TBP01x - 1.3 - Feedstocks

Welcome to this unit about feedstocks.

The choice of feedstocks is an important factor in any production process, but especially in sustainable biobased production. Why do feedstocks need to be renewable and which types are available? How to select a source, and how to use the sugars that are present inside the feedstocks? and how can we ensure a choice that is sustainable?

Before the industrial revolution , when we discovered the potential of fossil fuel resources , we used agriculture, fishery and forestry for all our needs, including transport, light and heat and products.

In a way, a biobased economy helps us to return to this principle. Why is that beneficial? Implementing the biobased economy helps us to close cycles, such as the carbon cycle. We can use renewable crops and residues for our needs without emitting large volumes of greenhouse gases into our atmosphere. Of course, in comparison to 100 years ago, our energy and material demand per capita is much higher. We therefore need smart solutions to effectively use renewable energy and crops and residues to provide for our needs now and in the future. For example through optimizing yields of biomass production and making sure we use the biomass in a very efficient way.

When we look at feedstocks, there are many different types to consider. There are food crops such as corn, sugar cane, and oil palm. Of course, we primarily need these to provide food. In order not to compete with this too much, we would like to use the residues left over after these food crops have been harvested and processed. A third category consists of dedicated energy crops that are specifically adapted to provide for our energy and product needs, such as plants that grow fast, or have a low water or nutrient need. Examples are switchgrass, energy cane, elephant grass (miscanthus), jatropha and agave. Then, there are wood crops and forestry residues. A fifth interesting source of feedstocks are municipal and industrial waste streams.

The different feedstocks are often divided into categories. When the nutritional part of a food crop, such as the corn cob, is used for production of energy and products rather than food purposes, then this is referred to as 'first generation' biomass. 'second generation' includes using the residues of food crops, but also dedicated energy crops, wood, and waste materials. At present we have commercial production of first generation biomass. The sugars that are so readily available from these food plants are used for the fermentation process. To use the preferred second generation feedstocks more technology is needed to unlock the more hidden sugars in the crop residues or woody plant materials. That is expensive. Worldwide millions are spent to improve the technology and so to enable the commercial use of second generation feedstocks.

The generations also differ in other characteristics. While the food part of food crops have easily digestible sugars, the sugars captured in lignocellulosic compositions of second generation feedstocks are more difficult to utilize. So why do we want to use these more challenging second generation feedstocks? This is to reduce competition with food, arable land and water. Using residues can help to avoid land use changes, and energy crops can be engineered to reduce water usage for example. It can also provide more income for farmers. In the future water based feedstocks such as algae may become important as 'third generation' feedstocks. Such systems would completely eliminate the need for agricultural land.

Given that we have so many options for feedstocks, how do we select the most suitable one? Three factors could be identified that have an affect on this choice. First, the biochemical composition of the biomass itself is an important factor- what is the content of sugar and other components? Second, it is important to assess the yield of biomass per hectare, and the yield of sugar per tonne biomass. This, of course, is influenced by the biochemical composition of the feedstock. And third, the sustainability of the crop, including land and water use, fertilizer needs, ecological and social aspects, and green house gas emissions associated with the production and harvesting of the crop. Together, these aspects affect the overall business case, and amongst others determine whether the business case is sustainable in terms of costs and revenues.

As was explained before, there are general differences between the biochemical composition of first and second generation biomass. Even within one category, such as agricultural waste, there are clear differences in composition. Corn cobs have a relatively low lignin content, while cotton stalks contain a high percentage of cellulose. This is important, because the biochemical composition will be reflected in not only the yield of sugar per tonne biomass, but also in the number and intensity of pretreatment steps early on in the process.

When a feedstock is selected based on yield, the first yield that is considered is the tonnes of biomass produced per hectare. Second, the amount of sugar that is extracted per tonne of biomass. Later on in the process, each tonne of sugar will yield a certain amount of product. Yields differ between feedstock categories, specific crops, and even between different soils and climates.

To give you some insight in the variability in yields, here are some figures of crops from different geographical locations. Here you see their biomass yield per hectare, the yield of seed or grain, and the biofuels energy that can be gained from their sugars, lignocellulose, and residue. Later, you will learn how to calculate how much of a certain product you will be able to form based on these yields.

Sustainability is one of the drivers behind the switch from a fossil-based to a biobased economy. When selecting a feedstock, it is therefore important to realise what effect this choice will have on the sustainability of the process. Sustainability of feedstocks is an important but rather complex field. What are the ecological effects of producing the crop, including its effect on biodiversity and long-term water and soil quality? How does the production of a particular crop compete with available resources, such as arable land and water? And does it compete with food supply, what is the impact on local employment? These are social effects that we need to take into account. Further on in the process, the choice of feedstock will also influence the green house gas emissions associated with harvesting and processing. There are many aspects of sustainability that we need to take into account, both in the feedstock selection and in the rest of the process.

Thinking along these lines, much research is being done into dedicated energy crops. Plant breeding is applied to allow for more sustainable biomass production, for instance by increasing yields per hectare while reducing the use of water. They can also be selected and adapted to grow on marginal soils, or in between cropping cycles of food crops to improve soil quality. Another factor that is considered is selecting crops that are native to a certain region.

The focus of this course is on the use of second generation feedstocks. So what part of this lignocellulosic biomass can be utilized by microorganisms? The useful part contains cellulose and hemicellulose. These are both chain polymers, but there is a slight difference in the types of sugars of which these polymers are composed. Cellulose is easiest to utilize because it contains only 6-carbon sugars, like glucose, which most microorganisms can naturally digest. Hemicellulose contains these same C6 sugars, but is also partly composed of 5-carbon sugars. Many microorganisms used on a large scale in industrial biotechnology cannot naturally metabolize C5 sugars, and have to be engineered to do so in order to utilize the full potential of the biomass. The other part of plants is lignin , a complex and irregular polymer that is tough by design – it is made by the plant for structure and rigidity, and to protect it from its environment. Lignin can therefore not be digested by most microorganisms used in biotechnology.

To release the sugars for fermentation, the plant structure, consisting of cellulose, hemicellulose and lignin first has to be opened up to create space around the cellulose and hemicellulose chains. In the step, the often insoluble lignin can then be removed from the sugar polymers. Finally, in the third step, enzymes are added to hydrolyze these polymers to release their sugar monomers, which can then be metabolized by microorganisms.

This course focuses on producing biobased products using fermentation. Of course, there are other options than hydrolysis to open the plant structure and fermentation to process biomass for energy or products. For example through gasification to make 'syn-gas' or by a process called pyrolysis which produces bio-oils.

Concluding, in order to select the most suitable feedstock and processing method, engineers have to take all aspects into account. Only then can a process be designed that is economically and environmentally sustainable.

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