Anna Pazera, Marcin Bizukojć
Łódź University of Technology, Faculty of Process and Environmental Engineering
ul. Wólczańska 213, 90-924 Łódź
marcin.bizukojc@p.lodz.pl, anna.kacprzak@p.lodz.pl

Karina Michalska
Instytut Włókiennictwa
ul. Brzezińska 5/15. 92-103 Łódź
kar.michalska@gmail.com

THE VERBAL BALANCING MODEL FOR ENERGY AND CARBON DIOXIDE IN PRODUCTION AND USE OF BIOFUELS

Abstract
This paper presents the concept of a model for a computational tool for balancing energy and carbon dioxide for the production and use of biofuels. This model is based on the concept of life cycle analysis and covers all the stages of the processes of producing and processing raw materials for biofuels and generating energy from them. The purpose of the model and the computational tool is to demonstrate whether the biofuel produced in a series of unit processes can be called a renewable energy source in the full sense of the word, and whether its production and use is therefore sensible from an energetic point of view.

Key words
biofuels, LCA, life cycle analysis, CO2 balance

Introduction

The fossil fuel industry has been rapidly developing since the nineteenth century, but the combustion of fossil fuels (hard coal, lignite, natural gas, petroleum, bituminous shale) has significantly contributed to the increase of carbon dioxide in the Earth's atmosphere. Recent studies indicate that the level of 0.04% of this gas has been reached in the Earth's atmosphere [1]. The estimated amount of carbon dioxide in the pre-industrial period was 0.028%, and each textbook or any popular science book from the 1970s and 1980s of the 20th century indicated that the concentration of carbon dioxide in the Earth's atmosphere was 0.03%.

The outdated information is of course not a problem. The undeniable fact, however, is that carbon dioxide is capable of absorbing infrared radiation and is responsible for the intensification of the greenhouse effect. The so-called greenhouse effect is necessary to keep the temperature on the surface of the Earth at an average of around 15-20°C, allowing for the development of biological life. Unfortunately, its excessive concentration can intensify this effect, causing both local and global climate change.

Thanks to human activities, the coal balance on Earth has most likely been shaken. Before fossil fuels found mass application, fuels were burned, mainly wood and other plant materials, or feces of animals that existed on our planet in the contemporary geological age. Thus, the plants captured carbon dioxide, which could have been emitted during the biological decomposition of organic matter or its combustion. The problem is that at one point humans introduced coal to the entire pool of carbon in circulation on Earth, which in previous geological ages was captured during biological processes of decomposition of living matter and the contemporary geological processes. Thus, after hundreds of millions or even billions of years, the coal from the Carboniferous period, or even the natural gas and crude oil from the pre-Cambrian period, has been released into modern circulation. It should be emphasized that fossil fuels are the carbon from previous geologic ages, and the carbon bonded and metabolized by present living plants and other photoautotrophic organisms is the carbon being in modern circulation. These considerations can lead to the definition of a biofuel for the purposes of the concept presented in this paper. Any fuel intended for incineration, except hydrogen, must contain carbon as an element which, because of the exogenous oxidation (combustion) process, is converted to carbon dioxide. If this carbon comes from organic waste or sewage, or from currently living plants, then the fuel containing such carbon can be called a potential biofuel, which is of biological origin or created using biological processes, and simultaneously one of the forms of the RES renewable energy sources. On the other hand, if there is carbon bound in organic matter in other geological ages, then it is a fossil fuel that contributes to the increase of carbon dioxide in the modern circulation and cannot be called a renewable biofuel. Utilizing these modern coal raw materials as potential biofuels (RES) is often associated with their processing, and therefore with energy expenditure, before they are transformed into ecological energy. The problem is that this energy for biofuel processing needs to be delivered in some way and it would be best for it to be renewable (regardless of the renewable source). This is not always the case though. What is more logical is that the input of energy into the processing of the raw material for biofuel must be smaller than the energy recovered from it and the same is true for carbon dioxide. The CO2 balance may be positive, but only if we burn "contemporary coal", and it would be even better if it was zero, if not negative, so that only then would it be sensible to talk about some raw material as a biofuel, being a renewable source of energy. It would always be necessary to prepare and resolve such a balance. If this condition was not fulfilled, biofuel would still be a non-renewable source of energy. Therefore, it is impossible to state that biofuel is an RES if the condition described above is not met.

The purpose of this paper is to show that using only a certain raw material as a biofuel does not have an ecological benefit by itself, and that the performance of an energy and carbon dioxide balance is essential for assessing the potential substrate, its manufacturing technology and manner of energy use, to assess whether a given raw material and the processing associated with it deserves to be called a biofuel (RES) in the full sense.

