International
Biogas and
Bioenergy Centre
of Competence (IBBK)

Report: Comparison and assessment of technologies and Offers for Biogas plants on organic farms in Denmark

Comparison of different offers from German biogas Companies

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Introduction

Concerning Organic Denmarks request of the development of a standard biogas plant setup for organic farms in Denmark, the IBBK report compares anaerobic digestion technologies for manure and agricultural substrates, especially occurring on organic farms. For this report IBBK identified technology providers, who have long term experience with grass, clover grass and deep litter manure digestion. According to the given substrate input biogas plants in two sizes are considered. For this purpose the offers of the different providers are compared.

The different proposals comprehend a list of all components which are necessary for a smooth biogas operation. It was not possible to get the specific name of all components and suppliers, because German companies often do not disclose the names of their supplier companies. Anyway the proposals are really detailed and very different. So this report mentions 3 different types of biogas technologies which will be discussed within the report. As a summary IBBK has composed a comparison to show the pro's and con's of all proposals.

Standard Figures: As standard biogas figures in this document the figures of KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft, technical and constructional advisory council of agriculture) are taken. These figures are based on average figures of German energy crops and corrected to conservative values. Therefore a well operating biogas plant should be able to reach these values and even gain better results.

Technology assessment for larger plant

Available Substrates

For the bigger scale plant the following substrates are considered:

- 1.000 t chicken manure
- 1.000 t solid manure (cow)
- 7.500 t liquid manure (cow)
- 7.000 t clover grass silage

For detailed analysis, the existing "substrate infrastructure" has to be considered. This includes.

- Substrate qualities (dry matter, organic dry matter)
- Storage facilities for manure
- Storage facilities for silage
- Pumping and piping for liquid manure

- Transport distances (costs)
- Workforce and machinery for feeding

Dry Fermentation

Considering the available substrates a wet fermentation is proposed. Leaving out the liquid manure also a dry-fermentation can be considered. The main focus of this report is on the wet fermentation the dry fermentation is only briefly included.
For the dry fermentation a batch-system with garage type digesters is considered. The following parameters are the basis for calculation:

- Retention time: 35 days
- Recirculation per load: 60% of digested material
- 4 Garages: 731 m³ volume each
- Percolation tank:1220 m³

Table 1 shows the expected resulting biogas and methane yield.

Kg	Substrates	DM	ODM in DM	Kg oDM	Biogasyield [l/kg oDM]	Methan content [%]	Methane yield total [m³]
1.000.000	chicken manure	40,00%	75,00%	300.000	500	55,00%	82.500
1.000.000	solid manure (cow)	25,00%	85,00%	212.500	450	55,00%	52.594
7.000.000	clover grass silage	30,00%	90,00%	1.890.000	580	55,00%	602.910
9.000.000	total	30,56%	87,78%			total methane	738.004

Table 1: Input substrates and resulting biogas/methane yield for dry fermentation plant

Of the produced methane an electric energy yield of 2.804.415 $kWh_{el.}$/year can be achieved.
Considering 8000 annual full load hours, an installed electric capacity of around 355 kW will result.

Wet fermentation

Considering all substrates listed a wet fermentation with a completely stirred digester is proposed. Regarding standard figures the following methane/biogas yields can be derived of the available substrates.

Kg	Substrates	DM	oDM	Kg oDM	Biogasyield [l/kg oDM]	Methan content [%]	Methane yield total [m³]
1.000.000	chicken manure	40,00%	75,00%	300.000	500	55,00%	82.500
1.000.000	solid manure (cow)	25,00%	85,00%	212.500	450	55,00%	52.594
7.500.000	liquid manure (cow)	10,00%	80,00%	600.000	380	55,00%	125.400
7.000.000	clover grass silage	30,00%	90,00%	1.890.000	580	55,00%	602.910
16.500.000		21,21%	84,24%	2.948.485			
						total methane	863.404

Table 2: Input substrates and resulting biogas/methane yield for wet fermentation plant

There of an installed electric capacity of around 430kW[1] results. For further calculations see proposals.

Sauter system assessment of proposal

The Sauter system consists of a small pre-digester for the first digestion step, a main-digester and a digestate storage. The system is mixed by pumping the thin material from the bottom of the digester and spraying it on top of the digester content. The system does not need additional stirring devices inside the digester.

