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Implementationsstudie zur biotechnologischen Produktion von Biopolymeren unter Einsatz digitaler Modelle auf der Basis nachwachsender Rohstoffe und organischer Abfälle

von

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Kurzfassung

Das Umweltbundesamt (UBA) hat die Arnold-Sommerfeld-Gesellschaft e.V. (ASG) beauftragt, die ökologische Verträglichkeit und die Wirtschaftlichkeit der Herstellung von PHB zu demonstrieren.[1] Da es eine Gesamtanlage zum jetzigen Zeitpunkt nicht gibt, wird methodisch mittels Simulation dargestellt, wie zu sinnvollen Lösungen zu gelangen ist. Mit Blick auf den Absatzmarkt wurde ein Marktpreis für PHB von 1,28 €/kg als Zielgröße festgelegt.

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[1] Verbundpartner waren: Energy of Nature GmbH (EON) und Bio-Ingenieurtechnik GmbH (BIT).

Das Gesamtprojekt wurde vom UBA in zwei Teile gegliedert: die Grob- und die Feinmodellierung. Die Grobmodellierung impliziert ein noch nicht schlüssiges Konzept mit Hinweisen zum Forschungsbedarf, um eine Feinmodellierung durchzuführen. **Der Abschlussbericht kennzeichnet den Wissensstand der Grobmodellierung.** Schlussendlich wird eine ganzheitliche Betrachtung des biotechnologischen Herstellungsprozesses von PHB erwartet, um eine optimierte Produktion samt der Zuliefer- und Abnahmemärkte darzustellen.

Ein Konzept der PHB-Herstellung beinhaltet die Integration des Prozesses in Biogasanlagen. Das Endprodukt Biogas (Methan) der Biogasanlage ist Ausgangssubstrat für die Mikroorganismen zur PHB-Synthese.[2] Der methodische Ansatz geht von einer Modellierung des fermentativen Herstellungsprozesses der PHB unter Berücksichtigung eines ökologisch akzeptablen Produktlebenszyklus aus. Die Zielfunktion der Mikroorganismen ist definiert und mittels dynamischer „Linearer Programmierung" (in Visual Basic; „virtueller Mikroorganismus") integriert. Der Fermenter und die das Verfahren charakterisierenden Parameter sind mit dem Simulationswerkzeug **AweSim** in einem dynamischen Modell abgebildet.

Weiterhin werden Teilmodelle der einzelnen Verfahrensstufen entwickelt, mit digitalen Experimenten hinterfragt und mit dem Werkzeug dynamischer Simulation erweitert. So ist die Aufarbeitung der PHB im Modell der Mehrstufenextraktion mit Rekursionen bzw. durch funktionale Zusammenhänge beim kontinuierlichen Verfahren wiedergegeben.

Ein besonderer Vorteil des Modells ist die Austauschbarkeit einzelner Prozessketten und Verfahrenskomponenten, beispielsweise des Eigenschaftsprofils des Mikroorganismus, und der verwendeten Anlagentechnik. Von dem hier gewählten *Methylocystis species* GB 25 standen uns die meisten Daten zur Verfügung.

Im integrierten Gesamtsimulationsmodell werden die Modul- und Modellsysteme bzw. die Teilmodelle Biogaserzeugung, Fermentation und Extraktion zusammengeführt. Die abschließende Durchführung von Simulationsläufen und das Testen von Szenarien ermöglicht ein Experimentieren ohne tatsächlichen Kosten- und Materialaufwand. Jede neue Modellerkenntnis wird sofort in das nächste digitale Experiment überführt.

Die ökonomischen Szenarien belegen detailliert die Zielpreisrealisierung bis zu den angestrebten 1,28 Euro/kg PHB. Es wird die ökonomisch bedingte Konkurrenzfähigkeit der biotechnologisch hergestellten PHB mit dem im Eigenschaftsprofil vergleichbaren konventionellen Kunststoff Polypropylen (PP) aufgezeigt.

