Building tomorrow's biorefineries: Findings from case studies performed in the framework of the FP7 project BIOCORE

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biocore

A biorefinery concept for the transformation of biomass into 2^{nd} generation fuels and polymers

BUILDING TOMORROW'S BIOREFINERIES

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BIO-COMMODITY REFINING

BIOCORE is a European-funded FP7 project. The overall aim of this project, which mobilizes 25 partners from 13 countries, including an Indian partner, is to devise and demonstrate an advanced biorefinery concept that will use a variety of lignocellulosic biomass feedstocks to produce a portfolio of products, including fuels, chemicals, specialty chemicals and food ingredients. As part of BIOCORE, project partners have performed case studies, whose aim is to better analyse the feasibility of operating a BIOCORE biorefinery in precise locations in Europe and India. This summary report addresses the main findings of the case studies, including data related to local biomass availability, logistics, stakeholder opinions and likely acceptance of biorefining in their region.

The BIOCORE project aimed to use biomass to produce a range of products including bioethanol, several bulk and specialty chemicals and feed ingredients.

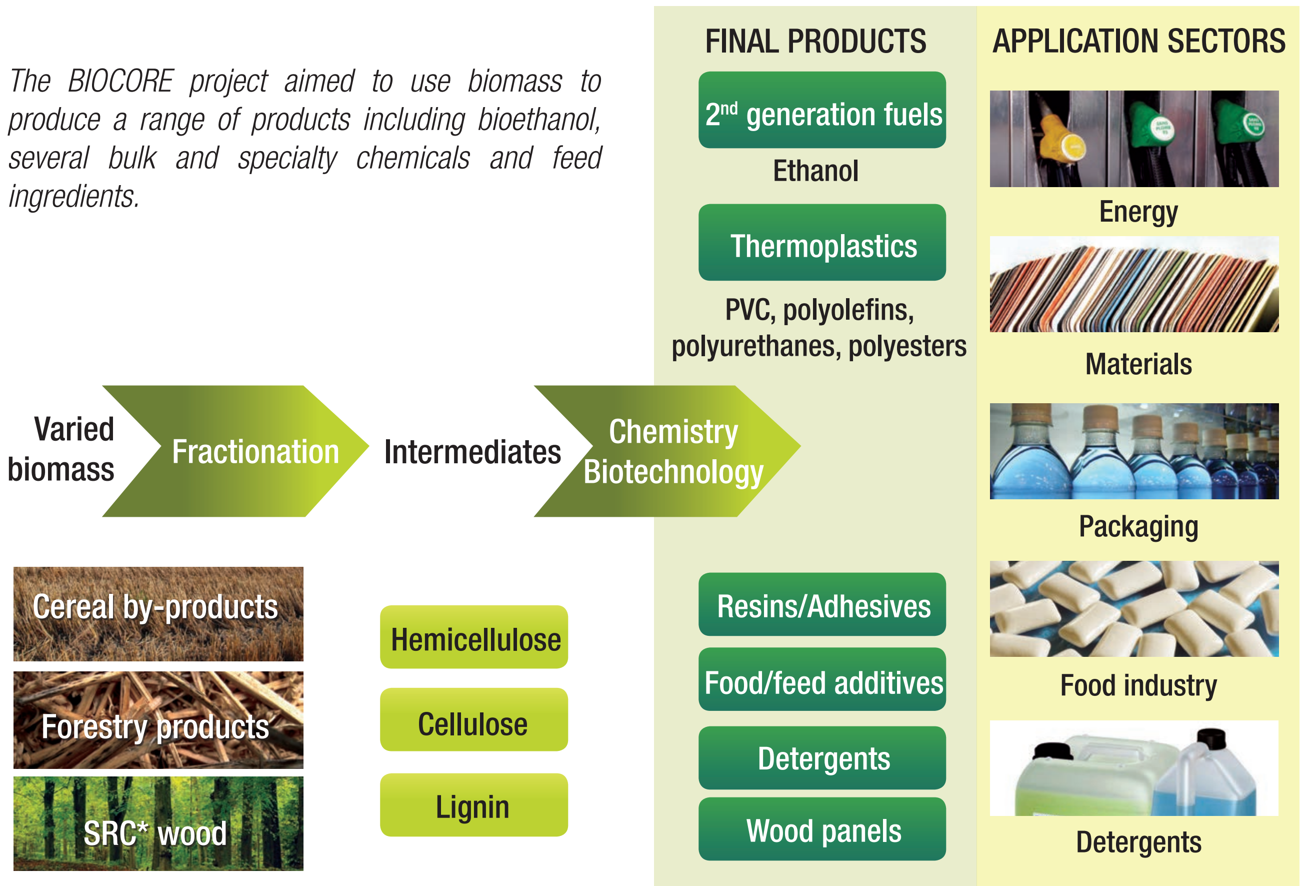


Figure 1 – Biocore schème. Source: BIOCORE ■

A BRIEF OVERVIEW OF BIOCORE'S CASE STUDIES

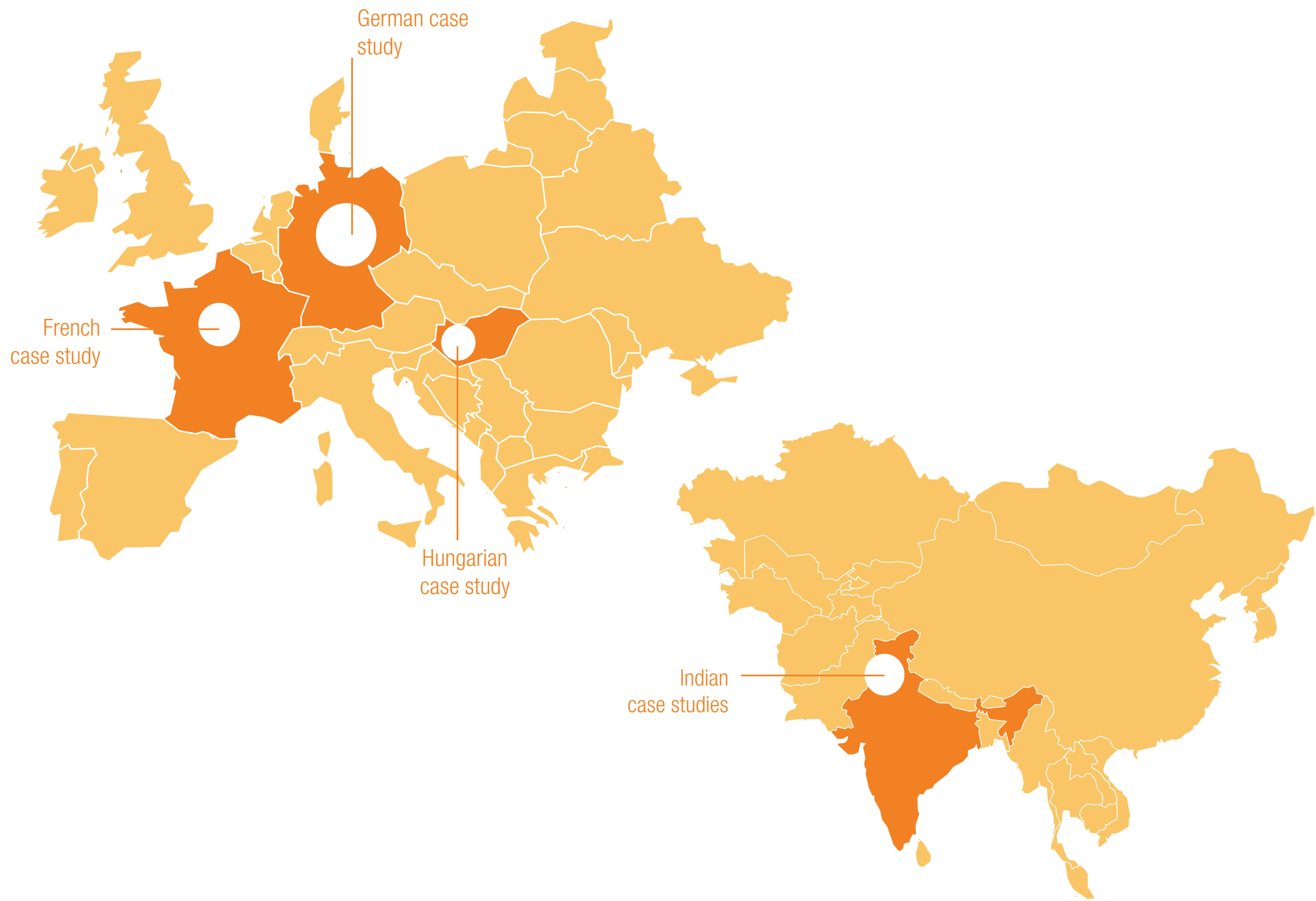


Figure 2 – Localisation of the BIOCORE case-studios. Source: BIOCORE ■

To reveal how biorefineries can be implemented within local contexts, the BIOCORE project set out to perform detailed case studies that were intended to provide information on local supply chains, logistics and environmental impacts. As a first step in the planning of these case studies, BIOCORE researchers assessed the availability of certain types of biomass feedstocks both in Europe (hardwood, wheat straw, SRC poplar, maize straw, and Miscanthus) and in India (rice and wheat straw), using data from a variety of reliable sources. Overall, this preliminary analysis of biomass availability provided the basis for the selection of several regions that then became the subject of more detailed research and enquiry. Accordingly, in the BIOCORE project, the Beauce (France), Nordrhein-Westfalen, Rheinland-Pfalz, Saarland and Hessen federal states (Germany), Zala, Somogy, Barany and Tolna counties (Hungary), Faridkot and Sangrur (India) were targeted for the implementation of the case study approach. In the following two sections, a brief summary of our initial findings concerning biomass availability are presented.

BIOMASS AVAILABILITY IN A NUTSHELL

BIOCORE researchers have ascertained that the amount of potentially extractable wheat straw in Europe represents approximately 35 Mt DM. This considerable reserve of available biomass can be completed by another 15 Mt of maize straw. Likewise, hardwood surplus in European countries amounts to between 2.5 and 5.5 Mt DM in countries such as France, Germany Italy, Poland, and Romania.

