BY EVA BELTRAN

UNDER THE GUIDANCE OF MRS SAMORÌ

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Renewable Resources

VALORISATION OF FOOD WASTE INTO BIOFUELS

ABSTRACT : the objective of this review is to link two major environmental concerns : food waste, and lack of resources to produce fuel. To this end, it gives some examples of how food waste can be used as biofuels.

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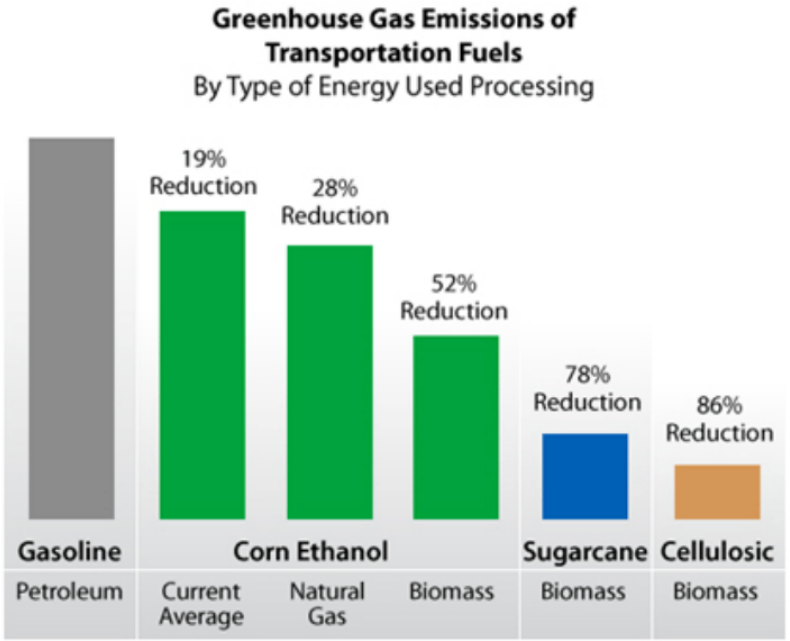
INTRODUCTION

Food waste can be either the by-products coming from the process of a food product, or the whole food product damaged, which has lost nutrients and quality and is then unmarketable. Most of the time, the food wasted contains valuable compounds that we can use for other applications like for example in the field of energy (biofuels), which is the most pollutant sector of human activity, particularly in terms of greenhouse gases emission. To obtain those compounds, we can use the biomass, particularly the lignocellulosic one coming from several industries like agriculture or food processing [5]. It is on one hand more sustainable but this is also more economic because this kind of raw material is abundant and cheap [5]. Bioethanol is one of the main alternatives to petroleum, used for transportation for example (brew). Biodiesel is also largely used because it is non toxic, biodegradable, and carbon neutral [6].

All those advantages made me think deeper about this subject, because finding an alternative to fossil fuel is needed to limit our greenhouse gases emissions, and prevent global warming to rise more than 2°C according to te Paris Agreement that we have to respect.

Moreover, the management of those wastes, which are full of organic compounds, can be difficult and energy demanding. This improvement can allow us to reach the goal of SDG 12 fixed by the United Nations, willing a change in the way we produce and consume goods and natural ressources.



FISH INDUSTRY WASTE [1]

Transport
Biodiesel
Up to 96% yield
Same properties
Methanol

Fish industry has a tragic impact on the environment for many reasons. Its waste is full of organic and inorganic compounds as well as chemicals, coming from the food and medication the fishes eat. It impacts ecosystems and pollute water. In 2000, we could count that over the 131 million tons of fish produced, 26% is not edible : it represents a lot of effluents which need to be managed.

Those by-products are commonly used for cosmetics, supplements or animal feeding but here we are focusing on biofuels. As fish waste contains a high amount of oil, it is relevant to use it for transportation diesel fuel.

Before being used, it has to be treated to break the organic chains. For that, the oil is filtrated and put in a reactor for one hour at room temperature with an oxidant and a catalysts (***Figure 1***). This process is repeated two times but the second one is shorter and doesn't require catalysts.

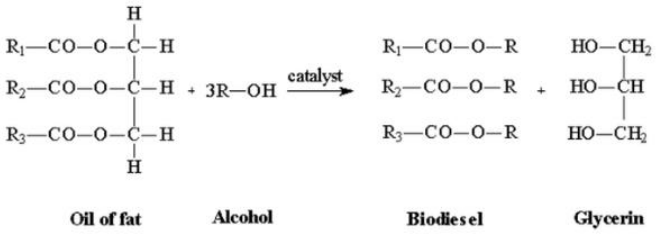


Figure 1 : production of biodiesel from oil

With this method, 95 to 96% of fuel is obtained, and the properties are similar to those of usual diesel. It doesn't produce toxic compounds as sulphur oxides or pollutants as polyaromatics and greenhouse gases like CO2.

