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Ecological Footprint Comparison of Biobased PHA Production from Animal Residues

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Utilization of waste streams is gaining more and more importance to reduce costs at the input side of a process. This affects not only costs, as environmental impacts can be minimized due to utilization of recovered waste streams too. ANIMPOL is an EU funded research project which is focused on the production of biopolymers from animal residues. This report compares conventional plastic production against fermentation of animal residues to polyhydroxyalkanoates (PHA) which constitutes a group of biobased and biodegradable polyesters. Beside PHA high quality biodiesel and meat and bone meal are produced which improves the economic feasibility of the whole process design. Through hydrolysis of specific residues the substitution of inorganic nitrogen can be achieved (Kettl et al., 2011a).
For comparison of different production scenarios Ecological Footprint evaluation, according to the Sustainable Process Index methodology (Sandholzer et. al., 2005; Narodoslawsky and Krotscheck, 1995) was applied. Sub-process sharp information is available to figure out ecological hotspots within every process step. Ecological optimization potentials as well as production cost reduction are pointed out to address cleaner production already in the process designing phase.

1. Introduction

Polymeric material is most commonly used as a packing material to ensure safe and efficient distribution of goods. This ever increasing production and packing, has made waste disposal an emergency for several countries. The waste disposal problem and regulations for safe and cleaner environment has served as driving force to stimulate increased research for the potential solutions like bio based and biodegradable polymers or other more sustainable materials.
This need have provided incentive for research and development of novel production techniques based on renewable resources. “White biotechnology” has been used for sustainable production of polymers, fine chemicals and fuels by utilising microorganisms or enzymes. Polyhydroxyalkanoates (PHAs) are one of the potential value-added products which are produced by certain bacteria from carbonaceous substrates (like carbohydrates, lipids, alcohols or organic acids) as carbon and energy reserves under unfavourable growth conditions due to imbalanced nutrient supply (Koller et al., 2010; Yu et al., 2008).
The biodegradable and biocompatible properties of make this potential substitute for some conventional plastics. The potential applications of PHA range from rigid plastics to ductile elastics make them interesting for various industries and medical applications. Nevertheless a major drawback of PHA production has been high production cost. In order to reduce the PHA production cost, substantial efforts has been made through efficient bacterial strain development, optimization of fermentation and downstream processing for PHA recovery. Keeping in mind that carbon substrate is the major cost factor in PHA production, selection of the carbon source is a critical factor in determining the cost of overall PHA production (Yu et al., 2008; Chee et al., 2010).

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Agriculture and food processing industries have enormous amount of waste discharge per annum which is a potential renewable carbon source for bio based PHA production. The utilization of these resources not only decrease carbon substrate cost but also solve waste disposal problem. Aim of the ANIMPOL project ("Biotechnological conversion of carbon containing waste for eco efficient production of high value added products"), financed under 7-th frame work program by the European union, is to produce biobased plastics (PHA) utilizing slaughtering waste streams.

2. Process Design Development

According to the flow sheet there are three main streams originating from the slaughtering process. Meat, non-rendering material (manure, digestive tract material, colostrum etc.) and rendering material (mainly fat, bones and blood). Meat and non-rendering materials are direct products which are consumed in the market while rest of the material is utilized as input for the sub processes. Main parts of the process design are hydrolysis, rendering, biodiesel, PHA production which are elaborated in the previous publications (Titz et al., 2012; Kettl et al., 2011a). The downstream processing of the PHA production includes fermentation media concentration using micro or ultra-filtration membranes, high pressure homogenization and centrifugation and washing.