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[2] DE 19721243 C2, 19.11.1998, Verfahren und Anlage zur effizienten energetischen und stofflichen Nutzung von Biogas, Bäzold, D., Kretschmer, A., Menschel, C., Panning, F., Scharr, S., Wendlandt, K.-D., Jechorek, M., Stottmeister, U., Münker, T., UFZ-Umweltforschungszentrum Leipzig-Halle GmbH, Energy of Nature – Projektgesellschaft für umwelttechnische Anlagensysteme Leipzig mbH

Eine regionale Realisierbarkeit der ökonomischen Szenarien im Konzept der Verteilten Produktion wurde mit dem Datenspektrum im Land Sachsen überprüft. Außerdem wurden schon erste Strukturierungsvorschläge für die „Verteilte Produktion" (Massenproduktion – zentrale oder dezentrale Strukturierung – übliche Aufarbeitungsverfahren) angegeben.
Wesentlich für die Konkurrenzfähigkeit der PHB auf dem Kunststoffmarkt ist, dass das Biopolymer auf Anlagen der kunststoffverarbeitenden Industrie weiterverarbeitet werden kann.
Alternative verfahrenstechnische Vorschläge und Hinweise wurden ansatzweise diskutiert. Das betrifft insbesondere die physikalische Aufarbeitung oder andere Verfahrenskombinationen zum Zellaufschluss.
Weitere wissenschaftliche Anforderungen für ein schlüssiges Biokunststoffkonzept ergeben sich (vom Grobkonzept zum Feinkonzept): Für die Anwendung von PHB als Massenkunststoff sind komplexe, maßgeschneiderte Rezepturen für den jeweiligen Anwendungsfall notwendig. Allein für PVC finden sich in der Fachliteratur über zehn Richtrezepturen.[3] Für PHB sind solche „komplexen Rezepturen" mit zwei und mehr Komponenten kaum untersucht worden. Weiterhin sind vor einem Einsatz als Massenkunststoff umfangreiche Prüfungen notwendig. Erweiterte Betrachtungen zu den Umweltauswirkungen und damit die Erstellung einer Ökobilanz nach den ISO-Normen 14040-14042 wird als sinnvoll betrachtet. In der Ökonomie werden Bilanzen auf der Basis von Stichproben erstellt, die als erwartungstreue, kostengünstige Alternativen angesehen werden können.
Zukunft: Es handelt sich im späteren Ausbau **nicht** um eine einzige Großanlage, sondern um ein System der „Verteilten Produktion". Dabei sind die einzelnen Anlagen an die jeweiligen Produktionsstandorte und –gegebenheiten angepasst und logistisch verknüpft.
Es wird ein Politikum werden, ob Biokunststoffe ähnlich behandelt werden wie beispielsweise Strom aus nachwachsenden Rohstoffen.

[3] Becker, G.W., Braun, D.: Kunststoff-Handbuch 2/1 Polyvinylchlorid. Carl Hanser Verlag, München Wien 1986, S. 530 ff.

Executive Summary

The Federal Environmental Agency (UBA) employs the Arnold-Sommerfeld-Society (ASG), to demonstrate the ecological compatibility and the economy to manufacture PHB[4]. There is no ready to produce plant available now. Instead the ASG uses models to simulate the virtual plant and to show how to find the desired solution. Studying the market of plastics we have committed a market-price for PHB raw-material of 1,28 € per kg.

The UBA has divided the project in two parts: first, the general description within draft models and second, a fine tuned model of combined modules. The general part (first step) describes a yet imperfect concept indicating research questions with conclusions, how to manage the second part. This report characterizes the knowledge of the general description.

Lastly we draw a holistic picture of the biotechnological manufacture-process and portray optimised production including the input-output markets.

One of the alternative sources of plastics (produced from non-petrochemical-raw materials) is the integration of the PHB-production-process in a biogas facility. The final product of a biogas plant is the gas that constitutes the raw-input for the PHB-fermentation-process.[5]

A model describes the methodology of the fermentation process. The processes will be ecologically acceptable within the product-life-cycle. In the present project-phase the represented processes are not yet completed.

Microorganisms strategies of adaptation is available to describe. The available, necessary substrates for bacterium limit them and determine growth, reproduction and product formation or a combination of the three. The objectives (function) of the bacteria are integrated and implemented with equations systems (linear programming) via Visual Basic ("model of the virtual microorganism"). The fermentation plant and their characteristic attributes are build in the simulation kernel "AweSim" as a dynamic model. The recovery is modelled as multilevel-extraction with recursions as functional relations within the process.