COOKING OIL WASTE [2]

This waste comes from food processes using lipids (to fry potatoes for example), which are oils (corn, coconut, olive...) or margarine for vegetal products, or butter, and other oils (from fish for example) to talk about animal-based products.

Biodiesel
Lipids
Transesterification
Low yield/efficiency

Those compounds are useful to produce biodiesel and are collected mostly in restaurants but can also be found in special bins of usual houses. It is interesting to valorise this waste because it can substitute fossil fuel but also reduce water and soil pollution as well as protect ecosystems threatened by landfilling.

The process to form biodiesel is a transesterification helped by a catalyst, using methanol (cheapest alcohol) to run this reaction (***Figure 1***). The principle is to reduce the triglycerides of the lipid in glycerol, which is done in three steps : each one releases an ester. To improve the sustainability of this process, methanol can be replaced by ethanol coming from renewable resources, but it will increase the cost. The last step consists in removing the by-products (crude esters and glycerol), and it is carried on by gravity, centrifugation, or decantation.

However, using cooking oil waste have some cons. First of all, it implies an ethical problem because they are edible and using it to produce fuel prevents the population suffering from hunger from profiting. Moreover, te yield is not so good, and it is more expensive to produce, and less efficient than usual fossil fuel. Improvements have to be made. To finish, a lot of treatments are needed for the oil because some compounds are undesirable like water which can cause hydrolysis so has to be removed by evaporation, heating the solution (under vacuum if needed). Free fatty acids are also present, leading to the risk of saponification (***Figure 2***), have to be eliminated by chemical reactions (esterification (***Figure 3***), neutralization...), and also random solid compounds removed by filtration or centrifugation.

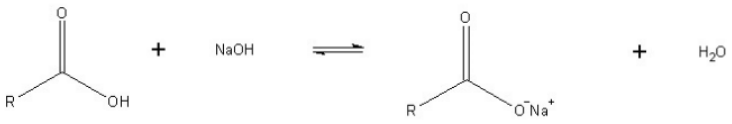


Figure 2 : saponification of a free fatty acid

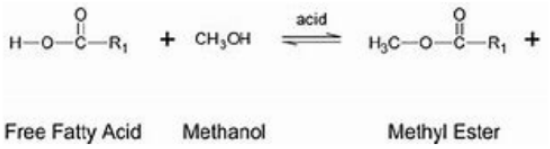


Figure 3 : esterification of a free fatty acid

FRUITS AND VEGETABLES WASTE

Even if we can obtain ethanol from fruits and vegetables waste, two main drawbacks have to be taken into account. First of all, the combustion of biofuel obtain is not complete and leads to undesirable deposits. On another hand, the oil obtain is way thicker than the one we usually use so it can complicate the applications. We will study anyway three methods to recover this kind of waste which seemed relevant to me [2,3,4].

Bio-ethanol
High viscosity
incomplete
combustion

01 Citrus wastes [3]

Swedish laboratory

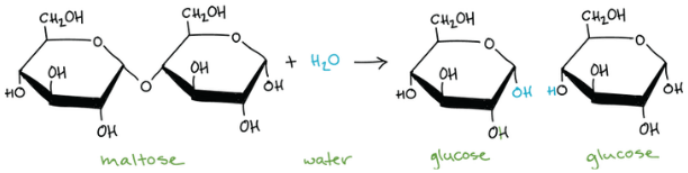


Figure 4 : example of an hydrolysis of carbohydrate into sugars

The process is set up on orange peels and consists in an enzymatic hydrolysis of carbohydrates to produce sugar (***Figure 4***) which is fermented into alcohol (particularly ethanol: it's a biogas). A mixture of enzymes : cellulose, pectinase and b-glucosidase, proved to be efficient.

In any case, limonene contained in this kind of waste has to be removed by filtration or steam stripping because it is a toxic compound for microorganism, lowering the activity of enzymes and therefore the yield. At the end of the process, some non-fermentable sugars ans residues are still present so they are used to feed cattle to reduce the waste even more.

Even if the process is simple and the cost of biomass is low, the enzymes are expensive, the hydrolysis is not as efficient as wanted and the pre-treatment of the product has a high energy demand.

02 Banana peels [4]

India (biggest producer of bananas in the world)

Bananas generate a huge amount of waste because 30 to 40% of its weight corresponds to the peel. As banana peels are full of sugars, and and carbohydrates, the valorisation of this product can be conducted to produce bio-ethanol through the fermentation process we already studied for the citrus waste. It also contains a little bit of lignin which allows enzymes to convert cellulose, hemicellulose, and pectin into simple sugars. Moreover, starch may mix with ethanol, making the yield increasing because of the higher sugar concentration in the soluble part.

