# POSSIBILITIES TO OPTIMISE FEEDSTOCK MIXTURES FOR BIOGAS PRODUCTION

**Leonhartsberger C., Bauer A., Mayr H., Eder M., Mair G., Amon T.**
University of Natural Resources and Applied Life Sciences, Department of Sustainable Agricultural Systems, Peter-Jordan-Strasse 82, A-1190 Vienna, Austria. Tel: +431 47654 3501.
thomas.amon@boku.ac.at

## 1 INTRODUCTION

A big advantage of biogas production is that a broad variety of organic substrates in view of availability and economic concerns can be used. In most of the biogas plants substrate mixtures from different energy crops, manures, organic wastes and residues from food-, feed- and bio-fuel industries are anaerobically digested. The economy of biogas plants depends mainly on feedstock prices and a continuous and stable fermentation process without any disturbances. The process stability as well as the velocity and rate of decomposition are affected by the chemical composition of the substrates and the full supply of the microbial community with essential- and trace elements. Well balanced feedstock mixtures are therefore a key for stable and optimised biogas yields. An example to energetically and economically optimise feedstock mixtures for biogas production is outlined within this paper.

## 2 MATERIALS AND METHODS

Anaerobic digestion experiments to measure the biochemical methane potential were carried out in accordance with VCI 4630 (2006). In detail, eudiometer batch fermenters of 250 ml capacity were used and the temperature was set at 38 °C. The inoculum used was obtained from two different biogas plants. In the batch fermenters, the substrates and mixtures were brought together with the inoculum in a total solid (dry matter) ratio of 1:3. In the laboratory experiments, the specific methane yield of every substrate and mixture was determined in three replicates. The amount of biogas production was monitored every day. Biogas and methane production is given in norm litre per kg of volatile solids ($l_N$ kg $VS^{-1}$). Methane concentration in the biogas was analysed up to nine times during the 40 days digestion period using a Gas Data LMS NDIR analyser (Dräger X-am 7000).

Prior to anaerobic digestion the nutrient composition (dry matter, volatile solids, raw ash, raw protein, raw fat, raw fibre, starch, sugar, N-free extracts, cellulose, hemi-cellulose and lignin) as well as the gross-energy content were analysed using standard procedures. The results from specific methane yield and the nutrient composition were used for the data sets to develop the methane energy value models for the mixtures. Multiple regression analytical methods (SAS Version 9.1.2; Enterprise Guide 4) were used to develop two methane energy value model types for feedstock mixtures. For the calculation of the optimum feedstock mixture a linear optimisation was carried out using the programme SOLVA (excel tool). To validate the theoretical investigations on a practical biogas plant the process parameters and input data were monitored for two periods (May to June 2006 and January to May 2008) at the research biogas plant under practical conditions.

## 3 RESULTS AND DISCUSSION

### 3.1 Nutrient composition of various feedstocks and specific methane yield

From several research projects and laboratory investigations a certain correlation between the nutrient composition and the specific methane yield was observed. In Figure 1 the nutrient composition according to Weender&Van Soest and the specific methane yields in $l_N$ $CH_4$ kg $VS^{-1}$ (given in the outlines boxes) of various substrates for biogas production are shown. Results indicate that the nutrient composition affects the velocity of degradation and subsequently the specific methane yield. Generally the higher the amount of easily degradable compounds like raw protein, raw fat, starch and sugar the higher the specific methane yields (e.g. maize silage - 347, sugar beet body - 380, stillage - 410 and rape cake – 489 $l_N$ $CH_4$ kg $VS^{-1}$). Substrates like rye (274 $l_N$ $CH_4$ kg $VS^{-1}$) and grassland biomass from extensive sites (241 $l_N$ $CH_4$ kg $VS^{-1}$) achieve lower specific methane yields due to a low amount of easy degradable and higher amount of hardly degradable compounds (e.g. raw fibres).

