Two phase automatic digestion of solid dairy manure

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Ladies and Gentlemen

My presentation bases on results of a feasibility study about dry fermentation on-farm we provided for the Finnish ministry of agriculture and forestry between 2004 and 2006.

The study included the documentation of a prototype plant of a dairy farm at Järna/Sweden about 50 km south of Stockholm.

Prototype biogas plant for solid manure at Yttereneby farm, Järna, Sweden

Lars Evers

Photos: Winfried Schäfer

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This is the continuously and automatically working prototype in Järna/Sweden developed by Lars Evers:

Interesting features of the plant are amongst others

- the recycling of a second-hand smokestack as reactor material,
- the inclined first reactor for mixing the solid manure by gravity force,
- the bottomless drawer technique for discharging,
- the fixed film technique for rapid methane generation,
- and a manure compost produced with low nitrogen losses.

The recently developed technology is in the process of testing and refinement.

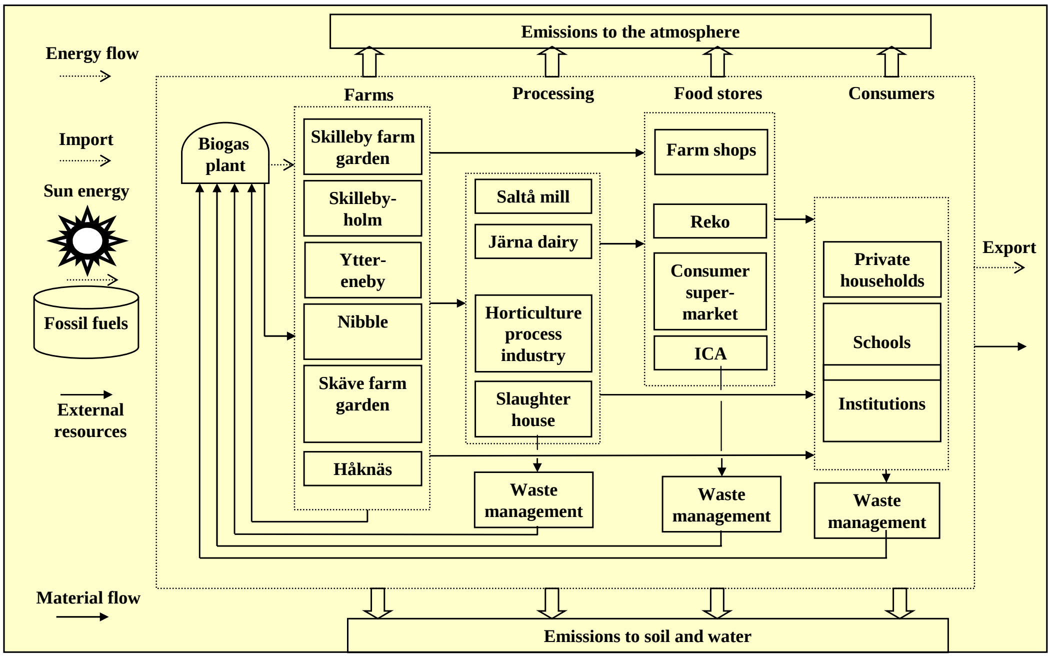
Both reactors are made of COR-TEN-steel cylinders of 10 mm wall thickness and 2.85 m inner diameter.

They are coated by 20 cm pulp isolation and corrugated sheet.

Why this reactor was designed?

Ecological recycling agriculture

Source: Granstedt http://www.jdb.se/beras/ BERAS- Baltic Ecological Recycling Agriculture and Society



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The local association of farms, horticulture enterprises, food processing units, food stores and consumers produces organic waste. The goal is, by

- promoting a high degree of recycling,
- reduced use of non-renewable energy,
- and use of the best known ecological techniques in each part of the system,

to reduce consumption of limited resources and minimize harmful emissions to the atmosphere, soil and water.

The biogas plant served as reference plant for nutrient recycling solutions within the BERAS-project of “The Baltic Sea Region INTERREG III B Neighbourhood Programme 2000-2006” of the European Union. Presently the bio-gas plant digests dairy cattle manure and organic residues originating from the farm and the surrounding food processing units.

