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Experience, reviews, discussions

Bioplastics: Development, Possibilities and Difficulties

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New possible ways of plastics manufacture and waste treatment are being searched when trying to tackle the problems related to the growth of waste quantities and decline in non-renewable resources. Presently, the most promising and effective way to solve the mentioned problems is production of bioplastics, but its way to recognition is very slow. One of the barriers is the absence of clear and united opinion throughout the EU Arising new discussions about biodegradable and biobased plastics will allow responsible authorities to update and adapt the legal law, which now almost does not include any reglement on bioplastics production and usage. The other issues of bioplastics are social aspects as this material can be made of primal food sources like crops, and the ecological ones because of their unknown effects on human health and the environment. Nevertheless, the main problem remains the same - the price of petro-plastics is still lower than that of bioplastics. Despite this, the biggest companies of the world are starting an initiative to manufacture this new kind of plastics and to widen the range of bioplastics usage in packaging. Considering today's situation and tendencies, at the end of this paper the recommendations for the improvement and speeding up of the processes related to bioplastics manufacture, usage and its waste management in Europe and Lithuania are presented.

Keywords: *bioplastics, PLA, thermoplastic starch, biopolymer, PHA.*

1. Introduction

In today's world it is impossible to avoid using plastic goods as they are universal and durable. One European citizen uses about 100 kg of plastic a year, and the basic material for its manufacture is oil. In the nearest future that will change, because an alternative to plastic is already created and is waiting for its golden age. It is bioplastics whose production is believed to minimise emissions of carbon dioxide and dependence on fossil fuel. Furthermore, compostable plastic is a good alternative to almost un-degradable petro-plastics whose waste can be found everywhere even in the oceans.

If the effect of plastic manufacture on the environment is compared to that of producing bioplastics, it is seen that in the latter 1- 4 kg less carbon dioxide is generated (considering one kilogram of production) without mentioning the much bigger energy consumption by the former. Worldwide

the usage of plastics grew into 250 million tons per year, but if at least one third of this amount were produced out of biomass, we would generate much less greenhouse gases. Moreover, if in the future all plastics were produced of biomass, it would make it possible to remove greenhouse gas out of the atmosphere, because growing plants use carbon dioxide.

Despite all the existing benefits of bioplastics, it is difficult to integrate a new material into the already existing market and functioning system. One of the reasons is a higher manufacture and market price and non-existent its waste management system. It is widely acknowledged that the usage of biotechnologies in industry is a necessary change, but there is almost no legal law for this rapidly spreading sector in the EU, let alone Lithuania. Also an insufficient research work is done on determining the effect of bioplastics on human health and the environment after their disposal.

The aim of this research is to review the current worldwide situation, to study future possibilities and difficulties related to biotechnologies and bioplastics while analysing political, legal and economic aspects of this subject.

2. Methods

Because of the aim of this research, the most suitable method to conduct it was to gather and analyse politically and legally related information from different sources of the EU and to connect it with the worldwide knowledge potential as well as with the existing and future possibilities.

3. Results and discussion

3.1. Politics

Considering a political aspect of bioplastics in the EU, there is no clear and unanimous opinion about this subject. Despite constantly developing technologies and growing pollution by plastics, the EU only now has recognised this problem and only in 2013 made a move to take matters in its hands by releasing the *Green paper on a European strategy on plastics waste in the environment*. The purpose of this paper was to encourage discussions and consultations of various governmental and nongovernmental institutions on what method of solving the plastic related problems they would think would be most suitable. Themes that were suggested for discussions included biodegradable and biobased plastics.

- One of the first of high priority question that should be answered is whether it is worth reinforcing the existing legal requirements by making a clear distinction between naturally compostable (for example, in households) and technically biodegradable (in special treatment facilities) plastics and whether such distinction should be subject to mandatory information.

At the beginning while there is no infrastructure of treating biobased and biodegradable plastic separately, this problem should be solved in a more common way by introducing consumer to a specific and effective labelling specially for bioplastics. Currently, in Europe and the USA, bioplastics are usually marked with a triangular symbol surrounding number 7 with ‘other’ printed below. However, this label has some drawbacks, the biggest of them being the absence of the polymer type specification and the polymer recyclability or biodegradability indication.

