CREATING A BIO-BASED ECONOMY

This lesson follows on from the 'Introduction to Bio-based Economy' lesson and highlights recent advances in science and how these will enable the creation of a bio-based economy.

LESSON OBJECTIVES

Students will be able to:

- Understand the role of a biorefinery and why it is needed
- Understand the unique challenges that the diversification of biomass entails
- Understand why corporations and governments are willing to fund research into the bioeconomy

- Ask questions from the front and write up answers on the board in a classroom discussion format:
    - What does the term refining mean?
    - What is a refinery in the context of oil and biomass?
    - Why do we need to refine these substances?
    - Use the BBC Bitesize resource to aid explanation of refining in the context of crude oil: https://www.bbc.co.uk/bitesize/guides/zshvw6f/revision/3
- Present to the class the challenges of biomass, focusing on the complexity of biomass meaning creation of pure chemicals is hard and needs robust separation processes. Information to assist this can be found in the factsheet.
- Explain the stages involved in taking biomass from the environment through to a product or fuel.

    Explain that research is ongoing into how exactly this will be achieved. Give some specific examples of advancements that have been made. The research is supported because of the size of the scale of the task at hand, and the absolute need for petrochemical replacement.
- Finish up by exploring questions that students can write 3-4 sentences to answer, these increase in difficulty to probe the extent understanding.
    1. Why do we want to start using biomass to make chemicals? (All students)
    2. What do we need to do to make this viable? (Most students)
    3. Given that waste from industries like logging, paper and agriculture can be used as a source of biomass, explain how a biobased economy is also an example of a circular economy. (Top students)

    Answers should loosely fit the following:

1. As a replacement for petrochemicals/pollution reduction/long term investment.
2. Establish new methods of processing/create a working biorefinery/make products cheap enough to compete with petrochemicals
3. Value is given to waste/relies on natural systems/the resource is renewable/waste is minimised

SUMMARY OF TASKS

RESOURCES/ EQUIPMENT

- 'Creating a Bio-based Economy' fact sheet

HOMEWORK/ EXTRA ACTIVITIES

- In another session the 'Home Separation' practical could be undertaken.

FACTSHEET: CREATING A BIO-BASED ECONOMY

FACT SHEETS HAVE BEEN DESIGNED FOR TEACHER USE TO AID CREATING OF TEACHING RESOURCES, OR THEY ARE FREE TO BE REPURPOSED FOR STUDENT USE.

PART 1 - INTRODUCTION TO REFINARIES

Refining is defined as: *removing impurities or unwanted elements from (a substance), typically as part of an industrial process* (oxford languages definition).[1]

For oil this means separating crude oil into fractions dependent upon the boiling point of the constituent hydrocarbons. This is called fractional distillation and there are online resources to show how this process works.[2] However, for biomass there is not yet a universal system, but the premise is the same: take the complex mixture of compounds from biomass and separate them into groups dependent upon a certain property of the compounds.

Separation is required so that the individual compounds can be used separately – this is like storing and purchasing flour, sugar, eggs, and milk in separate containers rather than having them all mixed up together. When chemicals are made, there is a requirement for them to be pure, so that when they are used to make a new product it is of the desired quality.

[1] https://www.lexico.com/en/definition/refine
[2] https://www.bbc.co.uk/bitesize/guides/zshvw6f/revision/3

A biorefinery is the key steppingstone that allows us to turn biomass into real chemicals that industry can use to make the products we use every day.

PART 2 – REQUIREMENTS FOR BIOREFINERIES

Unlike crude oil, biomass is generally a solid. Solids cannot be pumped through pipes and must be transported by other means, like vehicles. Solids also require additional steps to ensure they are fit for use. This means they are mechanically treated (cut up, whittled down, shredded) to increase the surface area, enabling more efficient follow-up processing.

Once a solid has been treated mechanically it is then processed in several different ways:

- Chemicals like acid can be used to break it down into simpler compounds
- Solvents can be used to extract a target compound
- Thermal treatments are also possible and may be undertaken after varying degrees of chemical or mechanical treatment. Such treatments include pyrolysis (a thermal decomposition in the absence of oxygen) or gasification (a thermal decomposition in limited oxygen), and these give usable compounds, one such example being syngas, a mixture of simple gases that can be converted into simple compounds.

Other processing steps involved include drying, centrifugation, filtration, distillation, crystallisation, and fermentation. Any number of these steps may be combined to produce a certain compound.

The job of the biorefinery is to streamline these steps and processes so that we can put raw biomass into one end of the system and get a target chemical or mixture out the other end.

Once the biomass mixture has been simplified to one – or a limited group of – compound, they can be chemically converted to useful platform chemicals, akin to those that we get from the fractional distillation of crude oil.[3]

PART 3 - CASE STUDY: GETTING 5-HMF FROM BIOMASS

5-HMF (5-hydroxymethylfurfural) can be used as a platform chemical, which many important chemicals can be subsequently made from it. It is a very promising compound for making bioplastics, which could replace those made from crude oil.

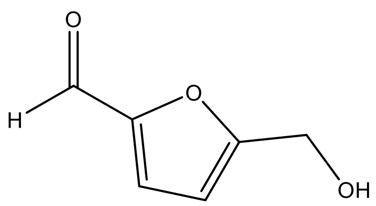

Figure 1: Chemical structure of 5-HMF

The process includes:

- Start with a biomass which contains cellulose, which is ground into smaller pieces
    - Cellulose is a large polymer made up of carbon, hydrogen, and oxygen atoms
- The cellulose is then broken down into sugars by enzymes. This step requires high purity cellulose and is quite expensive. It is one area in which additional research is needed to uncover more efficient means of generating sugar from cellulose.

