Key factors for achieving profitable biogas production from agricultural waste and sustainable biomass

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Key factors for achieving profitable biogas production from agricultural waste and sustainable biomass

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Abstract
Based on numerous investigations on increasing the biogas yield of manure, a new concept was developed to increase the economical operation of manure based biogas plants by combining up-concentration of manure with a more specific treatment of the recalcitrant lignocellulosic fiber fraction by implementing the treatment on the digested solid fraction. Catch crops have been identified as a sustainable co-substrate for biogas production with a high biogas potential. For exploiting this biomass for profitable biogas production, the biomass yield per hectare, harvest costs, TS concentration and specific methane yields are important parameters to be taken into account.

Keywords
Biogas plant economy; biogas yield; biomass yield; catch crops; pretreatment; solid-liquid separation

INTRODUCTION

The economy of centralized biogas plants is a balance between the costs for feedstock supply and the benefit from the biogas production of the feedstock. In a conventional biogas plant based on manure as feedstock, the benefit from the biogas production per ton of manure delivered to the plant is only marginal related to the transportation costs. Ironically, since fossil fuel prices have increased significantly in recent years, the transportation costs for the feedstock supply have risen and thus the economy of renewable energy production from manure has declined accordingly. Therefore, an economically feasible operation of large-scale biogas plants based on manure has most often only been possible in co-digestion with low-cost substrates with high methane yields. Low-cost high yielding substrates have, however, been either fully utilized in recent years (for example industrial organic waste in Denmark, Ravena & Gregersen, 2007) or the price of high yielding energy crops has raised significantly (for example maize in Germany). In order to make an economic operation of centralized biogas plants based on low cost biomass feasible, research and development has targeted in recent years on two aspects:

- to increase the methane yield per ton of manure and other waste biomass and
- to make new low cost biomass resources available for biogas production

During the recent years we have developed on the one hand concepts to increase the biogas yield of manure and to screen the potential of different new biomass resources. In the following we give an overview over the main findings from these investigations.

NEW MANURE TREATMENT CONCEPTS

In order to increase the methane yield per ton of manure and to reduce the transportation costs two approaches were investigated:

- to increase the total solids (TS) content of the manure transported and

- to increase the specific methane yield per ton volatile solids (VS).

For the first, the implementation of solid-liquid separation is applied at the farm and only the fiber fraction is supplied to the biogas plant. The separation of the fiber fraction at the farm is already often in place in Denmark since this gives the farmers the possibility to export nutrients and thereby subtract the amount of nutrients from their own nutrient balance. Through the separation the TS content is increased from typically 5-10% TS in the raw manure to about 30% TS in the fiber fraction. If the solid fraction is then supplied to the biogas plant, the methane yield per ton of biomass is increased by a factor of 3-6 without any further pretreatment. The drawback is that the separated fibers cannot be pumped; therefore the logistics have to be changed from tank trucks to container. And the organic matter of the liquid fraction will remain at the farm and the biogas potential will be lost if no digester facilities exist at the farm. Consequently, combining the supply of separated fibers from a number of farms and raw manure from others to achieve an overall higher methane yield per ton of transported biomass and maintaining the feed TS concentration below 12% would be the concept of choice.

For the second, numerous pretreatments have been tested, ranging from mechanical, chemical to thermal and enzymatic (Angelidaki & Ahring 2000, Hartmann et al. 2000, Lissens et al. 2004, Uellendahl et al. 2007 among others). The main findings for the treatment of raw manure were that

a) mechanical treatment has a limited effect about 5-10% increase in methane yield, but is rather low cost and possible to implement at large-scale
b) chemical treatment may have the drawback of jeopardizing the use of the effluent as fertilizer
c) thermal treatment (pressure cooking, wet explosion) may have a good effect, but the investment costs may be high
d) the pretreatment of raw manure is not adequate when the manure contains considerable amounts of dissolved organic matter, which is easily degradable without pretreatment and which might be even lost through the pretreatment

The effect of increasing the TS concentration and the specific methane yield on the methane yield per ton of manure is displayed in figure 1. The increase in specific methane yield of the particulate organic matter is based on experiments with prolonging the retention time, pressure cooking and wet explosion pretreatment of pig manure (Uellendahl et al. 2007).

