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Aikan Agri

Two-stage anaerobic digestion and composting of organic waste from urban and rural sources

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Contents

Preface

This project has been granted support under the Danish Environmental Protection Agency's Environmental Technology Development and Demonstration Programme and would not have been possible without this support.

The results of the project contribute to the improvement of the Aikan technology's market options, being a technology with focus on energy recovery from organic waste along with the recycling of nutrients.

The project has been followed by a steering committee with representatives from: The Danish Energy Agency, The Danish Biogas Association, DAKOFA, The Danish Waste Association, Hashøj Biogas Plant, The Municipality of Ringkøbing-Skjern and The Danish Environmental Protection Agency.

The project has been carried out be these Solum Gruppen staff members: Tests: Bjarne Jørnsgaard, Peter Brønnum and Pernille Hasse Busk Poulsen. Operation: Carsten Mikkelsen and Tonny Beck Galsklint. Financial issues: Henrik Mortensen, Martin Wittrup Hansen and Ask Tonsgaard.

1. Summary and Conclusions

In this project the Aikan® Technology (www.aikantechnology.com) has been further developed in order to be able to integrate it with existing or future biogas plants for manure, slurry or other liquid feedstock. The working title is Aikan Agri ®. The aim was to make plants that mainly handle liquid wastes capable of receiving, pre-processing, digesting and composting source-separated Biodegradable Municipal Solid Waste (BMSW) without segregating a major proportion of biodegradable material with the residuals. The development has been technically carried out in full scale at the Aikan plant *BioVækst* near Holbæk, Denmark.

The report highlights a number of important operational aspects of the Aikan Agri technology:

The pros and cons of various pretreatment methods are described. Based upon the results from specific tests, the effectiveness of the simple mechanical methods selected for use by small and large Aikan Agri plants is demonstrated. Waste with less than 15% of impurities can be treated without pretreatment, with the result that the total amount of organic potential in the BMSW can contribute to energy production and the compost yield. Through a rough screening of BMSW with more that 15% of impurities, less than 12% of the total methane potential ends up in the residual waste. The effect of this loss cannot be seen in the full-scale methane yields achieved due to the fact that only half of the laboratory potential is gained beforehand. Consequently, it seems that other process parameters have greater significance, than the segregation of a minor proportion. The physical handling by segregation might influence the methane yield positively. It was found that the purity of the compost, characterized by visible impurities, depends primarily upon the quality of the post-screening at a 10 mm drum screen. It must, however, be stressed that this is due to the gentle bag-opening procedure in the pretreatment process, which does not crush glass and plastics to small pieces.

The energy yield from Aikan Agri has been demonstrated through tests. The focus was on how, by means of the Aikan Agri technology, BMSW can contribute to a better economy in manure- and slurry-based biogas plants. The results show that almost 60 m^3 of methane per tonne of BMSW can be achieved. Cattle slurry contributes with 10 m^3 of methane (TS: 6-8%). The result also shows that the potentials of the wastes are approximately twice as large.

Energy and mass balances for the entire facility have been calculated. The result of the energy balance shows that approximately 13% of the energy produced is used in the operation (parasitic load). However, this includes heat consumption for sanitisation of BMSW to 70°C for one hour prior to treatment. The focus in the mass balance was preservation of nutrients and organic matter. The mass balance shows how much of the total input has been preserved in compost and digestate. The results reveal that 44.5 % of volatile solids, 84% of the nitrogen, 90% of phosphorus and 93% of potassium can be found in the end products.

The sanitisation aspect has been evaluated. In accordance with Danish legislation, BMSW must be treated at 70 °C for one hour in order to be considered sanitised, whereas slurry or manure from animals, treated separately, has no temperature requirement (due to the fact that slurry and manure is already spread on land by farmers without treatment). The integration of a BMSW system into agriculture-based plants creates the need to avoid cross-contamination between the two fractions. In the concept development it was found that because of the energy requirement the most feasible way was to sanitise the BMSW prior to processing. However, it was also demonstrated that the Aikan composting process provides 70 °C for more than one hour simultaneously in the entire solid mass. Consequently, if no liquid fertilizer is produced, composting is the most rational sanitisation method demanding no external heat energy.

The Aikan Agri concept consists of well-known components also used in slurry- and manure-based liquid biogas systems. The components are combined in a different way. The Supervisory Control and Data Acquisition (SCADA) for the process has been configured so as to be easily adoptable in existing liquid biogas systems.

A sophisticated financial model has been developed. The model is based upon practical operation of the plant in Holbæk, Denmark, and Capex and Opex inputs stem from concrete operation. By modelling financing, depreciation and framework conditions, the model provides an operating economy assessment of plants of arbitrary size. Business model calculations have been carried out for two plant sizes. A plant for 50,000 tonnes of BMSW and 300,000 tonnes of slurry, and a plant for 20,000 tonnes of BMSW and 100,000 tonnes of slurry, respectively, have been evaluated. The given Danish framework conditions were DKK 4.5 per m^3 of methane, gate fee for BMSW of DKK 450, no gate fee for slurry and no marketing costs for compost and slurry. Within these framework conditions, the payback period was as low as 1.3 years before taxes for the large plant, and 5.4 years before taxes for the smaller plant. Sensitivity scenarios for the framework conditions, however, showed that a simultaneous change of reduced gate fee for BMSW by 10 % reduced the sales price for methane by 10%, and increased marketing costs for digestate and compost by DKK 30 per tonne. Modifying these conditions changes the payback time to 7.9 years and + 10 years respectively.

2. Background, concepts and perspectives

This report is supported with funds from the Danish Environmental Protection Agency's Environmental Technology Development and Demonstration Programme. The purpose of the project has been to develop and test pretreatment methods and to further develop the Aikan technology in order to make it adaptable to existing slurry-based centralised biogas plants. The working title of the new concept is “Aikan Agri”.

With the Aikan technology, Solum Gruppen has developed a combined anaerobic and aerobic biological treatment method capable of transforming biologically degradable organic fractions - household waste, garden and park waste, sewage sludge, residues from food production, agricultural waste etc. - into energy and a fertiliser/compost fraction containing valuable nutrients, which are in this way preserved and recycled. The solid organic waste, for instance source-separated biodegradable municipal waste (BMSW), is mixed with a structural material, typically branches from garden and park clippings (GPC) before being placed in airtight process modules in which the mass is decomposed into a compost fraction and a liquid fraction (leachate), the latter being highly suitable for biogas generation.

Aikan is a robust two-stage process solving the traditional problems of clogging of pumps and pipes due to impurities contained in the waste. Also, with the microbial split into hydrolysis and methane production, Aikan solves the conflict between the wish for a high yield and the risk of inhibition further to too high feed. Leachate from the hydrolysis stage is a concentrated, readily decomposable and stable medium of a continuous and uniform quality; therefore, it may contribute positively to other processes - most evidently as a stable ‘booster’ in slurry-based biogas generation in which it can replace the organic residues that are normally added to the slurry, thus contributing to an optimal control and monitoring of the biological processes behind the biogas generation. The Aikan principle is shown in Figure 1.