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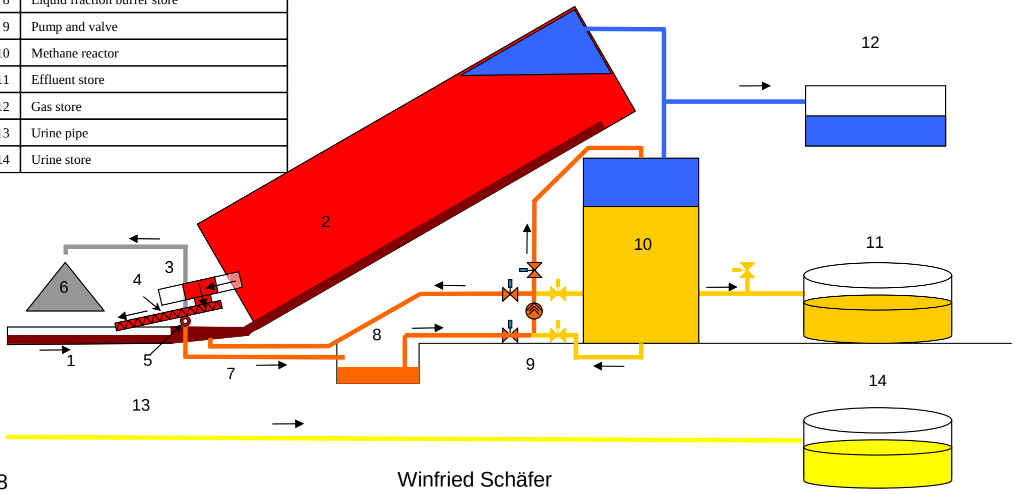
Flow chart of the prototype biogas plant at Yttereneby farm, Järna, Sweden

1	Feeder channel
2	Hydrolysis reactor
3	Drawer
4	Drawer discharge screw
5	Solid residue separation screw
6	Solid residue after hydrolysis
7	Drain pipe of liquid fraction
8	Liquid fraction buffer store
9	Pump and valve
10	Methane reactor
11	Effluent store
12	Gas store
13	Urine pipe
14	Urine store



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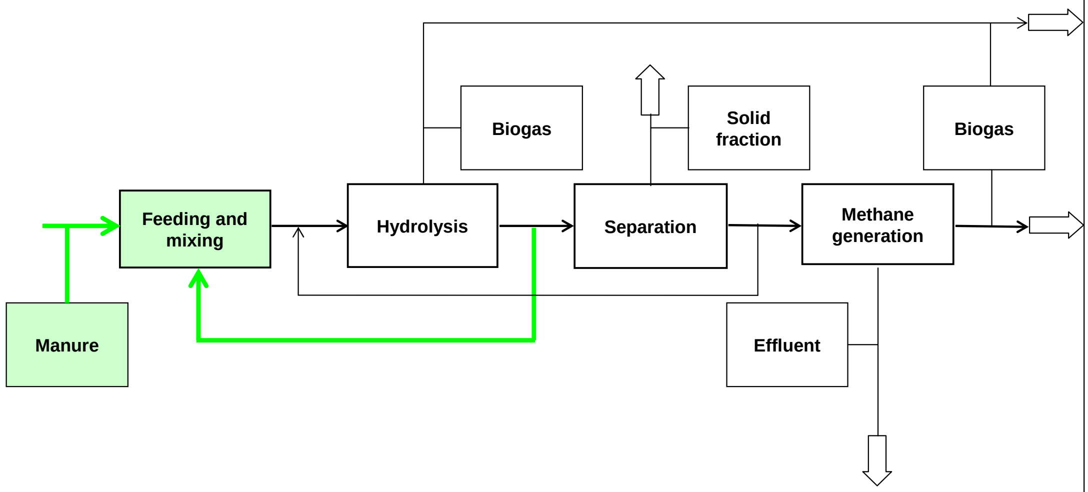
The flow chart illustrates the material flow :

A hydraulic powered scraper shifts manure into the feeder channel **1** of the hydrolysis reactor **2**. The urine **13** is separated in the stall via a perforated scraper floor and stored separately **14**. The manure is pressed to the top of the hydrolysis reactor. Gravitation slowly pulls the manure down mixing it with the substrate. The substrate is discharged through a bottomless drawer **3** in the lower part of the reactor. The drawer releases the substrate into the transport screw **4** beneath. The major part of the substrate drops into a down crossing extruder screw **5** where it is separated into solid **6** and liquid **7** fractions. The remaining material in the transport screw is conveyed back to the feeder channel and inoculated into the fresh manure.