The solution to this could be the existing two European labelling systems: the European Bioplastics ‘seedling logo’ and Vinçotte ‘OK compost home’ and ‘OK biodegradable’ labelling systems. The two of them always go along, as the first one is used on packaging that conforms to the EN13432 European industrial composting standard and the second should guarantee complete biodegradability in the light of specific requirements (HGCA 2009).

Fig. 1. Labelling systems that are currently used to identify bioplastics

- Another important aspect is the scope of biodegradable plastics application in which it should be promoted and what framework conditions should be applied to it.
- Bioplastics are already used in packaging by big companies like “Coca Cola”, but it is done only by their initiative. To make this solution more viable a certain promotion and support mechanism should be evolved in future. The bioplastics application range should be set thoughtfully because it differs slightly from the ordinary plastics.
- Another possible threat is oxi-degradable plastic and their recycling processes. There are no available data about what effect to the surrounding environment could be caused by enhancing materials in biodegradable plastic waste stream. Hopefully, some researches on the analysis of the threat will be done and if it is confirmed, safeguarding measures to protect plastic recycling processes will be taken.
- A frequent mistake is made when talking about biobased plastic, thinking that the term “biobased” means a waste treatment method but not the origin of the source. That is why the EU sees a possible threat in promoting biobased plastics. Since it can be made of food crops and if this type of plastics production significantly rises, it may have a negative impact on economic development. Therefore, the EU wants to establish a clear position about this matter and

wants to hear competent opinions before deciding that biobased plastic is worth promoting, and how it should be considered in relation to plastics waste management and resources preservation.

Treatment. Next step after the promotion of bioplastics and making it widely recognisable, its consumers have to be introduced to its waste treatment methods and a proper industrial waste management system of biodegradable plastics has to be established. The resulting end products of this treatment are water, carbon dioxide CO_2 and a little of biomass. So far the only impact while making this type of plastic is reduced, but the main purpose is to reduce the waste treatment costs as well as the waste formation rate. Only then the true potential of bioplastic will arise.

3.2. Law

The possible and on going slow integration of bioplastics into industry has barely any regulations in the EU, except those, for example, applied to package to suit the proper usage requirements. The usage of bioplastics is based solely on the initiative of the companies themselves.

When it comes to the waste management, there exist some regulations concerning labelling and composting. One of them is the above mentioned EN 13432 standard. If a plastic product is certified according to this standard, it provides a proof of their compostability. The European Packaging Directive 94/62 EC also makes reference hereto with regard to compliance with the Recovery Directives.

The compostability fact is approved, if five different tests are passed and positive results are obtained. Success in individual tests is not sufficient. The EU standard test methods are based on the scientific definitions of a range of the ISO standards regarding compostability. Only after passing these tests manufacturers are able to mark their certain products with "seedling" mark and advertise the product to be "compostable" or "biodegradable" (Standard EN 13432).

More detailed analysis about norms and standards for biodegradable agricultural plastics were conducted by some scientists (Briassoulis, D. et al. 2013).

So far until the conclusions after the release of *Green paper on a European strategy on plastics waste in the environment* are made and certain regulations are developed and included into the existing ones, more common and abstract laws will be applied considering bioplastics as ordinary petro-plastic.

Even though the impact of plastic waste on the environment and human health grows every year, there are no EU issued regulations that would deal with this problem. Only the European Packaging Directive 94/62 EC has included a specific plastic waste recycling goal. The Waste Framework Directive 2008/98 EC declares that producers' responsibility is one of the main principles of the waste management. This directive also sets waste management hierarchy, but still there is very clear contrast between the legislations and real waste management practice (Green paper 2013). The REACH 1907/2006 EC regulation is also very important considering plastics recycling and effective use of resources. Bioplastics could be a solution for removing harmful plastic supplements from the manufacture because according to the EU and REACH provision they cause great concern.

Strict compliance of the waste management regulations could basically improve the growth of industry and would also create new working places. Recently conducted studies have shown that if waste management regulations were fully implemented, then by 2020 72 mlrd. Euros per year could be saved and the circulation of recycling sector would increase by 42 mlrd. Euros. Furthermore, more than 400,000 work places would be created (Green paper 2013).

