

Biodegradable Packaging from Life Cycle Perspective

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Abstract: This paper presents and discusses results from LCA studies for the commercially important bio-based polymeric material - poly (lactic acid); petrochemical - low density polyethylene and new packaging material - polyethylene with oxidizing additives. During this study only 2 aspects - the energy used and greenhouse gases exhausted have been studied and calculated for first and second life cycle stage (materials production and processing). Summarized results testify that the greatest negative burden on environment gives oxo-PE, since oxo-additives promotes fragmentation of PE and excludes recycling. Additionally to energy use, another aspect is: metal ions – one of degradation product of oxo-PE - causing the soil contamination and threaten human health. PLA packaging material presents the most appropriate long-term development outcomes considering energy use and greenhouse gas emissions.

Keywords: life cycle assessment, poly (lactic acid), PE with oxidizing additives

I INTRODUCTION

Modern world-class manufacturing companies at any stage of development, along with economical factors, more and more focus on the environmental factor [1]. Today's market represents lot of different packaging materials and draws special attention to the biopolymers and biodegradable polymers. Environmental considerations have been, and will continue to be, an important motivation to develop and introduce bio-based polymers. This calls for a comparison of their environmental performance with alternative petrochemical materials.

Life cycle approach or life cycle thinking is a new principle in the product development. The main idea of this approach is to consider all environmental impacts arousing during life cycle of a product from its "cradle" (production of raw materials) to "grave" (safe disposal or recycling). Life Cycle Assessment (LCA) is an instrument designed to identify and to account all environmental impacts of product, process or service starting from its production stage and during its use, as well as in the end of the life [2].

The outcome of LCA provides important decision support information to industry and policy-makers on technology options that minimize environmental impacts, and so is a vital environmental management tool in the move to more environmentally sound technologies. The results of LCA studies are, of course, useful in themselves, but they also support the equally valuable concept of whole life cycle thinking when addressing environmental and sustainability matters [3].

During this study was performed qualitative life cycle analysis with some quantitative elements on commercially important bio-based polymeric material - poly (lactic acid) (PLA); petrochemical - low density polyethylene (LDPE) and

new packaging material - polyethylene with oxidizing additives (oxo-PE), focusing on impact to the climate change, which is among most urgent environmental problems. During the study introduced hereto two aspects - the energy used and greenhouse gases exhausted have been studied, based on literature data, and calculated for first and second life cycle stage (materials production and processing).

II LIFE CYCLE ASSESSMENT

According to the International Standardization Organization (ISO), the Life Cycle Assessment (LCA) is a technique for assessing the potential environmental aspects associated with a product (or service), by: compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with those inputs and outputs, interpreting the results of the inventory and impact phases in relation to the objectives of the study, see procedure in the Figure 1 below. LCA is used mainly for comparison among alternative products or processes or to identify the production steps causing the greatest environmental impacts [2; 4; 5].

Such a "cradle to grave" analysis (from extraction of raw material to waste management) incorporating manufacturing practices, energy input/output and overall material flows, is needed to understand major environmental impacts and sustainability. During this study a complete LCA was not performed due to limited time and limited access to the data, only some aspects assessed form life cycle perspective.

The environmental concern has been the main driving force for development and marketing of bio-polymers. Such driving force calls for a scientifically sound comparison among biopolymers and synthetic polymers, to ensure, that environmental protection targets have been really achieved. From the existing studies some conclusions can be drawn:

- 1) Biopolymers, comparing with synthetic polymers, have some advantages, e.g. lower consumption of fossil fuels and lower emission rate of greenhouse gases from the whole life cycle.
- 2) From the environmental point of view, the last phase in the life cycle of polymers – "grave"- is very important, since in case of the best scenario it is possible to recover the energy (combustion) or resources (biomass).
- 3) In order to promote biopolymers on the market, there is a need for improvements in the national waste management system to ensure energy recycling trough biomass production and combustion.
- 4) Another important environmental benefit in case of biopolymers is waste minimization, since often for production of biopolymers waste and by-products can be used.

