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# Weighing up the Future. The Mass Balance, the Circular Economy and Chemical Recycling

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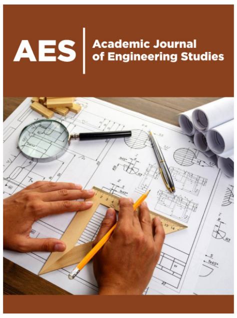


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### Abstract

In studying chemical engineering, students are taught the Mass Balance. In principle it is a simple accounting protocol that gives them the ability to track the inputs and outputs for all the matter in a chemical process, chemical plant, factory or facility. The beauty of this practice lies in its simplicity. From the mass alone a large number of assumptions can be made and ratified. Though it is a simple accounting technique it has far reaching application beyond a typical chemical plant. Herein, the Mass Balance is used as a building block to better understand our global system of materials and resource management. The practice of the Mass Balance can be used to understand our planet, based on the fact that chemical change occurs on a daily basis within a closed loop ecosystem. By applying the Mass Balance technique to the Earth one can quickly move to understand the basic need for the Circular Economy in that we realize materials are not limitless. And to achieve the end goal of a circularized economy one must have the ability to reuse materials in continuous loops, to achieve this a protocol of Chemical Recycling is suggested to be most promising.

## Introduction

The Mass Balance is a relatively simple concept, a logical connect for someone who is planning to make materials in an economic fashion, who wants to waste as little as possible and track the progress of the process. The first level of calculation is simple, dealing with gross values, typically including some basic working assumptions. Notwithstanding the errors associated with this first cursory calculation, the final answer is often very similar to the final answer to within a small margin of error; all this despite having greater clarity and truth. Further iterations lead to the counting of individual atoms based on changes occurring within chemical process to the extent that chemical stoichiometric balances must be calculated.

We live on a planet, flying through space, orbiting around our nearest star. Not much gets off this planet, not too much has been added to this planet either. We have what we have here, we should use it wisely. Basically, there is a limited amount of material on this planet and "throwing something away", does not mean it goes away. It is still on this planet. So, we still have to deal with it Planet earth is an ideal scenario for using the Mass balance calculation.

The Mass Balance relies on two simple principles that has three far-reaching implications:

A. Matter is not created or destroyed. Matter simply changes form. It can undergo chemical change, but it may not be destroyed or wiped out. This is the Law of the Conservation of Mass, first determined by Antoine Lavoisier in 1785.

B. Matter is made of atoms.

This implies that

a) For all closed systems the amount of matter entering and leaving the system can be tracked with a relatively high degree of certainty. (within a certain limit or margin of error).

b) The Mass Balance can be extended to count the number of atoms being input and output too. (within a certain limit or margin of error).

c) We can also calculate how much energy is based on the chemical changes that occurs, so that any given system can be understood in terms of energy input and output. This is another topic for another article, but it is worth mentioning at this time because cheap energy [1] is a fundamental driver underlying most economies.

Once a chemical plant is treated as a closed system, students can then know how much material and ingredients go in and out. But thanks to the first principle, we can be sure no new material will suddenly appear somewhere along the factory line, because matter is not created or destroyed, it just changes form.

For those who are not familiar with the idea or practice of the Mass Balance, let me use this simple example of water in a closed pot. If you add 1g of water to the pot, then regardless of what you do to that water, boil it, freeze it, let it sit still. You should always be able to take the water and find the same mass every time (1g). This does rely on the fact that the system is closed, whereby no additional water is added, and no water molecules are allowed to escape. This second part is actually quite tricky in real life for chemical engineers, and so the act of calculating accurate mass balances becomes very intricate.

Regardless, no new matter will suddenly appear at the end of the process. Like in cooking, if you want to make a pasta dish, you need pasta to start. Put simply, whatever matter goes in, must come back out at the end of the process. Maybe it changes its structure, but if we count all the molecules at the start of the process, we should be able to count the molecules at the end of the process.