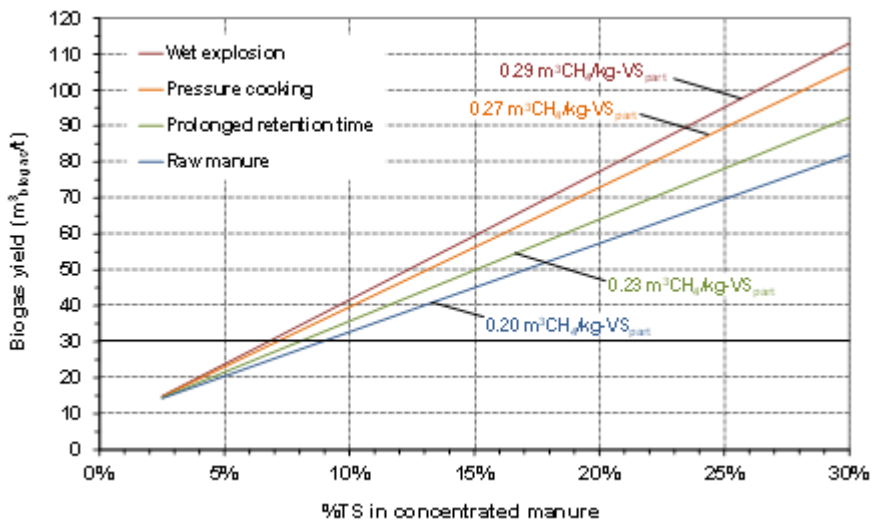

Figure 1. Effect of increasing the total solids (TS) concentration and the specific methane yield on the biogas yield of 1 ton of pig manure (6.6% TS, 80% VS/TS, particular VS: 65% VS_{part}/VS, dissolved VS: 35% VS_{diss}/VS)

What can mainly be seen is that the absolute increase in methane yield per ton of manure by the pretreatment is very much dependent on the TS concentration of the manure.

Based on these findings a new concept was developed with co-digestion of manure with separated manure fibers and implementation of wet explosion treatment of the digested fiber fraction (figure 2). This was shown to increase the specific methane yield of the digested fiber fraction by a factor of 2.3 and the biogas yield (65% methane) of the manure feed could be raised from 35 m^3/ton to 51 m^3/ton (Biswas et al. 2012). At the same time, the volume to be treated was reduced by 90% with respective reduction of the operational costs. This concept will be tested for the first time in large-scale at a biogas plant on Bornholm, Denmark, in spring 2012. In an upcoming EU project the combination of the separation and recirculation of the digested manure fibers with different treatments to enhance the digestibility will be studied.

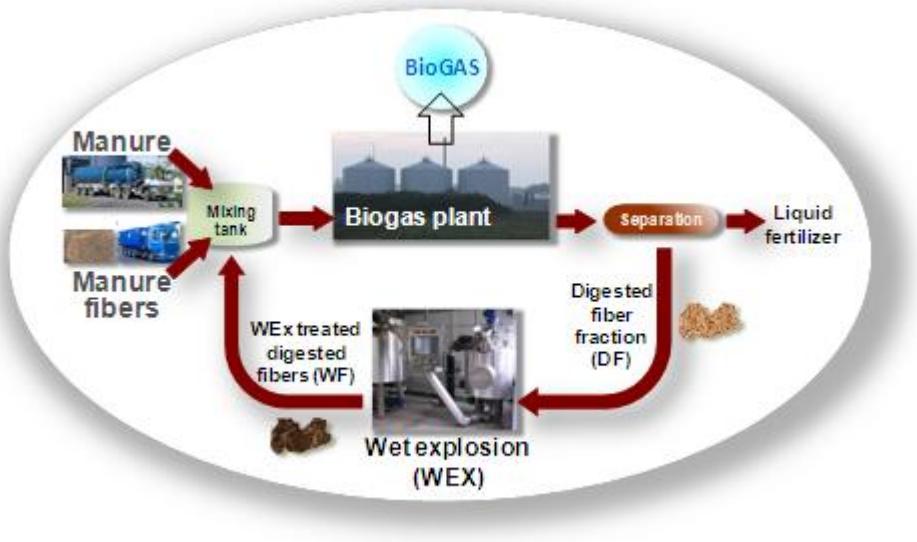

Figure 2. Overview of the new manure-to-biogas concept with WEx treatment of the digested fiber fraction

NEW SUSTAINABLE BIOMASS SUPPLY

Screening untapped biomass resources with a high biogas yield, which cultivation is sustainable and does not interfere with food production, attention was focused on catch crops. These are crops like oil seed radish, Italian ryegrass, white mustard etc. that are primarily grown after the main crop to avoid wash-out of the nutrients in the soil. The cultivation of catch crops is in some European countries already compulsory, like for example Denmark, where catch crops have to be established on 10% of the agricultural land (Nitrates Directive 91/676/CEE).