The Commission has understood the need to assess waste management more accurately on national, regional and locational levels and has set things in motion to do it.

Lithuania is not an exception and faces the same problems as the EU does. Our government is adapting mostly only the EU issued regulations to the national legislation base. Biotechnologies have started to be developed. To encourage this development and set common goals the Industrial Biotechnology Development in the Lithuanian Programme for 2011 – 2013 years was issued.

It declares that the main challenge to Lithuanian industry is to implement and use cheaper and biodegradable materials that could replace at least part of the plastics, which are manufactured using polymers synthesised from petroleum products. Since plastic manufacturing industry is quite vast in our country, successful implementation of this goal would enable long-term and much promising development and bigger opportunities to compete with foreign manufacturers considering the production of biodegradable package (LR No. Nr. 4-118).

To reach the goal stated above it was planned: to create technology which would allow the recycling of biopolymers to thermoplastic compositions, which would be used in package manufacture, to develop low molecular weight plastics for the production of functional compounds and to investigate their possible use by using bio-based methods, to create chemical modification techniques from natural compounds in order to get the environment friendly plastics and coatings.

3.3. Economics

Possible profit is one of the main factors that stimulates economics and motivates manufacturers to produce more innovative goods, which could compete with each other. Unluckily, the same principle cannot be applied to bioplastics yet. Bioplastic goods producers cannot expect that consumers would pay

more for their production just out of the idea to be more "green", when petro-plastics still cost less. This market will become more competitive and effective only when new product prices will become almost the same or equal to petro-plastics. That is the most important reason why bioplastics share in the total plastic market was only around 1 % in 2012. Another important factor is that most buyers have never heard about possible alternatives to ordinary plastics.

According to data of the Institute for Bioplastics and Biocomposites (IfBB), almost 40% of biopolymer production market was taken by other types of packaging that include carrier bags, the second biggest share is bottles – 32.5%. Other segments like technical applications, catering, consumer products and agriculture take 5 to 10 % each, other remaining segments take barely 3% of the total market. In IfBB forecast for 2016, they predict that bottles will experience the biggest growth – a 24% increase, technical application share will slightly increase by 2%. Other segments will experience a decrease: other packaging – 12 %, catering and agriculture – 5%, construction and other application will slightly decrease. Pharmaceutical and medical segments will remain stable.

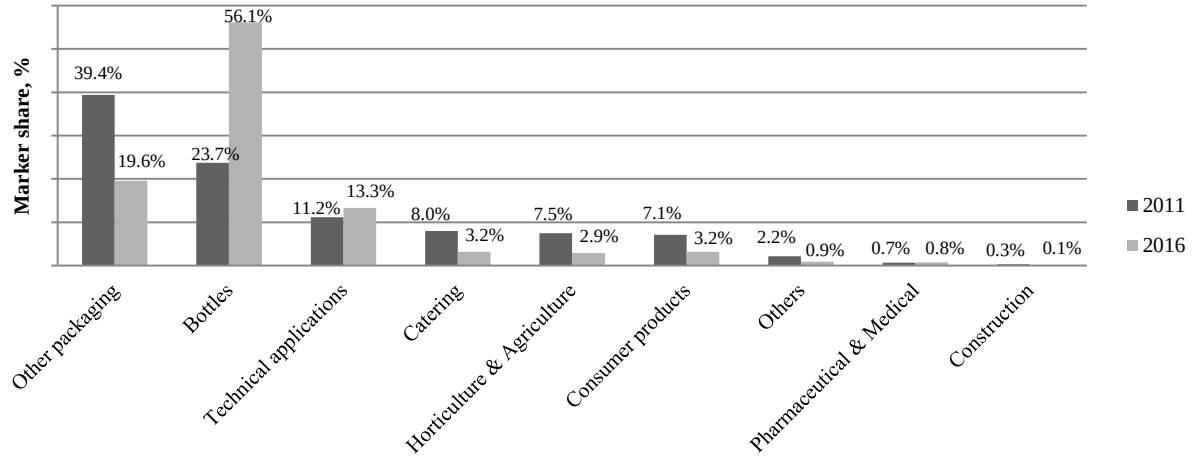

Fig. 2. Market size share of biopolymer production capacity in 2011 and 2016 (IfBB, 2013)