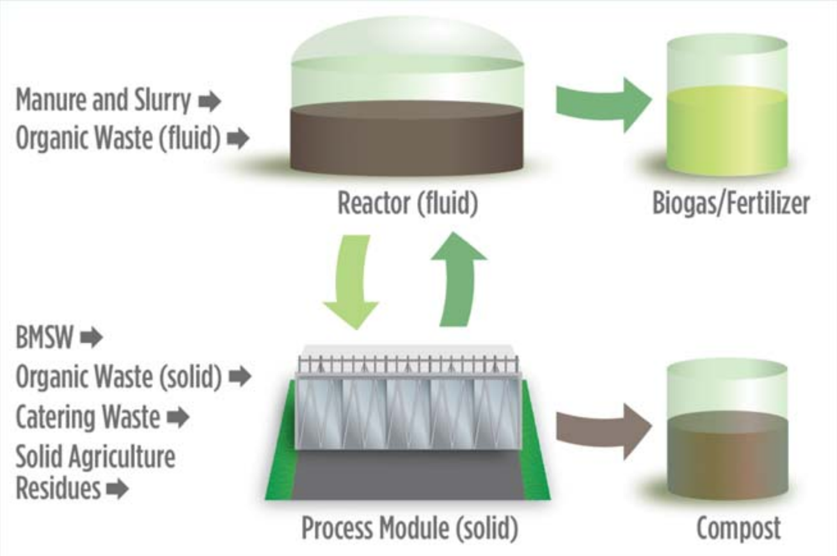

FIGURE 1
THE AIKAN PRINCIPLE: SOLID AND LIQUID WASTES ARE KEPT APART; ONLY THE LIQUID PHASE IS INTERCHANGED.

The traditional Aikan technology has a number of components in common with conventional biogas plants, such as reactor tanks, energy recovery system etc. At project start, Aikan was a verified commercial technology for the treatment of source-separated BMSW and it is sold and operated at market conditions. In Aikan, 1 tonne of source-separated BMSW is converted to 80 Nm^3 of biogas with a methane content of 70 %. Traditionally, biogas as an energy source has several benefits. In a combined power and heating generation the electricity efficiency rate reaches 40 % against 25 % upon incineration. If the biogas is upgraded to natural biogas, which would be evident due to the high rate of methane, the entire energy potential can be utilised. In the incineration of the same amount of waste less than half of this energy potential is utilised. The natural biogas can be used for vehicle engines or in other ways similar to conventional natural gas.

With the development of the Aikan Agri technology the far more common centralised biogas plants can also be used for the treatment of waste. This will be a cost-effective way of expanding the treatment capacity for BMSW, food waste from grocery stores and catering kitchen waste, and it will harvest the synergy with slurry-based facilities.

3. Materials and methods

3.1 Starting point – the Aikan plant in Holbæk, Denmark

The Aikan plant in Holbæk has treated source-separated BMSW since 2003 (see also; MST 2005). At the start of this project the Aikan plant consisted altogether of 10 process modules with biofilters, 2 reactor tanks, 1 biogas engine, 1 flare stack as a backup, actively ventilated maturation modules, and a reception hall for waste. In 2010 the plant was upgraded with further test facilities in view of developing the process further. This was done to allow for full test operation, also when the treatment capacity as such was fully utilised. At the start of this project, therefore, the plant had two test plants:

1. Pilot plant with 2 PM of 2 m^3 and 2 RT of 1 m^3
2. Full-scale plant with 2 PM of 600 m^3 and 1 RT of 500 m^3

In addition, laboratory facilities are found on the site. These fully closed systems were available for testing and development of the Aikan Agri system.

3.2 Expansion of test facilities

In connection with the project 2 insulated silos of 20 m^3 were established with the functions of digestion tank/biogas reactor and slurry pre-tank, respectively. The capacity of these silos is only for tests, however, the tanks are of such a volume that it would be possible to attain stable production. The plant was designed in a way that liquid could be pumped between all the different stages; see section 4.3.2.

Commented [JSK1]: Recieve(-) tank

3.3 Screening of pretreatment technologies

In the framework of this project it has evidently not been possible to test all the pretreatment equipment that may be used for source-separated BMSW and that is available on the market. Focus has been on finding equipment that would be relevant in terms of quality and price for small or large Aikan Agri plants and subsequently testing whether it would actually give the desired result. The procedure of the screening for equipment was a review of available Danish reports on pretreatment of BMSW in order to find inspiration for new methods (AFAV 2005, MST 2005). Information materials were collected with specifications from different machinery suppliers of relevance to this field and finally to enter a more detailed dialogue on the final installation.
In the selection, attention was given to the principles of the pretreatment by preparing terms of reference for the equipment; see section 4.2.1.

3.4 Test of pretreatment methods

The following equipment was used: Doppstadt DW 3060 shredder, Peecon Biga Industrial feed mixer powered by a Valtra tractor, a 80 mm stationary trommel screen (Doppstadt 518), 10 mm trommel screen (Terra Select T6) and a windsifter (KompTech Hurrikan) equipped with a magnetic separator. This equipment was tested at BioVækst in full operation with 100-200 tonnes of waste, which was pretreated for the biogas process and separated for the composting process.

The following machinery solutions were tested with separation of source-separated BMSW containing more than 15 % of impurities: BMSW was opened with the shredder or the feed mixer, sorted with a 80 mm screen and mixed with structural materials in the feed mixer; the mixer then conveyed the mixture to the process modules; see Figure 2 and Figure 3.

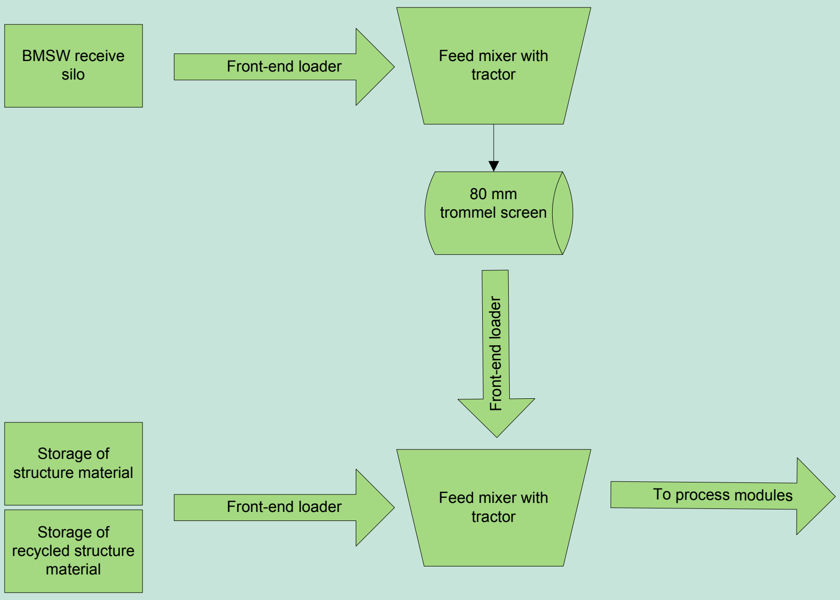

FIGURE 2
PRETREATMENT WITH FEED MIXER AND SEPARATION

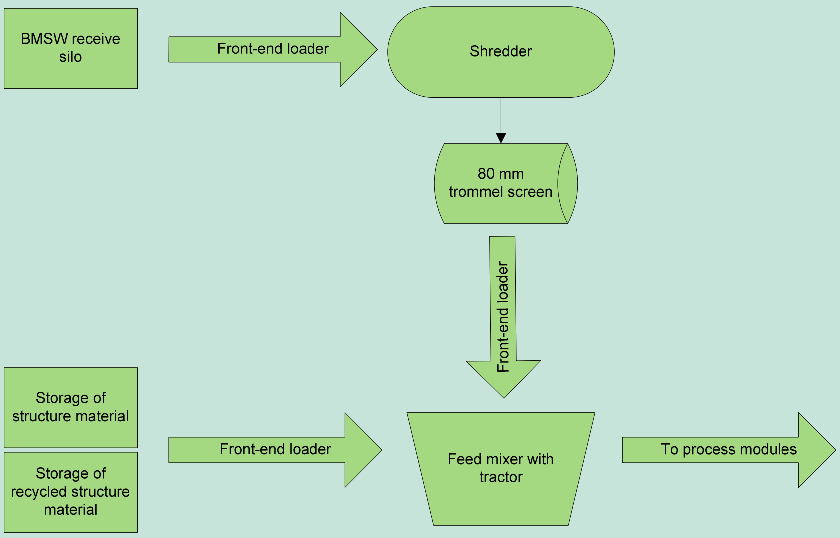

FIGURE 3
PRETREATMENT WITH SHREDDER AND SEPARATION

A front-end loader is used to feed the feed mixer and shredder. The reason is, partly, that the feed mixer and the shredder are mobile and, partly, that waste must be treated in batches. The advantage of this approach is that the order of the different treatment stages can be changed.