We figure out a description of processes from the raw-material to the final product. Based on existing data and suggested current technology the modelled processes are developed in their proceed-techniques and modules. For example the recovery is modelled as multilevel-extraction with recursions as functional relations within the process. Lastly we simulate dynamically in many variations in digital experiments.

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[4] project partners are: Energy of Nature GmbH (EON) and Bio-Ingenieurtechnik GmbH (BIT).

[5] DE 19721243 C2, 19.11.1998, Verfahren und Anlage zur effizienten energetischen und stofflichen Nutzung von Biogas, Bäzold, D., Kretschmer, A., Menschel, C., Panning, F., Scharr, S., Wendlandt, K.-D., Jechorek, M., Stottmeister, U., Münker, T., UFZ-Umweltforschungszentrum Leipzig-Halle GmbH, Energy of Nature – Projektgesellschaft für umwelttechnische Anlagensysteme Leipzig mbH

A particular advantage of the model is the exchangeability of single process-sequences and procedure-components, e.g. the properties and profiles of the bacterium, and the use of known technology. The data availability of *Methylocystis species* GB 25 was excellent for that project.

In the overall model system the biogas-production, fermentation and extraction are integrated. Usage of simulation model in the proven version enables experiments with low costs and no material consumption. Each result coming from new model-adaptation is transferred immediately into the next run of digital experiment.

The economic scenarios occupy detail the target price realization up to 1.28 €/kg PHB. The economically caused competitive power of the biotechnologically manufactured PHB with the conventional plastic polypropylene (PP), within aequivalent attributes is pointed out.

A regional feasibility of the economic scenarios called as distributed production, was examined for suggestions the reference of Saxonia. There are first concept for network productions descriped (mass production, central or decentralized structure, usual processing procedures).

It is substantially for the competitive power of PHB on the plastic market that the biopolymer can be processed in the plastic processing industry. Alternative processes were discussed for especially physical processing.

Additional scientific requirements for a solution of bioplastic concept (from the rough to the fine concept): To use PHB as mass plastic customizing is necessary. In the technical literature descriped more than ten complex prescriptions for PVC.[6] For PHB such prescriptions with two ore more components wasn't examined. Further extensive examinations are necessary to get editional mechanical datas. Extended views to the impact on the environment is useful as an life cycle assessment (LCA) according to the ISO standards 14040-14042. Balances in economy based on samples which are regarded as expectation-true, economical alternatives.

Future: The estaminated development is not a large-scale plant, but a system of the network production. The individual plants are adapted at the production scale and logistically linked. It will become a politicum whether bioplastics are similarly treated as regenerating raw materials.

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[6] Becker, G.W., Braun, D.: Kunststoff-Handbuch 2/1 Polyvinylchlorid. Carl Hanser Verlag, München Wien 1986, S. 530 ff.

Umweltforschungsplan
des Bundesministeriums für Umwelt,
Naturschutz und Reaktorsicherheit

Biotechnologie

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Implementationsstudie
zur biotechnologischen Produktion von Biopolymeren
unter Einsatz digitaler Modelle
auf der Basis nachwachsender Rohstoffe und organischer Abfälle
Kurzfassung des Schlussberichtes
Englische Fassung

von
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IM AUFTRAG
DES UMWELTBUNDESAMTES

August 2002

1 Goals of the study

Alternative sources of plastics produced from non-petrochemical-raw materials can be an important innovation and a contribution for a sustainable economy. Poly(3-hydroxybutyrate) (PHB), accumulated in certain bacteria as an energy storage material (reservoir), becomes a fundamental raw material for the plastic-processing industry, depending on their properties. "If we should succeed to produce that non petrochemical raw material, it will be an important contribution to the environment-protection."[1]

The Federal Environmental Agency (UBA) employs the Arnold-Sommerfeld-Society (ASG), to demonstrate the ecological compatibility and the economy to manufacture PHB[2]. There is no ready to produce plant available now. Instead the ASG uses models to simulate the virtual plant and to show how to find the desired solution. Studying the market of plastics we have committed a market-price for PHB raw-material of 1,28 € per kg.