When calculating the cost-benefit it was obvious that the costs for producing 1 m^3 of biogas was depending on the biomass yield and the specific harvest costs per hectare on the one hand and on the specific methane yield and the TS concentration of the harvested catch crops on the other. Figure 3 reveals that, in Denmark, with typical harvest costs of 1500 DKK/ha the production costs are getting below the revenue value of 1.15 DKK/kWh if biomass yield is higher than 1.8 to 2.7 ton-TS/ha, depending on the TS concentration and the specific methane yield of the harvested catch crop. Therefore, the choice of the most suitable catch crops is dependent on all these factors and measures to increase the biomass yield in the cultivation of catch crops are very important for en economically feasible utilization of catch crops for biogas production.

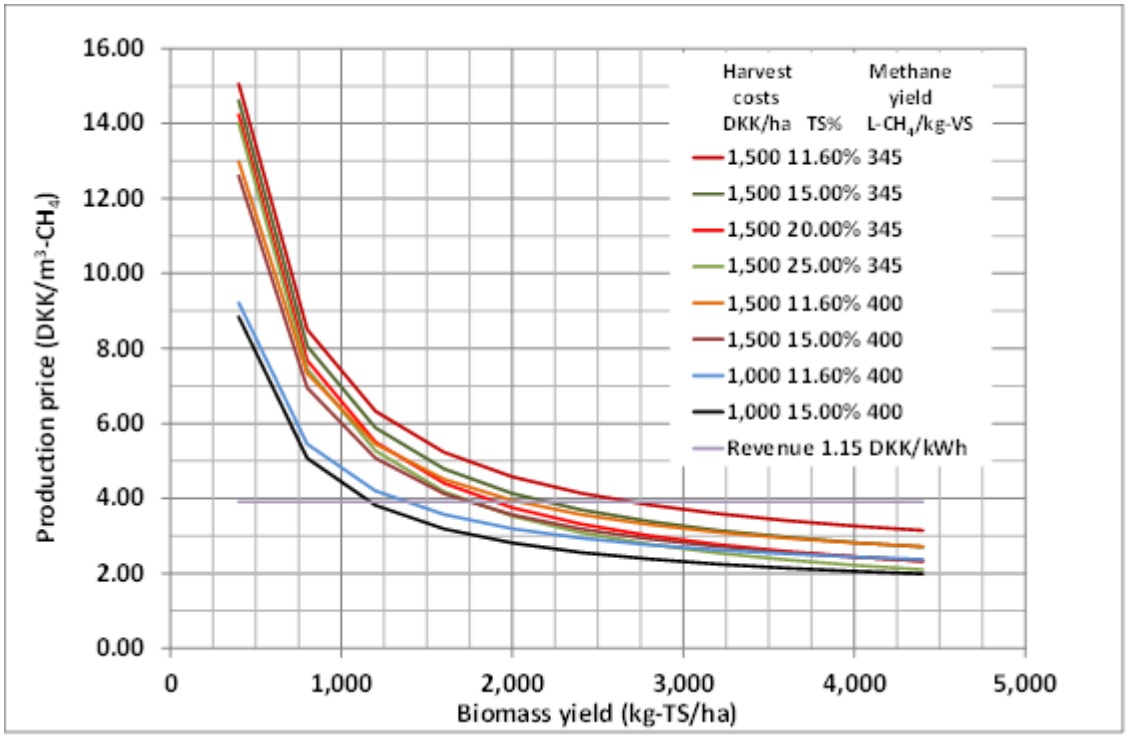

Figure 3. Effect of biomass yield, harvest costs, TS concentration and specific methane yield on the production price for catch crops

CONCLUSIONS

For profitable operation of manure based biogas plants the specific treatment of the recalcitrant fiber fraction. The choice of suitable catch crops for biogas production is not only dependent on the specific methane yield of the crop, but even more on the biomass yield per hectare and the TS% concentration.

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