Source-separated BMSW containing less than 15 % of impurities was not subjected to preseparation. The bags were opened with a feed mixer/shredder and BMSW was mixed with structural materials in the feed mixer; see Figure 4 and Figure 5.

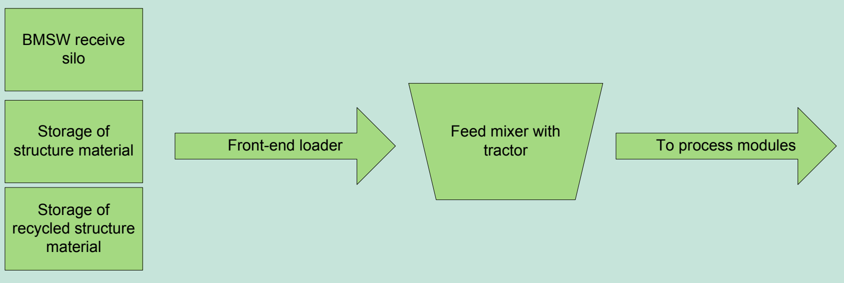

FIGURE 4
PRETREATMENT WITH FEED MIXER WITHOUT SEPARATION

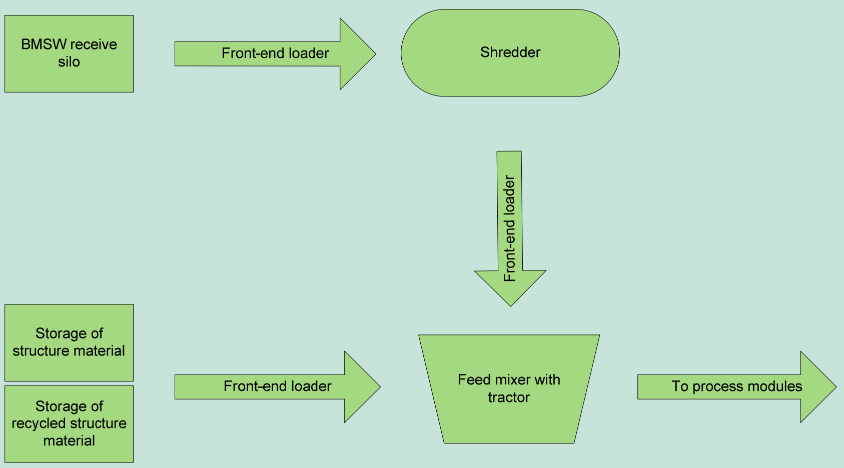

FIGURE 5
PRETREATMENT WITH SHREDDER WITHOUT SEPARATION

After digestion, composting and maturation the compost was screened in a trommel screen, regardless of the pretreatment (10 mm square-mesh).

For each batch and machine set-up samples were taken of the BMSW after the pretreatment stage and of the compost after screening. Also, the biogas yield was measured for each batch. The results can be seen in section 4.2.6.

3.5 Aikan Agri concept development

The Aikan Agri concept development comprised process design, yield measurements, quality measurements, preparation of technical documentation and brochures. The integration between Aikan and a conceptual, traditional centralised biogas plant for liquid waste/slurry was studied by setting up and testing the options in different combinations of the different components decisive for the flow of solid and liquid mass through the plant. Based on practical experience with the mass flow and test of various technical details the most promising concept was selected for the further process

design (see section 4.3.2). Based on test runs and results the requirements for the different components were specified and process and instrumentation diagrams (P&I) and functional descriptions were prepared or modified based on existing material. Two conceptual design options were prepared for green-field centralised biogas plant sizes for slurry/BMSW of 100/20 and 300/50 (x1000 tonnes), respectively. In many concrete scenarios a large number of components will already be found at the centralised biogas plant.
For the green-field plants the operating economy was calculated based on the results relating to energy yield and compost quality as well as the assumptions regarding framework conditions; see section 4.5. No operating economy was calculated in relation to extension of an existing plant, as in this case a generic model will rarely be relevant.

3.6 Determination of methane potential and yield

The methane potential was found in desk studies and own laboratory studies using a BioProcess Control AMPTS system (Automatic Methane Potential Test System), which measures methane development over time in reactor bottles. Furthermore, total solids (TS) and volatile solids (VS) were measured using standard methods (105 °C; 550 °C). For the representative sampling of solid waste several methods were tested. The challenge relating to sampling of source-separated BMSW is that since this material is very heterogeneous, samples must be large and be ground. Grinding is difficult due to the mixed nature of the materials. The method that was finally used was a cup drill capable of drilling through a waste profile consisting of both food waste and impurities. By sampling in different locations in the waste mass a representative sample can be taken. The samples were blended and shredded. Then TS was determined (105 °C for 24 hours), after which the then dry samples were ground. From these total solids samples, samples for the methane yield determination were taken and analysed in pursuance of the test description for BioProcess Control AMPTS.

The concrete biogas yield under operating conditions was determined in full-scale production in process modules and reactors. The rate of methane and the biogas generation were determined per tonne of treated BMSW and slurry, respectively, and the total yield was then determined. The production batches were made with around 100 tonnes of BMSW and around 10 m^3 of cattle slurry per batch. Conditions prevailing in a conventional plant will be reverse. Often there will be ten times more slurry than BMSW, but since the reactor is fed separately the biogas yield will merely reflect the composition on the input.

3.7 Compost quality – nutrients and impurities

The compost from each batch was passed through a 10 mm mesh screen. Each batch was treated separately, allowing for calculation of mass flow. Sampling was done by a third-party laboratory according to the specified method with a number of sub-samples mixed into a final sample. The compost was analysed for nutrients, heavy metals, xenobiotic substances, visible impurities, stability and hygiene – cf. the provisions of the Danish statutory order on sludge and standardised product sheet for compost (MST 1999 -2). Samples were also taken of the slurry used. This slurry was analysed for nutrients, but not hygiene etc.

3.8 Sanitisation of compost and leachate

Cf. the Statutory Order no. 1650 of 13 December 2006 on the use of waste for agricultural purposes (the Statutory Order on sludge) (MST2010) source-separated BMSW must be sanitised at 70 °C for an hour to attain the widest possible application. Alternatively, controlled composting at 55 °C for two weeks can be used - however with the restriction that “at farms with cloven-hoofed animals spreading and application of compost must be completed before seeding”. In Aikan Agri we have aimed at subjecting the compost to a temperature of 70 °C for 1 hour. First, we worked with sanitisation of liquid that is sent from the process modules to the reactor tank; however, in the energy balance calculation we saw that it is more rational to sanitise BMSW before starting the biogas generation.

In view of verifying the composting process temperature loggers were placed evenly in the compost mass, in both sides, bottom, centre, and at the surface. Temperatures were also measured during maturation in the open maturation boxes with active aeration. This was done as these boxes in a new Aikan Agri plant will be covered and thereby make up a secondary sanitisation stage. For leachate from the process modules energy calculations were made that subsequently formed the basis for the design of the sanitisation unit. The Aikan plant has a well-working external heat exchanger that maintains the temperature in the reactor tank. The sanitisation unit was designed in a way that the same heat exchanger can still be used as the primary source of heating. The project budget did not allow for the establishment of the sanitisation unit, and at that time the Aikan plant in Holbæk did not produce liquid fertilisers, and therefore such a unit would be superfluous. The energy calculation showed that the location of the sanitisation unit had to be different than what was initially planned.