## The Circular Economy

The Circular Economy is a concept that is recently gaining lots of attention. The basic idea is stop waste, this can be done via extended shelf lives for as long as possible. When the material or products finally reach their last straw and can no longer be used, they should not be discarded, thrown away, but we should find other uses. The notion of the circularity arises from the fact that those materials re-enter the marketplace and serve a valuable purpose for longer lifetime, in this way they can again contribute in an economical or meaningful sense. There are several steps to follow in order to accomplish a fully circular economy. At this point in time we are at the stage where we are finding new ways to use old stuff, in ways that could be considered as being similar to recycling and up-cycling old materials. But eventually we should be at a stage that everything is made in the first instance with longer lifetimes in mind, so they are built in ways that allow for easy re-use.

The Circular Economy is in effect just another form of the Mass Balance in that all the materials must be accounted for in the system. All the inputs and outputs must be recorded and for the circular economy to work, the outputs must become inputs again, in a never-ending circular fashion. In an ideal world all the required technologies would exist to continuously re-input used materials back into the economy. This is especially true in the case of plastic recycling and re-use because of the great environmental problems associated with the waste of plastic materials.

## Chemical Recycling of Plastics

Plastics have recently gained a lot of media attention thanks to the Attenborough effect. Quite a considerable mass of plastic has been made and this could serve as a very large store of carbon for future use. Historically speaking, cheap access to carbon through wood, coil, peat bog has greatly helped societies survive and expand. Therefore, it is wise to consider where the cheap access to carbon is now, and in the future.

Plastic recycling is one of the first answers that comes to mind, but in a recent study it was shown that this only prolongs plastics within the consumer cycle but does not stop it from going to landfill [2]. Recycling is not typically a continuous process, plastics cannot be recycled infinitely, actually they are usually just recycled once before they need to go to landfill. Nonetheless, recycling efforts should be increased, at the very least new technologies may be developed and discovered in this process.

A growing area of recycling has been building momentum for a few years that is called chemical recycling. It is different from the traditional recycling that is typically referred to as mechanical or physical recycling. In mechanical recycling plastics go in, then plastics come back out. Plastic is kept as plastic, usually with different properties compared to the first time it was made. In chemical recycling, plastics go in, but an entirely new material entirely comes out (e.g. carbon nanotubes) [4] after the process is complete.

## Physical Recycling Versus Chemical Recycling

Traditional recycling: known as mechanical or physical recycling. Plastic is input, plastic is the output. Physical or mechanical recycling takes the plastics, typically breaks them down into smaller parts, for example that are small pellets. The materials are then ready for recycling.

Chemical recycling: Plastic is input, but the output material could be a completely new material that is not plastic anymore. In this process the carbon atoms are treated as ingredients for making other things, other compounds entirely.

## Chemical Recycling of Atoms

Plastics are chemicals, just like water is a chemical. Plastics can be stripped down to their constituent units of carbon and hydrogen, that in turn can used as starting materials to make new materials. This is typically called chemical recycling because it deals with recycling the chemical elements (carbon and hydrogen) and not just the material (plastic). In this way the mass balance is used to count the atoms that are input and then output in a manner that helps to ensure that as much input material is re-used. The mass balance concept is useful because the new material is different from plastics, but made from the same ingredients, By teaching the Mass Balance and using it to count the atoms of matter, students gain the ability to count the inputs and outputs just as before. But by looking at chemical recycling it may inspire new opportunities and avenues of thinking that are more lateral compared to the linear process that we have today. Who really knows what we will make in the future? No one knows, but you can be sure they will use a Mass Balance along the way to help them with their accounting.

## Conclusion

The Mass Balance is a useful tool to gently introduce the notions of the Circular Economy and Chemical Recycling techniques. Carbon is one of the most important elements of the modern age, it has been used as a source of energy for millennia and now we are reaping both the rewards (modern living standards) and the potential downsides. The concept and practice of the Mass Balance can act as a first primer to ready students to better understand global problems.

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