In India, the northern states of Punjab and Haryana are well-endowed with excess biomass, especially rice straw that is currently an underused resource that underlies environmental pollution due to in-field burning. An annual paddy-wheat rotation occupies at least 60% of total cultivated land in Punjab and Haryana, with these crops providing approximately 145 Mt DM of surplus biomass per year.

A HIGH-LEVEL ROUNDUP OF BIOMASS AVAILABILITY IN EUROPE AND INDIA

India's abundant green gold

Recent biomass assessments reveal that unused cereal straws and wood residues are potentially abundant materials for biorefining. In India, a country that boasts a trillion dollar economy, 140 Mha of land are under culture. Agriculture is the mainstay activity, sustaining more than half of India's 1.2 billion population and accounting for 14% of the nation's GDP and approximately 11% of its exports. Moreover, Indian agriculture supplies raw materials for a large number of industries, including textiles, sugar, paper pulp, tyres and tubes. The total food grain production in the 2011-12 period was 259 Mt, composed of 105 Mt rice and 95 Mt wheat respectively, which entails the production of approximately 500 Mt residues, of which 145 Mt remain unused. Rice and wheat form the basis of the Indian subcontinent's staple diet, thus large areas are allocated to paddy and wheat cultivation. The agricultural pattern and availability of land makes the country biomass-rich, with a huge potential to meet its own energy needs. However, the socio-economic conditions of the agrarian population means that considerable amounts of biomass are channelled into the animal fodder and domestic energy (for cooking and heating) sectors. Nevertheless, the vastness of India means that socio-economic conditions vary significantly from region to region, with the north-westerly states of Punjab and Haryana figuring among the higher GDP and the top agricultural states. In these states, favourable climatic conditions provide the basis for an intensive annual wheat-rice cropping system, which places these states among the major contributors of wheat and rice in India. Owing to the cropping pattern in Punjab and Haryana, high production and productivity characterize agriculture in these regions, thus the annual production of agricultural residues is also high. Regarding the uses of these renewable resources, approximately 50% of wheat straw is used for a variety of purposes, but 90% of rice straw is burned in the field at the end of the harvest period. This is a widespread, traditional practice that allows the farmers to rapidly remove the rice straw from the field. The advantages of such a practice are that straw removal is fast (farmers only have 15-25 days to achieve this before wheat sowing), it implies very little labour cost, returns minerals to the soil and disposes of a residue for which there are no real alternative uses. However, these advantages are offset by extremely negative consequences for the environment, because in-field rice straw burning leads to severe annual peaks of air pollution. Presently, the Indian government plans to promote power plants fired by rice straw.

Figure 3 – Coppice harvesting. © CAPAX

Europe: a contrasted story

In Europe there is up to 215 Mt of harvestable cereal straw available. Approximately 50% of straw is from wheat cultivation, 25% from barley and 25% from maize. Overall, three countries lead continental Europe's cereal production sector (France, Germany and Ukraine) and are responsible for approximately 50% of the annual volumes produced. A lot of harvestable straw is actually used in Europe, thus extractable straw (*i.e.* straw that is really surplus after taking into account other uses, such as return to soil or animal bedding) amounts to 47 Mt, or 33 Mt if one excludes maize straw, with 45% of this coming from the three aforementioned countries.

Turning to hardwood resources, results from data analysis performed in BIOCORE indicate that France, Germany, Italy, Poland, Romania, and Turkey have the largest overall surplus hardwood reserves in Europe (Russia was not included). In particular, several regions display a potentially high capacity to supply surplus hardwood. These include a region that covers Eastern France to South-West Germany, Northern and Central Italy, forests in the former Yugoslavian region and a forested belt that crosses Hungary, Slovakia, Ukraine, Romania, and Bulgaria. However, many of these forested areas are mountainous, which has negative implications for economically-feasible wood extraction.

Figure 4 – Miscanthus harvest. © DR

Finally, since the development of energy, or biomass crops in Europe is often cited as a promising route towards greater, more sustainable biomass production, it is pertinent to note that Europe's current production of these is low, irrespective of whether one considers short rotation coppice (SRC) poplar, willow or eucalyptus, miscanthus, hemp, switchgrass, or reed canary grass. Overall production of these plants varies, with estimates ranging from circa 50 kt DM for certain crops and up to 250 kt DM for others (*n.b.* BIOCORE partners could not identify any reliable data for eucalyptus). Nevertheless, abundant data indicate that there is strong potential in Europe for these dedicated biomass crops, with certain species such as Poplar being well-adapted for growth in Central Europe.

Apart from SRC crops, there is a large variety of other dedicated biomass crops which may be annual (hemp) or perennial (miscanthus, switchgrass, reed canary grass). Cultivation areas for all of these crops are currently very small, hence the often used term 'niche crops', although this term is misleading since it implies that these crops cannot be deployed at industrial scale. The main reasons for the lack of development of both SRC and other biomass crops are that they are currently economically uncompetitive when compared to arable crops grown on fertile land. However, since the ultimate aim is to obtain competitive yields of biomass crops on marginal, or left aside land, this comparison is not really pertinent. Moreover, there is a perception that dedicated biomass crops require specialized machinery, although this is not always true. Finally, many farmers display a certain amount of reluctance regarding the adoption of biomass crops. This is linked to a multitude of reasons, but is often simply due to unfamiliarity with these crops.

ENERGY OR DEDICATED BIOMASS CROPS

Typically energy or dedicated biomass crops are plants that are specifically grown to supply biomass raw materials for the production of energy, biofuels or chemicals. For simplicity, these crops can be classified into two categories, which are woody crops and herbaceous plants. Woody crops include poplar, willow and eucalyptus, all of which can be cultivated in a short rotation coppice regime, which means that they can be regularly cut back to near ground level, with new growth occurring in the following years. The growth period between cuttings is variable for short rotation crops, but is usually situated between 2 and 5 years. Short rotation coppice crops are considered to be interesting, because it is often claimed that their input requirements are modest compared to agricultural crops and their yield is high (in excess of 8 tons DM per hectare, depending on pedoclimatic conditions). Perennial herbaceous crops include miscanthus (or elephant grass), switchgrass (or Panicum) and reed canary grass. All of these crops can be harvested at least once a year, but in some cases more than once, depending on soil quality and climate. Consequently, these crops display quite different average yields depending on the harvest regime, but for example miscanthus in northern France can produce up 12-14 tons DM per hectare and is reputedly very efficient with respect to the use of nitrogen (*i.e.* low fertilizer requirement).

TAKING A CLOSER LOOK AT BIOMASS AVAILABILITY – A CASE STUDY APPROACH

Taking into account the above findings and to conduct a series of case studies that are characterized by contrasting scenarios, five regions (three in Europe and two in India) were selected for in-depth analysis. The key characteristics of each case study are presented in Table 1. For most of the case studies, the operation of an ABU (advanced biorefinery unit) having an annual capacity of 150 kt DM of feedstock input was investigated. This factory capacity was considered to be well-suited to regional deployment in Europe, but in the light of the abundancy of lignocellulosic biomass in India, it was deemed rather low for the latter. Therefore, for the Indian case studies, the operation of higher-capacity biorefineries (500 kt per annum) was also investigated.

Country	Exact location	Primary feedstock	Fall-back feedstock	Biorefinery scale (kt)
France	Centre (Beauce)	Wheat / barley straw	Miscanthus	150
Germany	Midwest	Hardwood	Softwood	150
Hungary	Southwest	Wheat / barley / maize	SRC poplar	150
India	Sangrur	Rice straw	Wheat straw	150 and 500
	Faridkot	Rice straw	Wheat straw	150

Table 1 – Summary of the BIOCORE case studies. Source: BIOCORE ■

A SUSTAINABLE BIOMASS SUPPLY TO BIOREFINERIES IS POSSIBLE – BUT STRONG LIMITATIONS EXIST

The sustainable supply of feedstock will be a key element in the development of industrial bio-based products. To be sustainable, the supply of biomass must be economically-viable, stable over time and be relatively neutral in terms of environmental impacts. Moreover, biomass removal must be consistent with a global environmental approach to agriculture and forestry, and must address major issues, such as the maintenance of soil (*i.e.* maintain or improve stable soil carbon content, sustain a minimum rate of fresh carbon return to soil, minimize the rate of nutrient export and ensure low soil compaction and erosion) and water quality (reduce the use of nitrogenous inputs and herbicides), the reduction of water demand, the protection of local biodiversity (including common and rare species and habitats), limitation of landscape changes, reductions in GHG emissions and climate change adaptations. Therefore, establishing whether sufficient biomass feedstock can be procured from a given supply area is the first step in determining whether it is feasible to operate a biorefinery. A second step is to define mitigation actions (*i.e.* how to reduce the negative impacts of new farming practices or forestry management policy) wherever these are required.

Figure 5 – CIMV pilot. © CIMV ■

In BIOCORE, for each of the case studies, a careful analysis of feedstock availability was performed, assuming that the implantation of an ABU would occur in 2015 and that the unit would still be functioning in 2025, 10 years being a minimal investment period for such an industrial activity. This analysis took into account all competitive uses for the biomass.

One common feature of the findings of the biomass availability studies, irrespective of the case study region, was the fact that feedstock availability is expected to decrease between 2015 and 2025. The reasons for this negative evolution arise from the following assumptions:

• the quantities of biomass produced will be equal or lower than present levels;
• no extra land becomes available for the production of crops or trees;
• new agricultural trends (*e.g.* organic farming, diversification of crop rotations, conservation agriculture) will lead to less intensive production systems. Most of the time, these agricultural systems will provide beneficial environmental impacts, but will also reduce crop yield;
• external constraints, such as climate change, water availability and new environmental regulations will become stronger over time;
• competition for biomass will increase because of the development of biomass-fired power plants and the increasing use of firewood by rural households.

Figure 6 – From left to right: cellulose, lignin powder, wheat straw, C5 syrup. The CIMV technology allows extracting the cellulose, hemicellulose and lignin out of biomasse. © CIMV ■

Obviously, these assumptions do not take into account other aggravating factors, such as the feasibility of long-term contracting with farmers (*i.e.* social constraints), unforeseen logistical issues, new environmental regulations or unpredictable changes in feedstock availability caused by freak weather conditions, nor do they include other mitigating phenomena, such as the use of marginal lands for dedicated biomass crops, increased yields obtained using new plant varieties and the implementation of new policy, which might arbitrate in favour of the most resource and energy efficient uses of biomass. Nevertheless, based on our assumptions, it is clear that such a negative evolution of biomass availability needs to be taken into account, in order to avoid the deployment of industrial units whose capacities are too close to future projected biomass availability.