4. Results and technology development

4.1 Conventional centralised biogas plant for slurry and Aikan plant for source-separated biodegradable municipal waste (BMSW)

Conventional centralised biogas plants are different in their design and function, but generally they all have a number of components with specific functions in common.
Slurry and other wastes are unloaded in one or more reception tanks. At some plants the mass is conveyed for mixing in a pre-tank while at other plants it is fed directly into the reactor from the reception tank. Some plants also have a sanitisation tank in which the mass is heated before being fed into the reactor tank. At other plants the sanitisation takes place in the reactor. There may be several consecutive reactors of which the last is called the digestion tank. From the digestion tank the now digested liquid is pumped to one or more storage tanks before being spread onto the land. A separation unit may be found before or after the digestion. The purpose of such separation unit is to separate solid and liquid fertiliser so as to facilitate transportation of the solid part and in some cases to improve pumpability. Most often, the biogas is led to a gas storage; H_2S may be removed in a gas scrubber or, in the case of low concentrations of H_2S, by adding a small quantity of oxygen in the reactor. Conventional plants treating source-separated biodegradable municipal waste have a pretreatment stage separating plastic bags, metal, paper and other impurities. Robust solutions are called for; the challenge of attaining total separation is that much organic material generally sticks to the segregated part of the material, so it does not enter the biogas generation stage.

The Aikan technology consists of a simple and robust mechanical pretreatment stage where only the largest impurities are segregated with a trommel screen at the start of the process. The pretreated waste is mixed with structural materials in the form of garden and park clippings in a feed mixer. After that the waste is placed in so-called process modules. The liquid from the reactor tank is used to “wash” the waste in the process modules. From the process modules the drained-off liquid is conveyed to a conventional reactor tank that is used for slurry, wastewater and other liquid input streams. After digestion the same process modules are used to compost the solid residues from the waste by sucking air through the mass. The air from this composting process is led through a biofilter with temperature control consisting of a spraying system for the in and outgoing air. After treatment in the process modules the solid, fresh compost is led to maturation boxes for storage. When the compost is ready for sale it is again separated in a trommel screen with a magnetic separator and a windsifter. In this way the remaining small-size impurities are removed (glass, metal, etc.), and the windsifter removes plastics from the coarse fraction; this coarse fraction is reused as structural material.

4.2 Mechanical pre and posttreatment of BMSW

Organic food waste from households (BMSW), supermarkets and catering kitchens etc. always contains non biodegradable impurities of plastic, glass, metal etc. The amount of impurities varies much depending on the sorting ability at the different sources. At energy recovery plants with recirculation a segregation of these impurities must take place in order that the compost or liquid products based on the waste material can comply with current quality criteria; see MST 2010[1].

The pretreatment normally has several stages. Basically, these stages can be divided into dry and wet processes. The dry treatment stages are carried out in shredder, stamping press, screw press and various types of screens (trommel screen, star screen, vibrating screen) as well as ballistic separators, magnetic separators and windsifters. The wet treatment stages may be boiling under pressure, cold pulping, heating and addition of enzymes. It is a common feature of the wet stages that water is added to the waste, it is washed and then impurities and solid matter are filtered. The filtration of pulp from the wet stages may be done in a stamping press, screw press[2] and different types of screens. There are many combinations of pretreatment stages and many suppliers of the technical equipment. The purpose of this project was at the general level to look at the principles and make some technical choices based on these general principles.

4.2.1 Purpose and challenges in the Aikan Agri pretreatment

The purpose of the development of the pretreatment process was to improve the share of organic material that is treated biologically; the purpose was also to develop and test a farm-friendly pretreatment method for organic waste that makes it profitable for small centralised biogas plants using the Aikan Agri concept to receive and treat organic waste containing some impurities. The BMSW pretreatment serves several purposes. First of all, the collected bags must be opened to get access to the organic waste. Then it may be desirable to segregate waste types that are non biodegradable or harmful for the process; finally, it may be desirable to shred the waste to make it more accessible for the degrading microorganisms. The Aikan concept basically keeps dry and wet waste separate. The first principle of the pretreatment was therefore that no water was to be added. From a visual and practical point of view is it easier to segregate impurities when they are not shredded and homogenised with the other waste. Therefore, the second principle was that the pretreatment is as delicate as possible in order to preserve the nature of the different impurities before segregation. The third principle was that the pretreatment is flexible in relation to different waste compositions. The fourth and last principle was that the pretreatment technology is robust and easy to repair or replace in order to minimise downtime.

4.2.2 Waste quality and pretreatment needs

Many years of operational experience at Biovækst have shown that the quality of waste varies from less than 5 % of impurities to 35 % of impurities (fresh weight); it was known which sources delivered clean waste and which sources had more impurities. The same situation of varying waste qualities will be the case in most plants. The objective is to produce as much biogas and quality compost as possible from the waste regardless of its quality. There will always be a loss of material during the pretreatment process, since organic material sticks to the segregated impurities. By contrast, it may be difficult to sufficiently segregate large amounts of impurities in the last stages, unless it is done in several steps; in addition, large quantities of plastics that go through a complete biological process give a risk of release of unacceptable levels of xenobiotic substances even if the biogas and composting processes do degrade these substances. It should be mentioned that the composting process is better at degrading xenobiotic substances than the biogas process (MST 2002, MST 1999 and Rambøll 2008).
Therefore, waste with few impurities should be treated differently than waste with many impurities. In other words, a requirement for the pretreatment technique is that it must be easily refitted. This is achieved since it is possible to shift between different components.

4.2.3 Bag openers

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[1] The quality criteria for compost and solid and liquid fertilisers are decided in national and European legislation as well as industry standards.
[2] Filter belt presses, which are used for the dewatering of sewage sludge, cannot be used due to the amount of impurities. Filter belt presses are intended for fine particles.

When BMSW is collected from households it is almost always bagged. The bags must always be opened to make the waste ready for the biological decomposition. The bags may be biodegradable, based on paper or cornstarch or similar, or they may be of plastic. Some bag opener systems are sensitive to the type of bags; biodegradable cornstarch bags may get tangled up in the knives, but that was not the case for the equipment used in Aikan Agri. Bags may be opened with knives, beaters or rollers that may be fitted with or without the possibility of adjusting backstops. Beaters are not suitable since those beaters that are fitted onto fast shredders such as the Doppstadts AK series (www.doppstadt.com) or KompTech Axtor (www.komptech.com) will shred glass and plastics etc. in a way that impedes its subsequent segregation. Knives and rollers are found on slow shredders of the types Terminator from KompTech or the Doppstadts DW series.

Picture 1: Roller with knives and backstop Doppstadt 3060

The principle is that the knives are mounted on the roller that rolls slowly. The knives drag the waste through the backstop of the roller, see picture 1.

This bag opening method does not cut the bags or the waste in small pieces. Glass is crushed, but not in small pieces.

In this project the waste bags were opened with two different methods: the above-mentioned slow shredder, Doppstadt DW 3060 and a method only with knives and no backstop.

Knives without backstop may be mounted on screws or rollers. Or on a number of small shafts that mutually work as backstop (see picture 2).

In this project we used a Peecon Biga Industrial feed mixer with knives mounted on perpendicular rotating cones (see picture 3). This is a batch method: the mixing vessel is filled and emptied before the next batch is fed. The intensity of the treatment depends on the retention time of the waste in the mixing vessel.

Picture 2: Counterrotating knives working mutually as backstop (www.transdynamics.ca)

Picture 3: Mixing cones with knives, Peecon Biga Industrial

The advantage of the feed mixer is that it is gentler with glass items. Thereby, glass is easier to segregate but the capacity of the feed mixer was smaller than the capacity of the slow shredder. The feed mixer is already used at Aikan for mixing and feeding of the process modules, so it is a good option for use at small centralised biogas plant. The energy consumption per tonne is in the shredder solution the double of the feed mixer solution - this may also be a reason for selecting the feed mixer solution at small plants.

4.2.4 Pre and postseparation

In this project the preseparation was very simple: it consisted of a fixed trommel screen (Doppstadt 518) with a 80 mm round mesh and a total screen area of 22.5 m^2. The trommel speed was at 12 rpm. Mobile sorting facilities were not chosen; BMSW is very aggressive and experience shows that the conveyor belts become brittle very quickly.