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[3] https://benthamopen.com/contents/pdf/TOASJ/TOASJ-2-54.pdf

- To get the target compound, 5-HMF, a chemical conversion called dehydration is used, water molecules are lost from the sugars to give 5-HMF. We can use a cheap acid catalyst to do this, but there are many side reactions that give other compounds too, which complicates the process

There are different types of sugars produced during the second step, and some are a better starting material than others. Converting the various sugars all into one desirable form is possible but increases the cost of the process. This again highlights where more research is needed, we ideally want to take a mixture and generate pure target compounds cheaply from it. Some of these challenges are engineering challenges – how can we reduce the energy we put in to break down the biomass (cellulose in this case)? Some are chemical – how can we react our sugars to give pure and clean 5-HMF?

HOME SEPARATION PRACTICAL

OBJECTIVES

- Learn some simple chemical separation techniques
- Understand how these transfer to an industrial setting
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MATERIALS NEEDED

- Coffee filters
- Sieve
- Wide/flat dish
- Paper towel or filter paper
- Tall glass
- At least two from: honey, pancake syrup, washing up liquid, vegetable oil, rubbing alcohol, lamp oil.

BACKGROUND INFORMATION

- See the biobased economy lesson plan and factsheet for more information on the importance of chemical separations in creating viable products.
- Separations and processes that simplify complex mixtures into manageable chunks allow us to work with pure chemicals. Pure chemicals give us high-quality products that are fit for use by consumers. The more effective the separation technique is, the more we can do with a feedstock, like crude oil or biomass.
- Many of the techniques outlined in this practical have a corresponding industrial process that will look a bit different, but they largely operate using the same scientific principles

ADDITIONAL ACTIVITY

See if you can use the techniques below to separate a mixture of rice, salt, and flour at home. If you use water, try to get dry ingredients back at the end.

STEP-BY-STEP INSTRUCTIONS

SEIVING:

A really simple way of separating two things is sieving. This separates two solids of different sizes, for example rice and flour. You can try this at home by mixing a handful of rice into flour, and then pouring the mixture through a sieve. Rice will be caught in the sieve while flour will pass through.

FILTRATION:

If you have a fine solid mixed with a liquid, sieving will just mean both parts of the mixture pass through. Filtration uses a material that allows liquids to pass through, but not solids. At home you may have used coffee filters as this material. You'll be able to separate sand from water using this method. Filtration is used extensively in chemical research. We usually make chemicals in a liquid mixture, as this allows us to mix all the chemicals needed for a reaction to happen. Filtration allows us to collect a solid chemical from this mixture once it has been made.

DISTILLATION:

Water turns to steam at 100 ⁰C. Water also evaporates slowly at lower temperatures, leaving behind anything that's dissolved in it. This is how we get salt from seawater, for example. You can try this yourself with a homemade saltwater solution left out in the sun, the shallower the dish the faster the process will be. This process is distillation. We can also get clean water from saltwater using this method, although we need a way of capturing the water. The Royal Society of Chemistry offers excellent resources detailing how to do this and other separation practical activities at home.[4] In industry we use this to remove liquids from chemicals. Often the chemicals won't evaporate easily, and so liquids like water or organic solvents can be boiled off to give a pure chemical. We can also separate different liquids like this, for example this is how we refine crude oil into its components.

CHROMATOGRAPHY:

This technique separates chemicals based on their affinity for a solvent or solid phase. For example if you dip a paper towel into water and the water runs up the towel, the chemicals dissolved in the water will travel different distances up the towel depending on how attracted to the towel and/or the water they are. This can be visualised by spotting black ink at the bottom of filter paper and leaving the end dipped into shallow water. The ink will run up the paper with the water, but different components of the ink will move at different speeds, eventually separating the ink into its colours. In chemical industries we use this to separate mixtures of chemicals that cannot be filtered or distilled. Many examples of how to conduct a chromatography experiment at home exist online, for example at BBC Bitesize.[5]

PHASE SEPRATION:

This is separation based upon density differences. If you mix oil and water, you'll notice that the oil sits on top of the water and may form blobs on the surface. In industry we exploit this to separate chemicals. Our target chemical might be soluble in oily substances (lipophilic) and our impurities might not be and prefer to be dissolved in water. We can mix an oily solvent and water with our impure chemical to get the mixture to dissolve, and then selectively take the solvent. This will only contain our target chemical and leave behind the impurities in the water. You can see these phases in action by making a density column with home ingredients. In a tall glass you'll want to add the following liquids in the order that they're listed:

Honey, pancake syrup, washing up liquid, water, vegetable oil, rubbing alcohol, lamp oil.

Don't worry if you don't have them all, this just means your density column will have fewer layers. When adding layers, leave enough room in your container for the rest of the layers you want to add.

Add your first liquid without letting it touch the sides of the container, and then add the remaining liquids on top. When you pour in these other liquids, ensure you do it gently without disturbing the surface of the layer below – pour it slowly onto the end of a spoon just above the surface, or slowly trickle it down the side of the container. By the end, you should be able to see the distinct layers. ThoughtCo have a guide to this[6]

[4] https://edu.rsc.org/resources/separating-mixtures/1803.article
[5] https://www.bbc.co.uk/bitesize/guides/zqqtrwx/revision/4
[6] https://www.thoughtco.com/make-a-density-column-604162