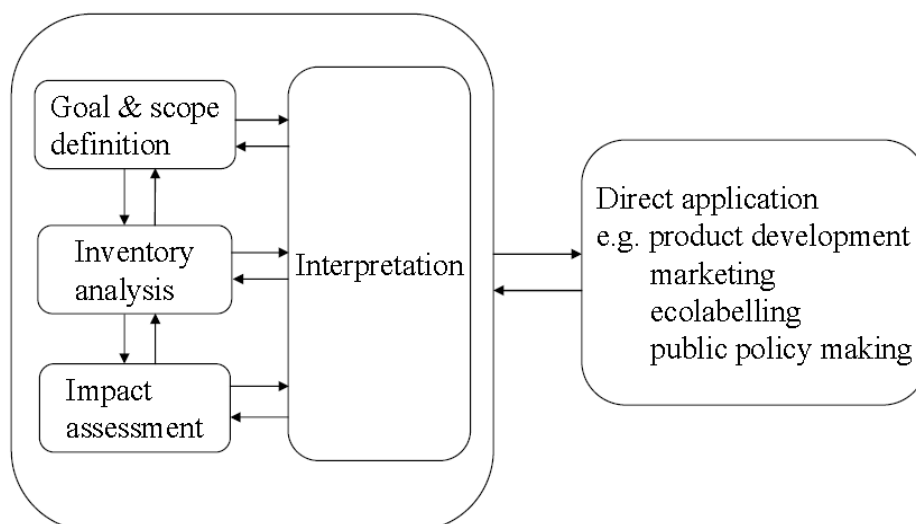


Fig.1. Process of life cycle assessment.

5) There is a need for more complete research on emissions (especially CH₄) from wasted bio-polymers in biological waste streams from households and municipalities. Besides, there is a need for a joint data base from LCA studies on biopolymers [6; 7].

Another new product, coming to the market, is oxo-polymer; although a synthetic polymer with special oxo-additives, it is believed to be more sustainable thanks to increased degradation rate in the environment

III RESULTS AND DISCUSSION

In this paper three popular packaging materials: LDPE; oxo-PE and PLA, were investigated from a life cycle perspective. Greater emphasis was placed on the qualitative analysis of the materials. In applications of the LCA which imply comparisons between alternative products, the object of the assessment is generally always the service provided to the user, i.e. the function which a given product has. This service must be defined and quantified. In the terminology of the LCA it is called the product's functional unit. As the functional unit (FU) was chosen the amount of packaging material to move 100 kg of products. A basis for investigation – was the weight of the packaging bags, with appropriate physical and mechanical characteristics to move the products (approximately 20 bags which one household use in the month). To perform the calculations LCA databases [8] and data from European Commission research project [1] have been used.

Main environmental impacts of the packaging material, which is specific with its short period of usage, occur during production, processing and, especially, during end of the life phase. Here in Latvia the recycling of polymers and waste combustion are rarely performed and the vast majority of wasted polymers are disposed off on landfills, where they can remain for hundred years. The best known is PE packaging, which life cycle is shown in Figure 2.

Black arrows represent the flow of energy necessary to ensure the processes. Incoming energy, which is consumed, is transferred to emissions of greenhouse gases. Outgoing black arrows show the energy recovered, and thus, positively influencing the total energy balance. The boxes indicated with bold line show the processes with positive contribution to the total energy balance e.g. recovery of energy or resources e.g. biomass.

Second system represents a new packaging material – a polyethylene with oxidizing additives (oxo-PE). Most often these additives contain metal ions (Fe³⁺, Mn²⁺ and Co²⁺ compounds), which facilitates degradation of PE in presence of UV-radiation, respective, sunlight [9]. The packaging bags from oxo-PE researched hereto contain following oxidizing additives: *EPI (EPI-TDPA DCP542)* and *Renatura (Renatura – Nor-X DPELLD 5410 BZ)*. According to the information from producer, the polymer studied hereto contains 2% oxidizing additives, but the exact content and type of additives is not disclosed. According to literature data, these additives can be different, and, for example, the concentration of cobalt in oxidizing additives may exceed 4 mg/kg [10].