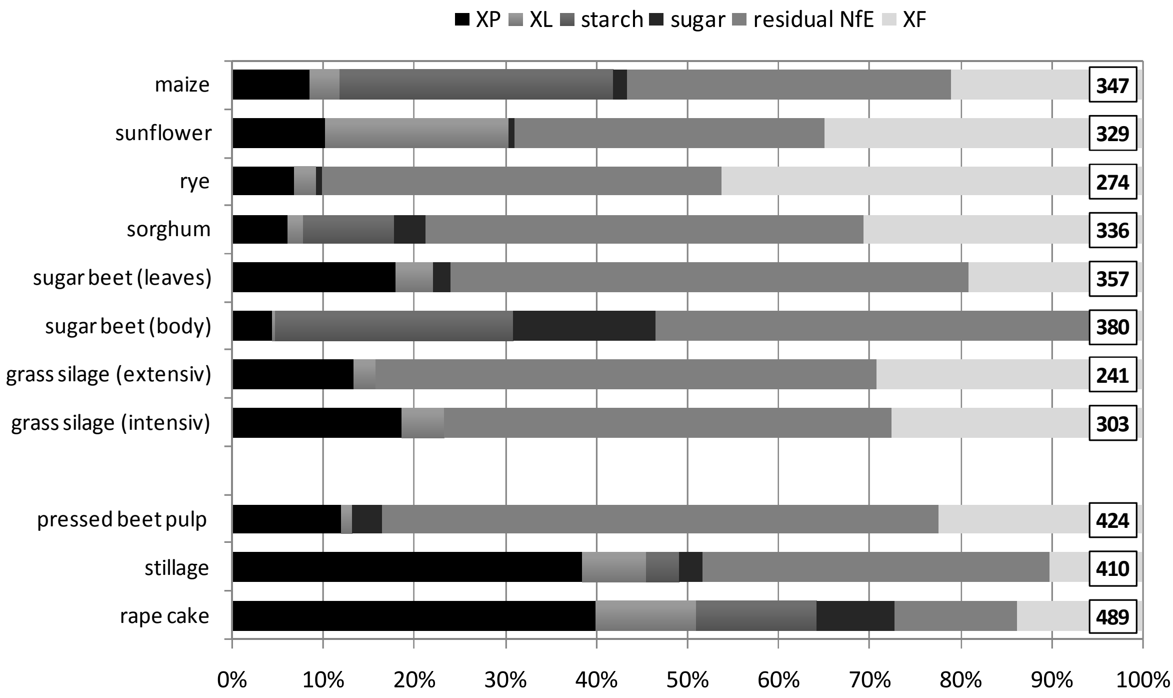


FIGURE 1 **Nutrient composition and specific methane yield of various feedstocks**

However the nutrient composition according to Weender&VanSoest is not always applicable to explain the specific methane yield. Within maize it could be demonstrated that at later maturity stages (after "dough stage") the specific methane yield is declining (Leonhartsberger et al. 2008) although the chemical composition remains more or less the same (data not shown). Therefore it can be assumed that the specific methane yield cannot be described sufficiently with the composition results of Weender&VanSoest and that the reduced specific methane yield is caused by the stable structure of the ligno-cellulosic complex that can't be degraded by the micro-organisms.

To overcome this phenomenon and to predict the specific methane yield from the nutrient composition of feedstock, regression models (Methane Energy Value Model - MEVM) were developed for the most common energy crops as well as for feedstock mixtures at the Institute of Agricultural Engineering. As the following results demonstrate, this tool can be also used for the energetically optimization of feedstock mixtures.

## 3.2 Methane-Energy-Value-Models for feedstock mixtures

In Table 1 regression models for a feedstock mixture that is based on a sustainable crop rotation system (Mixture 1) and a feedstock mixture that comprises by-products from biofuel- and starch industry (Mixture 2) are outlined. According to the available data on the nutrient composition two different models with differing accuracy are available. The models for Mixture 1 were developed on the basis of five different energy crops: sugar beet, maize, sun flower, clover, and green rye. In addition to energy crops also pig slurry and crude glycerol were used as substrates. The model type A and B have a coefficient of regression of 40 % and 67 % respectively. Both model types are significant.