Taking Indian banana production into consideration, we can say that this country is able to produce over 1,6 million tons of dried banana peels, which represents 440 million litres of ethanol every year. However, it is not enough to supplement all the country because we assume that India needs 1,5 billion litres of ethanol every year.

Even if this process is interesting, the yield is low because some sugars create strong bounds with the solid part which is not extracted by ethanol. Anyway, they can be extracted with an hydrothermal treatment but it means that it requires more energy.

03 Apple pomace [5]

Canada

Apple waste is present in a really huge amount because this fruit is used for juices, pies, fresh-cut, sauces... The pomace is the most useful because it contains polysaccharides and sugars that can be converted into ethanol as we saw before. We can count in mass 8.2% of glucose and fructose. Moreover, carbohydrates like cellulose (22.2% in mass) and pectins (9.9% in mass, found in the soluble fiber) respectively contain 23% and 10% in mass of polysaccharides which can be hydrolysed during an enzymatic process (more often, the enzyme used are cellulase, pectinase and b-glucosidase), leading to glucose and galacturonic acid which are fermentable sugars useful to create alcohol.

The yield can be improved because some lignin (21.2% in mass of the pomace) is broken, increasing the efficiency of the enzyme on cellulose, producing then more glucose turned into bio-ethanol. It has be proven that the maximum efficiency was for a temperature of 40°C and an acid pH of 4. Adding a buffer can also improve the yield, helping to produce more glucose.

BREW WASTE [6]

Beer
Spent husk
Treat lignin
Glucose : 75g/L

To produce beer, a lot of processes generating waste are occurring. For example, after the mashing of the grains and lautering, we obtain husk which is usually used to feed animals or to be landfilled. After some researches, it has been proven that this by-product could be recovered into biogas, organic acids, biopolymers, or molecules for pharmaceutical and food industry, but we will focus on the production of bio-ethanol which is the topic of the review.

Spent grain composition fluctuates depending on the brewing practices, but in this study, it was composed in mass of 14.42% cellulose, 34.21% hemicelluloses, 3.93% lignin and 47.43% of products which are not useful for the application we are focusing on. To reach a better yield, the lignin of the spent grain has to be treated upstream. A lot of methods can be applied (physical, chemical, biological...) but in this study, an alkaline treatment is chosen to extract cellulose fibre from the lignin. This step has to be carefully conducted because the basic environment is a risk for carbohydrates (including cellulose) degradation.

Thus, a blend of enzymes is added, and the saccharification of solubilized cellulose occurs, leading to fermentable monosaccharides (with a yield of 75g of glucose for 1L of solution) to finally obtain bio-ethanol.

DAIRY WASTE [7]

Bio-hydrogen
Cheese whey
Degradation of glucose
Anaerobic digestion
pH 5-6

In this study, the dairy waste used to produce bio-energy is whey (the liquid we recover after filtration of cheese paste, in the case of feta). Because of its high amount of carbohydrates, the fermentation of this product can lead to hydrogen by degradation of glucose under anaerobic conditions. This reaction is difficult to set up because of the high amount of organic matter and low basicity (becoming rapidly acid), so the pH has to be controlled and maintained between 5 and 6.

This waste cannot be released without treatment in the nature because it contains a lot of organic matter so it is harmful for ecosystems. Anyway, the untreated waste can be used as itself for the production of biogas, usually fossil-fuel-based. Hydrogen is a good source of energy because it doesn't release greenhouse gases, and is lot more efficient than fossil fuels. The yield can fluctuate depending on the composition of the whey, the amount of glucose, lactose and sucrose being the most relevant. A lower yield can be obtained if microorganisms are consuming the product, or another reaction from glucose can occur, leading to acetate.

CONCLUSION

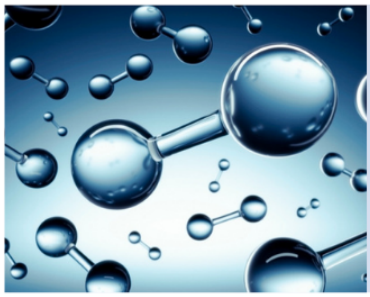
To conclude, we saw that food waste has an ecological and economical advantage as raw material for energy production over fossil carbon. We can produce three kinds of bio-fuel with the food we collect in agrifood industry, restaurants, and even at house level :

Bio- diesel

- From fatty acids we can find in fish waste and cooking oil
- Transesterification reaction
- Good yield and properties
- Need treatment, expensive, less efficient than fossil fuel
- Mostly usd for transportation

Bio-ethanol

- From fruits and vegetables (apple pomace, citrus, banana peel...) and husk (brew waste)
- Hydrolysation of carbohydrates to form sugars which ferment into ethanol
- Need enzymes (expensive) and treatment (for lignin)



Bio-hydrogen

- From whey (cheese waste)
- Degradation of glucose coming from carbohydrates
- Difficult to set up and the yield fluctuates depending on the composition

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