The liquid fraction is collected in a buffer container **8** and from there pumped into the methane reactor **10**. Liquid from the buffer container partly returns into the feeder pipe of the hydrolysis reactor to improve the flow ability. The effluent is pumped into a slurry store **11** covered by a floating canvas. A screw pump **9** conveys all liquids supported by five pressurized air-driven valves. The gas generated in both reactors is collected and stored in a sack **12**.

Feeding and mixing



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The process steps in detail:

Feeding and mixing the manure.

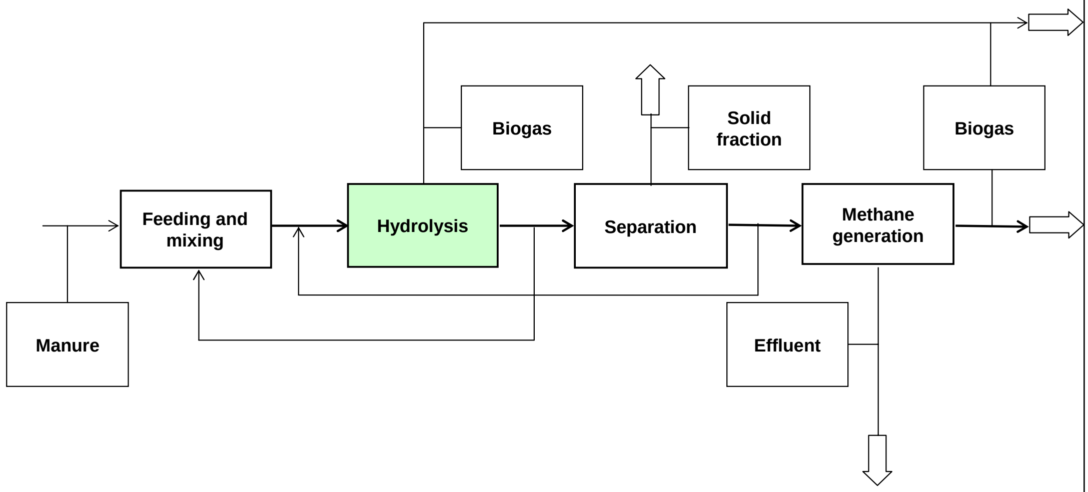
Feeding and mixing

The manure of 65 livestock units kept in a dairy stanchion stall is a mixture of faeces, straw and oat husks.

A part of the output of the hydrolysis reactor is conveyed back to the feeder channel and inoculated into the fresh manure.

The urine is separated in the stall via a perforated scraper floor

Hydrolysis



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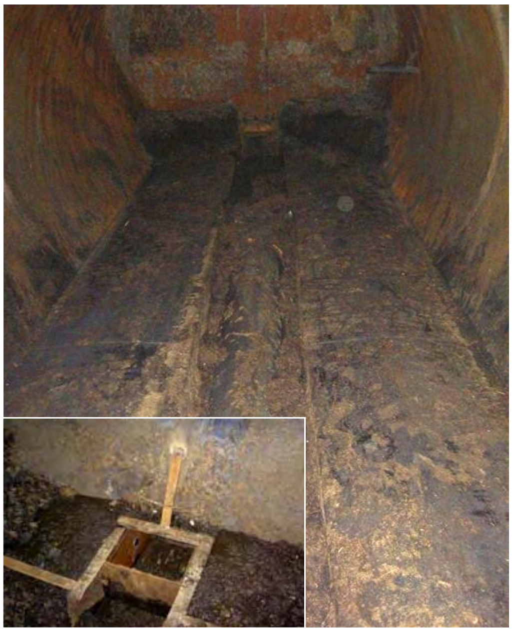
Process step two:
Hydrolysis

Hydrolysis reactor

Photos: Winfried Schäfer

Photo: Lars Evers



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The manure is pressed to the top of the 30° inclined hydrolysis reactor of 53 m^3 capacity.