The UBA has divided the project in two parts: first, the general description within draft models and second, a fine tuned model of combined modules. The general part (first step) describes a yet imperfect concept indicating research questions with conclusions, how to manage the second part. This report characterizes the knowledge of the general description.

Lastly we draw a holistic picture of the biotechnological manufacture-process and portray optimised production including the input-output markets.

2 Methods

One of the alternative sources of plastics (produced from non-petrochemical-raw materials) is the integration of the PHB-production-process in a biogas facility. The final product of a biogas plant is the gas that constitutes the raw-input for the PHB-fermentation-process.[3]

A model describes the methodology of the fermentation process. The processes will be ecologically acceptable within the product-life-cycle. In the present project-phase the represented processes are not yet completed.

Beginning with the organic raw material and a straight recycling-management we verify, that the low price- and mass-production is possible.

We figure out a description of processes from the raw-material to the final product. Based on existing data and suggested current technology the modelled processes are developed in their

[1] Meiß, K.-M.: Simulationsmodelle zur Optimierung der Polyhydroxybuttersäure-Synthese (Biopolymere) mit methanotrophen Bakterien, In: Biosystemtechnik, Kaden, H. (Hrsg.), Innovationsforum Waldheim, 2002, S. 21

[2] project partners are: Energy of Nature GmbH (EON) and Bio-Ingenieurtechnik GmbH (BIT).

[3] DE 19721243 C2, 19.11.1998, Verfahren und Anlage zur effizienten energetischen und stofflichen Nutzung von Biogas, Bäzold, D., Kretschmer, A., Menschel, C., Panning, F., Scharr, S., Wendlandt, K.-D., Jechorek, M., Stottmeister, U., Münker, T., UFZ-Umweltforschungszentrum Leipzig-Halle GmbH, Energy of Nature – Projektgesellschaft für umwelttechnische Anlagensysteme Leipzig mbH

proceed-techniques and modules. We simulate dynamically in many variations in digital experiments.

A result of this study, depending on well-known data and procedure, is a model for experiments and argumentation. A particular advantage of the model is the exchangeability of single process-sequences and procedure-components, e.g. the properties and profiles of the bacterium, and the use of known technology. The data availability of *Methylocystis species* GB 25 was excellent for that project. Complementary in this project structure and attributes of the PHB are compared with other plastics in properties and the production-technology.

3 Data and modelling

Starting points for this systemic model are literature, patents and experimental data from our partners. In addition we use data from the markets of organic materials and the plastics industry. From the view of a modeller the problem is defined by the words of “bad structured” and “dynamic” situation. Or in other term: The problem to be modelled is of unstructured and dynamic nature.

Microorganisms strategies of adaptation is available to describe. The available, necessary substrates for bacterium limit them and determine growth, reproduction and product formation or a combination of the three. The objectives (function) of the bacteria are integrated and implemented with equations systems (linear programming) via Visual Basic. The fermentation plant and their characteristic attributes are build in the simulation kernel “AweSim” as a dynamic model. The recovery is modelled as multilevel-extraction with recursions as functional relations within the process.

In the overall model system the biogas-production, fermentation and extraction are integrated. Usage of simulation model in the proven version enables experiments with low costs and no material consumption. Each result coming from new model-adaptation is transferred immediately into the next run of digital experiment.

The developed and ready system of the PHB-production is the basis of the following discussion.

4 Overview of the plant system (prototyp)

The plant system consists out of five main-plant-modules: the biogas facility associated with gas-engine (BHKW), the gas washer, the two-step fermentation plant, the recovery and possibly the customisation unit, that’s not yet final tuned.

4.1 Biogas facility and gas purification system

In a plant, Methane is produced from biogas by fermentation of suitable substrata (e.g. slurry or biological garbage from households and businesses). The reactor transforming substratum in a mesophile range by wet fermentation uses anaerobe bacterium to produce biogas. That biogas contains 66 Vol.-% CH_4, depends on the quality of the raw material. Normally, biogas plants produce heat and electricity. In contrast, our process goes not directly, but rather over a part-utilization for PHB-production. The gas reaches the purification (H_2S and CO_2), is transferred to a gas tank (middle pressure) and used in the fermentation. The fermentation deprives 40 % of methane, and the other gas is used in the power engine combined with additional air.