The digesters are made of concrete and are heat insulated. Additionally the digester can be made as a lagoon. The heating is done through a heat exchanger. The gas is collected in gasbags on top of the digesters. The gas is collected both from the digester and the digestate-storage. In the company's calculations the daily methane yield is 2.571m³. This is slightly higher than the IBBK calculations (see above) but, if the plant is ran well, not unrealistic. The organic loading rate of 1,9 kg oDM/ (d x m³) is chosen. Comparing this value to standard figures the organic loading is relatively low. This loading rate provides good and stable digesting conditions. The low loading rate in this case is probably necessary to provide stable conditions for a sufficient break down of the organic matter.

The gas is then lead to the CHP unit. As CHP a 500$kW_{el.}$ Jenbacher-GE engine is proposed.
In the company's proposal an electrical efficiency of 39% is calculated. The efficiency might be slightly over average but can still be rated realistic for a well maintained engine.
The electricity production of 3.659.415 kWh/year as a result of gas production and efficiency can be considered realistic under good conditions. The installed capacity of 500 kW results in only 7.319 full-load hours which gives still extra capacity.
The electrical own consumption of the CHP (2%) is realistic. The own consumption of the digestion of 3% is fairly low compared to standard figures. As a very special stirring system is installed, there

1 Presuming 40% electrical efficiency and 8000 full load hours per year. The calculations in the company proposals may deviate.

are no comparable figures available.

Altogether the proposal is based on realistic figures. A good plant operation is considered. Under optimal conditions the plant can even have a higher energy-output. After gaining some experience the plant configuration still gives the chance to increase the load and reach a higher electricity production.

Lipp system assessment of proposal

The Lipp system works with a separate hydrolysis step. After the hydrolysis there are two parallel digesters. At the end of the process there is a gas tight digestate storage. Digesters, hydrolysis tank and digestate storage are made of stainless steel (Verinox). The heating is installed on the outside of the digester walls and is therefore accessible and protected against acids and heat backings. For stirring, different types of devices can be installed according to costumers needs. In the offer it does not become obvious which stirring system is included.

As input substrates 1000 t of corn silage was added to the proposal. The company explains this by reduction of nitrogen content in the substrate mix for a better digestion conditions. According to our experience this is not absolutely necessary. Also reasonable substrate costs are considered.

Calculated with German standard figures the extra corn silage would produce another 50.943 m³ of methane. Adding the original substrate (863.404 m³ Methane) mix this would result in 914.347 m³ of methane. The Lipp calculations are 1.858.000m³ biogas at 55% methane which is 1.021.900m³ of methane. In the proposal the estimated gas yield is above the standard figures. This gas yield can realistically be achieved under good operational conditions.

In the proposal a 600kW$_{el.}$ is suggested. As electrical efficiency 42% is quoted. This efficiency is usually reached under laboratory conditions at the engine test stand. In reality an efficiency of not more than 39% should be estimated. Therefore the yield (based on the gas yield of the proposal) of electric energy should be 3.985.410kWh/a rather than 4.292.000 kWh/a.

Considering a higher gas yield and a higher electrical efficiency the company's calculated energy yield is 20% over standard figures. To achieve these results optimal conditions would be necessary.

D&K system assessment of proposal

The D&K proposal includes a plant consisting of one main and one post digester. There is no separate hydrolysis planned. It has to be mentioned that the digester size is pointed out as gross volume, so the actual working volume will be smaller. Considering the digester size an organic loading rate of 4,3kg oDM /d x m³ can be calculated. The hydraulic retention time will be 41 days. It has to be mentioned that D&K calculates the flow of draining water from the silage clamp as an

additional substrate. There are no detailed calculations about the drainage water included in the proposal. Very roughly a flow of around 1000m³/year can be estimated. This will slightly influence the values pointed out above. In general the values are realistic and promise good technical conditions.
For gas yields and Energy production D&K calculates with the standard figures that are pointed out above (see Table2). The only difference is that with the clover-grass-silage a dry matter content of 33% instead of 30% is calculated. Of that a deviation of standard figures of about 4 % derives. Using good agricultural practise this substrate quality can be achieved. If in reality "only" standard figures can be achieved, D&K proposes the use of around 2t/day grass extra to use all of the capacity.
Like at the Sauter proposal a 500 KW CHP is proposed. Considering standard gas yields this is a realistic size.
According to German laws the substrate has to be kept 150 days in gas tight space in order to avoid methane emissions. Therefore an extra final storage (not heated and insulated, incl. coverage and stirrers) needs to be built. However this might not apply to Denmark.
According to D&K there are good experiences with this kind of plant. It may also be downscaled by 20%.