Taking into account the finding that biomass availability is likely to decrease in the case study regions, and the fact that there are a certain number of uncertainties associated with the accuracy of these predictions (*i.e.* aggravating or mitigating factors that were not considered), it is nevertheless possible to conclude that ABUs could be sustained with a sufficient supply of feedstock in all of the studied regions. In the next part of this report, we will look more closely at how this can be achieved in each of the case study regions.

ORGANOSOLV TECHNOLOGY

Organosolv is a technology that was originally invented as an alternative paper-pulping process for the paper industry. Basically, the different organosolv technologies use organic solvents to dissolve the lignin and hemicellulose components of lignocellulosic biomass, leaving a solid pulp composed mainly of cellulose. Several types of organosolv technologies exist, but in BIOCORE two have been studied. The principal BIOCORE technology is the one developed by the French company, CIMV S.A[1]. This technology uses a solvent formed from a mixture of formic and acetic acid[2].This technology is operated at approximately 100°C and atmospheric pressure and can be used to extract cellulose from a wide variety of agricultural co-products including cereal straws, sugar bagasse and hardwoods, such as birch, hornbeam, poplar and oak[2]. Importantly, CIMV's technology is currently unsuitable for resinous tree species (only 10% softwood is tolerated in an essentially hardwood feedstock), because the presence of resin in the wood prevents the correct penetration of the solvent. Another organosolv technology that has been studied in BIOCORE is one that uses an ethanol/water mixture, and uses sulphuric acid as the catalyst. This technology is operated at temperatures above 180°C and can be used to extract cellulose from a variety of feedstocks, but rather like the CIMV technology, it cannot be used for wood from resinous tree species. Both of BIOCORE's organosolv technologies produce three principal product streams, composed of cellulose, lignins and hemicelluloses, respectively. In the BIOCORE case studies, it has been assumed that CIMV's technology will form the basis of ABUs that will operate using a minimum biomass supply of 150 kt DM per annum, and produce biomass intermediates that can then be transformed into useful products, such as biofuel, chemicals and even food/feed additives.

[1] http://www.cimv.fr/?lang=en
[2] Delmas (2008).Chem Eng. Technol., 31, 5,792-797.

Abundant straw reserves will secure feedstock supply in India

To establish whether the Indian case study regions can sustain an ABU operating at 150 or 500 kt DM per annum, the availability of rice and wheat crop residues, particularly straws, were assessed taking into account any competitive uses whenever wheat straw was considered.

In Sangrur, straw production currently amounts to 5.4 Mt per year. Wheat straw is largely used as animal fodder and in the paper pulp industry. Rice straw is usually burnt in the field, although this was not considered as a competitive use in the case study. After the subtraction of straw dedicated to alternative uses, it is possible to confirm that 2.5 Mt per year of straw is currently available, this being composed of 76% rice straw and 24% wheat straw.

The main changes in straw availability that are anticipated in 2025 are a 10% reduction in the number of dairy cows (*i.e.* lower fodder requirements) and a greater (30%) exploitation of straw for new uses, including packaging and biomass-fired power stations. Taking into account these factors, it is probable that the surplus of straw available for biorefining will still represent approximately 1.2 Mt per year, this quantity being composed of 67% rice straw and 33% wheat straw. Accordingly, a small ABU (150 kt capacity) would consume 6% of the available feedstock in 2015 and 13% in 2025, while a larger ABU (500 kt capacity) would consume 25% and 42%, respectively.

Similarly, the Faridkot region currently produces a considerable quantity of straws, with this amounting to 1.5 Mt per year. After deduction of competitive uses and stubble, it is estimated that approximately 650 kt remain available (74% from rice and 26% from wheat) for new industrial activities. As in the previous case, it is assumed that this quantity of surplus biomass will be affected in 2025 for the reasons evoked earlier. However, the number of dairy cows is expected to be more severely reduced in the Faridkot region (a 25% reduction) while the other uses for straw will take up an equivalent amount (*i.e.* 25%). In this case, it is expected that approximately 340 kt straw (60% rice straw and 40% wheat straw) will be available in the Faridkot area in 2025 for use by an ABU. In other words, an ABU using 150 kt per year would consume 23% of available feedstock in 2015 and 44% in 2025 respectively.

Figure 7 – Straw residues in India. © BIOCORE

Sufficient hardwood availability in Germany will support an Advanced Biorefinery Unit

Consistent with the known characteristics of CIMV's organosolv technology and, notably, its intolerance to wood from resinous species, the German case study was performed using the assumption that the feedstock of the ABU would need to contain at least 90% hardwood (with a maximum of 10% softwood being allowed). In terms of the actual wood conditioning, it was assumed that the ABU could be supplied with feedstock either in the form of logwood, wood chips (bark-free wood chips from saw mills), pellets (produced from saw dust) or wood shavings/micro-chips). Since many saw mills, pellets plants and timber-based companies operate in the case study region, this adds a certain feedstock flexibility to the scenario.

Although softwood tree species dominate in Germany (about 66% of standing trees), the states of Western Germany are characterized by a higher share of hardwood tree species. In Rhineland-Palatinate about 58% of standing trees are hardwood species and in Saarland this rises to 70%. In North-Rhine Westphalia and Hessen, hardwood trees represent approximately 53% and 55% respectively. Therefore, overall the regions targeted for the case study possess significant amounts of hardwood trees, compared to Germany as whole.

The German case study region possesses approximately 2.6 Mha of forest, of which 1.4 Mha are mature broad-leaved, hardwood tree species. The mean annual growth increment (MAI) is close to 8 $m^3\ ha^{-1}\ yr^{-1}$ for hardwood species and 15 $m^3\ ha^{-1}\ yr^{-1}$ for softwood trees. Currently, 31% of the MAI from hardwood and 65% of the MAI from softwood are harvested. Therefore, the under utilization of hardwood is inevitably leading to increasing hardwood stocks. The main drivers for this increase include the fact that there is relatively little demand for hardwood from both the German wood panel industry, which prefers softwood, and the pellet industry, which is almost exclusively using softwood.

Figure 8 – Woody biomass. © INRA, Nicolas Bertrand

In total, 7Mt DM of wood (*i.e.* dry matter of marketable wood) are collected annually and used mainly by saw mills (39%) and for domestic fuel (26%). As mentioned above, there are marked differences between the utilization of hard- and softwood, since more than 60% of hardwood is used as domestic fuel, while about 56% of softwood is used in saw mills. Therefore, if one considers the whole of the study region (8 Mha), the introduction of an ABU using 150 kt DM wood, consisting of 135 kt hardwood and 15 kt softwood would actually only represent a small increase of the current total harvest of marketable wood (2.2% for hardwood and 0.2% for softwood) from the forest area. Obviously, if one considers more local scales, then the impact of an ABU on wood extraction will be more significant and will represent significant proportions of available wood in some areas. Nevertheless, overall, it is reasonable to assume that forests could tolerate the increased felling associated with the implantation of an ABU. However, this assumption does not take into account concomitant increases in wood utilization for other purposes such as increased use for energy.

Feedstock diversification could secure long-term feedstock supply in Hungary

In the Hungarian regions targeted by the case study, it was anticipated that the feedstock for an ABU would be necessarily a mixture of hardwood (the surplus of wood harvested as firewood), surplus crop residues (wheat straw and maize stover) and short rotation coppice crops. Although more complicated to handle in terms of process logistics, this diversified feedstock portfolio constitutes a more robust biomass supply scenario than one that would rely on a single resource.

To assess the potential available feedstock, local crop yield patterns, environmental aspects, harvesting possibilities and competitive uses were all considered. Thus, while in the case of hardwood, only the local demand for firewood was taken into account, for wheat and maize straw it was necessary to not only assess harvested amounts (minus stubble waste), but also the quantities that are returned to the soil to maintain soil organic content (60% of total yield) and the amounts used by competitive demands, such as firing in cogeneration facilities and animal bedding. Moreover, in the Hungarian case study, climate impacts were considered, since recent drought episodes have been known to reduce the yield of cereal crops by as much as 26%, with up to 43% of the corn crop being lost.

Regarding land use change, this was also considered in the framework of the Hungarian study, since this can affect yield distribution. In this respect, it was estimated that afforestation is likely to continue, especially on the poorest quality arable land, despite the fact that the exploitation of arable land constitutes a more lucrative source of revenue, the driver for this being an increased need for firewood.

Taking all of these considerations into account, the Hungarian study revealed that the quantities of available feedstock will probably decrease by as much as 60% between 2015 and 2025. In each case, the main feedstock was identified as being maize stover and, in this respect, it was estimated that ABU deployment would require 21% of this biomass in 2015 and 62% in 2025, respectively.

According to the modelling results, a realistic feedstock supply for an ABU deployed in the Hungarian study region in 2015 would be:
• Maize straw: 120 kt DM (80%);
• SRC: 15 kt DM (10%);
• Hardwood: 15 kt DM (10%).

Figure 9 – Dominant land use in Beauce (wheat straw). © Andreas Krappweis ■

On the other hand, in 2025, this feedstock would be less dependent on maize stover:
• Maize straw: 90 kt DM (60%);
• SRC: 30 kt DM (20%);
• Hardwood: 30 kt DM (20%).

Advantageously, the decrease in maize straw availability results in a diversification of feedstock supply, this being made possible by the flexibility of the upfront organosolv technology.

Cereal straws might not be sufficient to sustain biorefining in France

France is the biggest wheat producer in Europe (EU-28), producing 35 Mt of soft wheat in 2012, with central France being the region that produces the largest amount of this crop (16% of France's production). Therefore, the Beauce region is at the heart of the EU's wheat belt. Taking this into account, BIOCORE's case study in France was centred on this region, focusing on a 50 km radius biomass catchment area, with the centre being the town of Chateaudun.