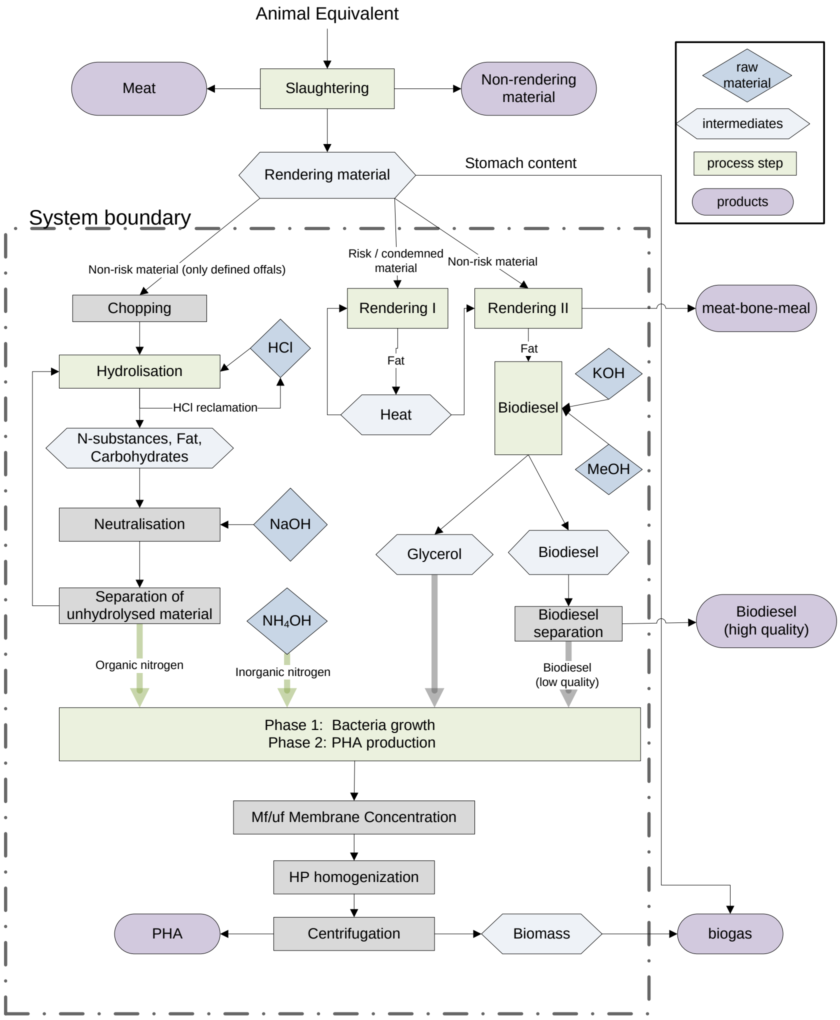

Figure 1: Flow sheet of process design for ANIMPOL

2.1 Ecological Assessment

In this study SPI methodology was used as LCIA method. It results in an ecological footprint, calculating the area necessary to embed the whole life cycle to provide products or services sustainably in the ecosphere. The Sustainable Process Index (SPI) developed by Krotscheck and Narodoslawsky (1995) is based on the assumption that the only income of our planet is solar energy. This income drives all natural processes and global material cycles (e.g. the global carbon cycle). The key resource to transform this income into utilisable material (e.g. biomass) or energy is area, e.g. Productive land, air and water have to be retained in a condition that allows them to remain the key production factors in a sustainable economy, therefore all emissions into the three compartments air, water, and soil are considered for the ecological footprint calculation following the principles that global material cycles must not be changed and that the local qualities of these compartments must not be changed either. Therefore the SPI value is a sum of seven different sub-areas which are area for infrastructure, non-renewable material, renewable material, fossil carbon, emissions to water, emissions to soil and emission to air. These areas are indicated by different colours and sum of all areas to provide raw materials, energy and to absorb emissions is the ecological footprint of the life cycle of the product or service.

The SPI may be used to compare different technologies (Kettl et al., 2011b), optimize the environmental performance of a single product (ecodesign) or to optimize the environmental performance of a company (Gwehenberger et al., 2007). The SPI as a tool looks at the whole product–service chain of PHA production and provides concrete and encompassing information about the environmental impacts of the processes in question.

2.2 SPI Calculations for different process

The ecological footprint (SPI value) for the final PHA product according to the process design accumulate evolved of every process key step is evaluated separately and cumulated to a final PHA footprint. Therefore base of evaluation for every key part is production of 1 t of PHA.

2.3 Animal residues or waste

Waste materials from slaughterhouses are considered with an SPI value of 0 m²/ton. The transportation of the waste material to the rendering plant is taken into account. For 1 t of PHA production 13.64 t of waste material will be transported within 75 km radius causing 150 km distance per trip. Total freight transportation is 2,046 tkm/ton of PHA production. SPI value for transportation using 28 t transportation trucks is 173,855 m^2.