The framework for the energy and carbon dioxide balance

To facilitate the answer to the question posed at the end of the introduction, we need to present a concept of the energy and carbon dioxide balance. Life cycle analysis [4] is a good tool to be used as a model here. Although its idea was to determine how an industrial product impacts the environment in manufacturing, use and processing stages, this concept can be used in part to determine the renewability of a given biofuel.

Let us therefore assume in our deliberations that there are three phases of life of a raw material that is supposed to become a biofuel:

1. The biological growth of plant raw material as a living photoautotrophic organism or the production of flammable or biodegradable waste (liquid or solid) in relation to human existence or activity;

2. The processes of raw material processing aimed at producing a biofuel suitable for direct combustion or the process of production of liquid or gaseous biofuels (a fermentation process with the participation of microorganisms and the accompanying upstream and downstream processing);

3. The process of combustion of the potential biofuel.

The most important element of the balance is the matter of energy consumption for unit operations related to the processing of the biofuel. Each time this energy comes from non-renewable sources, this involves a positive carbon dioxide emission. Potential Biofuels (RES) can be perceived in two ways: as biomass for direct combustion or for processing into liquid or gaseous biofuels (ethanol, butanol, methane), hence items 1 and 2 are double points, separated by the conjunction "or".

In connection with item 1, it is to be added that, where the potential biofuel is waste organic matter, we do not carry out the energy and carbon dioxide balance due to its formation. If waste could not be avoided under the waste management hierarchy contained in the Waste Act (Waste Act from December 15, 2012), then it is still required to treat it as an active biodegradable biological waste under the same Act. At each of these three stages, the production or consumption of energy and carbon dioxide emission/binding (including the exception in paragraph 1) may occur. At each of these stages, it is still necessary to specify the unit operations necessary for its execution.

A detailed description of these steps is presented in Table 1. The energy and carbon dioxide columns will contain the following symbols (+): consumption of energy with carbon dioxide emission and carbon dioxide emission from the industrial process, (-): energy and carbon dioxide production and consumption in the process, and 0: neutral process (no emission or balancing) from the point of view of energy consumption and carbon dioxide emission. The number of these symbols is a subjective estimate of the size of this emission consumption.

Table 1. The balance of energy and carbon dioxide for the processing of biofuels

	Energy	**CO_2 ***

1. Increase in plant raw material (plantation only for energy purposes)		
a) soil preparation and sowing/planting of plants	++	++
b) vegetation of plants	0	– – –
c) agrotechnical operations during plant vegetation	++	++
d) biomass collection	+	+
1a. Creation of biodegradable/flammable waste resulting from:		
a) the industrial process (biodegradable industrial waste)	0	0
b) agricultural activity (straw, hay, etc.)	0	– –
c) human existence (organic fraction of municipal waste)	0	0
2. Processing of raw material for biofuel		
a) transport		
- car	++	+++
- railway	++	++ or 0 **
- river	++	+
b) mechanical grinding of plant raw material and/or pellet production (for direct combustion)	+	+
c) drying the biomass before burning (if necessary)	+++	++ or 0***
2a. Production of liquid or gaseous biofuel from waste or plant raw material		
a) hydrolysis of plant (lignocellulosic) raw material to obtain organic biodegradable chemical compounds (monosaccharides and their derivatives)****		
- thermal hydrolysis	+++	+++
- chemical hydrolysis	++	++ or 0
- enzymatic hydrolysis	+	0
b) internal transport of raw materials in the facility (pumping, conveyor belts, etc.)	+	+
c) preparation of fermentation batch and biosynthesis (keeping the temperature constant in the bioreactor, batch mixing energy)***		
- methane fermentation	+	++
- alcoholic fermentation (ethanol)	+	+
- ABE fermentation (n-butanol)	+	+
- hydrogen fermentation (hydrogen)	+	+
3. Separation and purification of the fermentation product (rectification for liquid biofuels, which is a heat and diffusion process, drying and removal of hydrogen sulfide for biogas)		
- methane fermentation (biogas)	+	+ or 0***
- alcoholic fermentation (ethanol)	++	+ or 0***
- ABE fermentation (n-butanol)	++	+ or 0***
- hydrogen fermentation (hydrogen)	++	+ or 0***
4. Combustion of the potential biofuel		
- burning of plant or waste biomass	– – –	+++
- combustion of liquid or gaseous biofuel	– – –	+++
- combustion of biohydrogen	– – –	0

Source: The author's own study

* a zero-carbon dioxide balance can be assumed when vehicles or diesel engines are powered by biodiesel type fuel.
** in extreme cases, electric rail transport could be supplied with only renewable energy or nuclear energy (no carbon dioxide emissions); the share of individual types of energy counts globally for the whole country
*** if we are using a different renewable energy source or nuclear energy
**** every fermentation process is associated with carbon dioxide emission as a feature of microbial metabolism