Regarding the detailed nature of the feedstock in the French case study, cereal straw was mainly wheat with some barley straw. Also, the possibility of the introduction of miscanthus as a back-up source of biomass was also considered. To calculate the potential availability of straw, first the total amount of straw was calculated by multiplying cultivated surfaces by the known straw production per hectare, which for the study area currently represents 2.7 Mt (assuming 6.2 tons DM per hectare — straw and stubble). In a second step, competitive uses were deducted. These include:
• Animal bedding requirements (0.2 Mt), which is exported to border regions;
• Environmental issues (SOC maintenance): 2 Mt (75% of total production : 100% stubble and 66% of straw);
• Organic farming area (2%).

This resulted in 430 kt DM of wheat and barley straws available in this area for a proposed bio-refinery. This potential straw availability does not take into account social factors, such as the willingness of farmers to sell their straw. Therefore, this potential is considered as a maximum.

For the year 2025, straw production in the Beauce region has been projected to amount to 2.4 Mt (without taking into account straw on organic farming areas). Competitive uses are expected to be:
• Animal bedding requirements (360 kt), which is exported to border regions;
• Environmental issues (SOC maintenance): 2.0 Mt (100% stubble and 66% of straw);
• Other uses: 20 kt;
• Other feedstock: 15 kt of niche crops.

These additional competitive uses result in a potential availability of only 200 kt of straw for the proposed ABU in 2025. This surprising conclusion is actually linked to two key factors. First, the calculation to determine the quantity of straw that is actually extractable takes into account the straw that is returned to the soil to maintain soil organic carbon levels. According to agronomic studies and the replies of farmers in the study region, on average 66% straw is ploughed back into the soil for this purpose on an annual basis. Local farmers are very aware of the need to maintain soil carbon levels and are thus vigilant on this point. Second, in central France, 10-20% of the annual straw production is exported for animal husbandry purposes (*e.g.* bedding).

Although the use of alternative biomass was not accounted for in the French case study, it is noteworthy that hardwood could be extracted from a neighbouring forest (the forest of Orléans), which is currently not subject to exploitation. Moreover, it is possible that there is scope for dedicated energy crop production, for example SRC poplar. It is perfectly feasible to envisage the use of these feedstocks in a future BIOCORE ABU. Nevertheless, the work of BIOCORE researchers revealed that the feedstock needs of an ABU (*i.e.* 150 kt straw) in 2025 would be close to the technical biomass potential of the studied catchment area (*i.e.* a 50 km radius around Chateaudun).

	European union			India		
	France	Germany	Hungary	Sangrur		Fardikot
ABU capacity (kt)	150	150	150	150	500	150
Feedstock available in 2015 (kt DM)	430	Availability far superior to demand	700	2 500		650
% of total biomass used by an ABU in 2015	35	Wood extraction increased by 2.2 (HW) % and 2 % (SW)[1]	21	6	25	23
Feedstock available in 2025 (kt DM)	200	Availability far superior to demand	240	1 200		340
% of total biomass used by an ABU in 2025	75	Wood extraction increased by 2.0 %(HW) and 1.8 % (SW)	62	13	42	44
LUC impacts	1 Kha of miscanthus instead of wheat	none	1.4Kha of poplar instead of wheat or maize and 4 Kha of forest instead of wheat or maize	Not expected		Not expected

Table 2 – Summary of the case study results. Source: BIOCORE ■

[1]HW: hardwood; SW: softwood

STAKEHOLDER VIEWS ON THE BIOCORE BIOREFINERY CONCEPT

As part of BIOCORE's case studies, stakeholders from each region were questioned in order to capture their views on biorefining and to measure their level of acceptance of the BIOCORE concept.

A majority of stakeholders support the biorefinery concept and consider that it constitutes a promising solution for the substitution of fossil-based products. In most of the study regions, stakeholders consider the implantation of an ABU as a high-tech development that would be a source of skilled job opportunities. Additionally, stakeholders perceive the ABU concept as being resource-efficient, sustainable and of potentially high benefit for regional development.

Generally, stakeholders thought that the use of biomass in an ABU would be preferable to its use as a solid fuel for direct heating. Also, stakeholders displayed awareness of biomass use hierarchy, considering that advanced biorefining is a good way to get more out of biomass than just liquid fuel. When asked to compare the ABU concept to other recent developments, such as biomass-fired heat and power plants, stakeholders believe that the latter are a step in the right direction, but most preferred the idea of a biorefinery.

Stakeholder views in India

The stakeholders that were identified in India include representatives of the paper pulp industry, dairy units for fodder, cattle owners, transporters, aggregators and farmers. Overall, these stakeholders displayed interest in the general idea of putting surplus biomass to better purposes, but insisted upon the fact that any alternative exploitation plan would have to offer sufficient incentives. In the case of farmers, they were willing to abandon rice straw burning and participate in the collection of straw as long as this will lead to financial gains. Regarding the paper pulp industry, its representative insisted upon the fact that rice and wheat straw availability is strongly dependent on the presence of a robust logistic supply chain and suitable storage facilities. All industrial stakeholders declared that, although they were aware that the deployment of an ABU entails significant investments and the acquisition of complex technologies, they felt that the manufacturing of a whole portfolio of products by an ABU was an advantage compared to a biomass-fired heat and power facility, which only produces a low value product (*i.e.* energy). Finally, representatives of government authorities insisted upon the fact that their state was more than willing to promote and support the deployment of an ABU, providing that the technology was first adequately proven at pilot/demonstration scale.

All stakeholders greeted the idea of producing bioethanol from a crop residue with a considerable amount of enthusiasm. Petrol and diesel are recognized as valuable commodities across the globe and India is no exception.

POLICY MEASURES AGAINST RICE STRAW BURNING IN INDIA

The following introduction to an article that appeared in November 2012 sums up India's problem of rice straw burning and the increasingly perceived need for change:

"When the rice harvest season finishes in a few weeks, fields in India will turn black as farmers burn thousands of acres. This practice shows one of the failures of the Green Revolution, with devastating regional and global consequences. A food-security-obsessed India cannot ignore these issues for much longer."
(http://www.opendemocracy.net/openindia/amritpan-kaur/india-burning)

Following 2012's autumn harvesting and rice straw burning campaign, and the ensuing severe winter smog in Delhi, India's Environmental Pollution (Prevention and Control) Authority (EPCA) decided to order the state governments of Punjab, Haryana and Uttar Pradesh to ban rice straw burning. It is intended that this measure will be enacted under section 19 (5) of the Air (Prevention and Control of pollution) Act, 1981, with the aim to eradicate rice straw burning within a 2-year time frame. At the district level, authorities will issue notices before the harvesting period informing that burning of straw will be an illegal activity under the Indian penal code. To accompany this evolution in policy, the Indian federal government has notified that it will provide support in the form of a 50% subsidy for purchase of equipment, such as the Zero tillage machine and rotavator, which leaves less rice straw in the field compared to a conventional combine harvester.

Therefore, any bio-based product that could adequately substitute these fuels is likely to be put on an equal, or higher, footing than the fossil alternative. All stakeholders considered that an ABU dedicated to the sole production of bioethanol from cereal straws would also be quite acceptable, provided that it can be shown that this can be achieved in an economically-viable way and at a sufficiently large scale. This opinion was underpinned by the conviction that the local production of bioethanol would constitute an additional source of revenue for all of the stakeholders and a means to reduce the fuel imports, which is considered to be a significant burden on the exchequer. Finally, Indian stakeholders were enthusiastic about the fact that the CIMV technology produces a hemicellulose-rich stream that can be used directly as an animal feed supplement. The consumption of meat in India is rising and consequently the need for animal feed is intensifying. Importantly, rice straw *per se* is not perceived as being a good animal fodder source (although it is used as animal fodder in some southern Indian states), thus the idea of increasing the nutritional value of rice straw through biorefining is an attractive concept.

Figure 10 – Open field burning of crop residues. © TERI

Stakeholder views in Europe

Germany

German stakeholders proved to be very interested and open-minded when confronted with the idea of a wood-based ABU in their region. However, they were also aware that the deployment of such a facility would increase the demand for wood. Nevertheless, stakeholders confirmed that their region currently exports a large amount of wood and wood pellets and felt that the local deployment of an ABU would provide an opportunity to increase the value of the locally-produced wood within the region and thus generate greater economic benefits for the region. Stakeholders also underlined the fact that the regional wood pellet production plants are currently operating below their capacity (about 60% of capacity is exploited) and consequently new uses for wood pellets would be welcome. The pellet industry, which is well established in the region, would be very interested in producing biorefinery wood pellets if competitive prices could be paid. However, a main concern was raised by the stakeholders. This is related to the fact that log wood (mainly hardwood) is currently used for traditional domestic heating purposes in rural areas. Further enquiry revealed that most extraction takes place from state or communally-owned forests since rural communes are under political pressure to supply logs for domestic heating to households. On the other hand, privately-owned forests are generally not being exploited to their full potential. This is mainly due to the fact that private ownership is fragmented and so the forests areas owned by any single person are small. However, it is also clear that traditional heating (open fire, stoves etc.) in rural communities within the German case study region is undergoing a revival. The drivers of this trend are numerous and include the feeling of well-being and comfort that are derived from the use of open fires and stoves, the householder's desire for energy autonomy and the perception that this mode of heating is sustainable and supports local industry. Interestingly, the rather energy inefficient nature of domestic log burning fires does not appear to be perceived or admitted by the users and supporters of this traditional heating technology.

Hungary

Hungarian stakeholders representing the counties of Baranya, Somogy, Tolna and Zala counties, confirmed that the region boasts one of the highest forestry production levels in the country. Therefore, they believe that forestry in their counties can satisfy increased demand for wood. However, the plantation of dedicated biomass crops on unused land could extend diversity of the firewood supply. According to the agronomists, this would be a positive step in favour of biodiversity too. However, the Hungarian study region is also characterized by numerous hills and elevated areas, which limits the quantity of useful arable land. Moreover, droughts do occur in the region, though infrequently. Finally, it was rather difficult to ascertain yields of biomass in the target region, because exploitations are generally rather small and scattered, with pedoclimatic and geographical characteristics being quite variable. As a result, yields can apparently differ with those reported in the databases. Therefore, to correctly ascertain biomass availability in the study region it would be necessary to perform on site interviews with farmers. Overall, the stakeholders that were questioned prefer a balanced approach towards plant production and animal husbandry, where the latter is an activity that requires biomass for fodder and animal bedding. Therefore, it is probable that small scale biorefineries will be more acceptable in the Hungarian target region. This conclusion is further supported by the fact that the region is also equipped with a biomass-fired power plant that is already using regionally-produced wood and straw.