There were 1,274 Mt of various types of bioplastics made in 2012. Almost 43 % of this amount consisted of Bio – PET 30 (biobased content amounts to 30%), all other types were quite equal – almost 16% of Bio – PE and almost 15% of PLA and PLA bends. Other materials that were used to produce bioplastics were starch blends (11%) and biodegradable polyesters (9%). In general, 3,761 billion Euros income was generated by bioplastics in 2012. The Institute has foretold that in 2016 this income will reach 13.7 billion Euros and 70% of the market will be taken over by Bio-PET 30.

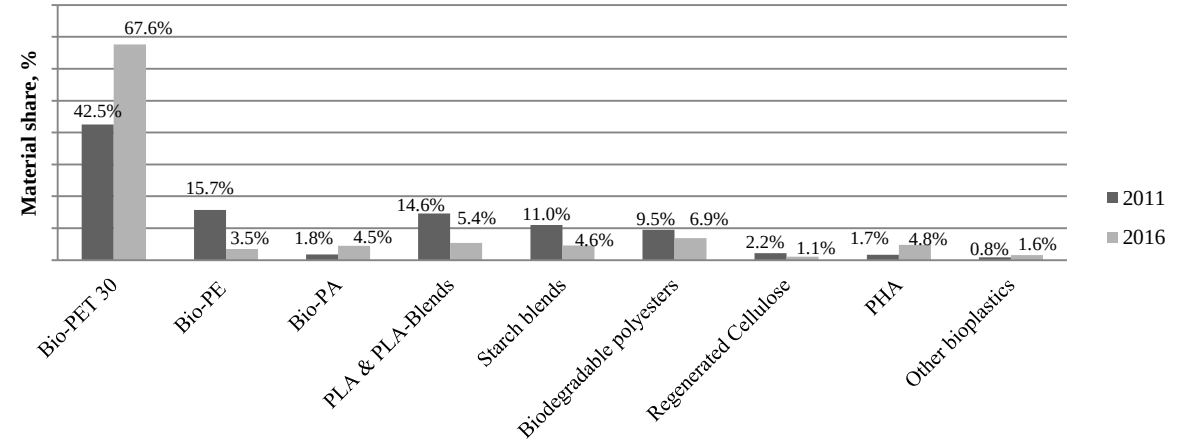

Fig. 3. Material share of biopolymer production capacity in 2011 and 2016 (other bioplastics include cellulose derivatives, PCL, Bio-PC, Bio-TPE, Bio-PUR, Bio-PP) (IfBB, 2013)

As we can see the biggest share of the market was taken by bioplastics, which has only 30% of biodegradable materials in their content. In their laboratories scientists try to create 100% biodegradable plastic from sugar extracted from various types of plants, but to transfer and make these technologies viable and effective in industry will take many more efforts and investment. So far, these processes are slowed by many regulations and the government's unclear position about bioplastics, because first of all new material should be 100% biodegradable in order not to get into the dumpster and to have the same properties as petro – plastics.

There is a company in the USA called "Cereplast", which produces bioplastics from tapioca, corn, wheat and potatoes. They manufacture bioplastics from starch extracted from previously mentioned resources. Out of 1 t of potatoes they can make around 0.24 t of thermoplastic starch by adding plasticiser to pure potato-starch during the extrusion phase (see material flow chart in Figure 4.) *(IfBB, 2013)*.