The capacity of production is estimated in a range of 330,000 m³/ d (121 of Million m³/d) depending on technical points.

4.2 Fermentation

Fermentation works at a pressure of 3,5 bar in an unsterile milieu in two steps at ph 5,7 in a continuous process. The 1st step it is plant a fermentor with 20 m³, in the 2nd step two in the same size each. The appointed plant-size is an estimation for understanding and comes on a module-basis "up-“ respectively “down-scaled”. In the growing-phase biomass lingers to optimal conditions in about 6 h. Productivity in accumulation is about 6,5 kg CTS/t/h[4]. In the set time biomass grows up, so that 88 kg CTS/h can be harvested and transported to the 2nd step. During the output-building phase, microorganisms accumulate the polymer in about 12 h (under the condition of nitrogen-deficiency) and the productivity is fixed to 4,1 kg PHB/t/h. An output of 110 kg PHB/h can be expected.

In our study we install “Tauchstrahlfermenter”, that distinguish themselves by relatively high oxygen-transition-rates at low energy-demand.

4.3 The model of PHB-fermentation

The model consists of two integrated modules: first, the properties of bacteria as a decision-system: the so called “model odf virtual microorganism”, second, the network-architecture by using the simulation kernel AweSim. Data entry points of tables are stoichiometrically and based on the C_1-referred sum-formulas. With help of molecular masses and amounts of material we are able to compute the consumption coefficient α. Next milestones are the verification of microorganisms properties and the adjustment of laboratory data, so that the

[4] in the model it is definded: biomass-dry-mass (BTS) = cell-dry-mass (CTS) + PHB.

model represents reality as exact as possible. AweSim's event control projects the dynamic parameters which substantially influence the fermentation process.

The network of AweSim combines the biological and process engineered modules. While the microorganism strives to be self-sustaining by maximizing its own biomass, the economic goal of maximization of PHB is opposed to this. However, both goals are combined through skillful control of the plant.

4.4 Product isolation and extraction

Another process is the preparation of the fermentor output. This output consists of water mainly. A small fraction of fermenter output consists of microorganism-biomass, which constitutes itself of proteins and PHB. The isolation of PHB is the aim of that process-step, taking care of the amount of consumption.

The present market differentiates the final products of the processing according to their quality of cleanliness. Therefore the combination of particular procedures focuses on this criterion.

The output is concentrated directly at the fermentor via separation ensuring proper recycling of water. Depending on availability of energy, a drying process still follows at same location. After drying the material, it arrives at the pre-extraction, where the cells will break down. Figure 1 shows laboratory versus simulated values. Simulated values (based on a simple modified formula) are an acceptable estimation of laboratory data. A more detailed model can be generated from a more exact reproduction of laboratory data.

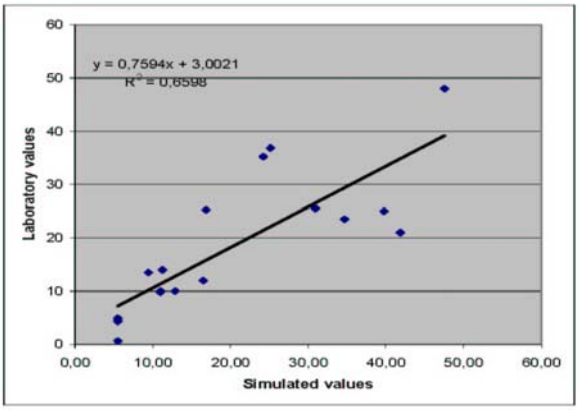

Figure 1: Laboratory versus simulation values

The extraction process using solvents in a continuous counter-current process is projected/simulated with an adapted material-transport model.

The average deviation of the simulation results from the laboratory data amounts to fewer than 10 %. In addition there are further possibilities for product isolation, e.g. opening of cells by enzymes or high pressure as well as direct press-injection of BTS.

