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Is it reasonable to produce biodegradable plastics for a higher environmental friendliness during end of life? – an environmental comparison of incineration and land filling looking at GHG and sustainability -

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Typical plastics are mainly made from the nonrenewable resource crude oil. Typical characteristics are lightweight, non-breakable and pliable. End of Life (EoL) plastic parts are recycled, used as carbon substitute (e.g. steel melting) or are incinerated (with and without energy generation). In Japan most of the EoL plastics are incinerated. For a sustainable future, a move from consuming nonrenewable resources to the use of renewable resources is necessary.
Biodegradable plastics are called CO_2 neutral, because they are made from biomass. Therefore biodegradable plastics are expected to contribute to the reduction of greenhouse gas emissions. If they are land filled, they are degraded by bacteria and finally decomposed to CO_2 and H_2O. But, considering higher technical properties of "biodegradable" plastics, the decomposing time is increasing and the biodegradability is decreasing. That means, plastic parts are stored for a long time e.g. on land fill sites.
Why should biodegradable plastics not be considered as sustainable if incinerated?
This LCA study demonstrates that incineration of biodegradable plastic is more sustainable than simply disposing it. For the presentation of the results different emissions (CO_2, N_2O) as well as energy consumption were selected. At the end the advantage of the incineration regarding sustainability is obvious in comparison to the land filling of biodegradable plastics.
Key words: LCA, biodegradable plastic, polylactic acid (PLA), CO_2 neutral

1. INTRODUCTION

Plastics are used in all our life and we are almost not able to avoid those. The amount of Japanese plastic production was about 100,000 [t] in 1955. A peak in the domestic production was reached with 15,200,000 [t] in 1997. A slight decrease of the production amount was in 2002 with a production rate of 13,580,000 [t]. The increase of plastics production means a higher plastic waste accumulation[1],[2].

Biodegradable plastics have been attracting the public, because biomass is a renewable resource as compared to crude oil or natural gas. Regarding IPCC, CO_2 emissions released during incineration of biomass are carbon neutral. The reason is that CO_2 is absorbed out of the atmosphere during plant photosynthesis.

After the use phase of polylactic acid (PLA) based biodegradable polymer, different options about the end of life are possible: On the one hand we can landfill the PLA and it will finally decompose to CO_2 and H_2O. On the other hand we can incinerate the PLA. Both options are CO_2 neutral, but the advantage of the incineration is the output of usable energy. In this publication, we will show the advantages and disadvantages of both possibilities.

2. GOAL AND SCOPE OF THE STUDY

This paragraph covers the description of general goal and scope of the study as well as the functional unit and the system boundaries in this LCA study.

First of all we did a comparison of the production of conventional plastic (here PPO/PA and PC/PBT) vs. the biodegradable plastic.

In a second step we took a look at the EoL of biodegradable plastic: incineration (quantitative) and land filling (qualitative). In this case we did not consider the part production as well as the use phase because of the assumption that a product (e.g. fender of a car) out of conventional and biodegradable plastic would have the same weight.

2.1 Functional unit

The functional unit in the first part is 1 kg plastic produced (PLA, PPO/PA and PC/PBT)

In the second part it is 1 kg of discarded PLA after the use phase.

2.2 System boundaries

Here we considered the production of the biodegradable polymer and the incineration.

The system boundaries in this LCA study are shown in Figure 1 and the country specific boundaries are listed in the following:

Production

- The corn growing used U.S. system boundaries, because corn has been dependent on imports from U.S. in Japan (import ratio is 92.0% from U.S. [3]).
- The corn wet milling used Japanese system boundaries [4],[5],[6],[7],[8].
- The PLA production process used Japanese system boundaries.
- Part production was not considered in the study (we assumed the same weight for conventional plastic as well as for the biodegradable one.)

Use phase

- Use phase was not considered (see the above comment on part production).

End of life

- The incineration process of PLA used Japanese system boundaries. The data is derived from a simulation model developed with industry data from a mono plastic incineration.
- The land filling was only considered qualitatively because of the lack of leaching data.

The LCA was carried out using GaBi4, which was developed by IKP and PE Europe GmbH. The following paragraph describes the production process of biodegradable plastic more detailed.

3. PLA PRODUCTION FLOW

The first step to be considered is CO_2 absorption during the corn growing on the field. During that time all fertilizers and pesticides (including the production) as well as tractors (combustion of diesel) are taken into consideration. The corn is harvested and cleaned. Then the cleaned corn is steeped and the kernels are softened. The corn steep liquor is produced by condensing steep water. In the next step the germ is separated from the kernel and the corn oil is extracted from the separated germ. Then, the fiber and the gluten are separated from the solid residue and the starch is extracted. All other products except the corn steep liquor and the isolated starch are used in the food industry. Therefore the mass allocation was applied.