Polyethylene (PH) oxidation, is a set of chain reactions in which polymer macromolecules split forming oxygen containing fragments with free radical structure (including hydroperoxides, POOH) (equations 1-4) [10]:



Additives – mostly compounds of valence transition metals (M), such as cobalt, promote decomposition of hydroperoxides, thus accelerating the whole oxidative destruction of polyethylene (see scheme) (equations 5-8) [10]:

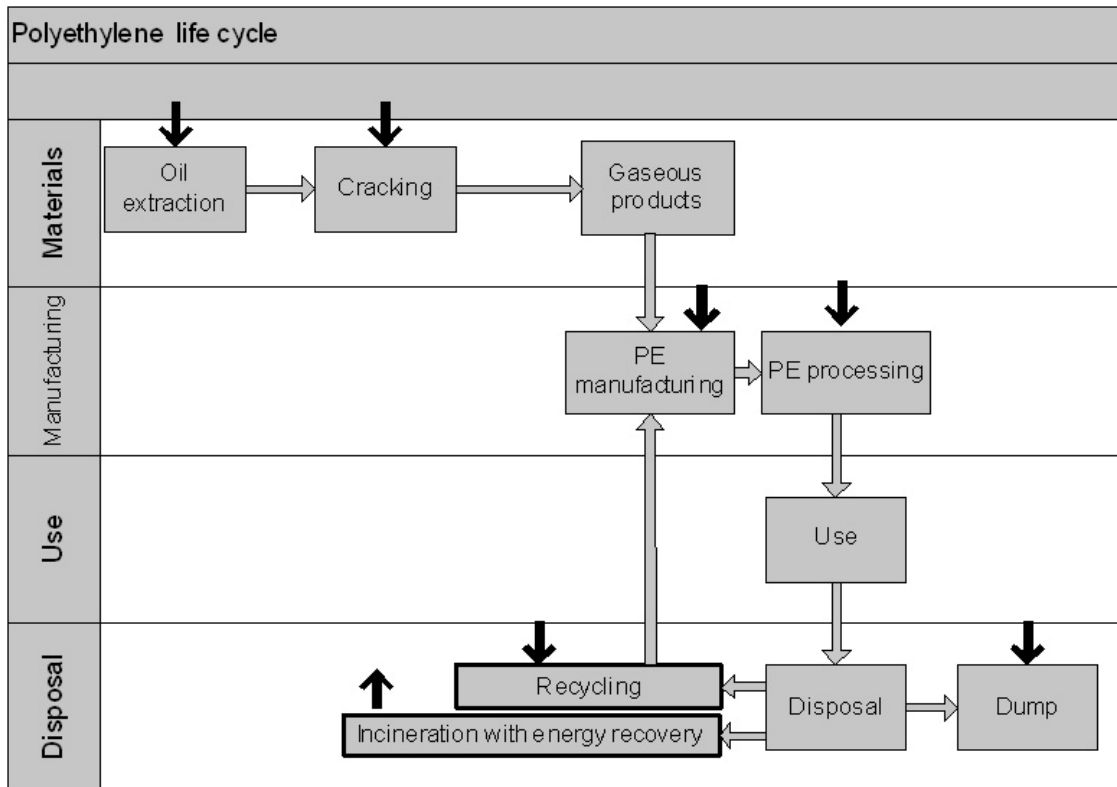


Fig.2. Life cycle of PE

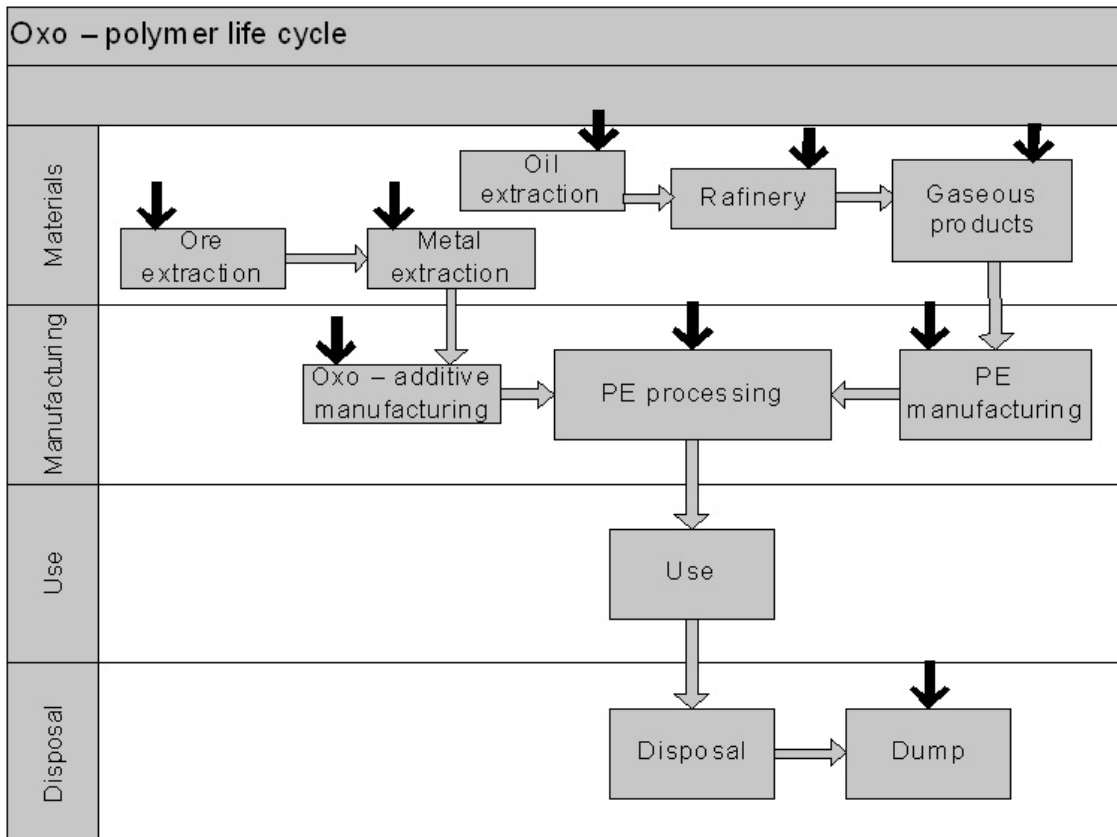
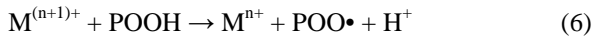
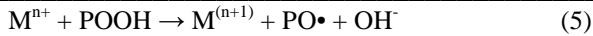


Fig.3. Life cycle of oxo-PE



Although this packaging material is marketed as “biodegradable”, the *Biodegradable Materials Interest Community Association (IBAW)* does not recognize these new materials as biodegradable and environmentally friendly, since its decomposition products deliver metal ions into the environment, and originated small particles of PE are not further included in the natural nutrient circulation. Thus IBAW views the oxo-polymers as environmentally toxic and with a high likelihood to cause carcinogenic or mutagenic reactions in living organisms. The Organization of European Bioplastics expresses the same opinion asserting in its reports: the oxo-polymers products do not only threaten the natural processes in the environment, but also plastics recycling processes [10; 11]. Oxo-PE life cycle is shown in the figure 3:

Two non-renewable resources are used for production of material: oil and metal ores. Since polyethylene decomposes in the environment over many decades, the oxo-additives only diverts our attention from the waste, making waste more fragmented and less noticeable, thus excluding PE preprocessing.

The third system studied is packaging material poly (lactic acid) made from renewable agricultural resources. After fulfillment of its function this material has the ability to return and to integrate into the natural circulation of nutrients in the environment, see Figure 4.

The graph shows that the PLA, unlike as synthetic polymers, is saving non-renewable resources and offers the most extensive waste management options. Compared to synthetic polymers, the PLA system emits much less CO₂. Generally it is assumed that rate of CO₂, released into the atmosphere during degradation or combustion of biomass is equal to the absorption rate of CO₂ during the growth of biomass, therefore, such material does not affect global warming. Thus, PLA system forms closed cycle, where the decomposition products of the material are able to turn back to the environment into natural nutrient cycling, and thus, can be re-used as organic fertilizer to further production of raw materials for lactic acid, such as maize cultivation. From these considerations, we can draw conclusions in favor of the PLA packaging.

Life cycle findings indicate that PE shows the possibility to recover the recourses by recycling and incineration. Oxidizing additives exclude any potential for energy recovery due to material fragmentation and cracking; while PLA is characterized by biggest processing capabilities and recovering resources (compost, recycling and incineration). These conclusions agree with other literature findings [9; 10].