5 Logistical concept and reduction of cost drivers

The after-fermentation processing (see chapter of product isolation and extraction) constitutes ca. 2/3 of the entire variable manufacturing cost.

The logistical concept centralizes (as far as process engineering allows) all procedure sections with cost driver function and all ecologically precarious applications:

- not centralized pre-production,
- local higher-concentration with following transport to the processing system and central pre-processing and
- recycling of organic wastes of the extraction to the peripheral production locations.

Actual planning and implementation problems are thus neither to be found in the biological processes nor in the control of the individual systems, but rather in the interaction of the process steps of the whole system. Problem targets are either the continuous production of the PHB granulates in defined quality and quantity or, depending upon market situation, the complete rerouting into other products with other product properties. As electricity production happens in parallel, different portions can be steered into the generation of electricity or into plastic raw material production.

From an engineering viewpoint (e.g. effectiveness) the process can be driven thereby in the suboptimal range, while a production steered in such a manner still counts as economically efficient. In addition to that viewpoint regional fermentation gas production of necessary quantity must be ensured; another logistical problem.

An additional goal is the substitution of process steps against others or the combination thereof. Furthermore it is conceivable (and that is also commonly used technology) that PHB is not exclusively manufactured over the fermentation gas track, but rather also via other substrate process chains to be opened, for example via methanol or sucrose and their derivatives. All non-ready products arrive again in the pre-processing and extraction.

Cost advantages are achieved by optimally adjusting the allocation of plant components, their logistical connection, and their interplay with above-mentioned systems.

6 Balances of material and energy

The material- and energy balances are defined: the sum of the balances input minus sum of the balances output and the difference between produced and used is equal to the temporal varation with in the described field (unit plants, volume elements).[5]

The represented material- and energy balances are used to submit the economically optimised process to a discussion of ecological perspectives.

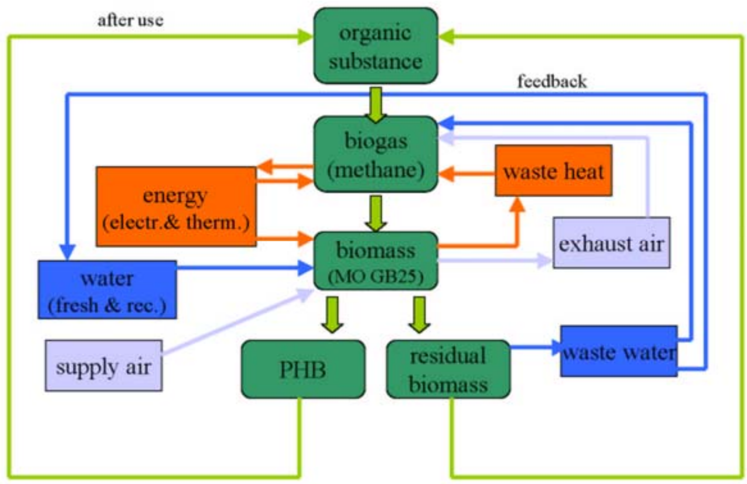

Figure 2: Schematic network of material and energy of plant-design

The concept describes the coupling of several material and energy networks, which are depicted in figure 2. First we regard the simplified process steps of the PHB synthesis: the organic material is converted (fermented) in the facility into biogas. Developed methane is used in a further process step (fermentation phase) as carbon source to produce biomass. Biomass remaining after the separation of PHB is recycled as substrate and fed back into the process of biogas production.

Another network connection is realized via feedback of used PHB materials (e.g. as packing), particularly those of the foodstuffs industry where food has direct contact with the packing material, which is difficult to be cleaned. In the BHKW both electricity and heat is produced. During the total process much waste heat is developed, which is not usable, because of the small temperature difference. It has to be disposed of in the cooling towers.

The thermal energy from the BHKW can be used for all endothermic processes. It develops a surplus, whose application must be investigated in the next phase, the fine tuned model. The gas-, water- and energy-balance as well as the extraction of the PHB are described in detail.