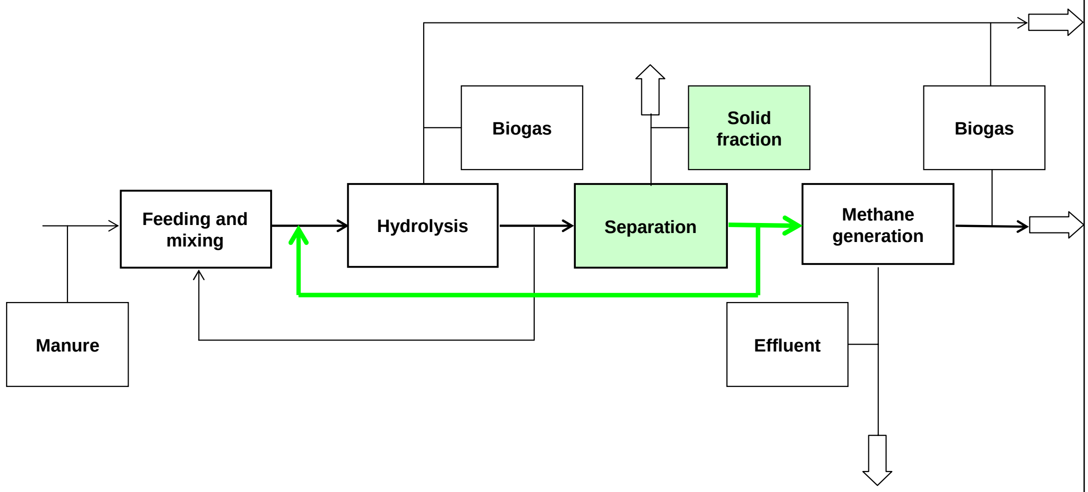
The bottom of the hydrolysis reactor is on both sides of the feeder pipe provided with hot water channels.

The 400 mm wide feeder pipe is made of PVC.

The substrate is discharged through a bottomless drawer in the lower part of the reactor

The drawer is guided within a rectangular channel and powered by a hydraulic cylinder.

Separation



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Process step 3:

Separation of the solid and liquid fraction after hydrolysis.

Separation


Photos: Winfried Schäfer


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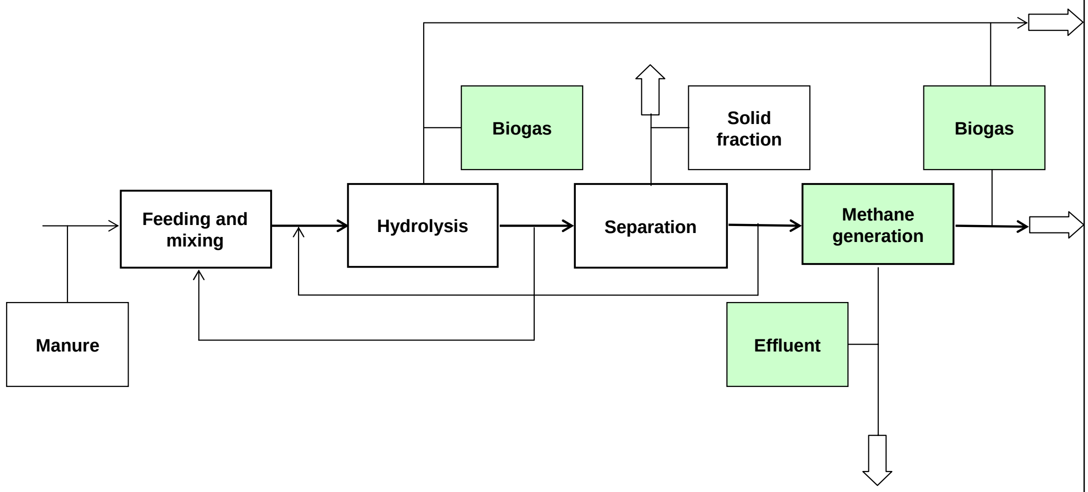
From the transport screw the major part of the substrate partly drops into a down crossing extruder screw where it is separated into solid and liquid fractions.