Overall, regarding the Hungarian case study, any future plans to implant an ABU would require the careful appraisal of the actual quantities of biomass that are currently available and what quantities will be available in the future, taking into account the development of competitive uses. Moreover, it is probable that it would be necessary to implement a cooperation-based, cascade system for biomass use, involving all of all the stakeholders, including those that develop competitive uses.

France

In the French case study, the capacity of the modelled ABU would be close to the technical biomass potential of the available biomass in the area in 2025. On the other hand, the existing supply chain for the collection, storage and commercialization of straw is a positive factor that argues in favour of biorefining.

One of the main challenges that a biorefinery activity would face in the French study region is the need to convince farmers to sell surplus straw within the framework of long term contracts (5-10 years). This is primarily because local farmers' attention is focused on grain production. Therefore, they are reluctant to envisage any commitments that might have a negative impact on grain yields in the future. Presently, most of the stakeholders (farmers, advisers, cooperatives) that were questioned believe that surplus straw export is risky, because it could ultimately harm soil organic carbon levels and thus jeopardise grain yield, even though agronomic models demonstrate the feasibility of increasing straw export. This conviction is likely to be reinforced by high grain prices that satisfy the economic needs and expectations of the farmers.

A BIOCORE BIOREFINERY IS NOT JUST ABOUT LOCALIZING BIOMASS – IT ALSO RELIES ON SUPPLY CHAIN LOGISTICS AND BIOMASS COSTS

Biomass logistics supply chains – lessons learned in BIOCORE

To implement an ABU in any given area it is necessary to build a cost-effective supply chain, which provides not only for biomass production and harvesting, but also collection, storage and pre-processing, in a manner that ensures a stable all-year supply of biomass to the biorefinery. To achieve this, it is vital to take into account a variety of factors, including geographical features, biomass seasonality, biomass transport and storage logistics, and the need for drying, all of which will contribute to determining the best location for a future ABU.

In BIOCORE, supply chain logistics were analysed in the framework of the case studies, accounting for all of the features that determine the way in which biomass is delivered to the biorefinery's gate. The approach relied on the collection of a large amount of data describing current (2015) and future (2025) scenarios, with respect to crop yields, biomass competitive uses, technical and economic aspects of biomass processing, and infrastructure logistics, including data on the quality and availability of transport options and the cost of transportation. To select best localizations for an ABU in each of the case study areas, an objective-oriented optimisation procedure was used, targeting cost minimization.

Overall, decisions regarding the choice of the biomass that will constitute the feedstock of an ABU will depend on a variety of factors. The first among these are linked to the production process itself and includes considerations such as seasonality, relative abundance and biomass quality. In the case of annual crops, biomass production must be sufficiently abundant to ensure an all-year round supply, and storage facilities must be dimensioned to cope with year round storage of large quantities of biomass, which obviously engenders higher infrastructure costs. On the other hand, the choice of a woody biomass feedstock is likely to require less storage capacity, but will necessitate more intensive biomass processing facilities, for example a biomass dryer and chipper. A combined feedstock composed of both cereal co-products and woody biomass constitutes an ideal solution from supply security and storage points of view, but implies heavier investment costs, for example to equip the ABU with two process lines.

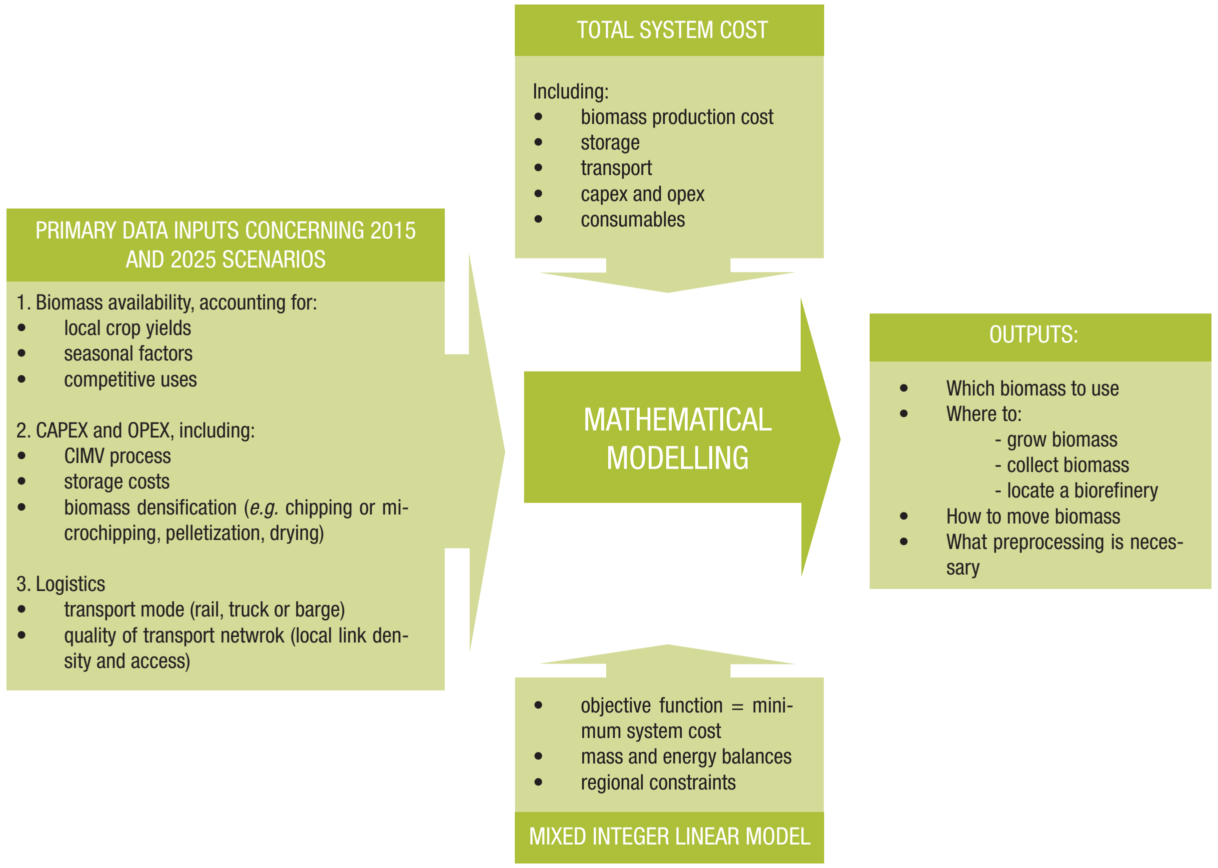


Figure 11 – Objective-driven modelling framework used to design the biomass supply chain in BIOCORE's case studies. © IMPERIAL

Long term supply stability (*e.g.* over a 10-20 year period) is a vital factor for the success of an ABU, and will in some cases justify a higher initial biomass feedstock cost. Unsurprisingly, to secure long term feedstock supply, it is wise to target feedstocks for which there are few, or no, alternative uses (*e.g.* rice straw in India). While dedicated perennial biomass crops, such as Miscanthus or SRC poplar, will also secure long term supply, the implantation of these crops will require carefully negotiated contracts between the ABU and farmers, which account for the inherent risk for the farmer. This risk is mainly linked to the fact that the presence of perennial crops severely comprises the farmer's short term decisional flexibility, removing his/her possibility to plant annual crops if these are more profitable.

The BIOCORE case studies also revealed that, whenever possible, it is advantageous to integrate an ABU into an existing biomass logistics infrastructure (*e.g.* localize a biorefinery close to a paper mill), since this will favour business economics, although there is always a risk of increased competition for the same biomass resources. In this respect, it is obvious that the implementation of ABU's, either in Europe or India, should be preceded by a careful appraisal of current and future scenarios regarding biomass use, and by early involvement of all relevant local stakeholders.

Specifically regarding the case studies that were performed by BIOCORE researchers, the analysis of biomass supply logistics revealed the following key points:

- In the French study, biomass availability was found to be currently sufficient to supply an ABU. However, it was clear that the supply catchment area could be quite fragmented, depending on whether and to what extent individual farmers would be willing to sell surplus straw.
- In the German case study, a clear integration benefit was identified, especially for access to existing hardwood chipping and pelletizing facilities, which are present in the region. Moreover, the presence of rail and fluvial transport options provided cost-effective alternatives to road transport.
- In the Hungarian case study, the establishment of a mixed feedstock composed of cereal co-products, woody biomass and dedicated crops provided the basis for cost optimized biomass transportation solutions and also offered a viable solution to avoid longer term biomass depletion. Moreover, the study of a mixed feedstock scenario revealed that this could be advantageous with respect to the flexibility of the product portfolio, since certain feedstocks will influence for example the overall volume of lignin produced per ton of biomass.

• In the Indian case studies, it was clear that the exact location of the ABU is a key factor, and must favour proximity to the biomass storage facilities. Nevertheless, future steps to promote the use of more efficient straw baling technology will progressively reduce the overall cost of the supply chain logistics. Moreover, quite clearly the industrial use of rice straw as opposed to in-field burning is an extremely positive driver in the Indian scenarios.

The origins of biomass cost in overall supply chain economics

The first source of biomass cost is related to all of the processes that permit the production of the biomass and its delivery to the boundary of the field. For cereal straws for example, this includes harvesting costs, but also accounts for the intrinsic value of the straw, assuming that it could be used as soil organic matter (*i.e.* replacing a certain amount of nutrients that would otherwise be purchased). Therefore, the minimum price for straw is the price that will compensate the farmer for these costs. In the BIOCORE case studies, it was estimated that nutrient costs account for 50-60% of the minimum costs, the rest being attributed to the harvesting and loading of bales.