Technology assessment for smaller plant

Available Substrates

For the smaller scale plant the following substrates are considered

- 375 t chicken manure
- 200 t solid manure (cow)
- 1.500 t liquid manure (cow)
- 2.800 t clover grass silage

Dry Fermentation

As for the bigger plant a short overview about the possibilities of a dry fermentation is given. Therefore the liquid manure has to be left out.
For the dry fermentation a batch-system with garage type digesters is considered. The following parameters are considered.

- Retention time: 35 days
- Recirculation per load: 60% of digested material
- 4 Garages: 307 m³ volume each
- Percolate tank: 447 m³

Table 3 shows the expected resulting biogas and methane yield.

Kg/a	substrates	DM	ODM in DM	Kg oDM	Biogasyield [l/kg oDM]	Methan content [%]	Methane yield total [m³]
375.000	chicken manure	40,00%	75,00%	112.500	500	55,00%	30.938
200.000	solid manure (cow)	25,00%	85,00%	42.500	450	55,00%	10.519
2.800.000	clover grass silage	30,00%	90,00%	756.000	580	55,00%	241.164
3.375.000	total	30,81%	88,04%			total	282.620

Table 3: Input substrates and resulting biogas/methane yield for dry fermentation plant

Of the methane yield an electric energy yield of 1.017.432kWhel./year can be achieved. Considering 8000 annual full load hours, an installed electric capacity of around 130 kW will result.

Wet fermentation

Considering all substrates listed a wet fermentation with a completely stirred digester is proposed. Regarding standard figures the following methane biogas yields can be derived of the available substrates.

kg	substrates	DM	oDM	Kg oDM	Biogasyield [l/kg oDM]	Methan content [%]	Methane yield total [m³]
375.000	chicken manure	40,00%	75,00%	112.500	500	55,00%	30.938
200.000	solid manure (cow)	25,00%	85,00%	42.500	450	55,00%	10.519
1.500.000	liquid manure (cow)	10,00%	80,00%	120.000	380	55,00%	25.080
2.800.000	clover grass silage	30,00%	90,00%	756.000	580	55,00%	241.164
4.875.000	total	24,41%	85,56%	1.018.213			
						total methane	307.700

Table 4: Input substrates and resulting biogas/methane yield for wet fermentation plant

Thereof an installed electric capacity of around 150kW[2] results. For further calculations see proposals.

Sauter system assessment of proposal

The Sauter system consists of a small pre-digester for the first digestion step, a main-digester and a digestate storage. The system is mixed by pumping the bottom material of the digester and spraying it on top of the digester floating layer in short thrown hard spray beams. The system does not need additional stirring devices inside the digester.

In the proposal of the small plant no detailed calculations is included.

2 Presuming 40% electrical efficiency and 8000 full load hours per year. The calculations in the company proposals may deviate.

As digester size 2.281 m³ is chosen, there of a working volume of around 2.015 m³ results. The organic loading rate of 1,39 kg oDM/d x m³. In the proposal an organic loading rate of 1,9 kg oDM/d x m³ is mentioned, because Sauter used 3.000 t of liquid manure. The organic loading rate of 1,39 kg oDM/d x m³ is quite low and leaves a lot of tolerance for additional substrates. The hydraulic retention time in the digester (post digester not included) will be 109 days. The conclusion of the calculation is that the dimensioning of the digester leaves a lot of space for additional substrates. However it has to be considered that especially in that kind of system with no horizontal mixing a longer retention time to break down the substrates will be necessary.

The gas yield with 1.016 m³/d is calculated and can be assessed realisticly. Considering standard German values 841 m³/d is estimated with 1.500 t liquid manure. The gas is collected both from the digester and the digestate-storage.

For the CHP unit a Hagl-MAN Engine is proposed. The electric efficiency pointed out in the proposal is next to 37 %. Average values of CHP-gas engines show a considerable little lower efficiency of 190 kW Engines compared to 500 kW (bigger plant) engines. Realisticly an efficiency of 36% can be estimated. Considering the gas yield calculated by Sauter-figures, this results in a electrical energy yield of 1.378.803 kWh_{el}/year. Considering 8000 full load hours per year a 169 kW CHP would be sufficient. So the 190 kW-Engine leaves space for additional biogas production.

As a general result it can be pointed out that the digester-dimensions is designed bigger due to the given process. The digester volume may be reduced. The overall calculations regarding gas- and energy yield can be assessed as realistic under good plant-operating conditions.

