities that link lignocellulosic biomass sources to often remote markets. To valorise this potential, it is considered that a limited number of lignocellulose commodities should be defined and international trade should become standardized.[10]

The aim of this paper is to define commodities based on lignocellulosic biomass, explain the required characteristics, and present the candidate commodities.

Table 1 The largest 10 crops on earth and the estimated field and mill residues based on FAOstat (2018)[6] data and own estimates of residue production per ha per year

Largest 10 crops in the world		**Total field**	**Total mill**
	Million hectares	Million ton DM crop residue per year	
Maize	185	1,038	Not estimated
Rice, paddy	163	816	Not estimated
Wheat	220	729	Not estimated
Sugar cane	27	264	264
Oil Palm	19	192	52
Barley	49	173	Not estimated
Sorghum	45	103	Not estimated
Sunflower seed	25	66	8
Millet	31	43	Not estimated
Seed cotton	35	35	Not estimated
Total	**800**	**3,459**	**316**
All crops worldwide:	1,414		

2 Locating large scale lignocellulosic biomass conversion facilities

Although it is predicted that large quantities of lignocellulosic biomass are potentially available sustainably, mobilizing these biomass sources is the major bottleneck. In a study on setting up biobased commodity chains[11], a number of business developers were asked what determines the attractiveness of locating a conversion facility such as a second generation ethanol plant. In Table 2, the factors that were mentioned for assessing the attractiveness of locating a biorefinery near the biomass source vs. near a large logistical centre are compared. Sanders et al. characterized these logistical centres as a delta area with excellent logistical services and population concentrations, with existing industrial structure and an entrepreneurial and innovation potential.[10] It was seen that locating large scale lignocellulosic biomass conversion facilities near a large logistical center scores better for all criteria except for the cost of the biomass supply. This shows it is favourable to bring biomass to major application markets through logistical centres.

Table 2 ***Factors determining the attractiveness of locating a large scale biomass conversion facility such as an advanced biofuel plant near biomass vs. at a large logistical centre. Based on Dam et al.[12] and EU CELEBio project[13]***

Location: Factor	Near the biomass	At a large logistical center (i.e. harbour)
Cost of biomass	+	
Security of supply		+
Availability of infrastructure		+
Economy of scale		+
Availability of personnel / expertise		+
Value of residues		+
Sum	1	5

2.1 Cost of biomass supply

The cost of biomass supply will in general be higher than for a fossil equivalent. Even if a higher price can be paid for biomass because of GHG advantages the cost of biomass supply is very relevant. The cost of biomass supply is lowest in areas near the biomass production site, where only local collection and local transport have to be paid. If the biomass production is seasonal, as with corn stover or straw, local storage will have to be paid also. At remote (large scale) conversion facilities the cost of biomass supply will be much higher as it will require much larger transport distances. Especially if the biomass is bulky, wet and has a low energy density, handling and transportation become costly. And also difficult to store as it may be vulnerable to degradation.

2.2 Security of supply

Even in an area with a lot of biomass availability, the security of supply may not be assured to a factory over the long term as crop production in an area may change and suppliers (farmers, wood producers) may increase their price over time. Also drought, flood or other unpredictable events may disrupt supply. There are also variations in quality due to seasonal changes and applied cultivation and harvest practices. Therefore, it is difficult to ensure large volume and constant supply of biomass at the right quality.

A constant, large supply within quality specifications, can guarantee stable and high conversion yields necessary for a viable business operation such as a cellulosic biorefinery.[14] Conventional systems rely on feedstock (predominantly) agricultural residues such as wheat straw and corn stover or forest (by)-products procured through contracts with local producers, locally stored, and delivered in a low-density form to the nearby conversion facility. This system is associated with feedstock supply risks. Biomass feedstock variability over the course of continuous full-scale operation, often violates machinery design specifications.[15] Intrinsic biomass characteristics, including moisture content, composition (fibre, protein, starch, sugars, oils, etc.), ash and ash compositions, bulk density, and particle size/shape distributions are highly variable and can impact the economics of transforming biomass into value-added products.[16]

Due to its ability to mobilize biomass from different sources, large scale centers with good logistical connections can source biomass at large quantities also over long distances and secure the required feedstock at a constant quality.[17]

2.3 Availability of infrastructure

In (remote) areas where biomass is abundant, roads and other infrastructure may be lacking and need to be established from scratch. In logistical centres such as harbours several transportation options exist (sea, road, rail) and utility supply is available. Pre-existing supply chain infrastructure, storage and production facilities can be utilized. These logistical centres have already established supply to industrial facilities for large scale biomass conversion. Due to the ability to sell biomass on behalf of small biomass suppliers and distribute biomass storage, processing, transport costs over larger quantities, logistical centres lower the cost of biomass supply.[17]

2.4 Economy of scale

Factory scale determines the processing costs per unit of product especially for processes that require heat transfer, such as electricity production or ethanol production[10]. The net present value (NPV) of a project increases as scale increases because of lower cost of processing per unit. This makes it more economical to process at a larger scale. However, in conventional biomass supply systems, at a certain point the NPV of the investment decreases as size increases because the benefit of a larger scale does not compensate the increasing transportation cost of the biomass feedstock. This is illustrated in Figure 2.