[5] Bockhardt, H.-D., Güntzschel, P., Poetschukat, A.: Grundlagen der Verfahrenstechnik für Ingenieure, Deutscher Verlag für Grundstoffindustrie, Stuttgart 1997, S. 33

7 Compare demands of primary energy and CO_2-emission

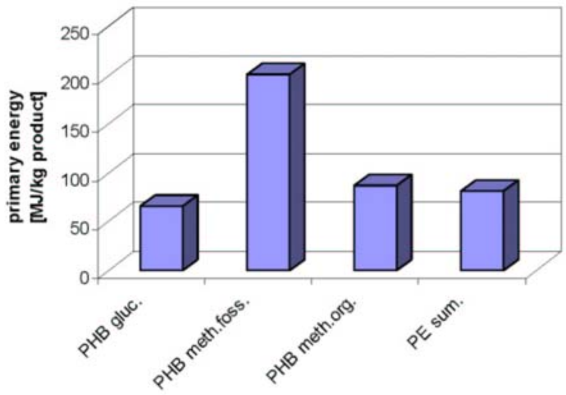

Figure 3: Demand of process energy for PHB-production based on organic sourced methane compared with PHB from glucose and petrochemical methane and PE

Clear and comprehensive reports of a product life cycle for PHB could not be found in the literature. Just a few studies and estimations exist, in which one can find only evaluations of the primary energy needed as well as the contribution to the CO_2-emission during the production and the waste disposal.

Figure 3 depicts the primary energy requirements for the PHB production, which are comparable to the ones for polyethylene.

8 Proceeds- and cost-situation

It is allegedly the high manufacturing cost, which is an impediment for mass-production of PHB and thus a substitution of conventional plastics on a petrochemical basis. In this study we have falsified this assumption and corrected this view with quantitative proof.

Optimisations are to be included as much as possible in all systems of technological, economic and politico-economics fields. This is not a novum, though in many publications this aspect is forgotten without justification.

9 Estimation of the costs of PHB production

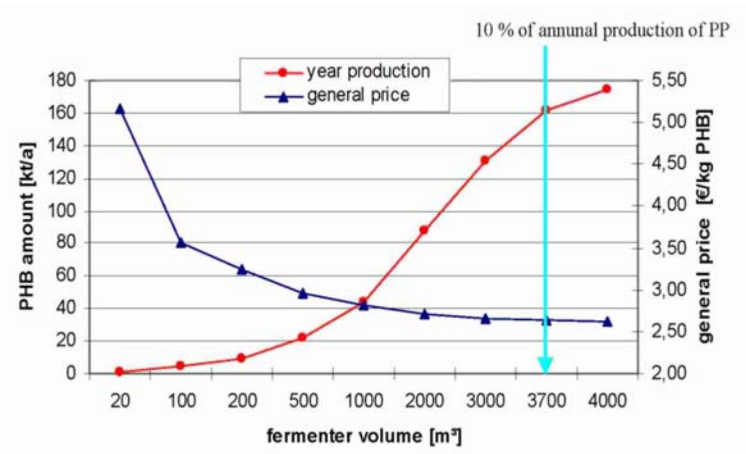

Figure 4: Influence of scale up on PHB amount and price

One modelled scenario illustrates the cost situation of the system (base version) before the optimisation. It describes the network of an integrated production with its functionally defined dependencies, how it is to be found for example with the oil refining or also with agricultural processes.

The total costs of production result from the fixed costs (e.g. investments), which are independent of the output level, and the variable costs (e.g. operating cost, overhead costs depending on working plant). In addition, proceeds come from power-production.

We regard cost factors, which essentially determine the total production.

Subsidy of the price of raw materials: If biogas would be delivered free of charge, amounts counting to the manufacturing costs in the base version would still be 5.49 €/kg, the total price 4.10 €/kg PHB.

Increases of PHB content to 78 % result in prices still at 4.25 and / or 3.23 €/kg PHB. An increase tenfold of fermenter-volumes on 200 m³ and a saving of 20 % of the extraction costs lead to prices of 2,25 or 1.23 €/kg PHB. With fermenter-volumes of 100 m³ and 30 % extraction costs, the manufacturing cost is reduced to amounts of 2.27 €/kg, the total price to 1.25 €/kg PHB. Savings, which depend on a economies of scale, are achieved by reduction of fixed cost. The consumption-dependent-cost like the raw material costs per kg PHB, remain constant.