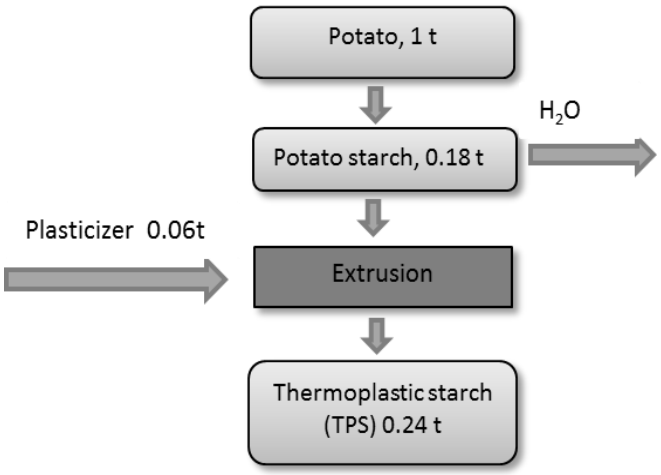

Fig. 4. Material flow chart of the production of thermoplastic starch (TPS) (IfBB, 2013)

The director of this company has calculated that when oil price reaches around 95 dollars per barrel, his company production will become cheaper than that made of petro-plastics and the demand for bioplastics will increase allowing their company to work more effectively. Only when the oil price starts growing at a fast pace, the bigger plastics producers like "Dupont" and "BASF" will have no other option left just to switch to the production of bioplastic. That will be a big break, when all bioplastic industry and science experience the uprise.

One of the main advantages of bioplastic is that it can be made of recyclable materials i.e. from food waste to straws, sugarcanes or corn. You don't have to grow food plants for the production of bioplastics, instead, you can choose recycling of waste and save the land suitable for farming, for the production of human food. When you dispose of biodegradable packaging, it decomposes into water and carbon oxygen in few months and this process has no negative impact on the environment.

Certain environment conditions (temperature and moisture) and microorganisms are necessary for the degradation of some types of bioplastics (like PLA) after their usage time ends. Those are most commonly produced by the biggest bioplastics manufacturers in the world.

Recently scientists have discovered a way to strengthen the production of bioplastics and to make it more efficient. Scientists from the Danish company "Haldor Topsøe" have developed a special catalyst which transforms carbohydrates to lactic acid. Scientists have found out that a special grid developed from titanium, tin or zircon works like catalyst i.e. it strongly fastens sugar molecules degradation to lactic acid.

Raw materials and related problems. The European Commission initiated the international project called "Animpol" in 2010. Its purpose was to create a best possible set of technologies that would allow people concerned to utilise waste streams from slaughterhouses, from animal rendering industry and waste fractions from conventional biodiesel manufacture for the production of improved biodiesel and biodegradable high-value polymeric materials (PHAs). This would allow them to treat the waste more efficiently than before, and to produce almost 35 000 tonnes of bioplastics at an industrial level annually. If this method were proven to be more effective than other methods used for that type of waste treatment, it would bring profit at the industrial level, it would let eliminate bigger part of toxic solvents that are used while producing bioplastics by applying different technologies.

Nowadays slaughterhouse waste is simply burned, but using this utilisation method a lot of useful materials, like lipids, are destroyed. Instead of being burned, it could be used in the production of biodiesel and crude glycerol, which would result after the following treatment in PHA-rich biomass. Another stream of PHAs would be produced from the methyl esters of saturated fatty acids that can have a negative effect on the properties of biodiesel when used as an alternative motor fuel (see Fig. 6) (ANIMPOL 2010).

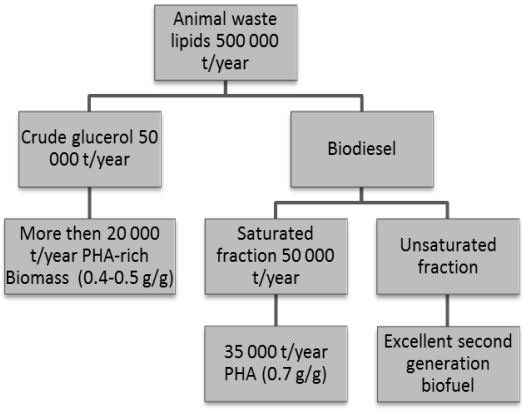

Fig. 5. Amount of available animal waste lipids and the potential PHA production

While solving the plastic related problems in the future instead of today, the role of biopolymers will still grow up. The most important thing is whether we (EU) import raw material for bioplastic production from other countries, or we are able to produce it ourselves.

There are more studies on the utilisation of waste to produce biodegradable polyesters, polyhydroxyalkanoates (PHA) (Shahzad, K. et al. 2014).