Figure 2 ***Net present value of a lignocellulose to ethanol (second generation) plant versus size of plant (feedstock use). Adapted from*** **[18]**

Edwards et al.[19] illustrate that most of the available straw in Europe for electricity production is not mobilized due to limitation on building big power plants (>50 MWel).
In other words, using lignocellulosic biomass locally is restricted by size limits due to restrictions imposed on the daily traffic of heavy trucks shipping straw to the power station. In the USA and Europe biomass to electricity and biorefineries for second-generation ethanol production have been set up in regions with a surplus of crop residues. To date these initiatives struggle and are often abandoned. This is often due to difficulty in lignocellulosic biomass supply in large volumes. These plants relied on supply up to 100 km perimeter mostly delivering biomass directly from the field. They also had low on-stream reliability because the variability in quantity and quality impede continuous operation.[20]

In regions with less biomass availability, it is not economical to build a factory. This can mean that "*the biomass is stranded*" and cannot be utilized [21]. Lamers et al (2016) also recognize the problem of biomass vs conversion scale and state that to be able to utilize stranded biomass and achieve required volumes of biomass for conversion facilities, advanced feedstock supply systems are needed with a network of distributed biomass pre-processing centres (depots) and centralized logistical centres.[14] This system allows large volume of biomass supply for the development of large-scale biorefineries and achieving economic feasibility. Furthermore, it contributes to efficient use of these resources, a key goal of the circular economy, by allowing efficient use of available resources.

2.5 Availability of personnel / expertise

Availability of personnel and level of expertise can be difficult to attain if the conversion facility is located near the biomass source. This also applies to supporting personnel required, such as contractors who perform maintenance. On the other hand in industrial centres with good logistics next to the available infrastructure, there is presence of highly skilled workforce.[22]

2.6 Value of residues

Large scale biomass conversion plants produce residues which are preferably sold and not cost money to discard. If the conversion facility is located near a biomass source in remote areas, it can be difficult to find a market for the residues produced in the process. On the other hand, conversion facilities located near logistical centres benefit from established industrial infrastructure which allows synergies to be made. Ethanol plants produce CO_2 which can be an input for the beverage industry nearby. Fermentation residues may be processed into feedstock for nearby factories. Lignin may be used for energy generation or better, for bitumen replacement or production of chemicals. Furthermore, large scale factory clusters are developing heat distribution systems which allow factories to supply surplus heat to other factories or to urban areas. Multi output valorization of biomass provides resource efficiency and lower environmental impacts and cost of production per product.

3 What is a real biobased commodity?

Can we get the best of both worlds: Low cost biomass and still large scale efficient conversion? In economics, a commodity is defined as an economic good that is used in commerce and has full or substantial *fungibility*: that is the ability of a good to be interchanged with other goods of the same type with no regard to who produced them. Commodities are most often intermediate goods and used as inputs in the production of other goods or services.

We argue that it is essential to define and develop a limited number of biobased intermediates (commodities) to mobilize the lignocellulosic biomass potential and link this potential to the new biobased markets. At this moment different intermediates are already produced which need to be linked to production at conversion locations. These intermediates will bring benefits such as efficient biomass use and lower costs only if they are real commodities.

What is a *real* biomass commodity? In Table 3 a list is shown of the five requirements for a biomass commodity. Biomass is converted into the intermediate (commodity) locally at a limited scale that fits the biomass scale. The intermediate is then transported (long distance) to conversion facilities that have optimized (generally large) scales for conversion into biobased products such as fuels, chemicals, heat and electricity. The commodity needs to have a standard quality and be produced in large quantities by many different producers.