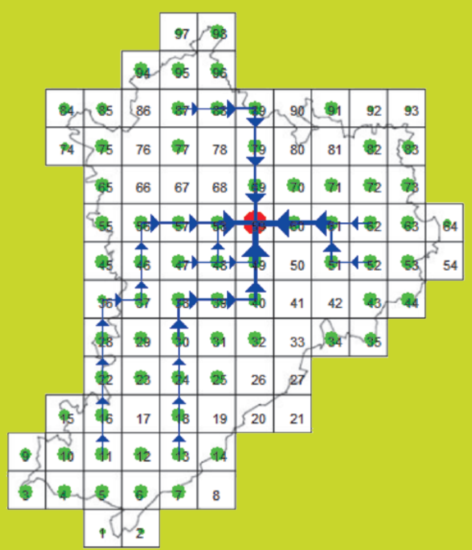
In other cases, biomass production costs can include felling and delivery to the roadside (woody biomass), or compensation for the use of land that would otherwise serve for the growth of another crop (*i.e.* in the case of dedicated biomass crops). In this latter case, assuming that a farmer has multiple choices of how to use land, it is necessary to identify the highest revenue option (*e.g.* wheat or maize in Europe), which will then determine the level of compensation.

The second cost contributor to the overall biomass procurement cost is composed of all the steps that define the transport and delivery of biomass to the factory gate, starting from the field boundary or roadside. In BIOCORE, to more closely assess this cost, taking into account knowledge gained from the case studies, two alternative transport scenarios were considered for each of the regions under study. For example, in the French region, the first scenario considered that biomass transportation would rely uniquely on road transport, while a second scenario assumed that rail transport could also account for a part of the supply chain. In India, the alternative scenarios were based on slightly different criteria, in as much that while both only considered road transport, the first one assumed that the straw would be only semi-baled, while the second scenario involves the introduction of advanced baling technologies.

Regarding the BIOCORE biomass production price estimates, the cost of Indian rice straw is the lowest, with an average price of approximately 29 € per ton DM. In Europe, production costs for wheat, barley or maize straw are higher, with average costs ranging from 40 to 52 € per ton DM. Moreover, it is noteworthy that according to BIOCORE estimates, wheat straw prices in India are similar to those in Hungary (40 € per ton DM), with the average price being 35 € per ton DM. In contrast, woody biomass is a more expensive feedstock for biorefining, although the origin of the wood strongly influences price. For example, while forest products could cost as little as 50 € per ton DM in western Hungary, these will cost on average 65 € per ton in the German study region. Moreover, when in situ wood chipping (*i.e.* before roadside delivery) is included in the price, this increases to an average of 70 € per ton DM, which is the same as the average estimated cost of dedicated crops, such as short rotation coppice poplar.

LOCALIZING A BIOREFINERY

Mathematical modelling performed in BIOCORE provided a way to identify the best localization for a biorefinery in any given geographical zone for which sufficient data is available. An outcome of this modelling is visualized in the figure. The area represented by the square of the grid is variable depending on the region understudy, but in this case it is 10 km². The ABU is symbolized by a red spot, while the biomass (*i.e.* wheat) producing zones are indicated by green spots. A snapshot of the biomass supply routes to the biorefinery is indicated by the blue arrows. This particular example represents a region (Beauce) in France's central cereal belt.



Biomass supply chain to an organosolv biorefinery in the Bauce region as derived from the optimisation modelling approach. Source: BIOCORE

Figure 12 – Transportation of feedstocks within Punjab. © TERI

Concerning the transport, processing and storage component of biomass procurement costs, it was generally ascertained that the use of transport modes such as railways can favourably influence overall costs. For example in the French and Hungarian studies, the smart integration of railways and trucks could produce up to 10% cost reductions. However, the use of railways is rendered difficult when the biomass production zones are scattered across a territory. In the German study this reduction was already intrinsic to the basic scenario, since the region under study is well-equipped with rail and fluvial infrastructures. Also, in the German study the proportional weight of transport in the overall procurement cost was lower, because the transport of woody biomass, especially dense derivatives such as pellets, is much more cost efficient than the transport of baled straw for example. Finally, in India, the cost of transport was found to be very much dependant on the availability of modern baling technologies that provide the means to make higher density bales. The complete implementation of baling in the two study regions was predicted to reduce the proportional weight of transport in the overall biomass procurement cost from 13 to 7% (Faridkot) and 25 to 21% (Sangrur) respectively. Figure 13 shows the breakdown of feedstock procurement costs into the contribution of biomass production and logistics. This comparison assumes for each feedstock in each case study that the full demand of 150 kt DM would have to be supplied solely with this feedstock, whereas in reality the supply chain model allowed a mix of feedstock.

Logistics cost results from the activities related to the biomass supply from the farm up to the biorefinery gate (*i.e.* storage and transportation costs) and is calculated from the optimal feedstock supply system cost sorted out per biomass type. Storage cost is calculated as a surcharge paid to the famer for the area of land used to store biomass; a nominal value of 24 € per ton DM of straw is assumed, although mass losses occurring during the storing period, inevitably worsen this figure. Transportation costs, being proportional to the delivery distance and the freight shipped, indirectly reflect current land use allocation, local biomass availability and the quality of the network infrastructure. The biorefinery localization would benefit from the supply of local biomass to reduce logistics cost, as is shown in the figure for poplar plantations in the Hungarian case, as opposed to the large fragmentation of barley supply zones in the French case.

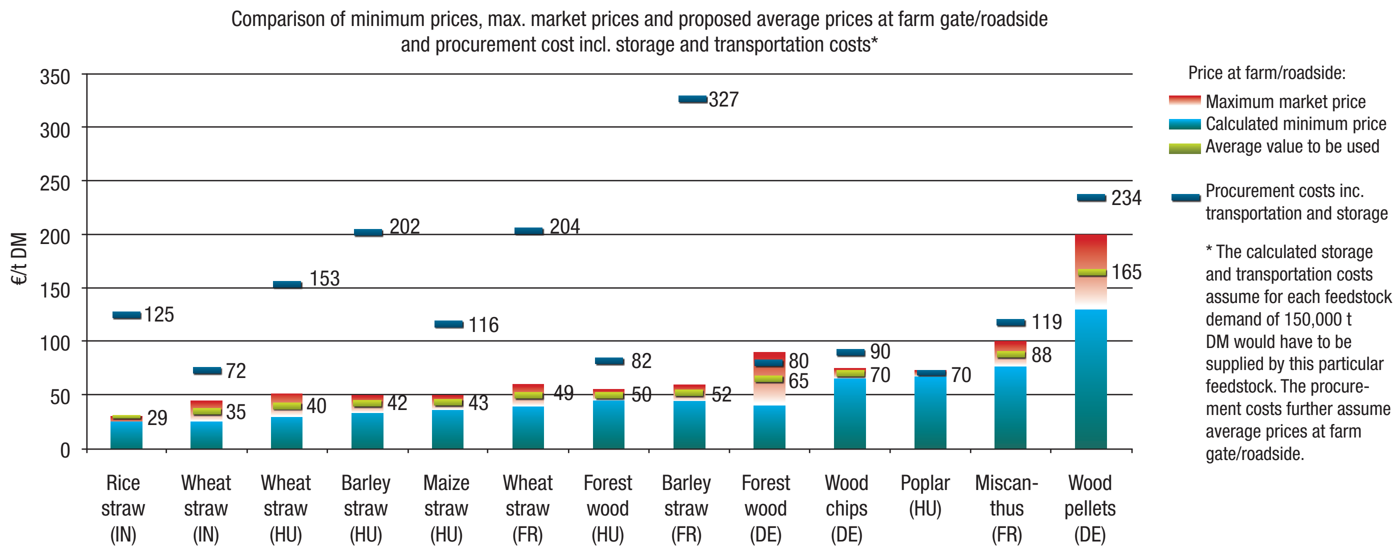


Figure 13 – Overall comparison of feedstock procurement costs. Sources: nova 2013, Imperial 2013

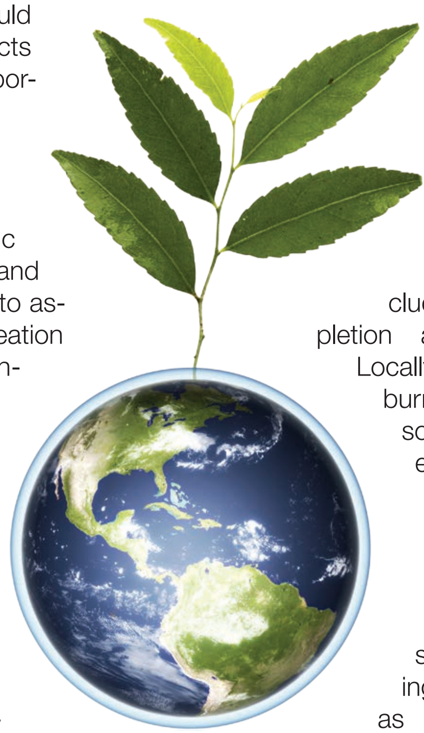
BIOMASS PROVISION WILL PRODUCE BOTH NEGATIVE AND POSITIVE ENVIRONMENTAL IMPACTS

An overview of potential environmental impacts related to biomass provision

Within the scope of the BIOCORE case studies, environmental impacts caused by biorefinery-induced production and/or extraction of biomass were studied in order to gain a first idea of how an ABU might influence its environment[3]. To perform this study, impacts linked to biomass production, harvesting, transport and storage were taken into account.

Overall, in Europe the impact of biorefining was to some extent always found to be negative for the environment, mainly because it is predicted that the implementation of ABUs will intensify forest exploitation, reduce the restitution of soil organic matter and nutrients, and generally alter crop rotations. However, in the Hungarian region this conclusion might not be valid, because if ABU implantation were to lead to afforestation of arable land, then land erosion would be mitigated and groundwater quality would be improved. It is also estimated that the establishment of an ABU would not affect European environmental priorities.

In the French case study, the probable increases in environmental pressures are all linked to intense farming, although the implementation of just one ABU is unlikely to have a significant impact on the overall analysis for a region that is already subject to intense agricultural activity. Nevertheless, it is noteworthy that the Beauce region is particularly sensitive to water issues, whether these be water pollution or water availability issues (*i.e.* a declining water table), so any new developments might amplify these problems. Possible water issues were also evidenced in the Hungarian case study, although this was mainly linked to a possible negative effect of an ABU on water quality rather than availability. Similarly, the Hungarian study revealed that negative impacts on soil would be engendered by straw extraction. Interestingly, because the Hungarian scenario included the plantation of short rotation coppice poplar, a land use change (LUC) issue was also generated. However, although the LUC was seen as a loss of food-producing capacity, it was also observed that it could have positive impacts by reducing the exportation of soil organic matter and improving soil biodiversity. The impact of LUC on macroscopic biodiversity (fauna and flora) was less easy to assess, since the creation of SRC poplar plantations will increase the number and diversity of habitats, but will also intensify forestry operations that can disturb wildlife.