Lipp system assessment of proposal

The Lipp system works with a separate hydrolysis step. After the hydrolysis there are two parallel digesters. At the end of the process there is a gas tight digestate storage. Digesters, hydrolysis tank and digestate storage are made of stainless steel (Verinox). The heating is installed on the outside of the digester walls and is therefore accessible and protected against acids. For stirring, different types of devices can be installed according to costumers needs. It does not become obvious which stirring system is included in this particular offer.

Again in this proposal an extra substrate amount of 1000 t corn-silage is included. Therefore the results are not really comparable to those of the Sauter system. As a digester working volume around 1500 m³ is proposed. Including the corn silage the substrate feed will be 1.331 t oDM per year, which results in an organic loading rate of 2,443kg oDM/m³ x d. This is a realistic figure which still leaves tolerance for additional substrate load. The hydraulic retention time will be 93 days and leaves a lot of biological redundancy.

As biogas yield Lipp calculates 777.000 m³ at 55 % methane. This is a methane yield of around 427.350 m³/year. Calculating German standard figures a gasyield of 1.131m³/d eq. 412.815 m³/year.

Therefore the Lipp calculation can be assessed as realistic under good operating conditions.

For the CHP unit Lipp calculates an electrical efficiency of 39%. As pointed out above an efficiency of 36% is realistic according to standard figures. Considering the gas yield calculated by Lipp the electricity yield will be 1.538.460 $kWh_{el.}$/year rather than 1.667.000 $kWh_{el.}$/year.

Considering both expected gas yield and CHP efficiency the proposal expects an electric energy yield 12 % above the German standard figures. This can be realistic under good operating conditions.

D&K system assessment of proposal

For the smaller plant a digester working volume of (gross: 1526m³) 1.374 m³ is chosen. Considering the substrates of Table 4 an organic loading rate of 2 kg oDM/ m³ x d results. Also a hydraulic retention time of 102 days results. It is clearly mentioned in the offer that the digester size leaves space for additional substrate flow (and gas yield). It has to be mentioned that D&K calculates the flow of draining water from the silage clamp as an additional substrate. There are no detailed calculations about the drainage water included in the proposal.

Also in this calculation a dry matter content of 33% for the clover-grass-silage is calculated. This can be realistic considering good agricultural practise. But of that derives a deviation from standard figures of 8%.

As in the Sauter proposal a CHP size of 190 kW is proposed. This is realistic under average conditions. As an extended CHP capacity a 250 Engine is proposed this will only be necessary if additional substrates are used.

Summary of technical proposal assessment

Comparing the figures of the proposals to standard figures the yields are generally higher. This is not unusual because companies generally asses their technology as superior compared to the standard. See Table 5

	Sauter	Lipp	D&K
Big Plant	8%	20%	8%
Small Plant	3%	12%	4%

Table 5: Additional energy yield calculated in proposals compared to German standard figures

It has to be considered that the Lipp calculations are based on a higher CHP electrical efficiency. According to our expertise this is not realistic according to existing data. It has to be obsereved if latest developments in CHP technologies can achieve these efficiencies in long term use. Figure 1

and 2 show the typical CHP efficiencies for 500 kW and 190 kW.
Considering the gas yield, it has to be said that in the German standard figures are conservative as pointed out at the beginning. Therefore the gas yields pointed out in the proposals can be realistic.
To run the plant successfully and reach the results pointed out it is important to:

- have steady substrate amounts and quality and efficient substrate logistics,
- be aware of the biological process and do regular measurements of important parameters,
- be able to interpret the measurement and react adequately in early stages of disturbances,
- run the whole plant well maintained and react to technical problems at an early stage.

Under these conditions a plant operation according to the results pointed out in the proposals is realistic.