Table 3 Requirements of a biobased commodity

1. Easy to store and transport → high energy density, dry, low volume, low ash, nutrient depleted
2. Fungible → “exchangeable” = standard quality
3. Standardization of transport, contracting, insurance, conversion systems
4. Functioning markets: Trade systems, Financial instruments (futures, etc.) High tradability
5. Sustainability: Standard sustainability certification systems

In Figure 3 the idea of lignocellulosic commodities to link biomass to markets is illustrated. As explained above there are a wide variety of lignocellulosic biomass sources (agricultural and forestry residues, industrial processing (agro-food, forestry) residues, energy crops and wood) and each have different physical properties and composition. Though consisting mostly of fibre (lignocellulosic material) they may also contain smaller or larger amounts of carbohydrates, lignin, proteins, oils and minerals. This provides a challenge towards commoditization. Extracting proteins and nutrients and using the remaining for production of the commodity would allow higher economic returns and more uniform composition of the commodity. Furthermore, nutrients generally have little or negative value for most biobased applications and are better returned to the soil. Different types of biobased commodities can be produced following different pre-processing options (e.g. pelletisation, pyrolysis, torrefaction, hydrothermal liquefaction). Many options exist for end uses of commodities. They can be used in combustion units for generation of heat and power at different scales (from residential pellet stoves to industrial boilers and power plants). Alternatively, for gasification and production of fuels and chemicals. They can be used in fermentation and/or upgrading units to produce chemicals and fuels. Alternatively, they can also be used for materials (such as plastics and composites).

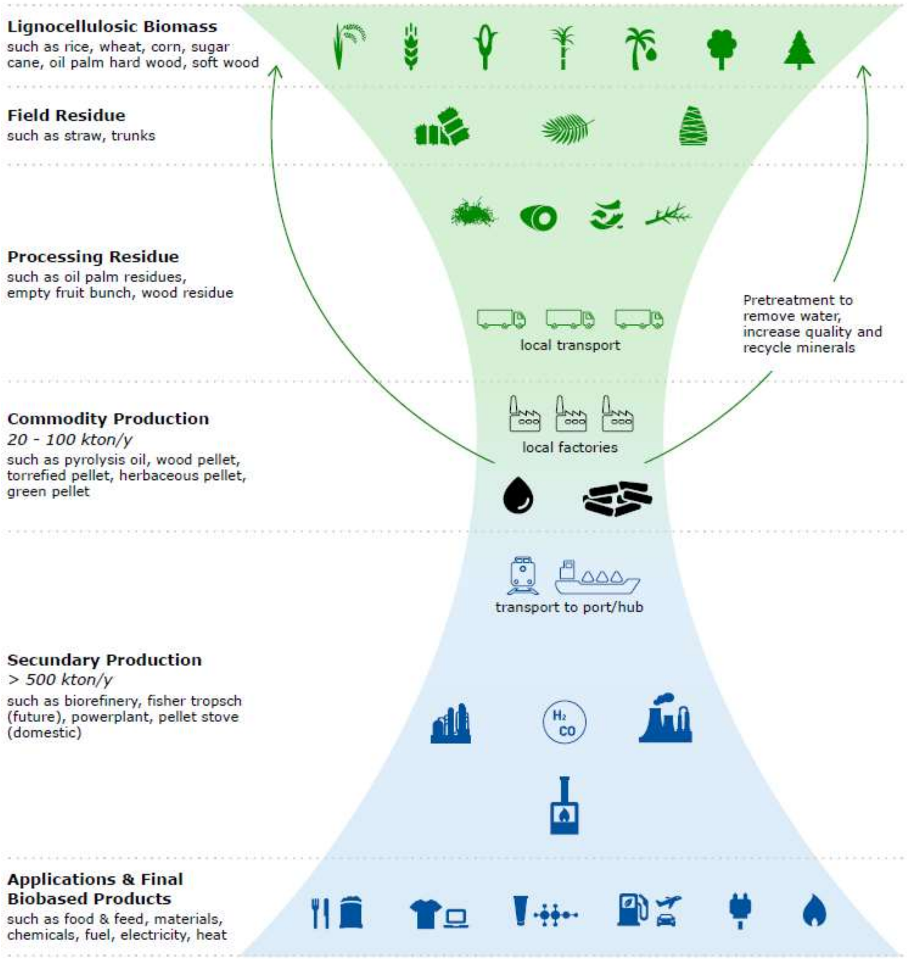

Figure 3 ***The role of biobased commodities to link lignocellulosic biomass sources to international market. The arrows signify the return of minerals and water to the land or farm***

3.1 Physical characteristics

The commodity should be easy to transport and store, meaning that it has a high energy density and is easy to handle in bulk. It should also have a low ash and nutrient content. This is especially critical for herbaceous biomass such as rice straw, grasses, corn stover, and many other processing residues which contain high amounts of nutrients and therefore ash. Nutrients and ash (silica, phosphate, potassium, magnesium, calcium, etc) have no value for energy or fuel or chemicals production but do have a value for soil as nutrients. Accordingly, having this pre-processing close to field, and achieving separation and return of water and nutrients to field is important.[23]

3.2 The commodity should be fungible

Fungible means that the commodity should have a standard quality making it interchangeable. Quality should not differ across different producers. Key technologies (e.g. torrefaction, pyrolysis, hydrothermal liquefaction) are at different stages of development; these are necessary to achieve the standard quality of the biocommodity.[10] For many intermediates, quality standards are available such as for wood pellets. Successful adoption of standards by the market is important.