The liquid fraction is collected in a buffer container of 2 m^3 capacity and from there pumped into the methane reactor.

The solid fraction from the extruder screw is stored on the dung yard for composting.

Liquid from the buffer container partly returns into the feeder pipe of the hydrolysis reactor to improve the flow ability

Methane generation



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Process step 4:

Methane generation.

Methane generation, gas and effluent storage

Photos: Winfried Schäfer

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The effective reactor capacity is 17.6 m³.

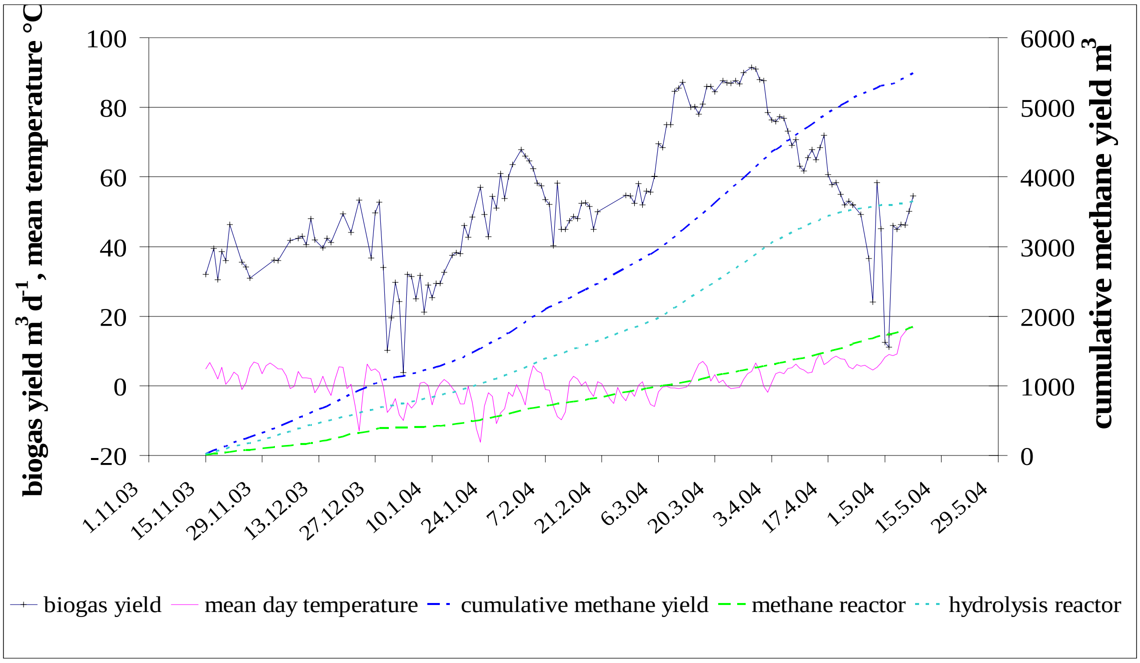
The methane reactor is 4 m high and filled with about 10 000 filter elements offering a large surface area for methane bacteria settlement.

After a retention time of 15 to 16 days at 38°C the effluent in the methane reactor is pumped into the slurry store

The gas generated in both reactors is collected and stored in a sack.

A compressor generates 170 mbar pressure to supply the burners of the process and estate boiler with biogas for heating purposes.

Biogas yield



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The biogas production of the plant started in 15th of November 2003. The biogas production until the beginning of the pasture period 8th of May 2004 is shown here. A frozen gas pipe biased the gas yield measuring results in January and corrosion problems in the gas pipe of the hydrolysis reactor impeded correct measurement of the gas yield in April. The actual cumulative gas yield may therefore be higher than the measured one.