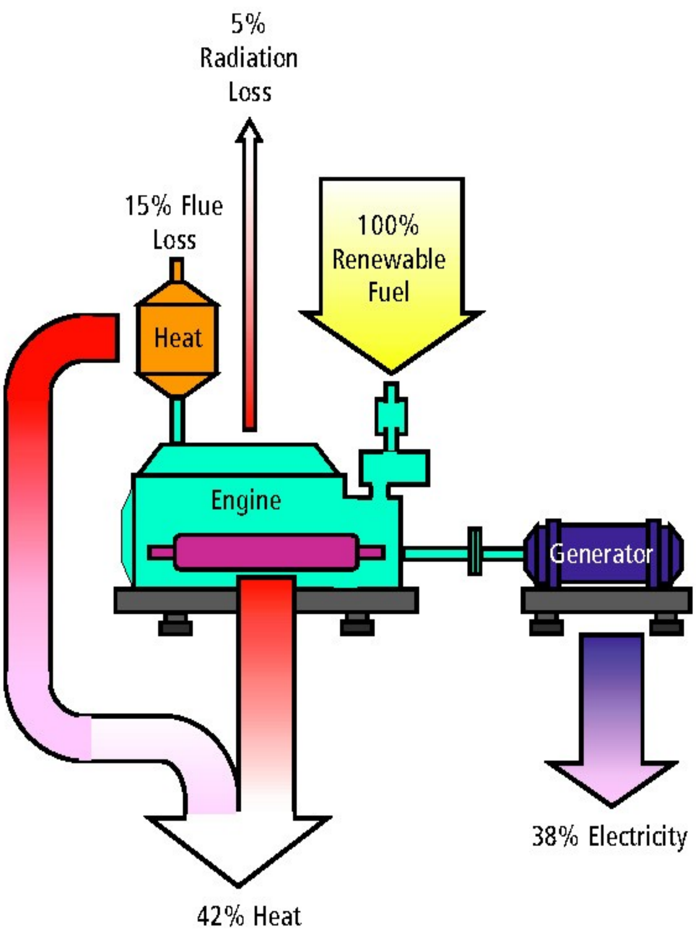

Figure 1: CHP Efficency 500 kW

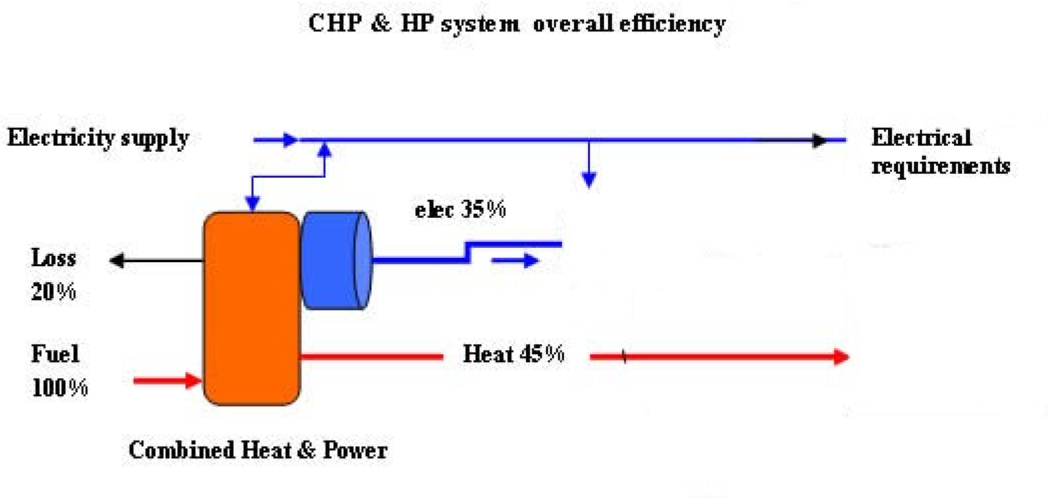

Figure 2: CHP Efficiency 190 kW

It also gets obvious that companies offering biogas plants tend to “oversize” the capacity of the plant in order to be able to cope with an extra load of substrates. It has to be considered carefully if this capacity is really needed. It has to be calculated if there is a chance to purchase substrates for a reasonable price. Also it has to be taken into account that extra substrates require extra storage and logistic capacity.
D&K is the only company which briefly explains this circumstances. In an email the company also mentioned, that the volume can be reduced by 20 %.
In most of the configuration proposed, the CHP capacity is the limiting factor. Therefore it has to be taken into account that, if the substrate input is increased to the limit of the biochemical process, also an extra CHP unit has to be purchased. Otherwise the biogas will be wasted into the atmosphere or flared

Assessment of investment

In the D&K proposal the concrete works for the digesters are not included. The work is also not executed by D&K GmbH. The costs for concrete works have been reported by D&K via email and phone. To make the proposals comparable for the CHP-unit the values of the Sauter proposal are calculated. Which is a 500kW GE-Jenbacher and a 190kW Hagl-MAN engine (price only basic version) .

The investment for the Plant is calculated as shown below.