It is important to define how tight the quality criteria should be and what would be the acceptable variation in the product.[10] Having excessively tight criteria as well as having many standards and types will create an obstacle for market development.

3.3 Standardization of systems in the utilization chain

If the quality is standardized it will also be possible to standardize transport but also contracting, insurance and conversion systems. This leads to much lower transaction costs. A standard contract means that no costly negotiations are necessary. Standard quality and transport means that insurers know what the risks are, which should lower insurance costs. Last but not least, a commodity with a standard quality will allow for standard conversion systems to be produced in large quantities. Systems will not have to be adapted to specific biomass types but to a standard commodity, making it possible to build many of the same systems thereby lowering construction costs.

3.4 Functioning markets

A commodity market is where buying, selling, and trading of commodities take place. The markets are competitive, liquid and international.[24] Competitive concerns the requirement of presence of many buyers and sellers to assure prices can be set according to demand and supply. Liquidity concerns how easy it is to convert an asset into cash, presence of adequate short-term supply and demand and international requiring globally integrated markets. Investors and traders can buy and sell commodities directly in the spot (cash) market or via derivatives such as futures. With a futures contract the holder is obligated to buy or sell a commodity at a predetermined price on a delivery date in the future. These futures can be used for price risk management allowing buyers to have a guaranteed security of supply at a fixed price.

A true commodity will need to be tradeable with an enough volume so that a buyer can insure security of supply for his conversion system. Producers of the commodity will be able to sell their product in advance to get financing for operating and not need to rely on own capital or loans. Investments will be more secure as the supply of the feedstock produced or used can be secured at a fixed price. Operators can ensure feedstock supply by buying in advance and not be dependent on one-on-one relations which make them vulnerable in case the other party defaults. Additionally, a trade system will allow transparency and trust which should lower the prices. The Baltic biomass exchange has shown that this indeed works (see section 5).

Currently most lignocellulose biomass is still sold ono-on-one; it is difficult to get a long term contract for the supply of consistent quality of feedstock at a reasonable price. If a trading system is present, the market has instruments to deter risks and improve market stability. This should lower the cost of biomass supply, minimize the risks associated with price fluctuations, and allow for efficient use of the available biomass. Worldwide trade of large quantities of these biobased commodities is required for the transition from a fossil-based to biobased economy.

3.5 Standard sustainability certification systems

The use of biomass for the biobased economy is mostly driven by the wish to increase sustainability. This means that the sustainable production and supply of biomass need to be ensured. As evidenced from the recent debate, the major concerns are related to life cycle greenhouse gas emissions, food security, (indirect) land use change, preservation of high carbon stocks and biodiversity. Also social impacts are included in many sustainability standards. Several sustainability standards and certification schemes have been developed accordingly that define the sustainability criteria to be met. Certificates are attained by the operators that show compliance with the sustainability requirement of the schemes.

Certified operators are required to implement a chain of custody system where certified material shall be traceable along the supply chain which includes each stage of processing, conversion, transformation, manufacturing, trading and distribution. It is important that differences in these sustainability certifications systems do not hinder the development and tradability of biomass commodities. Harmonization of the sustainability certification systems is necessary to improve trade.[25]

The recast of the Renewable Energy Directive (REDII)[9] include mandatory sustainability criteria for biofuels used in transport and bioliquids, and solid and gaseous biomass fuels used for heat and power at the EU level. All biomass supplied should be sustainable regardless of what the end use is (energy or otherwise). Accordingly, sustainability criteria should be required globally and also for use in other biobased sectors. The sustainability criteria, certification and assurance systems should also be harmonised.

4 What are the (candidate) lignocellulose commodities?

4.1 Wood chips

Currently wood chips are mostly used locally and traded at relatively short distances. They are currently mostly used for energy purposes and raw material in pulp and paper production. Wood chips are highly heterogeneous, the characteristics differ according to place or origin, tree species, soil and weather conditions, etc.

4.2 Wood pellets

Wood pellets are produced by a simple production process of pelletisation. The low moisture content and relatively high energy density provide ease of handling, storage, and transportation. Despite the rise in cost of the pellets as a result of drying and pelletising, more biomass can be shipped using traditional dry bulk ships as opposed to the more expensive wood chip carriers.[26] Several quality standards exist for wood pellets (EN 14961-2:2011, European and ISO 17225-2:2021, global).