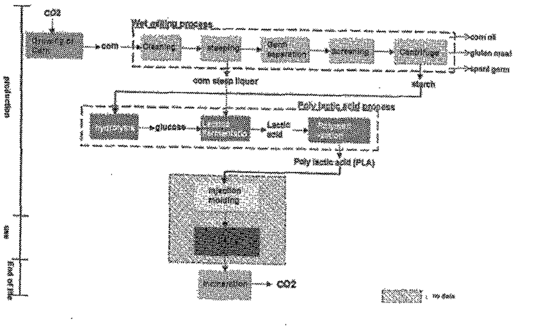

Figure 1 : PLA production flow

Starch that is used for biodegradable plastics is hydrolyzed to glucose by amylase. Lactic acid is made from fermented glucose and then PLA is synthesized by lactide polymerization. The use phase was not considered as mentioned above. In the EoL phase the incineration of PLA takes place. The complete process flow over the Life Cycle is shown in figure 1.

4. RESULTS

This chapter shows selected results with the focus on CO_2 (CO_2 neutrality for biomass), N_2O (fertilizer use for corn crowing) and energy (energy production during incineration).

4.1 PLA versus conventionnel plastic production

	PLA	PPO/PA	PC/PBT
Primary energy	100	334	270
CO2	100	127	107
N2O	100	32	15

In this paragraph a comparison of the production of 1 kg of biodegradable plastics (PLA) and conventional plastics (PPO/PA and PC/PBT) is shown. Table 1 indicates the relation between PLA plastics (set 100%) and the conventional plastics in percentages. Higher percentage means worse environmental impact and lower percentage vice versa.

Table 1: Comparison of PLA to conventional plastic used in material production

Considering the assumption out of chapter 2, the CO_2 emission during the PLA production and end of life is lower than PPO/PA and PC/PBT because of the CO_2 neutrality. The Primary energy is much higher for the conventional plastics because of the use of crude oil as basis material (calorific value is included in the primary energy result) and the energy intensive production. The PLA production has a disadvantage for laughing gas emissions because of phenomena which is described in chapter 4.2.

4.2 CO_2 emissions during the Life Cycle of PLA

Figure 2 shows CO_2 emission for each process step over the Life Cycle of 1kg PLA (except for the use phase; see chapter 2). CO_2 emission from the lactic acid production is contributing approx. 41% of the overall released CO_2 emissions. The process with the second highest contribution is the starch production with approx. 28%.

The dark gray part of CO_2 emissions is released from fertilizer production and the use of tractors and harvesting machines during the corn growing. The negative light gray part shows the amount of absorbed CO_2 from the atmosphere. The two light gray columns (in the corn growing phase and incineration phase) are canceling out each other because the amount of CO_2 being released during incineration is the same as the plant has taken up during growth. There is a small amount on CO_2 during incineration, which is not neutralized by the CO_2 taken up during growth but is caused by additive materials, energy used to run the incineration process, etc.

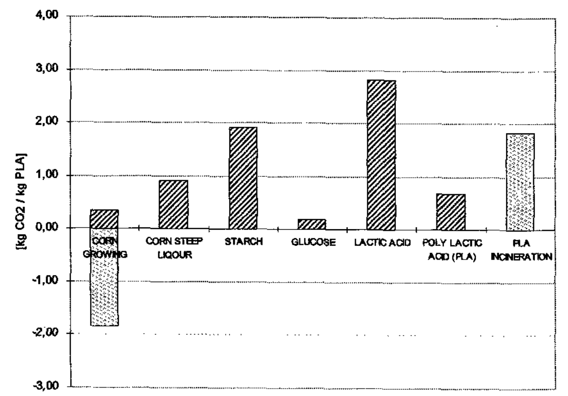

Figure 2: CO_2 emission in Life Cycle

4.3 N_2O emission during the Life Cycle of PLA

Figure 3 shows N_2O emissions over the Life Cycle and the contribution of each process step.

N_2O emission during corn growing contributes approx. 77% to the overall Life Cycle. The main reason is the release of nitrogen derived from fertilizer. According to the IPCC guideline from 1996, the coefficient was calculated to 0.0125 kg N_2O-N/kg N input. The amount of N_2O emission per 1t nitrogen contained in fertilizer is 39.29kg N_2O /t N input [9].