Much promising polylactic acid (PLA). This material is one of the most popular for producing bioplastics and is made of dextrose (sugar) extracted from biological raw materials, such as corn starch (mostly in the USA), wheat, tapioca roots, starch or chips (mostly in Asia) and sugarcanes (the rest of the world). The primary PLA producer in the USA is "Natureworks" which produces around 130 000 tons of bioplastics under the name of Ingeo. Other companies involved in PLA manufacturing are PURAC Biomaterials (The Netherlands) and several Chinese manufacturers.

PLA like most thermoplastics can be processed like fibre and film by extrusion, injection, moulding, film & sheet casting and spinning. This variety of possible choices provides access to a wide range of materials and possible application areas. One of the routes to PLA is by synthesising corn-based starch, when out of 1tonne of corns by processing it by means of hydrolysis, fermentation, dehydration and polymerisation you can produce around 0.42t of PLA.

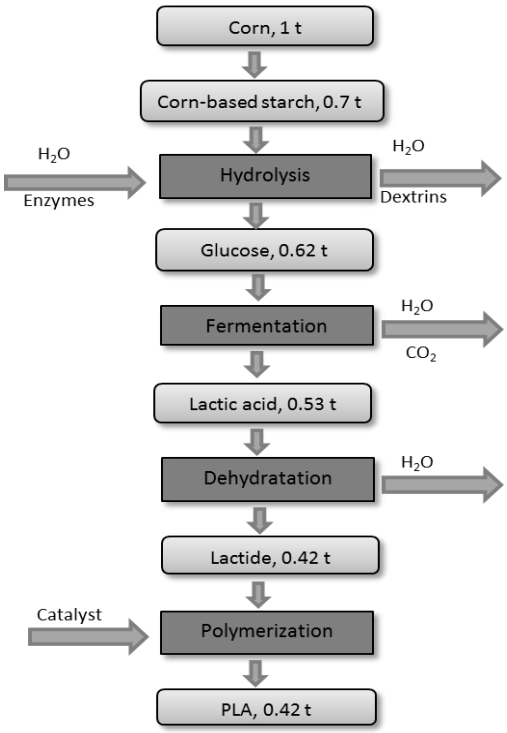

Fig. 6. Material flow chart of PLA production (IfBB, 2013)

Due to PLAs ability to degrade into innocuous lactic acid, the range of PLA application is vast: medical implants in the form of anchors, screws, plates, pins, rods and as a mesh to 3D printing, not forgetting the more usual packaging material. PLA could be even compared to PET-A, and some types of PLA have bigger MFI (melt flow index), so it could be produced by casting and can replace polystyrenes

(PS) in many ways. Since PLA is appropriate to produce fibre, it can replace polypropylene (PP) in the manufacture of certain products.

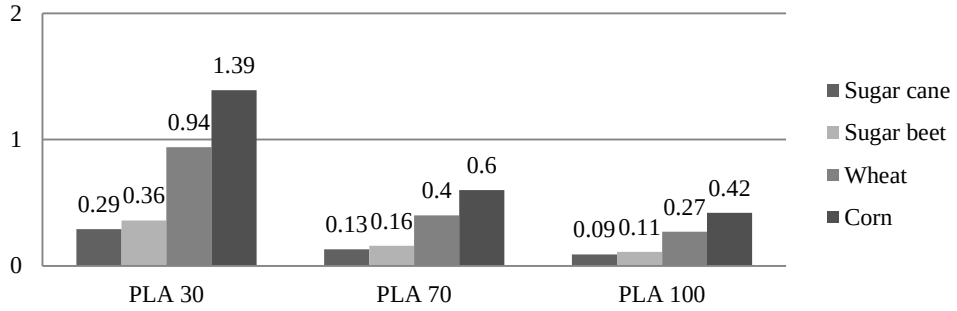

Fig. 7. PLA and PLA blends biopolymer output per metric tonne of feedstock (IfBB, 2013)

PLA is marked by SPI resin identification code 7, all types of PLA are biodegradable in certain environment and are certified under the demands of EN12342. It can be treated in industrial treatment plants where the temperature and humidity should be kept higher than 70°C and 70% respectively. Polylactic acid can be also chemically recycled to monomer by thermal depolymerisation or hydrolysis. When purified, the monomer can be used for the manufacture of virgin PLA with no loss of original properties (cradle-to-cradle recycling). Since this material is hygroscopic, collected waste should be dried before the treatment.