	Big plant 500kW	Small plant 190kW
Investment as proposed	596.000 €	471.300 €
Concrete digester	124.000 €	106.000 €
Final storage	178.000 €	
CHP Unit	375.750 €	98.000 €
Sum net	1.273.750 €	675.300 €
VAT 19%	242.012 €	128.307 €
Sum gross	**1.515.762 €**	**803.607 €**

Table 6: Calculation of overall investment of D&K proposal

The net investment costs as quoted in the proposals are:

Bigger plant:
– Sauter: 1.402.764 €
– Lipp: 1.855.700 €
– D&K 1.273.749 €

Smaller plant
- Sauter: 996.404 €
- Lipp: 1.035.900 €
- D&K 675.300 €

Neither in the Sauter nor in the D&K proposal a flair and an exhaust gas treatment is included. It has to be checked if the legislation requires these components. For the 500 kW extra costs of around 140.000 € can be estimated. In the Lipp proposal the flair is included (not the exhaust gas treatment, extra 120.000 €).

The following table shows the Investment costs per kW installed CHP capacity as quoted in the proposals. As pointed out above the CHP capacities are slightly "oversized" so investment per real energy output might be slightly higher.

Euro/kW installed	Sauter	Lipp	D&K
big plant	2806	3092	2547
small plant	5245	4143	3555

Table 7: Investment costs for biogas plant per kW installed CHP-capacity

Generally the figures show reasonable costs compared to average figures. The only plant that has quite high investment costs is the smaller Sauter plant. This maybe due to the big volume digester. It is advised to further enquire for digester size at Sauter. To clarify these circumstances the fig. 2 was mentioned.

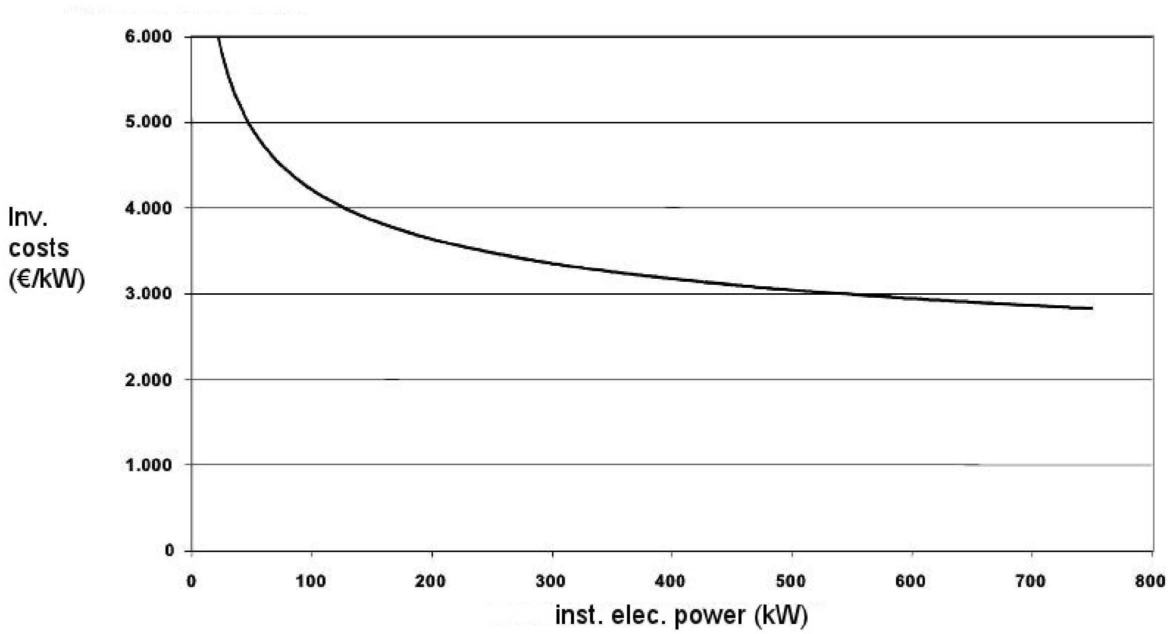

Figure 3: Specific Investment costs in €/kW

Furthermore a special focus need to be on the additional costs that derived from additional works that are not included in the proposed costs. These have to be closely estimated an added to the investment.

Finally is to say, that it is really difficult to compare these 3 different proposals. All 3 proposals intensively vary:

- Lipp uses 1000 t additional maize silage
- Sauter has a totally different System comparing with the standardized biogas plants
- and the D&K GmbH the concrete works for the digesters are not included.

It has to be mentioned that the proposals include different components (e.g. the Sauter and D&K proposal includes only a very basic CHP setup). Therefore the given figures can only be seen as an rough overview and the proposals have to be contemplated individually.

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