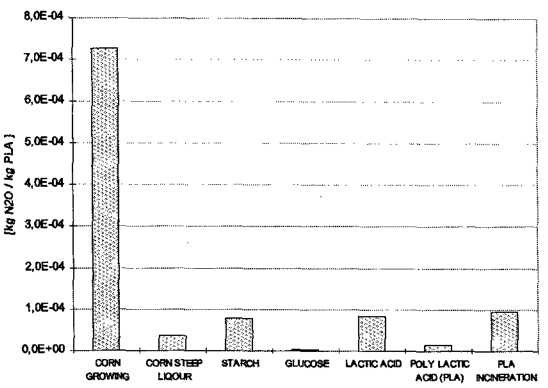

Figure 3 : N_2O emission in Life Cycle

4.4 Primary energy consumption during the Life Cycle of PLA

Figure 4 shows the primary energy consumption. It is obvious that the lactic acid production accounts for more then 76% of the total primary energy consumption over the PLA production and end of life. The corn growing contributes with approx. 12% to the overall consumption. The column on the right side shows a negative as well as a positive part. The positive part is showing the consumption covering the energy consumption during e.g. the production of auxiliary materials as the negative part shows the power generation by incineration.

4.5 Benefit by incineration -producing power and steam-

PLA's domestic demand reached 6000t/year in Japan[10]. If we assume the demanded amount of 6000t PLA would be incinerated, the recoverable electric power would be 5.7E6 [MJ]. Primary energy supply is 9.00MJ for power generation of 3.6MJ (generating efficiency is 40%) [11]. It needs 1.4E7MJ primary energy to generate 5.7E6 MJ electric power. If the energy consumption during PLA incineration is considered, we can recover 1.2E7 MJ primary energy. To make it better understandable, the recoverable electric power is converted into a crude oil equivalent. The used conversion factor for crude oil (net calorific value of 36.3 [MJ]/1L crude oil [11]) was published by the Agency of Natural Resources and Energy. That is equivalent to 3.2E5 [L] crude oil.

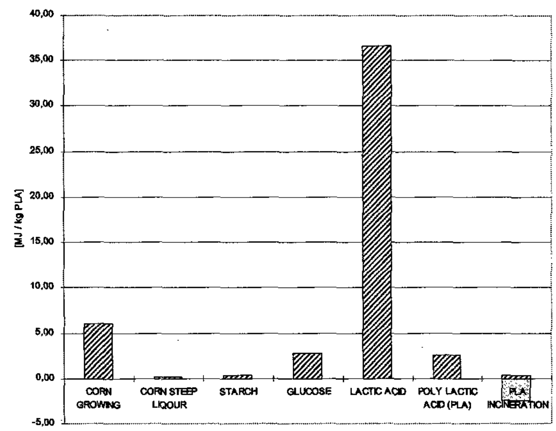

Figure 4: Primary energy consumption in Life Cycle

5. CONCLUSION

Comparing biodegradable (PLA) and conventional (PPO/PA and PC/PBT) plastics the primary energy demand and the CO_2 emission from the PLA production is lower. Only the N_2O emissions are higher because of the fertilizer use and the combined N_2O release from soil (see chapter 4.1).

Concluding out of the comparison we took beside the production of PLA also the EoL phase of the biodegradable plastic into consideration. We compared the incineration (quantitative) with the land filling (qualitative) of the biodegradable plastics.

Considering one of the main benefits of the renewable materials, the CO_2 neutrality over the Life Cycle, it becomes quite clear that incineration is a more sustainable and environmental friendly scenario.

Assuming a Japanese PLA capacity of 6000t/year for incineration the generated power due to incineration would be 5.7E6 [MJ] (1.6E6 [kWh]). Considering the energy consumption during PLA incineration, we can assume to recover 1.2E7 [MJ] primary energy. This equals 3.2E5 [L] of crude oil. For a sustainable thinking it is more reasonable to incinerate than to landfill. The sustainability is a further important benefit beside CO_2 neutrality of biodegradable polymers.

In Japan it became more difficult in recent years to get land filling space because of the Japanese limited land. Additionally the decomposition rate depends on the application of the PLA (e.g. higher technical properties needs more stabilizers).

As an overall outcome it does not make sense to landfill biodegradable plastic (e.g. PLA). One reason is the CO_2 neutrality by generating energy out of PLA. And in combination with the CO_2 neutrality the sustainability is a big advantage. In case of generating energy from the incineration of PLA non renewable fuels would be replaced by renewable fuels.

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