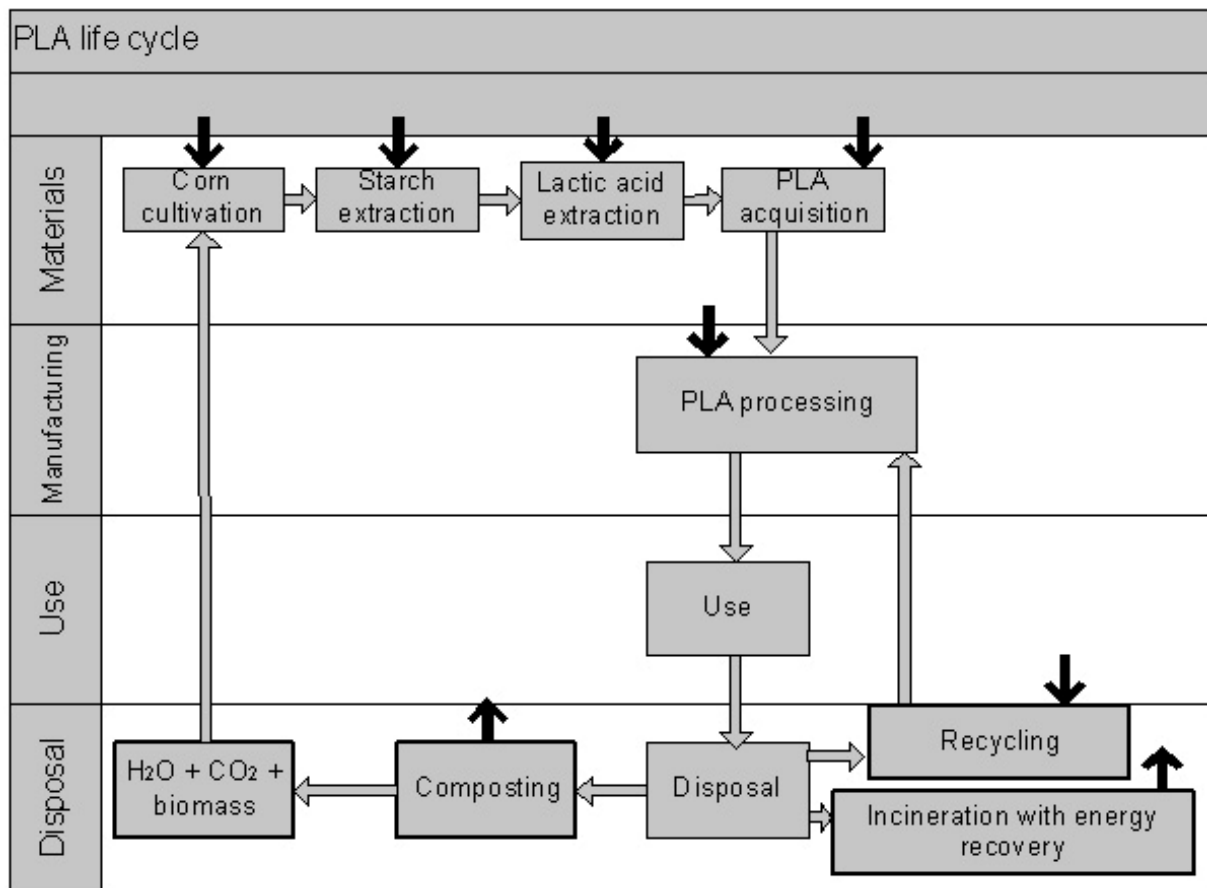


Fig.4. Life cycle of PLA

TABLE 1
ENERGY CONSUMPTION AND GHG EMISSIONS OF PACKAGING MATERIALS

Material	Energy MJ/kg	Weight, kg/FU	Energy MJ/FU	GHG Emissions kg CO ₂ eqv/kg	GHG Emissions kg CO ₂ eqv/ FU
PE	76	0,2	15,20	4,80	0,96
oxo-PE		0,2	15,20	4,80	0,94
PE	76	0,196	14,90	4,80	0,94
Fe	68	0,00132	0,09	-	-
Mn	52,78	0,00132	0,07	-	-
Co	109,1	0,00132	0,14	-	-
PLA1	54	0,3	16,20	4,00	1,20
PLA2	40	0,3	12	3	0,90
PLA3	29	0,3	8,7	1,89	0,57
PLA4	26	0,3	7,8	1,80	0,54

Further based on the available literature data the energy needed and greenhouse gas emissions were recalculated to the FU. To perform the calculations data from LCA databases and from European Commission research were used. In order to compare the diversity of biopolymer production and its impact on the environment four different PLA production scenarios were compared: PLA1 – first year production from corn, PLA2 – production from whey, PLA3 – bio-refinery, PLA4 – long term production. Obtained results allow us to compare energy consumption and greenhouse gases (GHG) emitted for PE, oxo-PE and four different PLA scenarios; data are shown in Table 1.