In contrast to the design calculations, the methane reactor produced less gas than the hydrolysis reactor. The methane reactor generated in average in the first period 34 vol% and in the second period 11 vol% of the methane. This indicates that the process management has to be improved in such a way, that the load rate of the first reactor is reduced and the load rate of the second reactor is increased.

Mass balance

Mass	FM kg d^{-1}		TS kg d^{-1}		VS kg d^{-1}	
Year 2004	Spring	Autumn	Spring	Autumn	Spring	Autumn
Input faeces	1717	2172	123	199	99	176
Input straw	27	58	24	44	23	37
Input oat husks	256	198	238	181	218	162
Sum input	**2000**	**2428**	**385**	**423**	**340**	**375**
Output solid fraction	920	1188	271	317	243	282
Output effluent	1023	1176	58	45	41	32
Output biogas	57	63	56	62	56	62
Sum output	**2000**	**2427**	**385**	**423**	**340**	**375**

FM: Fresh mass TS: Total solids VS: volatile solids

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We calculated the mass of faeces by subtracting the weighed mass of straw and oat husk form the weighed mass of manure.

From oat husks and straw, originate 53 to 70% of the volatile solids of the input material. In the solid fraction remained 70 to 75% of the total solids, in the effluent 10 to 15% and within the biogas 14.8 to 14.9%.

Performance parameters

R1: Hydrolysis reactor; R2: Methane reactor		R1	R2	R1+R2	R1	R2	R1+R2
Year 2004		Spring			Autumn		
Effective capacity	m^3	53	18	71	53	18	71
Mass input	kg FM d^{-1}	2000	1045	2000	2430	1184	2430
Specific weight input	kg m^{-3}	946	968		989	1015	
VS input	kg VS d^{-1}	340	61	340	375	35	375
Biogas mass	kg d^{-1}	35	22	57	58	6	63
Methane mass	kg d^{-1}	12	9	21	19	2	22
Output mass	kg FM d^{-1}	1045	1023		1184	1176	
VS output	kg VS d^{-1}	61	40		35	30	
Retention time	d	25	16		22	15	
Loading rate	kg VS m^{-3} d^{-1}	6	3		7	2	
Biogas yield	l kg^{-1} VS	85	313	141	125	147	139
Methane yield	l kg^{-1} VS	48	204	85	71	96	80
Volume efficiency	l m^{-3} d^{-1}	544	1093	681	887	297	740

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From the mass balance we calculated the performance parameters of the plant:

Please, note that the solid fraction is removed after digestion of the manure in the first reactor. Therefore, the loading rate cannot be calculated for the whole plant. This methodical problem makes it difficult to compare this plant with one-stage plants.

The results confirm that the first reactor is overloaded and the production potential of the second reactor is not utilised. Recommended load rate for dairy manure is 3 to 5 kg VS m^{-3} d^{-1}. This value is probably suitable for the first reactor too. Fixed film reactors like the second reactor can according to Lo et al. (1984) work with a loading rate of 32.8 kg VS m^{-3} d^{-1} at the same biogas yield level .

Consequently, the average methane yield of 80 to 85 l CH_4 kg^{-1} VS is low compared to findings of other dry fermentation plants. Baserga et al. reached in 1994 186 l CH_4 kg^{-1} VS from straw and manure of beef cattle. Møller et al. measured in (2004) 100 to 161 l CH_4 kg^{-1} VS from dairy cattle faeces and 100 l CH_4 kg^{-1} VS from straw at 40 days retention time.

The volume efficiency of the plant is slightly better than the average of common slurry fermenters. Oechsner et al. evaluated in (1998) 66 plants and measured in average 630 l biogas m^{-3} d^{-1}. The latest evaluation of FNR (2005) shows similar values: About 70% of the 59 evaluated plants achieved a volume efficiency of 250 to 750 l biogas m^{-3} d^{-1}.