4.3 Torrefied pellets

Torrefaction is a thermal pre-treatment process typically at 200-350°C in the absence of oxygen used to produce high-grade solid from woody biomass or agricultural residues. Torrefaction is followed by pelletisation to facilitate transport. A slightly higher energy density, makes it attractive for long distance transportation but no major trade flows have yet occurred.[27] Torrefaction lowers problems associated with decomposition of biomass during storage and results in a more homogeneous product, important for fungibility.

4.4 Pyrolysis oil

Pyrolysis is thermal decomposition occurring in the absence of oxygen. Fast pyrolysis at around 500°C yields an oil (bio-oil or pyrolysis oil) as the main product. Pyrolysis offers a flexible way of converting solid biomass into an easily stored and transported liquid, which can be used for the production of heat, power and chemicals. Fast pyrolysis requires feed to have less than 10% water. If biomass source has higher moisture content, drying of the biomass is required before pyrolysis. Pyrolysis oil production is demonstrated at commercial scale but no trading systems exist currently. Quality standards, such as ASTM Burner Fuel Standard D 7544 for Fast Pyrolysis Bio-oil, have been developed.

4.5 Herbaceous pellets

Besides wood, herbaceous biomass such as agricultural residues and grasses (e.g. switchgrass and miscanthus) can be used in production of pellets. Straw pellets and recently also sugarcane bagasse[28] have been commercially used for this purpose. Yet other feedstocks have also been studied such as sugarcane trash and empty fruit bunch.[23] Several quality standards exist for non-woody pellets (EN 14961-6:2012, European and ISO 17225-6:2021, global). Herbaceous biomass has high ash and nutrient content which can cause technical problems such as corrosion, deposits on hot surfaces and the slagging of ashes.[29]

Therefore, before turning into a commodity, the nutrients need to be extracted locally and returned to the soil. Therefore, before turning the biomass into a commodity, the nutrients need to be extracted locally and returned to the soil. The recent CAPCOM project tested this and showed that it is possible to remove 90% of potassium, sodium and chloride content. The pelleting process was smoother after pre-treatment and the produced pellets good durability.[23]

4.6 Bio-crude

Bio-crude is a liquid biofuel produced by hydrothermal liquefaction. Like pyrolysis oil, bio-crude converts biomass into a liquid form that is more easily stored, transported and fed into downstream processing. The advantage of hydrothermal liquefaction compared to pyrolysis is that wet biomass can be used as feedstock and the liquid product has a considerably lower oxygen content[30] and therefore a higher energy content. Several continuous pilot setups have been built, but bio-crude is not yet available at commercial scale.

5 Case study. Evidence of lowering of price and increased efficiency?

To promote transparency and competition in the market for energy resources Baltpool Biomass Exchange was created in Lithuania.[31] The following standardized products are traded in the Exchange: 4 types of wood chips, 3 types of wood pellets, milled peat, 2 types of recycled wood and one lignin and wood biomass mixture.[32] Hereby the traded biomass should meet standard qualities. Both private and state companies are allowed to sell and buy biomass through the platform. The platform aims to create price stability for both the biomass seller and purchaser. Since the biomass product should meet standard qualities, the purchaser is not dependent on a single seller anymore and the market becomes more competitive. All of biomass exchange operations are licensed and supervised by Lithuania's national energy regulatory council. The biomass exchange emerged from the national power exchange in 2012 and, by now covers biomass trade in Lithuania, Latvia, Estonia, Poland, Denmark, Sweden, and in Finland with high prospects to expand to other neighbouring countries.[33]

Biomass for heating was traditionally an important fuel in Lithuania, but it gained a strategic importance with an uprise of natural gas prices that drove the transformation of Lithuanian heating sector from natural gas to biomass. Before the creation of the biomass exchange, Lithuanian biomass market exhibited a large difference in biomass prices (up to 25%) among the districts.[31] Besides, there were a limited number of biomass suppliers, especially big ones, on the market. The purchase practice was not transparent and there were high barriers for new market participants.

The Biomass Exchange increased market transparency and efficiency in Lithuania: by 2015 biomass prices fell up to 40% (depending on region) as compared to 2012 and price difference between neighbouring municipalities almost disappeared.[34] In 2014-2016, the average biomass price at the exchange was 5-15% lower than the average price paid by CHP plants off-exchange.[31] The exchange also solved the biomass supply concentration problem shifting from a highly concentrated market with few large players to low/medium concentration which is considered to be a competitive marketplace.