Deeper analysis of this type of biopolymer was made by some scientists (Piemonte, V. et al. 2013).

Inspirational examples. One of the biggest drinks producers in the world "Coca-Cola" signed an agreement and started working with the companies that had already had big advantage in the production of bioplastics in 2009. These companies promised that until year 2015 they will create a technology that will let to produce 100% biodegradable bottles from natural resources and not from oil. So far they are focused on moving towards their goal of "Coca-Cola" released and in 2012 they used bottles which consisted of one quarter of bioplastics. Drinks in these bottles are already sold in 20 countries worldwide and the market is growing every year. Due to different features of the drinks, bioplastic share in a bottle differs, for example, "Coca-Cola" bottle has 22.5% of bioplastics, when "Odwalla" juice line package is 100% made of bioplastics. So far "Coca-Cola" is unable to adapt its bottles for carbonised drinks, but the company hopes that by 2015 they will be able to create multifunctional bioplastics and by 2020 sell them worldwide.

One of the biggest shopping networks in Lithuania started selling bioplastics shopping bags. It is easy to recognise them by their appearance and they quickly catch buyers' attention. These bags are produced in Italy of a biodegradable material called "Mater-Bi", which basically consists of corn starch. They are as strong as ordinary shopping bags and can be used multiple times until they wear off. The processability and performance of a biodegradable polymer Mater-Bi, and its blends with either a sample of poly or with bacterial biomass containing PHAs were compared in the article published by R. Scaffaro et al. in 2012 and 2013.

French food industry concern "Danone" started using "Ingeo" bioplastic in packaging their yogurt in 2011. This package was created together with the WWF (World Wide Fund For Nature) organisation and approved by the German IFEU institute as making lesser impact on the environment. From then "Activia" yogurt is supplied to German food market only in bioplastic packaging. The concern counted that this innovation helps them to save enough energy for the consumption of 13 000 German households per month.

The yogurt package is made of corn starch which was certified under the criteria of the ISCC standards in 2011. It means that plants that are used to make bioplastics were grown taking into account social and ecological principles. Also the usage of this bioplastic decreases the emission of carbon dioxide by 25% and the usage of oil product by 43 % compared to previously used dish.

4. Conclusions

1. Neither the EU nor Lithuania has a clear vision and regulations how to reduce plastic consumption and a growing rate of waste quantities in landfills, and what would be the most suitable way of dealing and recycling this kind of waste. For this reason the EU is systematically initiating the discussions considering this matter and what would be the most efficient way to act towards it while going forwards to sustainable plastics and their life cycle.
2. While the impact of plastic waste on the environment is increasing, there are no applicable laws for this problem considering the EU, let alone Lithuania. There are no specific requirements and regulations for plastic waste management and recycling processes. The creation and application of the suitable legislative framework together with full compliance would encourage the growth of industry and the creation of new working places.

According to the new law plastic waste should be reused and recycled and not be sent away for a slow decay in landfills.

3. Bioplastic production and adaptation to mass production should ease difficult situation of plastics, but this not very popular decision has been hardly made. One of the arising problems is the bioplastic production from possible food resources. In addition, the impact of new substances on human health and the environment is vaguely known. The third barrier is that there is no suitable collection, recycling and composting system for this type of plastics on the national basis in any EU country. But the main aspect which slows all the processes is a higher price compared to petro-plastics. The break will be reached only then, when bioplastic and petro-plastics packages will cost the same.
4. Despite all barriers, a few years ago the biggest companies started to invest in bioplastics and nowadays they package their production in new material. In will not take long until other companies follow their example, because it is certain that it will be unavoidable and much cheaper when the price of technologies and production will drop in the future.

5. Recommendations

First steps towards the development of bioplastics manufacture and their wider usage are taken: discussions on the most important legislation issues have started, the biggest packaging producers began to sell their products in bioplastic packaging.