In summary, the following conditions for production of PHB can be used to indicate a target price of 1,28 €/kg or less: direct press injection of the biomass (complete renouncement of the extraction), enlargement of the fermenter-volume and increase of the PHB content combined with reduction of the extraction costs; decentralized smaller fermentation-facility and centralizing extraction with intelligent logistics.

10 Markets for raw materials and products

Optionally we assume to be able to replace at least 10 % of the present annual output of 1,5 millions t PP (thus 150,000 t) by PHB or PHV:

1. PHB is suitable for the production of short-live-cycles articles suitable (period < 1 year).
2. At the end of the product lifecycle the bio-degradability is most important and to be used.
3. The biocompatibility or innocuousness can be an application criterion.
4. Modifications of the performance characteristics are unknown and still not tested, particularly concerning the long-term and mechanic stability, even for products in the electronic and automobile industry. An exception would be the interiors of automobiles, which could be produced with PHB right now.
5. PHB or its copolymers are usable as thermoplastics for injection moulding and blast piping.
6. An important field of application of PHB is the sensor technology.

Summary of target application fields for the mass production of PHB:

Area of application	Examples
Articles for household and sanitary	tanks, kitchen table-ware, cold treatment, straws, suit-cases for tool, articles for camping how bucket and dishes, tableware and cutlery for fast food, drinking bottles for babies and so on, tooth finery cup, brushes for tooth and hand, one-way shavers
Accessories for cars	Consoles, hat racks, door inside panelling, trunk lining
Packing	Packing container of all kinds, , containers for the pharmacies, screw-type caps, bottles for cosmetics, liquid soaps and liquid detergent, box for cream, clicking catches
Pharmacies/ agriculture	Medicine depot for humans and animal, one-way syringe, depots for insecticide and pesticide in form of granulates, planting pots and bowls
Office materials, furniture accessories, toys	Lamps, parts of chair; ball-point pen, felt-tip pens, filling owner, ink cartridges, rulers, tubes for coolies, plastic toy of all kinds
Electrical connections, electronics	Insulators, clips for cable, magnetic cards
Sports	Boards of surfing, kayaks, golf tees

Table 1: Sample applications of PHB (excerpt)

11 Conclusion

The economic scenarios occupy detail the target price realization up to 1.28 €/kg PHB. The economically caused competitive power of the biotechnologically manufactured PHB with the conventional plastic polypropylene (PP), within aequivalent attributes is pointed out. A regional feasibility of the economic scenarios called as distributed production, was examined for suggestions the reference of Saxonia. There are first concept for network productions descriped (mass production, central or decentralized structure, usual processing procedures).

It is substantially for the competitive power of PHB on the plastic market that the biopolymer can be processed in the plastic processing industry. Alternative processes were discussed for especially physical processing.

Additional scientific requirements for a solution of bioplastic concept (from the rough to the fine concept): To use PHB as mass plastic customizing is necessary. In the technical literature descriped more than ten complex prescriptions for PVC.[6] For PHB such prescriptions with two ore more components wasn’t examined.

Further extensive examinations are necessary to get editional mechanical datas.[7]

[6] Becker, G.W., Braun, D.: Kunststoff-Handbuch 2/1 Polyvinylchlorid. Carl Hanser Verlag, München Wien 1986, S. 530 ff.

[7] Dr. Winkler, project group of the ASG, 15.03.2002

Extended views to the impact on the environment is useful as an life cycle assessment (LCA) according to the ISO standards 14040-14042. Balances in economy based on samples which are regarded as expectation-true, economical alternatives.

Future: The estaminated development is not a large-scale plant, but a system of the network production. The individual plants are adapted at the production scale and logistically linked. From evaluation of GA (Gemeinschaftaufgabe) it can be described effects of job market as well as total wages and tax effects. There are explicit results from “Institut für Arbeitsmarkt- und Berufsforschung der Bundesanstalt für Arbeit”. Since we know of the enormous quantities of biomass is arises in the future area of the European Union, for example in Poland and Tschechien, it can be estimated enourmous export chances. It will become a politicum whether bioplastics are similarly treated as regenerating raw materials.