2.4 Hydrolysis

SPI for offal hydrolysis is the sum of calculated SPI values for offal transportation, electricity consumption for chopping, acid reclamation, heat consumption for heating, acid consumption and base consumption for neutralization. As explained in the previous publication (Titz M et al., 2012) offal hydrolysis is the source of complex organic nitrogen to be used in the fermentation process. Available amount of complex organic nitrogen is 4.4 kg/t of PHA production. SPI value for hydrolysis is **9,338,949 m²/t** of complex organic nitrogen.

2.5 Rendering

SPI calculations for rendering process are divided into two parts depending on material to be processed. Products from condemned waste material are only used for heat production, (Rendering II in this particular case). In contrast to Rendering II processes the main part of the waste stream produces meat and bone meal (MBM) and tallow.

2.6 Rendering I

As explained in (Titz et al., 2012) input material will be condemned material (all body parts from TSE suspected and confirmed animals) which is not allowed for the processing of tallow. SPI for Rendering I is the sum of calculated SPI values for condemned material transportation, electricity consumption, heat consumption, waste water treatment and process water. The outcome of rendering I is about 0.7 MWh of process heat with an SPI value of **32,507 m²/MWh** which will be used for heating purposes in Rendering II.

2.7 Rendering II
This is the main rendering process processing extra fat, bones and animal viscera to produce tallow and MBM. Tallow is further utilized to produce biodiesel while MBM will be sold to the market. In Rendering II inputs for SPI calculations are waste transportation, electricity (EU27-mix), heat (produced from Rendering I), heat from natural gas, waste water treatment and process water. This process is a multi-output process because the main product is tallow and as secondary product we get MBM for selling to the market. Thus SPI value is allocated to both products according to production mass ratio. SPI for products is **231,498 m²/t** of tallow/MBM. This value of SPI for tallow production is used in SPI calculation for biodiesel production.

2.8 Biodiesel
Biodiesel is produced by trans esterification of fat with methanol in 1:6. Other inputs during biodiesel production are KOH, H_2SO_4 and heat. The cumulative SPI value is **658,360 m²/t** of biodiesel production. This SPI value is a cumulative value allocated by applying mass allocation between biodiesel and glycerol.
SPI value for biodiesel as well as glycerol is **284,774 m²/t**. Crude biodiesel will be further processed to low and high quality biodiesel fraction. Low quality is about 55 % of crude biodiesel which will be used in PHA production and rest 45 % high quality biodiesel (biodiesel HQ) will be sold in the market according to project outline. Biodiesel separation process is not fixed yet, so energy and chemical input data is missing. Due to this reason the SPI value per ton of biodiesel LQ and HQ are the same as for crude biodiesel.

2.9 PHA production and downstream processing
PHA production and downstream processing is comprised of fermentation process, PHA separation and purification process. The following table represents SPI the inventory data which comprises nitrogen input from the offal hydrolysis, NH4OH as an inorganic nitrogen source, glycerol and biodiesel as carbon sources, chemicals according to fermentation media requirements, energy and water inputs. Table 1 represents inventory inputs for PHA production calculated according to mass flow calculations. The calculated SPI value is **1,085,298 m²/t** of PHA production.

Table 1: PHA Production Inventory Data

PHA production inventory data		
input	inventory	units
Organic nitrogen	0.0044	t
Ammonium Hydroxide	0.0767	t
Glycerol	0.2371	t
biodiesel	1.8588	t
Inorganic chemicals	0.0782	t
Net electricity EU27 mix	0.3214	MWh
waste water treatment	8.1178	m^3
Process Water	8.1178	m^3
Process energy, natural gas	2.8980	MWh

3. Results and discussion

The footprint distribution for different inputs has been shown in Figure 2. It shows that maximum footprint which accounts for 54 % is produced by the carbon source (biodiesel (LQ) and glycerol). The other two most prominent factors are net electricity EU-27 mix and steam consumption (from natural gas), sharing 17 % and 19 % of overall foot print respectively. Although organic nitrogen mix from hydrolysis is very low, it has significant share in the overall footprint. The reason for high footprint of this process is high energy and inorganic acid and base consumption.