The next step should be the decision to what purposes the usage of biodegradable plastics should be encouraged considering the EU and national initiatives and what main conditions should be stated considering this aspect. One of the biggest priority areas is packaging, because disposed plastic packaging takes biggest part of plastic waste. In this case no big revolution can be expected, but it should be thought about strictly set transition periods, during which the biobased or biodegradable plastic share in one packaging unit would be constantly increased. This does not have to be the whole unit from the beginning of this initiative, a starting line should be stated and then periodically, from 2 to 3 years, constantly raised.

An important aspect is strict legal separation of biobased and biodegradable plastics by defining them in the legislative framework. This information is essential to consumers and to waste management companies because it should help to protect recycling processes and to spread the adequate information about a suitable method to treat the waste of this kind. Information about a plastic type should be conveyed through the specific packaging and production marking system, which is discussed in the paper, but firstly it should become a must and information about the meaning of the marks should be introduced and announced much wider than it is now in Europe, let alone Lithuania.

It is hoped that the proper legislative framework will be prepared by 2015. Until then the production of bioplastics from agricultural and livestock waste will increase. This will make it possible not only to eliminate part disposed of in landfills or incinerated waste, but even to convert it into raw material. While trying to make this alternative more attractive than disposal or incineration to those who sell or dispose of it, certain state subsidy programmes should be issued to support the companies manufacturing this kind of bioplastics. Financial support should be given to buy required technologies and to adapt them and the subsidies should help to keep buying prices higher.

When bioplastic share in the common market will reach at least 20 %, then the creation of a suitable bioplastic waste treatment system will become very efficient and worth focusing on. A conclusion could be drawn that the efficiently functioning collecting system will let separate and collect the bioplastic waste technologically compostable and compostable on household conditions and that would make possible the functioning of at least 2 large volume technical composting units without losses spread around the country thus minimising transportation expenses.

Even if the creation of suitable bioplastic waste treatment system did not give positive results at the start, the increased manufacture and bioplastic market share would have a significant impact on reduction in pollution caused by industry. These measures would let reduce carbon dioxide emissions by 25% and the usage of oil by 40%, compared to the packaging previously used (per one unit of production). Also it would reduce the usage of energy while producing plastics, because plastic industry now is one of the biggest industry sectors consuming the biggest amount of energy for one unit of production.

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Bioplastikas: plėtra, galimybės ir problemos

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Nuolat ieškoma naujų galimų plastiko gamybos ir atliekų tvarkymo būdų, kurie leistų spręsti su didėjančiu atliekų kiekiu ir mažėjančiu neatsinaujinančių išteklių vartojimu susijusias problemas. Šiuo metu vienas efektyviausių metodų spręsti šias problemas – bioplastikai, tačiau jiems skiriama mažai dėmesio. Vienas iš trukdžių – tai, kad Europos Sąjungoje nėra aiškios ir vieningos politikos. Skatinant diskusijas apie biologiškai skaidų plastiką ir plastiką, pagamintą iš biologinių medžiagų, bus atnaujinta ir pritaikyta teisinė bazė, kuri dabar beveik nereglamentuoja bioplastikų gamybos ar vartojimo. Taip pat yra socialinis (ši medžiaga gali būti gaminama iš maistui tinkamų medžiagų, tokių kaip javai) ir ekologinis (nėra tiksliai žinomas poveikis žmogaus sveikatai ir aplinkai) aspektai. Tačiau pagrindinė problema išlieka vis ta pati – iš naftos pagaminti plastikai yra pigesni nei bioplastikai. Nepaisant visų iškylančių problemų, didžiausi pasaulio koncernai jau ėmėsi iniciatyvos gaminti siūlomą medžiagą ir taip pakuoti savo produkciją. Ateityje tikimasi išplėsti šios pakuotės panaudojimo ir pritaikymo mastus bei padidinti biologiškai skaidžios masės dalį, sudarančią visą pakuotę. Išanalizavus esamą situaciją ir vyraujančias tendencijas, darbo pabaigoje pateikiamos rekomendacijos, kurios leistų pagerinti ir paspartinti su bioplastikų gamyba, naudojimu bei atliekų tvarkymu susijusius procesus Lietuvoje.