Figures 5 and 6 presents the calculated energy consumption and GHG emissions:

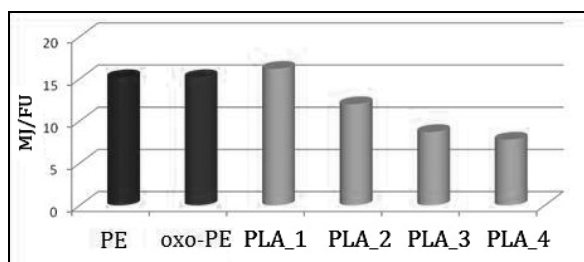


Fig.5. Required energy consumption for the manufacture of packaging material (FU)

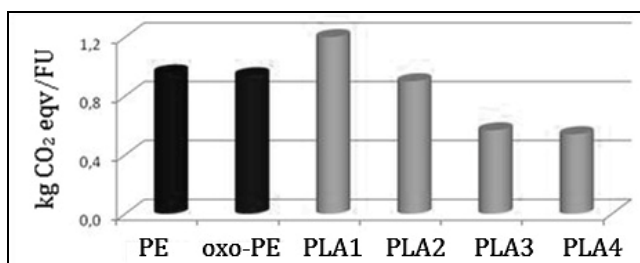


Fig.6. GHG emissions from the packaging material manufacturing (FU)

From the Table 1 it follows that the energy consumed correlates with GHG emissions, except to the metal ions. To properly compare oxo-PE with other packaging materials and

evaluate impacts of additives a more in-depth LCA should be performed.

Oxo-PE packaging puts additional load on the environment as metallic ions pollute the soil and poses a threat to human health: the central nervous system and respiratory disorders, internal organ damage, etc. Manganese can affect the human nervous system, invoking dizziness and coordination disorder. In case of high exposure e.g. at production facility, manganese can cause allergies, Parkinson's disease, impotence, and even paralysis [12]. Cobalt is an essential element of life, but at higher doses it can lead to mutagenic or carcinogenic effects like nickel. Frequently observed reaction to cobalt exposure is dermatitis. In high doses cobalt is very toxic and can cause death. Cobalt in the body can enter together with food, through respiratory system, or through skin [13].

The inference is that the manufacturer is providing incomplete information on the packaging material and deceives the consumers concealing that packaging material not only threatens the environment and human health, but also limits the polymer recycling processes.

In Latvian Republic the Law on Natural Resources Tax regulates the use of natural resources aiming at:

- promotion of economically efficient and environmentally sound use of the natural resources,
- reduction of environmental pollution,
- promotion of new, environmentally friendly technologies,
- supporting sustainable development of national economy,
- financial support to environmental protection measures [14].

In 3rd November 2009 a new regulation of Cabinet of Ministers Nr.1281 were accepted related to labeling of plastic packaging and disposable dishes from biopolymers and oxopolymers [15]. With the entering into force of these regulations, The Law of Natural Resources Tax (Annex 7) provides a lower tax rate for degradable materials, compared to the commonly used polymers. Thus, new rules promote the economic sectors and industry, dealing with oxo-polymers despite of currently ambiguous information about the real sustainability and environmental soundness of these materials.

IV RESULTS

Results of the study indicate that the greatest negative burden on environment is given by oxo-PE, since oxo-additives promote fragmentation of PE and exclude recycling. Another negative impact of oxo-PE material is formation of metal ions – one of degradation product of oxo-PE – contaminating soil and threatening human health. PLA packaging material most likely complies with criteria for sustainable products considering energy use and greenhouse gas emissions. The current study allows draw some recommendations for producers and recyclers of the packaging producers, and legislators as follows:

1) When introducing new products on the market, producers may not rely only on the information provided by manufacturers of material, but obtain also information from the latest scientific researches;

2) Reconsider the development priorities and objectives regarding marketing of oxo-PE packaging products carrying out more complete LCA study;

3) During preparation and introduction of new laws and regulations collaborate with research institutions and follow the life cycle approach considering all effects of potential improvements.