Since Baltpool was established, the share of biomass in fuel supply in district heating went from 27% to 80% in 2020 and biomass consumption had a steady annual growth with a double-digit increment.[34] In 2017, biomass traded via Baltpool supplied 97% demand of Lithuanian district heating companies with 2 million tons of wood chips and 1,600 MW of heat. In 2018, biomass was traded with >5,000 executed transactions.[34]

The Exchange's systematic risk management system and services of independent laboratories for quality testing strengthen the security of biomass supply at the expected quality. Biomass price is determined through an anonymous open auction mechanism. Biomass exchange benefits both sellers and buyers. Sellers gain easy access to the market and have equal requirements with all market participants. Buyers have the biomass price established in an effective way. The trading process is faster and cheaper. Accordingly, the transparency in market increased and standardization of products as well as supply procedures, trading and delivery rules was achieved.

6 Discussion and Conclusions

Lignocellulosic biomass needs to be processed before long distance transport to increase energy density and ease of transportation, handling and storage.[10] This can be done through a wide range of processes such as pelletisation, chipping, pyrolysis, torrefaction and hydrothermal upgrading. This will require cost of pre-processing but will reduce cost of transportation, handling and storage and further conversion and in the end the overall cost of supply.

In 2018, IEA Bioenergy Task 43 launched an initiative to identify successful examples of biomass logistics and distribution points for bioenergy and the bioeconomy: bio-hubs. In a workshop organized together with the BioEast Initiative, three examples were presented.[17] In agrarian bio-hub at Tschiggerl Agrar GmbH (Austria) farmers deliver their agricultural by-products (straw, corn cobs, hay) where in this logistics centre they are processed (dried, crushed and pelletized) and supplied to the region where they are used for different purposes including feed, bedding and energy without disturbing the usual crop production activities and generating additional income to farmers. In Nordic countries beside roundwood different biomass sources are available (e.g. forestry residues, short rotation coppices and from agriculture) that are utilized to a minor extent. Establishing Nordic Bio-hubs is important to design supply systems that match industrial demands and optimize biomass utilization. The last example is a virtual bio-hub called East Europe Hub to foster bioeconomy that connects stakeholders with information on know-how on supply/demand to generate higher value-added wood-based products in short chains. Additionally, in a workshop organised with Natural Resources Canada potential bio-hub development in regions across Canada were discussed.[22]

Pre-treatments and densification, at these bio-hubs allow transforming raw biomass feed streams into commodities with uniform properties.[35,36] For agricultural residues having this pre-processing close to field, it is important to achieve separation and return of water and nutrients to field.[23] For agri-food and forestry industry residues pre-processing to commodity is preferentially integrated within existing plants (e.g. sugar or palm oil mills, sawmill). Bio-hubs will streamline processing, storage and transportation, make a variety of biomass types available at a single location and provide a place for trade. Bio-hubs in the neighbourhood of harbours will provide a potential for the export of the biobased commodities.

Commodities can then be shipped for remote large-scale downstream processing.[37] Ports, both on the exporting side and on the importing side, will have a major influence on the formation of biomass chains. The supply of raw materials for the biobased economy potentially can be increased by import of biobased commodities to countries with a lack of large volume domestic biomass sources, but with a good logistical (harbours) and industrial infrastructures.

7 Conclusions

Trade in biomass will be greatly enhanced with the definition of a limited number of standard ‘biobased commodities’. It is necessary that all parties involved work towards creating these commodities that can link all the potentially available and diverse lignocellulosic biomass resources worldwide with global markets. Now they are needed to cover demand for electricity and heat, and in future increasingly diverted to meeting need for chemicals, materials and heavy transport, marine and aviation fuel applications in the biobased economy. Diversifying the outlets for produced biomass also provide resilience to biomass suppliers.

Commodities are needed to make efficient use of available lignocellulosic biomass thereby contributing to mitigating climate change and transitioning to circular economy. They also support replacement of fossil resources while reducing competition for land and food. They are required to be able to bring stranded biomass to economy as well as large scale lignocellulosic refineries feasible. Real lignocellulose biomass commodities can lower the cost of biomass supply and provide security of supply at standardized quality. Baltpool is a real case example showing how this works for stabilising prices and ensuring supply and quality.

Wood pellets, pyrolysis oil, herbaceous pellets, torrefied pellets, wood chips and bio-crude are described here as candidate lignocellulose commodities. To bring these about several recommendations are provided where establishing of bio-hubs close to biomass sources where the commodities can be produced and distributed is an important step.