Star screens and vibrating screens are not suitable for wet materials such as BMSW. The capacity of star screens for dry materials is high, but the mesh is clogged with wet, mixed materials such as BMSW because the bags are tangled up in the stars.

Postseparation of the finished compost was done with a Terra Select T6 mobile trommel screen mounted with a 10 mm mesh with a total screen area of 33 m^2. The trommel speed was not stated by the supplier.

The screening residue was treated with a windsifter KompTech Hurrikan mounted with a magnetic separator.

4.2.5 Mixing and feeding

BMSW was mixed with structural material consisting of shredded branches and recycled structural material from previous batches in a 10:2:3 ratio by weight. Weighing and mixing was done in the feed mixer which is mounted with weighing cells. The feed mixer backs into the process module where the mixture is unloaded with the back-end conveyor belt (see picture 4).

Picture 4 Feeding of waste in process module

Experience has shown that it is important for the process that waste is not compacted during feeding. This happens, for instance, if a front-end loader is used. Compact waste hampers the percolation of liquid and the suction of air.

4.2.6 Effect of pretreatment on biogas yield

At the reception at the Aikan plant BMSW is generally placed in (plastic) bags. To secure the largest possible exposure of the organic fraction in the hydrolysis the waste is shredded and preseparated. This is described above in section 3.4.

The purpose of shredding is to open the bags and - together with the subsequent segregation of, for instance, large items of plastics etc. - to secure efficient percolation and washing out of organic material to the reactor tank. But inevitably the segregation also removes some organic matter with the segregated materials (rejects) since it sticks to this reject.

The purpose of this test series was to demonstrate the effect of shredding and to study whether a higher gas generation is possible if no segregation is carried out. Therefore, a series of tests were made of the effect of different pretreatment options on the biogas generation. The combinations are illustrated in Table 1.

TABLE 1
OUTLINE OF WASTE QUALITY AND THE DIFFERENT PRETREATMENT OPTIONS USED PRIOR TO DETERMINATION OF GAS YIELD IN THE PROCESS MODULE.

Treatment	Impurities	Shredding (shredder)	Preseparation (trommel screen, 80 mm)	Mixture with structure chips (feed mixer)
1	> 15 %	x	X	x
2	< 15 %	x		x
3 & 4	< 15 %			x

The treated waste was then digested in the process module and the generation of biogas and methane was measured. The gas yield per tonne of unseparated waste from the different treatment options is shown in Figure 6. The finished compost from all treatment options was subsequently sorted in a 80 mm mesh trommel screen and a windsifter with magnetic separator. The compost quality is discussed in section 4.3.5.

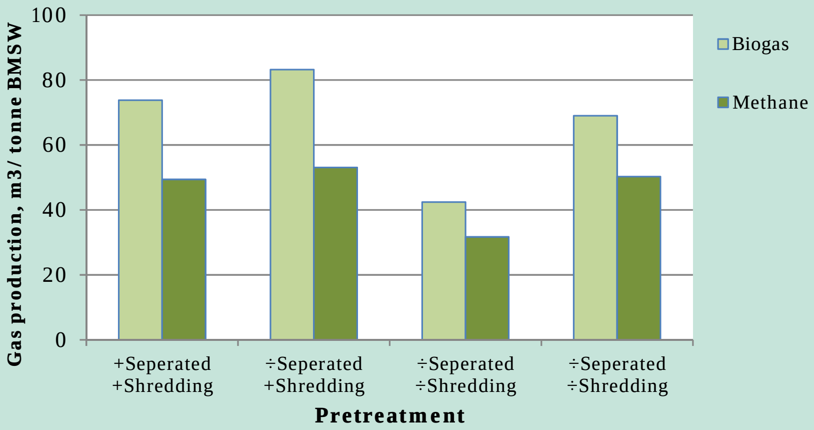


FIGURE 6
YIELD OF BIOGAS AND METHANE FROM THE DIFFERENT COMBINATIONS OF PRETREATMENT OF BMSW: SEPARATED/NON-SEPARATED AND SHREDDED/NON-SHREDDED. IN ALL PRETREATMENT OPTIONS BMSW IS MIXED WITH STRUCTURAL MATERIALS BEFORE BEING FED TO THE PROCESS MODULE.

Figure 6 shows that there tends to be a positive effect of shredding in the form of yield per tonne of BMSW since the treatment options 1 and 2, which include shredding, give higher yields than treatment options 3 and 4 without shredding. However, there is no unambiguous effect of reject segregation, since treatment option 1 with separation is poorer and better than treatment options 2 and 3 without separation, respectively.

The share of the total biogas potential of the waste removed in the reject was quantified in laboratory tests. Representative samples of a batch of unseparated BMSW with a reject content of approximately 20 % were taken with cup drill and digested in the Aikan gas laboratory. The results showed that the biogas potential in the decomposable organic matter on the reject makes up around 12 % of the total biogas potential in the unseparated BMSW.

4.3 Aikan Agri technology

The Aikan Agri technology is based on connecting relatively well-known components in a new process design. The technical solutions are thereby flexible for adaptation within the framework of the process. Energy yields and compost quality reflect the chosen feedstock (BMSW, solid and liquid fertiliser etc.). Sanitisation is based on the demonstration of the temperature impact, but for the solid masses it will largely also be supported by microbial competition and antagonism. The operating economy is affected by a number of key parameters that relate, partly, to feedstock and, partly, to market and/or political issues; therefore, the construction calculations have been made scalable and flexible - in this report two variants of a plant are discussed.

4.3.1 Purpose and challenges in development of technology

The aim of the development of the Aikan Agri technology was to arrive at a competitive solution with regard to environmental technology for combined treatment of the cities' organic waste and agricultural biomass in the form of manure or crop residues. The technological challenge consisted in controlling and optimising the gas generation in a two-stage process and in ensuring that impurities were segregated and the waste was sanitised. At the same time it was important to keep investment needs low and to secure a good operating economy through the choice of robust techniques.

4.3.2 Process design

In the traditional model of Aikan digested liquid percolates from the reactor tank through the solid waste to enriching the liquid with readily decomposable hydrolysed organic material. This is a closed circuit in liquid balance since the liquid removed in compost is replaced with surplus liquid in incoming BMSW. In a traditional wet biogas plant slurry is pumped into the reactor and largely the same quantity is removed as fertiliser liquid after digestion. Thus, there is a continuous flow of liquid through the plant.

In our work we studied the following possibilities of exploiting the advantage of keeping hydrolysis and methane production separate:

1. Pumping slurry over the solid waste in order to retain fibres contained in the slurry here, if possible
2. Using liquid from the primary slurry reactor for washing
3. Using digested slurry for washing

The idea of pumping slurry over the process module turned out to be very demanding for nozzle system and pumps. Even if the model was tested with a coarse filter and a self-cleaning return flow filter on the watering system nozzles with a diameter up to as much as Ø11 mm were clogged after a short while. Also, the slurry tended to form a layer of relatively low permeability on top of the waste. Against this background work with option 1 was discontinued.

Digested liquid from the reactor at the conventional biogas plant, all other things being equal, is less decomposed than digested slurry from the digestion tank. Table 2 in section 4.3.3 shows the ranges in TS and VS from various materials. The advantage of using digested slurry from the reactor tank would still be to transfer some of the solid organic matter to the compost in the process module. However, the same challenge as in the direct pumping of slurry - the need for different dimensions of the nozzles - was also seen here. It was assessed that the advantage of filtration of dry matter did not balance the fact that the remaining potential in the liquid would have to “start from scratch” in the system. Therefore, option 2 was discontinued.