In Mixture 2 the following feedstocks were used to develop the model: pig manure, maize silage, maize remains from starch industry, potato remains from starch industry, maize draff from bioethanol industry, as well as glycerol and rape cake from biodiesel industry. As shown in Table 1, the model type A has a coefficient of regression of 87%. The type B model has a coefficient of regression of 91%. Both models are therefore highly significant. From the results of the lab experiments on the specific methane yield it was obvious that the convertibility of energy in the fermentation process is higher for feed mixtures compared to monofermentation of individual feedstocks (Machmüller et al. 2007).

TABLE 1 **Methane Energy Value Models (MEVM) for feedstock mixtures**

| Mixture | Model Type | Equation | $r^2$ | Level of sign. |
|---|---|---|---|---|
| **1** | A | CH4 = 434.22 (±59.48) - 0.39 (±0.60) XA - 0.97 (±0.46) XP - 1.70 (±0.53) XL + 0.37 (±0.20) XF | 0.396 | 0.003 |
| | B | CH4 = 650.54 (±127.35) + 18.87 (±22.83) XP/BE - 134.91 (±48.49) XP/ADL - 4.79 (±1.13) XL + 3.32 (±16.84) CEL/ADL + 2.54 (±28.45) HCEL/ADL + 0.42 (±0.12) STC | 0.673 | <0.001 |
| **2** | A | CH4 = 195.37 (±56.00) – 1.16 (±0.20) XA + 1.14 (±0.31) XP – 2.88 (±0.67) XL + 1.28 (±0.31) XF + 0.52 (±0.09) Gly+Meth | 0.867 | <0.001 |
| | B | CH4 = 1053.54 (±84.89) – 40.77 (±) XF/BE – 12.26 (±) XP/BE – 37.54 (±) XP/ADL – 122.27(±) XL/ADL – 0.49 (±0.08) Gly+Meth | 0.905 | <0.001 |

## 3.3 Energetically and economical optimisation of feedstock mixtures

In order to energetically and economically optimise feedstock mixtures on a practical biogas plant laboratory investigations on the specific methane yield to develop the Methane Energy Value Model and a linear cost calculation was carried out. As feedstock maize (silage and CCM), pig slurry as well as by-products from biofuel industry (glycerol and pressed rape cake) were used. From the laboratory investigation the optimal mixture in terms of highest specific methane yield (456 $l_N$ $CH_4$ kg $VS^{-1}$) was found to have 30 percent of raw glycerol related to dry matter.

TABLE 2 **Example of an energetically and economic optimisation of feedstock mixtures**

| **Costs raw glycerol** [€ per t FM] | **75** | **100** | **60** |
|---|---|---|---|
| **Content of raw glycerol** [% in the mixture] | 22 | 5 | 53 |
| **Methane yield** [$m^3_N$ kg $VS^{-1}$] | 454 | 414 | 452 |
| **Substrate Input** [t FM $d^{-1}$] | 3.4 | 5.4 | 2.1 |
| **Costs Mixture** [€ per $m^3_N$ $CH_4$] | 0.206 | 0.234 | 0.175 |

In Table 2 the results of optimum methane yield and feedstock costs are shown depending on the raw glycerol costs. Assumed were prices of 75, 100 and 60 Euros per t FM glycerol. The lowest costs per produced methane (0.175 € per $m^3$ $CH_4$) could be achieved if the price for raw glycerol is 60 € per t fresh matter. At this price the raw glycerol content in the mixture would have 53 % and the specific methane yield of the mixture is 452 $l_N$ $CH_4$ kg $VS^{-1}$. At higher raw glycerol prices the input of other feedstocks as well as the costs will increase.