In the German case study, the forest scenario obviously did not produce the same impacts as those observed for the French and Hungarian cereal-based scenarios. However, it was predicted that soil quality would be affected by the implementation of an ABU, notably because of the fact that an increase in wood extraction will diminish the return of nutrients to the forest soil and will increase effects linked to mechanized activities in the forest environment (*e.g.* soil compaction and erosion).

In the Indian scenarios (the Faridkot and Sangrur case studies), the establishment of the ABU produced an overall impact that was quite different from those observed in Europe. The Punjab state is a territory that is under quite intensive agriculture and rice-wheat cropping system (RWS), which already puts the environment under pressure. The main sources of this pressure are linked to the fact that rice straw is burnt in the field, although they also include water depletion and pollution. Locally, rice straw burning degrades soil biodiversity, exports vast amounts of soil carbon and is the cause of significant gaseous emissions, including GHGs, such as methane and NOx. As a result, the implementation of an ABU in Faridkot or Sangrur was predicted to have very positive environmental effects, both on air and soil quality, since the burning of one ton of rice straw produces 1.46 tons of CO_2 and 60 kg of

CO, as well as particulate matter, SO_2 and other hazardous gases (including methane and NOx).

At the same time, the EIA did not reveal any significant negative effects, such as ground water depletion or salinization. Indirectly, having a valuation for rice straw will encourage farmers to continue growing rice. Importantly, the establishment of an ABU in Punjab state is predicted to have no negative impacts on Indian environmental priorities, but instead will support recent legislation banning rice straw burning.

For all of the case study scenarios, the implantation of ABUs obviously had negative impacts on territorial GHG emissions linked to the biomass extraction, transport and storage processes, since new industrial activities inevitably lead to extra emissions, which are due to an increased use of fossil fuels (mainly liquid motor fuels). However, the amount of GHG emissions linked to biomass extraction, transport and storage was actually proportionally quite low when compared to the energy needs and GHG emissions required to produce biomass and the associated inputs (*e.g.* fertilizer). Therefore, the extra emissions linked to the extraction of cereal co-products has to be somewhat relativized. This is particularly true in the Indian example, in which the feedstock for the ABU is a default, unused product of the rice-wheat cropping system.

Is it possible to offset ABU-related negative environmental impacts?

Any strategies aimed at mitigating the negative impacts of biomass provision have to be directly related to the impacts caused by the implementation of an ABU. As noted above, in the European case studies the environmental pressures and impacts caused by the establishment of an ABU are mainly related to the intensification of production and extraction processes, whether this is the extraction of stemwood from forests or cereal straws from the field. The generic effects of these processes are the degradation of soil and water quality, a risk for biodiversity (fauna, flora and/or microbial diversity) and in the case of dedicated crops, a loss of crop rotation and thus the ability to produce food or feed, due to the plantation of a perennial crop.

The preventive actions that can be implemented to mitigate such effects are numerous and diverse. In the case where the feedstock of the ABU is woody biomass, it could be feasible to reduce the use of stemwood by using other forestry co-products, such as branches or sawmill co-products. Nevertheless, importantly, in the case of the BIOCORE ABU, the use of branches will be difficult because of the requirement to debark the incoming wood resource before organosolv refining. Likewise, in the field of forestry, mitigation can also call upon forestry management practices that guarantee the integrity of forest resources and if possible improve them. In this respect, it is noteworthy, that recent evidence suggests that the European forest-based carbon sink could be nearing saturation and that new forest management policy might be part of a strategy to avoid this[4]. Similarly, poorly managed or neglected forests are a fire risk in some areas of Europe, notably in France, Greece and Portugal. Therefore, good management practices that involve a controlled extraction of woody biomass can provide a means to maintain the carbon sink potential of the forest and mitigate fire risk. In the area of cereal-based agriculture, mitigation can involve the use of new agricultural techniques, such as reduced or no tilling methods. Likewise, when the establishment of an ABU involves straw extraction, mitigation can be achieved by fixing strict return to soil minima. Although a rather simple, somewhat arbitrary answer to a rather complex problem, the return of 70% of crop residues would provide a reasonably good guarantee that in most cases soil organic carbon is maintained. Other measures could include circular practices, such as the return of minerals (phosphorus, potash, silica etc.) after the biorefinery process, providing that this can be achieved without engendering unreasonable energy expenditure linked to long distance transport

[3] In BIOCORE, the whole biorefinery concept is also being submitted to a multi-criteria sustainability analysis that includes life cycle analyses (LCA) and elements of environmental impact assessment (EIA). The results summarized in this report form part of a separate EIA on biomass production.

[4] Nabuurs, G-J et al. 2013. First signs of carbon sink saturation in European forest biomass. Nature Climate Change 3, 792–796.

of minerals between the ABU and the field. Another mitigation strategy that can be applied to all biomass feedstocks, is to better arbitrate between competitive uses. For straw, this could result in a reduction of the straw that is allocated to livestock husbandry, which implies that this industry would have to identify an alternative to straw, or that livestock production is reduced. For wood, this could involve the reduction of wood use for inefficient domestic purposes, such as open fire burning (*c.f.* findings of the German case study). To implement these measures, it will no doubt be necessary to introduce policy that better defines how biomass should be used, proposing a hierarchical scheme that favours for example the use of biomass to make carbon-dense products, rather than combustible materials, or if energy is the target, favouring liquid fuels for transport over static heat and power generation.

Finally, regarding dedicated biomass crops, mitigation could involve the reduction of LUC effects. To achieve this it will be necessary to develop an appropriate regulatory framework that specifically treats the issues of dedicated biomass crops at the project or regional scale levels. This legislative framework should define the mechanisms to minimize direct and indirect LUC effects and the loss of food/feed production capacity, and should be applicable to all projects that use biomass as a feedstock, including combined heat and power plants, biogas plants, biorefineries, etc. Moreover, regarding LUC, policy should also take a wider view and provide a basis to compare LUC linked to, for example, a biorefinery project with that associated with urbanization. In this respect, it is note worthy that urbanization is one of the major sources of arable land loss in Europe. In the decade 1990-2000, Germany lost over 200,000 ha and France lost approximately 180,000 ha.

SOME KEYS TO BUILDING A SUSTAINABLE BIOREFINERY BASED ON A STRONG BUSINESS

One of the critical features of any project that relies on the use of biomass is the security of the biomass supply chain. Therefore, a biorefinery project can only become financially viable if it is associated with a feedstock provision plan that secures biomass supply for at least a 10-year period. It is only when this condition is fulfilled that a project can become eligible for financial support by the investor community. Other critical factors include the appropriate localization of the biorefinery activity and the adoption of adequate technology.

Choosing the right biomass feedstock

The ideal ABU will confer the highest added-value to the incoming biomass, while operating with minimal costs. To achieve this, one needs to consider the scale of the ABU in relation to the critical investment and operating costs, and make strategic choices regarding the product portfolio. To manufacture low value-added products such as biofuels, a large scale ABU with a significant feedstock supply is necessary, while a smaller ABU operating with a smaller amount of feedstock could be well-adapted to the manufacture of high value products (*e.g.* specialty chemicals or cosmetics) for limited size markets (figure 14). Obviously, the availability of an abundant source of low-priced biomass argues in favour of large scale ABUs, as is the case of sugarcane in Brazil. However, in the current period of rapid change, biomass prices are increasingly volatile and susceptible to changes in the future. Therefore, the construction of sustainable ABUs in Europe requires careful planning and dimensioning. This latter aspect was taken into account in the BIOCORE case studies.

Component (% dry weight)	Wheat straw	Rice straw	Hardwood	SRC poplar	Miscanthus
Hemicellulose / xylose	21	21	29	21	19
Cellulose / glucose	36	36	46	48	42
Lignin	20	15	23	24	23
Sum of usable components	77	77	98	93	84
Ash	6	15	0.5	2	2
Others	17	13	1.5	5	14
Moisture (% weight)	10-20[A]	10-20[A]	40-60[B]	47-55[C]	20-50[D]

A –baled straw, Liu et al. Energy and Power Engineering 3 (2011)325-331; B - freshly felled, C - Pearson et al. Industrial Crops and Products 31 (2010) 492–498; D – http://www.seai.ie/Publications/Renewables_Publications_/Bioenergy/Miscanthis_Factsheet.pdf