Digested slurry has the lowest TS content and at any plant it is expected to be the best digested liquid. Therefore, model 3 was selected as the final test solution. Since digested slurry also has a certain content of solid material (fibres) it was decided to include a coarse separation of the liquid before percolation. The fibres from the separation are mixed with the solid input materials in the process modules. The flow model is shown in Figure 6 below:

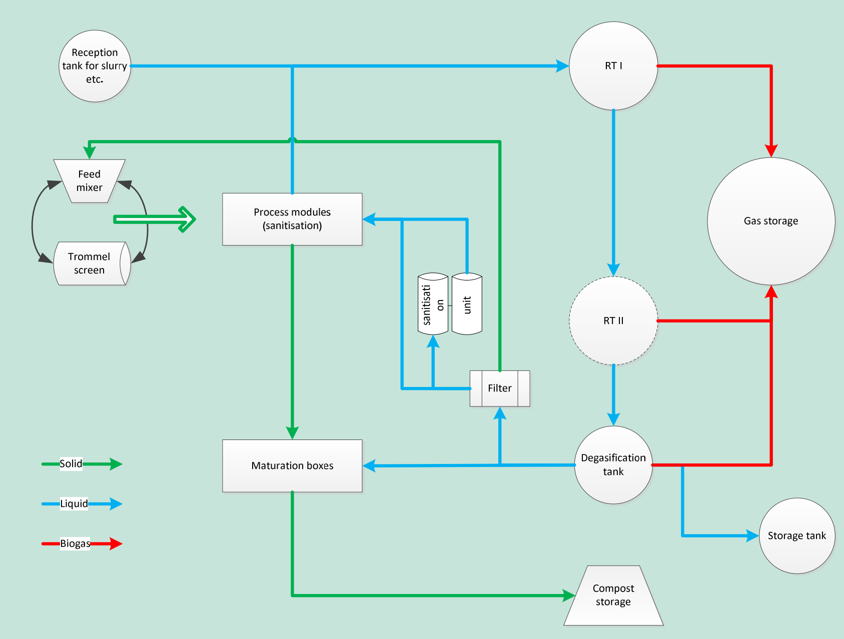


FIGURE 7:
AIKAN AGRI PROCESS DESIGN (TEST MODEL 3)

The chosen model has several advantages. The flow of liquid from the digestion tank to the process modules is exclusively determined by the need for washing out hydrolysed leachate from the solid waste. In addition, digested slurry is sprinkled over the mature compost; liquid evaporates and nutrients pass from liquid to solid form. The traditional handling of volumes at a centralised biogas plant can run in parallel to taking out a minor part for percolation of the solid waste. This ensures that the ratio between solid and liquid raw materials is not decisive for the process. In this way the treatment system for solid and liquid raw materials can be expanded successively without losing the advantage of combining the solid and the liquid system. This is an extremely important precondition since most plants are expanded successively and the supply of raw materials fluctuates.

With the current rules liquid and compost from food waste must be sanitised at 70 °C for an hour in order to be used without restrictions of hygienic nature. Slurry and other agricultural raw materials must not be sanitised.

At the start of the process, therefore, the sanitisation unit is used to heat BMSW to 70 °C for an hour. When this sanitisation has been carried out BMSW can be treated together with slurry without any considerations for hygiene. The compost can still be sanitised through subsequent composting, but it is not a statutory requirement.

4.3.3 Gas potentials and yield

For the assessment of the Aikan Agri concept the methane potential contained in BMSW and different types of slurry and deep litter was determined in the Aikan gas laboratory with the BioProcess Control automatic methane potential test system (AMPTS) according to the standard procedure (see www.bioprocesscontrol.com).

The results of the surveys are shown in table 2 together with results of corresponding surveys from elsewhere.

TABLE 2
CHARACTERISTICS AND METHANE POTENTIAL FOR SELECTED SUBSTRATES FROM AGRICULTURE AND SOURCE-SEPARATED BIODEGRADABLE MUNICIPAL WASTE (BMSW). THE POTENTIALS ARE RESULTS FROM SURVEYS MADE IN THE AIKAN LABORATORY IN 2012, COMPARED WITH RESULTS FROM SIMILAR SUBSTRATES FOUND IN OTHER SURVEYS. FOR AIKAN THE FOLLOWING ARE ALSO STATED TS: TOTAL SOLIDS (% OF FRESH WEIGHT) AND VS: ORGANIC SOLIDS (% OF TS).

	Aikan			Others
Substrate	**TS, %**	**VS, %**	**Methane potential, in CH_4/kg VS**	**Methane potential, in CH_4/kg VS**
Cattle slurry	6 - 8	77 - 81	110 - 240	120[a] 210 - 260[b]
Swine slurry (fibres)	16	70	130	110[a] 220 - 330[b]
Deep litter	27	89	135	260[b]
BMSW (leachate)	8 - 9	69 - 75	180 - 420	550[c] 400[d]

[a] https://www.landbrugsinfo.dk/Planteavl/Plantekongres/Sider/pl_plk_2013_resume_45-1_Karen_Joergensen.pdf?download=true

[b] http://www.biopress.dk/PDF/FiB%20nr.%2034-2010_04%20-%20DK.pdf

[c] Rohold, Lars, 1995, "Optimering af biogasanlæg", *(Optimisation of biogas plants)*, Examination project carried out at the Nordsjælland biogas plant, Technical University of Denmark, 1995.

[d] Hartmann, Hinrich, Angelidaki, Irini og Ahring, Birgitte K. 2001 "Anaerob nedbrydning af organisk husholdningsaffald sammen med gylle, Del 1", (*Anaerobic decomposition of organic household waste with slurry, Part 1*) Biocentrum-DTU, January 2001.

It is seen that the yield variation within the different types of substrate is large, but all Aikan values are relatively comparable with the results from other surveys.

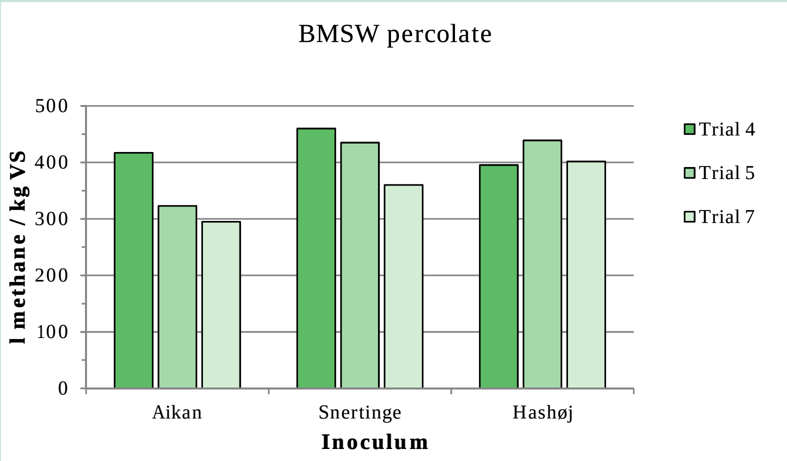
4.3.4 Effect of inoculum on gas yield from BMSW and slurry

In the laboratory it was also studied whether there was an effect of inoculum on the gas yield from various substrates, since it is to be expected that the microbial ecosystem in inoculum adapts to the substrate (slurry, BMSW).

The *substrate* used was cattle slurry from a nearby farm and leachate from the Aikan process module 11 (PM11).

The *inoculum* used was digested slurry from a thermophilic process supplied by the energy company of Snertinge, Særslev and Føllenslev and reactor tank liquid (mesophilic process) from the biogas plant of Hashøj (in the following called Snertinge and Hashøj, respectively). In addition, BMSW leachate from the Aikan reactor tank 1 was used (RT01).