Let us analyze the stages of "life" of a potential biofuel as a renewable energy source. If the raw material that is to become a biofuel is biomass, its production is primarily associated with negative carbon dioxide emission. Through photosynthesis, plants that are photoautotrophic, including algae grown for the same purpose, bind carbon dioxide in Calvin's cycle, using it as a source of carbon for building their own cell mass. During vegetation, photoautotrophic organisms are simultaneously self-sufficient in terms of energy, drawing on the energy of the solar radiation in the light-dependent photosynthesis phase with the participation of the chlorophyll dye [2]. From a technological point of view, when plants or algae grow in dedicated biofuel farms, the energy used for the agrotechnical treatments needs to be included in the energy balance. This energy almost always comes from non-renewable sources such as diesel fuel. Only the use of a biodiesel type fuel can improve this carbon dioxide balance. If this biomass is from waste such as straw or hay, then energy consumption can be defined as zero in the balance, since the raw material would have been produced anyway, and the purpose of plant farming was different than the production of the raw material for the manufacture of biofuels, such as the production of food or animal feed. The carbon dioxide balance is obviously negative here (photosynthesis).

The balance would be similar if we were dealing with other biodegradable or combustible waste of plant or animal origin. Because they would have been created, hence the energy to produce them equals zero in this balance. The same applies to the balance of carbon dioxide. The processing of raw material (Item 2) involves different process and unit operations. They have a common feature though in that energy must be input into these processes. The energy input is associated with carbon dioxide emissions if this energy comes from non-renewable sources (see the footnote under Table 1). When choosing the raw material processing methods, caution must be taken because excessively complex and multi-stage processing can adversely affect the overall energy and carbon balance and virtually diminish the renewability of the energy source that the processed biofuel was supposed to be.

Further biofuel life stages pertain only to liquid and gaseous biofuels (Item 2a). After the processing stage, solid plant biomass is practically ready for combustion, and if this plant biomass is to play the role of a fermentation batch, then the stages of its processing are different, such as the hydrolysis of lignocellulosic materials to monosaccharides. This stage can be omitted if there is liquid biodegradable waste, such as whey. Biosynthesis of liquid and gaseous biofuels obviously involves energy expenditure on heating of the bioreactor and its mixing, and emission of carbon dioxide as a fermentation product that can never be avoided. It should be noted that in the case of biogas production, carbon dioxide is often above 20% of volumetric vent gases. There is no energy left, and carbon dioxide emission remains. In alcoholic fermentations like ethanol and butanol, the proportion of carbon dioxide in vent gases is lower. The energy expenditure on maintenance of the bioreactor at work is, however, relatively small compared to raw material preparation and subsequent product recovery.

In the case of liquid biofuels, the process of rectification is energy-intensive. Of course, combustion of a potential renewable energy source equals carbon dioxide emission. The exception is biohydrogen, but its production has not yet gone beyond the semi-technical scale, due to the complex metabolism of the microorganisms it is produced by and their sensitivity to the product of their metabolism, hydrogen. These are limits on a biological and biochemical level. This is without regard to the problem of storing hydrogen as a fuel. Of course, carbon dioxide emission is predicted during the combustion of a biofuel, but we assume that this carbon dioxide will be captured by the plants when they are biofuel raw material (zero or negative carbon dioxide balance). In case of waste, the carbon dioxide balance will always be positive, but here we remember that the carbon contained in it is derived from the processing of contemporary raw materials rather than fossil fuels. Of course, we burn biofuels to produce heat. This balance must always be positive. Otherwise all the actions described above would make no sense.

Conclusion

The renewability of a given source of energy, like biofuel, is not entirely clear without a detailed energy balance, considering its source, the process of production of that biofuel, and the energy output resulting from the combustion of that biofuel.

Carbon dioxide balance is also essential. The conditions that must be fulfilled are the positive energy balance and the zero or negative carbon dioxide balance when using bioenergetic plants, and the positive balance, with the source of energy being "contemporary" coal, if waste was to be processed.

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VERBAL MODEL FOR ENERGY AND CARBON DIOXIDE BALANCING IN PRODUCTION AND USE OF BIOFUELS

Abstract
In this paper, we presented the concept model of the calculation tool for balancing energy and carbon dioxide in the production and use of biofuels. This model is based on life-cycle analysis, and covers all stages of the manufacture and processing of raw materials for biofuels, and the extraction of energy. The purpose of the model and calculation tool is to assess whether the biofuel produced in many processes can be called a renewable energy source in the full sense of the word, and whether its production and use makes sense from an energy point of view.

Key words
biofuels, LCA, life cycle analysis, CO_2 balance