Composting

Manure

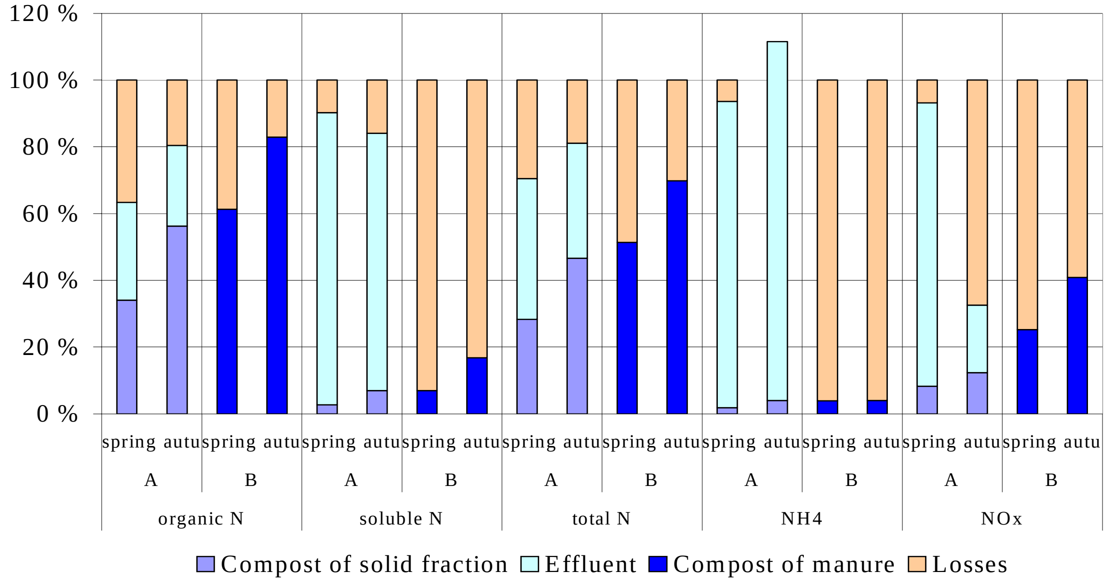
Solid fraction

Photos: Marja Lehto

Besides biogas, the plant produces a new product: Compost from the solid fraction here in comparison with compost from input manure

Nitrogen balance of manure treatment

A = biogas + compost from solid fraction.
B = aerobic compost only, no biogas
100% = nitrogen of solid manure input



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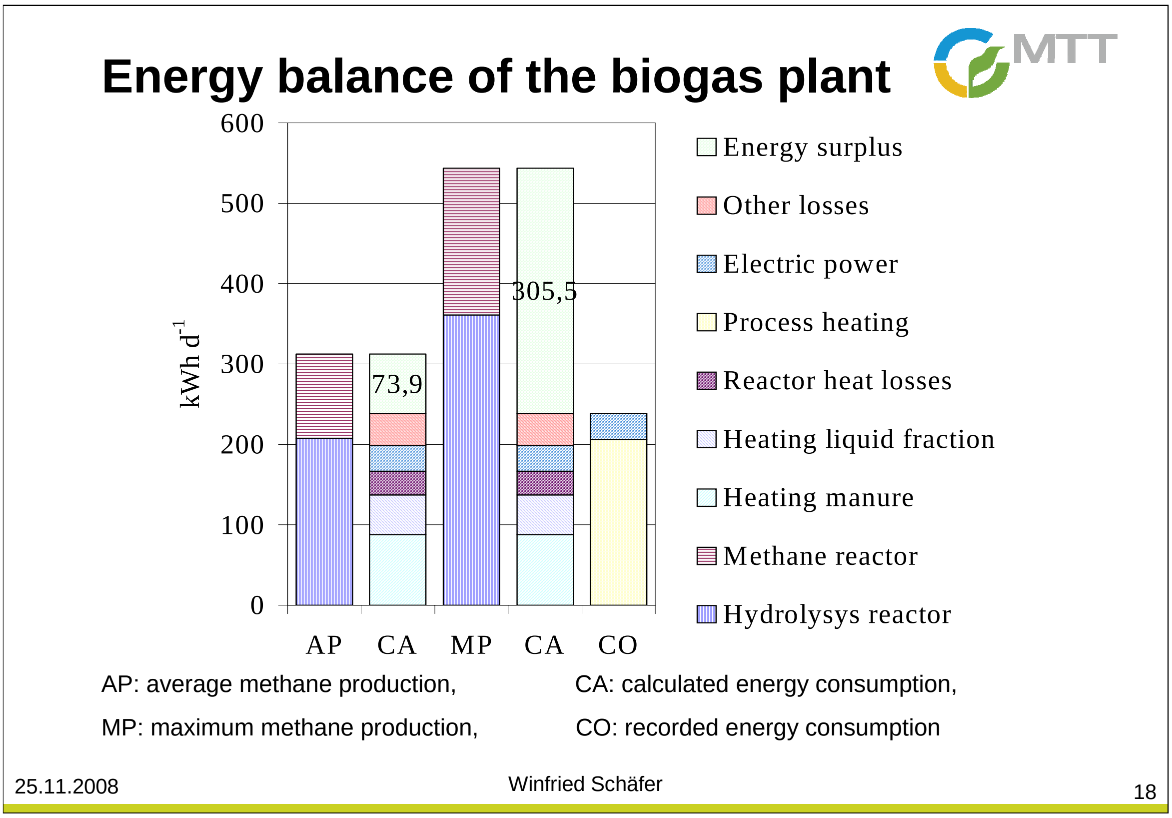
Total nitrogen losses ranged between 19% and 29% in process A (effluent from the biogas plant plus compost from the solid fraction) and between 30% and 48% in process B (the aerobic manure treatment before the biogas plant was established). Similar values we found for NH_4: up to 6% losses in process A versus 96% in process B. The results confirm the calculations of Möller (2003) that biogas production increases recycling of NH_4 and reduces overall nitrogen losses compared to mere aerobic composting.