What is needed?
Only a few biomass commodities have to be defined that cover all lignocellulosic biomass types (wood, grass, straw, bagasse, processing residues, etc.) and also all applications such as heat, electricity, fuels, chemicals and materials. The standards have to be as wide as possible and avoid frivolous or unnecessary demands. To achieve this all players in the production chain (biomass producers, machine builders, regulators, insurers, bankers, transport, final users) have to be involved. This will require international collaboration or else the potential bulk lignocellulosic biomass utilization will not materialize.

8 Acknowledgements

The authors gratefully acknowledge financial support by IEA Bioenergy Task 43 and funding from the Wageningen University & Research Knowledge Base program: Towards a Circular and Climate Positive Society (Project KB-34-012-002).

References

1. Turmel, M. S., Speratti, A., Baudron, F., Verhulst, N. & Govaerts, B. Crop residue management and soil health: A systems analysis. *Agric. Syst.* **134**, 6–16 (2015).
2. Krausmann, F., Erb, K. H., Gingrich, S., Lauk, C. & Haberl, H. Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. *Ecol. Econ.* **65**, 471–487 (2008).
3. FAO. *FAOSTAT statistical database*. (2018).
4. Panoutsou, C. *et al. Biomass Futures. Biomass role in achieving the Climate Change & Renewables EU policy targets. Demand and Supply dynamics under the perspective of stakeholders*. (2011).
5. Panoutsou, C. *S2BIOM, D8.1 Overview of the current status of biomass for bioenergy, biofuels and biomaterials in Europe*. (2016).
6. Njakou Djomo, S., Gabrielle, B., Staritsky, I., Elbersen, B. & Annevelink, B. *Magic, D.5.2 – High Resolution Maps of Potential Biomass Supply from Marginal Lands around a Biorefinery*. (2021).
7. IEA. *World Energy Outlook*. (2018).
8. Rogelj, J. *et al.* Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. in *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,* (eds. Flato, G., Fuglestvedt, J., Mrabet, R. & Schaeffer, R.) (Cambridge University Press, 2018).
9. EC. *Directive (EU) 2018/2001 of the European Parlement and the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)*. (2018).
10. Sanders, J. P. M., Annevelink, B. & van der Hoeven, D. The development of biocommodities and the role of North West European ports in biomass chains. *Biofuels, Bioprod. Biorefining* **3**, 395–409 (2009).
11. Dam, J. van. Sustainable Biomass Production and Use, Lessons learned from the Netherlands Programme Sustainable biomass 2009 - 2013. *Netherlands Enterprice Agency* Available at: https://english.rvo.nl/topics/sustainability/sustainable-biomass/publications-results/overview-results-lessons-learned. (Accessed: 21st March 2020)
12. van Dam, J., Elbersen, W. & van Ree, R. *Setting up international biobased commodity trade chains. A guide and 5 examples in Ukraine.* (2014).
13. CELEBio project. Available at: https://celebio.eu/. (Accessed: 15th October 2021)
14. Lamers, P., Searcy, E. & Hess, J. R. Transition Strategies: Resource Mobilization Through Merchandisable Feedstock Intermediates. *Dev. Glob. Bioeconomy Tech. Mark. Environ. Lessons from Bioenergy* 165–185 (2016). doi:10.1016/B978-0-12-805165-8.00008-2
15. Kenney, K. L., Smith, W. A., Gresham, G. L. & Westover, T. L. Understanding biomass feedstock variability. *Biofuels* **4**, 111–127 (2013).
16. Williams, C. L., Westover, T. L., Emerson, R. M., Tumuluru, J. S. & Li, C. Sources of Biomass Feedstock Variability and the Potential Impact on Biofuels Production. *Bioenergy Research* **9**, 1–14 (2016).
17. IEA-Bioenergy: Task 43. *Bio-hubs as keys to successful biomass supply for bioenergy within the bioeconomy*. (2020).
18. Kaylen, M., Van Dyne, D. L., Choi, Y. S. & Blase, M. Economic feasibility of producing ethanol from lignocellulosic feedstocks. *Bioresour. Technol.* **72**, 19–32 (2000).
19. Edwards, R., Šúri, M., Huld, T. A. & Dallemand, J. F. GIS-based assessment of cereal straw energy resource in the European Union. in *Biomass for Energy, Industry and Climate Protection* 17–21 (2005).
20. Hess, J. R., Ray, A. E. & Rials, T. G. Editorial: Advancements in Biomass Feedstock Preprocessing: Conversion Ready Feedstocks. *Front. Energy Res.* **7**, 140 (2019).
21. Gonzales, D. S. & Searcy, S. W. GIS-based allocation of herbaceous biomass in biorefineries and depots. *Biomass and Bioenergy* **97**, 1–10 (2017).
22. IEA-Bioenergy: Task 43. *Bio-hubs as Keys to Successful Biomass Supply for the Bioeconomy*. (2020).
23. Meesters, K. P. H. *et al.* Production of Clean Agro-Pellet Commodities (CAPCOM) from Agro-Residues. *Eur. Biomass Conf. Exhib. Proc.* 791–794 (2021). doi:10.5071/29THEUBCE2021-3DO.6.4
24. Olsson, O., Lamers, P., Schipfer, F. & Wild, M. Commoditization of Biomass Markets. *Dev. Glob. Bioeconomy Tech. Mark. Environ. Lessons from Bioenergy* 139–163 (2016). doi:10.1016/B978-0-12-805165-8.00007-0
25. Mai-Moulin, T., Armstrong, S., Dam, J. van & Junginger, M. Toward a harmonization of national