Table 3 – Composition of assessed feedstocks. Source: IFEU 2013

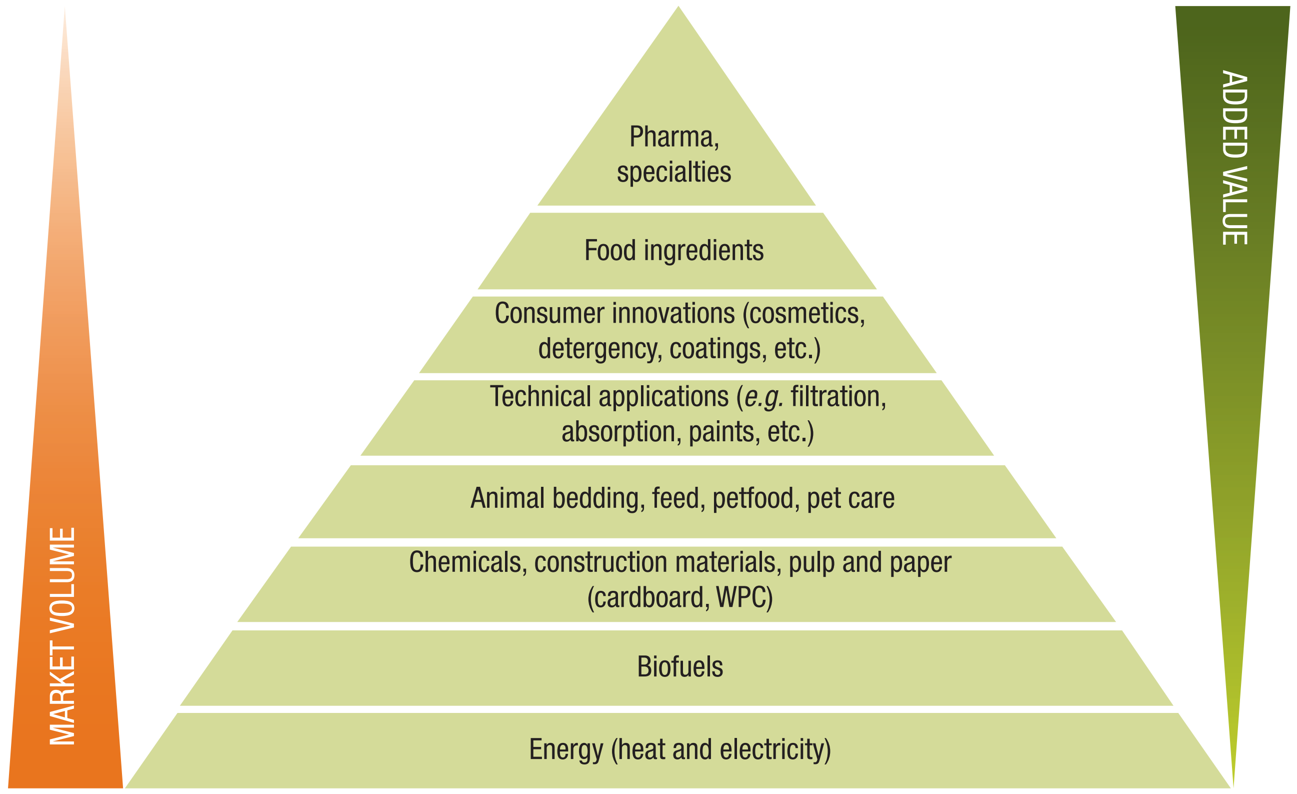


Figure 14 – Biorefinery product portfolio. © CAPAX

Beyond the question of biomass prices, the choice of a feedstock for biorefining should take into account the intrinsic characteristics of the biomass, preferring biomass that is most suited to the refining technology and the products that are targeted. Moreover, feedstocks that provide specific value that is not obtainable from non-sustainable resources should be preferred. Table 3 shows some of the characteristics of the biomass feedstocks that were considered in BIOCORE. All of these resources are suitable for the organosolv technology, but they differ in the relative proportions of the valuable components (*i.e.* cellulose, hemicelluloses and lignins). Clearly, if lignin-based products are identified as the products that generate the highest added-value, then it might be pertinent to privilege the use of woody or dedicated biomass crops, rather than wheat straw in order to maximize the yield of lignin. On the other hand, accounting for the fact that certain biorefinery technologies, such as the one operated by CIMV S.A., require the use of quite dry feedstocks (*i.e.* moisture content ≤15%), it might be judicious, for example, to favour the use of cereal straws in order to avoid the need for costly drying facilities. Nevertheless, although wood is quite moist at felling, depending on climatic conditions, some drying can be achieved at the roadside, so the actual moisture content of wood entering an ABU is likely to be near to 30%.

Target market demand as the business driver

In BIOCORE, the aim was to develop a fully sustainable biorefinery concept, considering equally all elements of sustainability. Nevertheless to initiate a biorefinery project it is clear that market demand for the products and services will be a determining factor. Therefore, at the outset, the sustainability criteria need to be translated into concrete and attractive targets that can form the basis for a business case. These targets can include products that directly substitute existing ones, new products with new technical properties and perhaps new uses, and/or services, such as local or global environmental benefits that can be quantified and thus rendered visible to the different stakeholder groups. Among the considerations that underpin the identification of market demand are questions concerning the size of the market, the level of demand and the added-value for investors in terms of ROI and ROE), issues that are being investigated elsewhere in the BIOCORE project. Overall, to demonstrate that end-user markets exist, and thus prove the bankability of an ABU project, it is necessary for the would-be entrepreneur to secure long-term take-off agreements with future clients (end-user companies).

Select the right location for an ABU

The BIOCORE case studies also partially revealed the importance of location. Quite clearly, beyond the question of biomass localization, the exact choice of a site to implant an ABU also depends on other factors. These include a whole range of issues, such as the presence of an appropriately skilled labour force, the quality of local transportation infrastructures and the proximity to end-user industries. Regarding infrastructures, the case studies performed by BIOCORE researchers in India illustrate a key requirement for the implementation of ABUs, which is adequate storage capacity. In principle, in the Punjab state as a whole biomass storage facilities are adequate. However, in certain localities it could be necessary to increase storage capacity in order to reduce costs associated with transport of biomass from the storage site to the ABU. Other factors might include the existence and nature of specific policy and stability thereof, and the appetite of local stakeholders to participate and possibly invest in an ABU project. This last point was very clearly perceived during the BIOCORE case studies and thus early stage local stakeholder involvement is undoubtedly recommendable.

Account for the expectations of biomass suppliers

Persuading local biomass producers to diversify their business model to include the production of biomass for biorefining is unlikely to be straightforward in the majority of cases. This is because many farmers and forestry owners will be mainly concerned about securing their primary revenue, which corresponds to their current business activities, and/or protecting their assets. For example, the main concern of a cereal producer is to ensure that grain yields remain stable (or improve) over time. Therefore, any modifications to farming practices, such as a reduction in the amount of organic matter and/or nutrients returned to the soil will obviously provoke a certain measure of hesitation, or even resistance. Regarding forest owners, concerns will be different from region to region. However, many small forest owners, for example in France, whose assets often form part of a family patrimony are likely to display concerns about the potential degradation of the forest environment and/or the financial risks involved.

Overall, with regard to potential biomass suppliers it is necessary to bear in mind stakeholder concerns and expectations. Notably, biomass suppliers will wish to obtain the best price for their biomass, even if the biomass previously had little or no value. Moreover, farmers and forestry owners will require guarantees of prompt payment and fair agreements that account for unforeseen business developments (*e.g.* all parties benefit, or suffer, from fluctuations in profits). Finally, the biomass supplier will also prefer to obtain flexible conditions with regards to the quality of the delivered biomass and will require guaranteed all year round take-off.

Select the right technology

The technological choice for an ABU is a difficult matter, since this will largely depend on the product portfolio that is targeted. In BIOCORE, the choice of organosolv technology was driven by the requirement for near-optimal use of the incoming feedstock to provide biomass intermediates that can be converted into a wide range of products. One of the major strengths of the two organosolv technologies that have been tested and operated in BIOCORE resides in the fact that several different feedstocks types can be used. The Hungarian case study illustrates this point and shows how the use of an appropriate technology might secure a long-term supply of biomass even in a region where the amounts of individual biomass categories are likely to be limited. Once the suitability of a technology has been established, it is also necessary to consider its maturity. An indication of technological readiness is the number of operational hours, which should be at least 7500 h to constitute a solid demonstration.

FINAL COMMENTS AND SUMMARY OF RECOMMENDATIONS

The case study research performed within the framework of the European FP7 project BIOCORE has revealed the following key points:

- There is a considerable reserve of available biomass in both Europe and India. However, to better ascertain whether biomass is available as a biorefinery feedstock it is necessary to perform a detailed and exhaustive regional-scale analysis, accounting for competitive uses and available supply chain logistics and taking into account the fact that biorefinieries will need to operate for 10-20 year periods.

- It will be possible to secure a biomass feedstock for biorefining in target European and Indian regions, but this will be subject to a certain number of environmental, economic and social limitations that must be carefully considered before biorefinery projects are launched. Positive or negative environmental effects of increased biomass extractions depend very much on the specific location and biomass scenario.

- Supply logistics form an important part of total feedstock procurement costs. Therefore, optimization of regions in terms of available modes of transport and storage facilities is vital for the establishment and growth of biomass-based industries.

- The implementation of advanced biorefineries will more often than not be associated with negative environmental impacts. However, through careful analysis and planning it is conceivable that many of these can be offset without jeopardizing the biorefinery activity.

- Biorefineries that are designed to operate with diversified feedstocks will have a clear advantage over those that are depend on single biomass resources. Feedstock diversification procures long-term supply security and diminishes the negative impacts of, for example, unforeseen freak weather conditions and seasonality.

- Stakeholder support for the advanced biorefinery concept is generally strong, with biorefining being perceived as a source of new wealth and jobs and a sustainable solution for the future. However, to implement biorefining as a viable industrial activity it is necessary to ensure early involvement of relevant stakeholders, notably biomass producers, and provide clear profit guarantees and fair contracts to ensure the sustainable supply of raw material.

- Competition for biomass will arise from a variety of sectors, but biomass combustion either in the domestic environment or in dedicated heat and power plants will be a significant part of this. However, it is noteworthy that today the viability of biomass-fired power plants generally depends on subsidies, and in the long term these units will not procure sufficient added-value to increasingly precious biomass. Therefore, the future of biorefining is partly dependant on future policy decisions regarding the use of biomass, and notably its carbon component. Specific policy support and subsidies for energetic uses will not favour the use of biomass for the production of chemicals, materials and other specialty products.

- The establishment of advanced biorefineries will largely depend on whether solid business cases can be developed. To achieve this, it will be necessary to take into account biomass supply issues and market opportunities, and identify robust operationally-proven technologies.

ANNEXES

The annexes to this report are only available in electronic form. These can be obtained at the following address:

http://www.biocore-europe.org/page.php?optim=reports-and-public-deliverables

D 1.1 Availability of LC biomass types of interest in the study regions

D 1.2 Assessment of procurement costs for the preferred feedstocks

D 1.3 Understanding the agronomical and environmental impacts of alternative constraints on practically realisable production scenarios in the regions of interest - Environmental Impact assessment

D1.4&1.5 Description of alternative supply chains and their performance measures for the biorefinery and for a time-phased, scaled up biorefining industry validated through regionally specific models

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GLOSSARY OF TERMS USED

ABU – Advanced Biorefinery unit

DM – Dry matter

EIA – Environmental Impact Assessment

EPCA – Environmental Pollution (Prevention and Control) Authority

GDP – Gross domestic product

GHG – Greenhouse Gas

HW – Hardwood

kt – thousand metric tons

LUC – Land use changes

MAI – Mean Annual growth Increment, or annual surplus growth

Mha – million hectares The BIOCORE project

Mt – million metric tons

NOx – Nitrogen oxide

ROE – return on equity

ROI – return on investment

RWS – rice-wheat cropping system

SOC – Soil Organic Carbon

SRC – Short Rotation Coppice

SW – Softwood

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