8A



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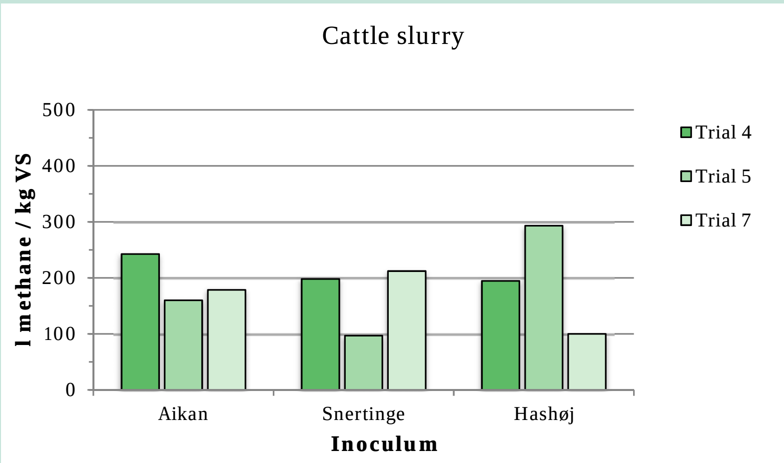


FIGURE 8
THE EFFECT OF INOCULUM ON THE METHANE YIELD FROM BMSW LEACHATE FROM AIKAN PROCESS MODULE (8A) AND CATTLE SLURRY (8B) MEASURED IN THREE TESTS. THE SUBSTRATES HAVE DIGESTED FOR 30 DAYS IN THREE DIFFERENT TYPES OF INOCULUM: 1) LEACHATE FROM AIKAN REACTOR TANK (RT01), 2) DIGESTED SLURRY (SNERTINGE) AND 3) LIQUID FROM REACTOR TANKS (HASHØJ). THE VALUES ARE NET METHANE YIELDS OF SUBSTRATES.

The methane yield from BMSW leachate is, as expected, higher than the yield from cattle slurry (difference between 8A and 8B), but there does not seem to be any effect of the inoculum type on the gas yield from the two substrates (variation between the three types both in Figure 8A and Figure 8B).

In addition, the effect of the inoculum type on the gas production velocity was also studied. The results showed a relatively large variation in the initial velocity between inoculum types, but the advantage is in some cases to the benefit of one type of inoculum and in other cases to the benefit of the other type. Thus, the results did not show an advantage of one specific type of inoculum.

4.3.5 Compost and nutrients

Compost based on BMSW has been produced at Aikan since 2004; every year at least five samples have been analysed. The compost has changed over time along with the further development of Aikan, but today it is well documented and the variation is well-known. The content of nutrients in slurry varies relatively much. Fertilisers based on a mixture and processing of slurry and BMSW, all other things being equal, give a more uniform product. Average values for NPK contents in different types of fertiliser and Aikan Agri compost are shown in Table 1.

TABLE 3
CONTENTS OF NUTRIENTS IN SLURRY (CATTLE AND SWINE), DIGESTED SLURRY, AIKAN BMSW COMPOST AND AIKAN AGRI COMPOST

Products	Total solids (TS)	Nitrogen (Total N)	Ammonium (NH4-N)	Phosphorus (P)	Potassium (K)
	% of fresh weight (FW)	kg/tonne FW	kg/tonne FW	kg/tonne FW	kg/tonne FW
Cattle slurry	5 - 9	2.8 - 4-2	1.6 -2.6	0.8	2.5 -3.5
Swine slurry	4 -7	2.9 - 5.5	1 - 5.5	1	2
Digested slurry (mixed)	3 - 6	3 -7	0.6 -7	0.9	2.8
Aikan BMSW compost	56 -65	12.7 -16.5	0.4 -2.2	4.1 - 5.3	5.9 -6.9
Aikan Agri compost	58 -66	15 -16	1.3 -3.4	4.3-9.8	5.7 - 7.4

The results show that the compost is a very transport-friendly fertiliser due to the large total solids content. It is not surprising that plant-accessible nitrogen in the form of ammonium is high in the slurry and that the Aikan Agri compost also has a higher ammonium content than ordinary BMSW compost. Nitrate is almost not present in the compost.

The compost stability was analysed in view of storage stability and compost value as a fertiliser. There may be different reasons for choosing “fresh compost” or “very stable compost”. “Fresh compost” may have the advantage that the largest quantity of nutrients will be found in the compost when applied to land, but the continued biological process will bind nitrogen so it may be more difficult to predict the release of nutrients during use. “Very stable compost” is a product from which nutrients will be released at a slow rate. The organic matter will be stable and will contribute directly to an improvement of the soil structure on non-organic soil. By contrast, the composting process in itself will cause loss of nitrogen (FØJO 2000). The loss of nitrogen has been assessed; see section 4.4. Energy and mass flow as well as studies conducted by others show that the increase of humus in soil very much depends on the amount of organic matter added. It was not part of this project to determine the cultivation value of the compost, but the stability, which was measured in three methods (self-heating, respiration and Solvita Composttest Kit), was “very stable” cf. the methods described in MST 1999 – 2.

The share of visible impurities (glass, metal and plastics) was between 0.38 % and 1.7 % of TS. Most European standards recommend a limit of 0.5 % of TS analysed with the sieving method. There was no correlation between the pretreatment methods and the visible impurities. Primarily glass and secondarily plastics were too high in some samples. Since the compost is screened on a 10 mm screen it is important to avoid shredding below 10 mm. In previous surveys of visible impurities it has been seen that recycling of structural material has a significant impact. Thus, it was found that the recycled structural material must be sorted one more time on a 10 mm screen prior to recycling.

4.3.6 Hygiene results and design

Throughout the project it was decided to sanitise the waste in the process modules at 70 °C for an hour already before starting the biogas process. This is done by soaking the material with 75 °C hot leachate from a buffer tank. In the course of the project, however, a solution was tested in which the sanitisation takes place in the compost stage for the solid mass and continuously for leachate from the process modules. The results are presented here - the option of sanitising the compost is relevant, for instance, where material is treated that is not digested and that should therefore not be soaked.

The aim was that compost and liquid from BMSW was treated at 70 °C for at least one hour, since sanitised compost gives the most application options, cf. MST 2010. The temperature of the process modules is measured continuously by following the temperature of the process air sucked out of the compost mass and by measuring the temperature of leachate in the biogas stage. The temperature of the process air gives an indication whether the process runs satisfactorily, but the temperature is subject to some uncertainty as a documentation of hygiene since the temperature will be an average of the entire compost mass. In addition, the temperature only gives a true and fair picture when the fans are in operation; this is normally the case for one third of the process time. When the fans are not in operation the outdoor temperature or an average of the outdoor and indoor temperature is shown.
To measure the concrete temperatures in the mass eight temperature loggers were fitted. The locations were bottom, mid, top, front, mid, back; see Figure 7.

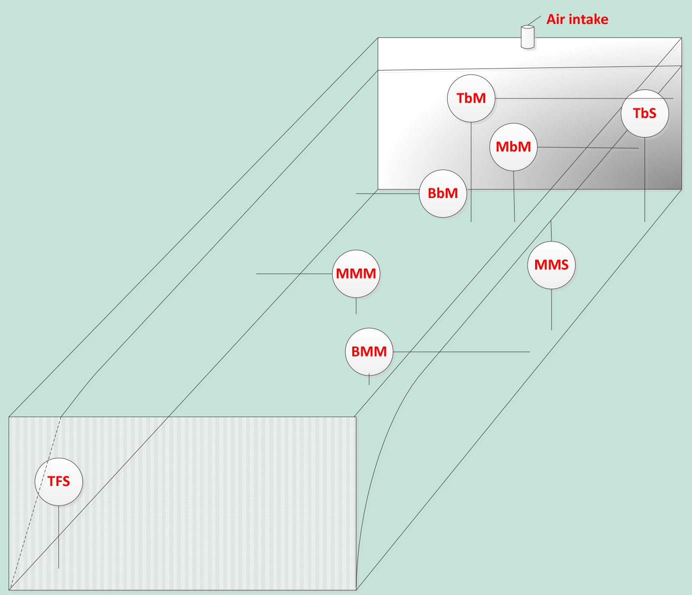


FIGURE 9
LOCATION OF TEMPERATURE LOGGERS (LEGEND REFERS TO HEIGHT/DEPTH/WIDTHS; T=TOP, M=MID, B=BOTTOM, F=FRONT, M=MID AND LOWER CASE B=BACK).