sustainability requirements and criteria for solid biomass. *Biofuels, Bioprod. Biorefining* **13**, 405–421 (2019).

26. Baruya, P. *World forest and agricultural crop residue resources for cofiring*. (2015).
27. Junginger, H. M. *et al.* The future of biomass and bioenergy deployment and trade: a synthesis of 15 years IEA Bioenergy Task 40 on sustainable bioenergy trade. *Biofuels, Bioprod. Biorefining* **13**, 247–266 (2019).
28. Raizen. *Raizen Annual Sustainability Report 2020-2021*. (2021).
29. Sampaio, I. L. M. *et al.* Electricity Production from Sugarcane Straw Recovered Through Bale System: Assessment of Retrofit Projects. *BioEnergy Res. 2019 124* **12**, 865–877 (2019).
30. Castello, D., Pedersen, T. H. & Rosendahl, L. A. Continuous Hydrothermal Liquefaction of Biomass: A Critical Review. *Energies 2018, Vol. 11, Page 3165* **11**, 3165 (2018).
31. Geletukha, G. & Zheliezna, T. *Creation of the competitive biofuel market in Ukraine, UABio Position Paper N 18*. (2017).
32. Baltpool International Biomass Exchange, Products. Available at: https://www.baltpool.eu/en/products/. (Accessed: 30th November 2021)
33. Baltpool International Biomass Exchange. Available at: https://www.baltpool.eu/en/biomassexchange/. (Accessed: 30th November 2021)
34. Jonutis, V. THE BIOMASS EXCHANGE – virtual transmission grid in biomass market. (2019). Available at: https://www.ieabioenergy.com/wp-content/uploads/2019/10/03_Jonutis_BaltPool.pdf. (Accessed: 30th November 2021)
35. Bunse, M. J. *Sustainable supply chains for maritime biofuels*. (2021).
36. Lamers, P. *et al.* Techno-economic analysis of decentralized biomass processing depots. *Bioresour. Technol.* **194**, 205–213 (2015).
37. Eranki, P. L., Bals, B. D. & Dale, B. E. Advanced Regional Biomass Processing Depots: a key to the logistical challenges of the cellulosic biofuel industry. *Biofuels, Bioprod. Biorefining* **5**, 621–630 (2011).
38. Kim, S. & Dale, B. E. A distributed cellulosic biorefinery system in the US Midwest based on corn stover. *Biofuels, Bioprod. Biorefining* **10**, 819–832 (2016).
39. Bals, B. D. & Dale, B. E. Developing a model for assessing biomass processing technologies within a local biomass processing depot. *Bioresour. Technol.* **106**, 161–169 (2012).
40. Kim, S. *et al.* EISA (Energy Independence and Security Act) compliant ethanol fuel from corn stover in a depot-based decentralized system. *Biofuels, Bioprod. Biorefining* **12**, 873–881 (2018).
41. Guo, X., Voogt, J., Annevelink, B., Snels, J. & Kanellopoulos, A. Optimizing Resource Utilization in Biomass Supply Chains by Creating Integrated Biomass Logistics Centers. *Energies* **13**, 6153 (2020).
42. Martinkus, N., Latta, G., Brandt, K. & Wolcott, M. A Multi-Criteria Decision Analysis Approach to Facility Siting in a Wood-Based Depot-and-Biorefinery Supply Chain Model. *Front. Energy Res.* **6**, 124 (2018).
43. Tumuluru, J. S., Wright, C. T., Hess, J. R. & Kenney, K. L. A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application. *Biofuels, Bioprod. Biorefining* **5**, 683–707 (2011).
44. Thompson, D. N. *et al.* Chemical preconversion: Application of low-severity pretreatment chemistries for commoditization of lignocellulosic feedstock. *Biofuels* **4**, 323–340 (2013).

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