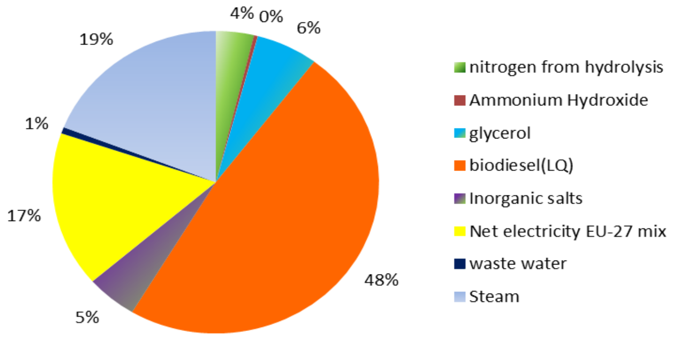

Figure 2: PHA production footprint distribution

The above results show the current progress in the PHA production using EU-27 electricity mix and natural gas as energy resources. Figure 3 represents the PHA-R production (PHA production using renewable energy source) fulfilling energy demands from completely renewable resources. For these calculations “net electricity biomass fired power station” and heat production from wood chips has been used as energy sources. The distribution of footprint is very different as compared to the conventional scenario. In this scenario carbon input source have even bigger share which is about 63 % while other important inputs are inorganic salts, complex organic nitrogen from hydrolysate and steam consumption respectively.

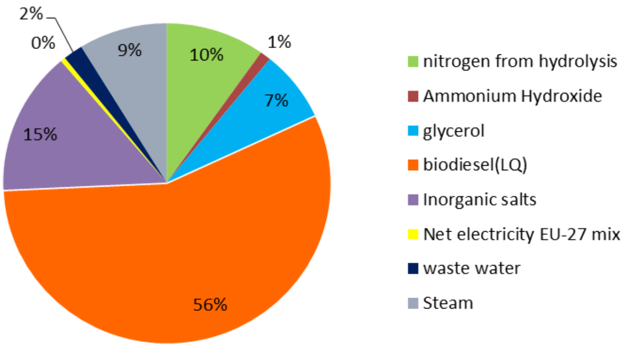

Figure 3: PHA-R production footprint distribution

Figure 4 compares the footprint per ton of PHA production, PHA-R production, based on the ANIMPOL process with a conventional Polyethylene low-density (PE-LD) production process. The overall footprint values per ton production of PHA, PHA-R and PE-LD are 1,085,298 m^2, 372,950 m^2 and 2,508,409 m^2 respectively. PHA production in the current scenario has 57 % lower footprint than PE-LD while PHA-R production scenario has 66 % and 85 % lower SPI value compared to PHA and PE-LD respectively. Although some data about energy consumption in biodiesel separation process is missing but results are very promising to compare ecological footprint bandwidth and relation between different products. Out of the sub-category “Area for fossil carbon” the life-cycle CO2 emissions can be calculated which would be 3.9 t CO_2 per ton PHA, 1.5 ton CO_2 per ton PHA_R and 7.4 t CO_2 per t Polyethylene LD.

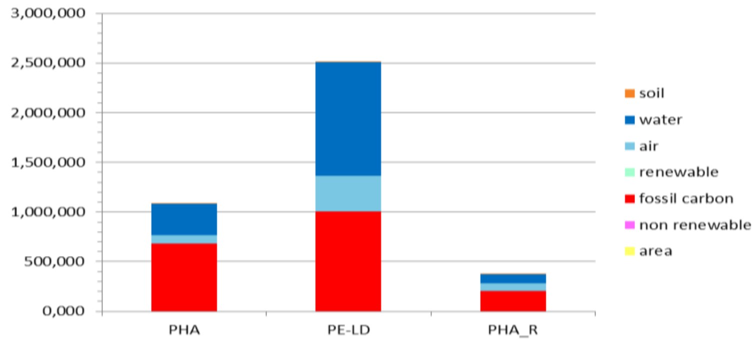

Figure 4: Comparison of overall footprint for PHA, PE-LD and PHA-R

4. Conclusion and outlook

The paper represents the ecological footprint analysis of PHA production utilising waste streams from slaughtering industry. The results clearly indicate that major footprint shareholders are carbon source for PHA production and energy consumption. Keeping in mind that starting material is a waste stream and carbon source for PHA production is produced through highly energy intensive rendering process and biodiesel production process. The footprint for carbon source can be reduced by process optimization, heat integration and using maximum renewable energy. The 2^{nd} scenario PHA_R production shows possible achievable footprint and CO_2 emission reductions. The process is in further optimization stage using heat integration and cleaner production studies. Furthermore economic analysis is also carried out side by side in order to assess the economic feasibility of the process.

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