Although only qualitative LCA was performed, the preliminary findings indicate that biopolymers and oxo-polymers also have considerable impact on the environment, and there is a need to more accurate study before using them as environmentally sound alternatives to other polymers.

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Zane Grigale, Jana Simanovska, Mārtiņš Kalniņš, Anda Dzene, Velta Tupureina. Biosadalošs iepakojums no aprites cikla perspektīvas.

Pētīti trīs dažādi iepakojuma materiāli: plaši pazīstamais biopolimērs – polilaktīds (PLA), sintētisks nemodificēts zema blīvuma polietilēns (PE) un jauns iepakojuma materiāls – polietilēns, kas satur efektīvas piedevas polimēra oksidēšanās stimulēšanai gaisa skābekļa vidē ekspluatācijas apstākļos (oxo-PE). Visiem nosauktajiem materiāliem tika veikta aprites cikla analīze (ACA) saskaņā ar ISO (Internacionālā standartizācijas organizācija) ieteikumiem un prasībām. Detalizēti tika analizēti divi svarīgākie aprites ciklu ietekmējošie faktori – materiāla sintēzei un pārstrādei patērētā enerģija un izdalītās siltumnīcas efekta gāzes daudzums pirmajam un otrajam aprites cikla posmam (materiālu iegūšanai un pārstrādei). Aprites cikla izvērtēšanai tika izmantotas ACA un Eiropas Komisijas datu bāzes. Apkopojot rezultātus, noteikts, ka vislielāko negatīvo ietekmi uz vidi rada polietilēns ar piedevām, kas paātrina polietilēna oksidēšanās procesu, galvenokārt veicinot peroksīdu (polietilēna oksidēšanās procesa starpproduktu) sadalīšanos. Polimēra oksidēšanās paātrināšanās piedevas veicina PE fragmentāciju, kas izslēdz tā atkārtotu pārstrādi. Paralēli – metālu (Fe, Mn, Co) joni, kas ir viens no oxo-PE sadalīšanās gala produktiem, būtiski piesārņo vidi un rada nopietnus draudus cilvēka veselībai. Veicot iepakojuma materiālu analīzi un salīdzināšanu vadoties no aprites cikla perspektīvas, kā arī nosakot enerģijas patēriņu un siltumnīcas efekta gāzu emisijas datus atsevišķu iepakojuma materiālu ieguves un pārstrādes posmā, konstatēts, ka no visiem pētītajiem materiāliem PLA iepakojuma materiāls uzrāda ilgtspējīgai attīstībai visatbilstošākos rādītājus.

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Зане Григале, Яна Симановска, Мартыньш Калныньш, Анда Дзене, Велта Тупурейна. Биоразлагаемая упаковка с перспективы цикла продолжительности

Исследовались три различных упаковочные материала: широко известный биополимер – полилактид (PLA), синтетический немодифицированный полиэтилен низкой плотности (PE) и новый упаковочный материал – полиэтилен низкой плотности, содержащий добавки, стимулирующие окисление полимера кислородом воздуха в условиях эксплуатации (охо-PE). Для всех названных материалов был проведен анализ результатов цикла продолжительности (АЦП) в соответствии с рекомендациями и требованиями ISO (Интернациональная организация стандартизации). Подробно проанализированы два важнейших фактора, оказывающих влияние на цикл продолжительности: энергия затрачиваемая на получение и переработку материала и количество выделяющихся парниковых газов на первом и втором этапе (получение и переработка материала). Для анализа цикла продолжительности использовались базы данных АЦП и Европейской Комиссии. Обобщение результатов показало, что наибольшее отрицательное влияние на окружающую среду оказывает полиэтилен с добавками, ускоряющими окисление полимера, главным образом способствуя разложению гидроперекисей (промежуточных продуктов процесса окисления). Добавки, ускоряющие окисление, приводят к фрагментации полимера (кусковому разложению), тем самым исключая возможность дальнейшей его вторичной переработки. Параллельно – ионы металлов (Fe, Mn, Co), одни из продуктов разложения охо-PE, загрязняют окружающую среду и серьезно угрожают здоровью людей. Анализ и сравнение исследованных упаковочных материалов с точки зрения перспективы цикла продолжительности, а также сравнение результатов по затраченной энергии и выделению парниковых газов, определенных на этапах получения и переработки материала, показали, что наилучшие характеристики, необходимые для долгосрочного развития упаковочных материалов, имеет ПЛА.