Produced and consumed energy between 23.11.2003 and 7.5.2004 is shown here. The mean day temperature was about 0.4 °C. In average 76.3% of produced methane was used for process heating. At most 56% of the produced energy was available for heating the farm estate. The calculated conductive and convective heat losses of the reactors were only 9.5% in contrast to 53.3% heat energy required for heating up the manure and the liquid fraction respectively. The overall heat consumption was 206 kWh d^{-1}or 103 kWh t^{-1} FM. Additionally 32 kWh d^{-1} or 16 kWh t^{-1} FM electric power was consumed. These values range above the energy demand of German biogas plants. The most recent biogas plant survey reports 44 to 94 kWh t^{-1} FM heat and 0.51 to 51 kWh t^{-1} FM electric power FNR 2005. The mean energy efficiency of the whole plant was 24% based on the produced energy and the maximum achieved efficiency was about 49%.

Conclusion

Heat energy max.	1.7 kWh kg^{-1}VS	up to 57 % surplus
N_{tot} losses	up to 39 %	reduced
NH_4 losses	up to 93 %	reduced
CH_4 generation	up to 64 %	from oat husks

"The goal is, by promoting a high degree of recycling, reduced use of non-renewable energy, and use of the best known ecological techniques in each part of the system, to reduce consumption of limited resources and minimize harmful emissions to the atmosphere, soil and water."

Mission accomplished.

Granstedt http://www.jdb.se/beras/ BERAS- Baltic Ecological Recycling Agriculture and Society

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Conclusions:

Dry fermentation technology up to now does not offer competitive advantages in biogas production compared to slurry based technology as far as only energy production is concerned. The results show that the ideal technical solution is not invented yet.

This may be a challenge for farmers and entrepreneurs interested in planning and developing future dry fermentation biogas plants on-farm.

Development of new dry fermentation prototype plants requires appropriate compensation for environmental benefits like closed nutrient cycle and production of renewable energy to improve the economy of biogas production.

The prototype in Järna meets the set objectives since - beside renewable heat energy - a new compost product from the solid fraction was generated. However, the two-phase process consumes much energy and the investment costs are high (>2000 € m^{-3} reactor volume).

Our final report is on-line available free of charge at www.orgprints.org/6590
The on-line documentation of the BERAS-project (BERAS - Baltic Ecological Recycling Agriculture and Society is available at http://www.jdb.se/beras/default.asp?page=18.

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