TABLE 3 **Example of an energetically and economic optimisation an a practical biogas plant**

| **Input [t FM $d^{-1}$]** | **1st measuring period** May – Jun 2006 | **2nd measuring period** Jan – May 2008 | **Relation [%]** |
|---|---|---|---|
| Pig slurry | 40.34 | 40.34 | |
| Maize silage | 6.31 | 4.27 | |
| CCM | 17.28 | 1.22 | |
| Pressed rape cake | 0.75 | 0.05 | |
| Glycerol | 0.00 | 9.4 | |
| **Process parameter** | | | |
| Specific methane yield [$l_N$ kg $VS^{-1}$] | 0.39 | 0.53 | + 35 |
| Hydraulic retention time [d] | 61.88 | 69.88 | + 13 |
| Loading rate [kg VS $m^{-3}$ digester $day^{-1}$] | 3.77 | 2.93 | - 23 |
| Degree of degradation [%] | 89.27 | 87.35 | - 2 |
| Input per day [t VS $d^{-1}$] | 15.03 | 11.61 | - 23 |
| **Feeding costs** [€ $d^{-1}$] | 3,366.30 | 1,267.44 | - 60 |

Out of this information the theoretical information was transferred to a practical biogas plant. In Table 3 the figures before (1st measuring period) and after (2nd measuring period) the optimization are shown. In the 1st period no raw glycerol was used. The main input was obtained by the energy crop maize in form of silage or CCM. In the second measuring period the content of maize was reduced and compensated by raw glycerol.

In the same Table the performance and process parameter of the practical biogas plant for both periods are shown. Through the optimization of the feed mix the specific methane yield could be increased by 31 %. Over the 5 month lasting period a stable fermentation process was observed. At the same engine performance the hydraulic retention time of the plant was increased by 13 % because less input per day is needed. After optimization of the feedstock 11.6 t instead of 15.0 t VS were used, and the loading rate was reduced by 23 %. For this example on practical conditions the feedstock costs have been reduced from 3,366 to 1,267 € per day (minus 60 %). Besides the lower feedstock costs, such optimizations can also result in a significant reduction of the construction costs of biogas plants.

## 4 CONCLUSIONS

The presented results have shown that an energetically and economic optimization of complex feedstock mixtures at practical conditions is possible. The Methane-Energy-Value-Model (MEVM) can be used to estimate the specific methane yields on the chemical composition of the feedstock mixtures and subsequently to optimize these mixtures in an energetic and economic aspect. A validation of the MEVM on the basis of energy crops and animal manures was carried out at practical biogas plants. Furthermore the results demonstrate that an optimization of the feedstock mix can substantially contribute to the efficiency of biogas plants. The integration of by-products from biofuel industries as co-fermentation substrate can be highly recommended in order to fully utilize all available substrates for energy production and to overcome the competition to food and feed production. The models will be improved and extended for further biogas plants that use residues from agrarian and food processing industries.

## ACKNOWLEDGEMENTS

The results were achieved from three projects that were financed by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW), the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT, Programme “Energy systems of tomorrow”) and the bureau of the government of Styria. Further support came from the European Commission through the sixth framework Program (DG TREN) where the Project EU-AGRO-BIOGAS: Contract No.: 019884 was realized.

## REFERENCES

Leonhartsberger C, Bauer A, Lyson D, Bodiroza V, Milovanovic D, Amon B, Rinnofner T, Friedel J K, Amon T 2006. Optimisation of biogas production through the cultivation of site-adapted energy crops and sustainable crop rotation systems. 16th European Biomass Conference & Exhibition, 2 – 6 June 2008, Valencia, Spain.

Machmüller A, Hrbek R, Kryvoruchko V, Amon T 2007. Biogas production from energy crops produced on sustainable crop rotations. 15th European Biomass Conference & Exhibition, 7 – 11 May 2007, Berlin, Germany.

VDI 4630 2006. VDI - Fermentation of organic materials. Characterisation of substrate, sampling, collection of material data, fermentation tests. VDI Gesellschaft Energietechnik.