Temperature curves are shown in Figure 8.

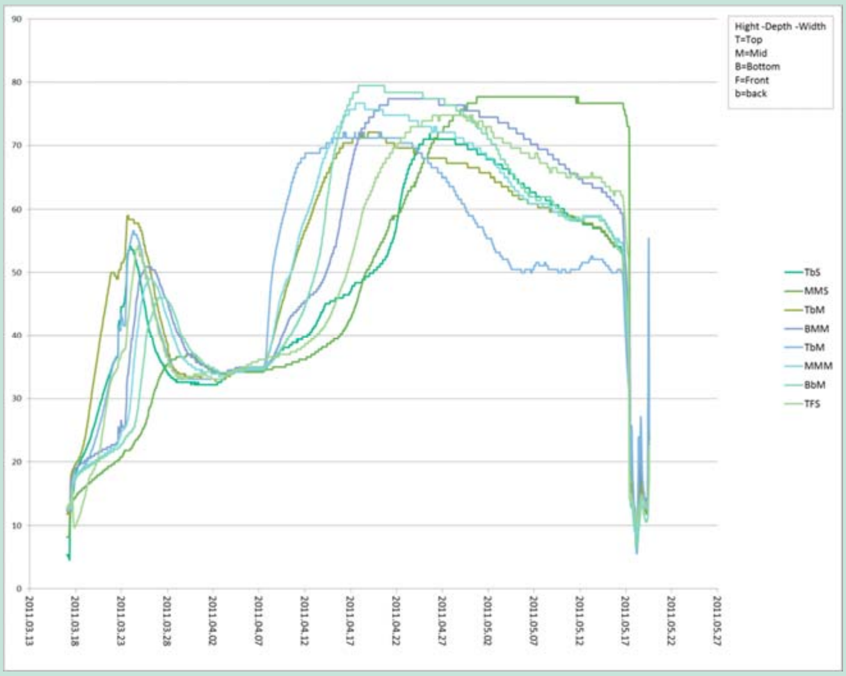


FIGURE 8
DEVELOPMENT OF TEMPERATURE IN THE COMPOST MASS FROM 13 MARCH TO 27 MAY.

The results show that it is not a problem to reach 70 °C for several hours/days in all locations. Several runs were made and it was seen that it is important to have an insulated process module and to avoid sucking in cold air during winter, since this will ruin the sanitisation of the surface.

When the compost is finished in the process modules, it is moved to the maturation boxes. In the maturation boxes the temperature easily reaches 70 °C in the compost mass, but not on the surface, which is open for climate impacts at Biovækst. These climate impacts also mean that during summer the compost dries out. It is not an advantage for the maturation that the temperature is high, since the decomposition is most efficient at between 45 °C and 55 °C. However, the boxes can be used as a security measure if the required temperature is not reached in the process module. At a new Aikan Agri the maturation boxes will be enclosed in order that the maturation takes place in a more controlled manner and independent from weather conditions.

From each process module around 50 m^3 of leachate is pumped to and from the module on a daily basis. When BMSW has been sanitised prior to the process this leachate can be used freely in the sanitary part of the plant. If this sanitisation is not carried out, the leachate would have to be sanitised prior to feed to the reactor tanks. The leachate has a temperature of between 30 and 40 °C. The leachate from the process module is pumped to an insulated tank. When this tank is full the leachate is kept at 70 °C for an hour in the tank before being fed to the reactor tank. The heat consumption for sanitisation replaces the heating that in any case takes place in the reactor tank, but the total heat consumption is still higher in this model. Heating is simple, using a heat exchanger

connected to a combination boiler and two sanitisation units (insulated tanks) that are used in batches.
The system is shown in Figure 7.

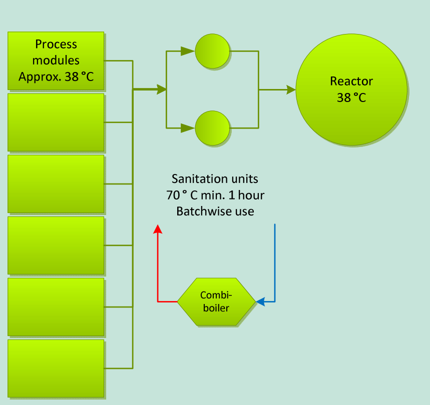


FIGURE 9
PRINCIPLE OF BATCHWISE SANITISATION

For microbial control of sanitisation it is easy to take samples from the tank, but the sanitisation takes place on liquid almost without any particles, so the sanitisation is considered to be very safe, since the rules of 70 °C for an hour apply to compost where the requirement says that the core of the particles must also reach 70 °C. It should be stressed that the reason for sanitisation of the liquid is only that the digested slurry is spread in liquid form. In the conventional Aikan plant fertiliser is not spread in liquid form.

4.4 Energy and mass flow

4.4.1 Mass balance

The energy balance and the rate of recycling have a large impact on the overall environmental performance and on the competitiveness of the plant. The plant is scalable and it is therefore not possible to set up a general energy and mass flow; however, a concrete plant based on 20,000 tonnes of BMSW and 100,000 tonnes of slurry of a mixed composition will be realistic in many contexts. Under normal circumstances there will also be other raw materials, but it is assumed that these materials are either similar in nature to BMSW (solid) or to slurry (liquid). To this should be added structural materials. Structural materials today are branches from gardens and parks. It could also be straw or other agricultural structural material, but these tests were made with shredded branches. Agricultural structural materials would contribute to a higher biogas yield. This is barely the case for branches.

An example of a mass balance is seen in Table 4. The mass balance is stated on the basis of in and outgoing quantities and analyses of them, and it is balanced in a way that there are no inexplicable losses. In practice, there will always be fluctuations, but it gives an indication of the basis for an Aikan Agri plant.

TABLE 4

GENERAL MASS BALANCE FOR AIKAN AGRI WITH 100,000 TONNES OF CATTLE SLURRY AND 20,000 TONNES OF BMSW (FRESH WEIGHT (FW), TOTAL SOLIDS (TS), VOLATILE ORGANIC TOTAL SOLIDS (VS).

Raw material	BMSW	Cattle slurry	Structural material	Unit
FW	20,000	100,000	4,000	Tonnes
TS	6,400	8,600	2,200	Tonnes
VS	5,840	3,800	990	Tonnes
				Tonnes
Total-N	180	400	24	Tonnes
Total-P	24	84	3	Tonnes
K	60	224	11	Tonnes

Recycled Products:	Aikan Agri compost	Digested slurry	Unit
FW	7,000	99,975	Tonnes
TS	3,850		Tonnes
VS	655	8,498	Tonnes
Total-N	108	399	Tonnes
Total-P	32	68	Tonnes
K	46	229	Tonnes
Methane		1,357	Tonnes

Outgoing from process				
		Unit		%
FW	15,668	Tonnes	12.6	% of total raw material
TS	3,495	Tonnes	20.3	% of total raw material
VS	5,899	Tonnes	55.5	% of total raw material
Total-N	97	Tonnes	16.1	% of total raw material
Total-P	11	Tonnes	9.6	% of total raw material

K	20	Tonnes	6.7	% of total raw material

Loss from the process is evaporation of water and loss in conversion to methane (CH_4) and carbon dioxide (CO_2). Nitrogen is lost in ammonia evaporation. The mass balance is subject to some measurement uncertainty, as it builds on analyses of in and outgoing materials. The loss of phosphorus, for example, cannot be explained in other ways than by measurement uncertainty since no evaporation of phosphorus is expected. After several runs, however, the mass balance will become increasingly precise.
But the mass balance does give an overall picture of expected yields, which is important for the overall profitability of the plant.

Commented [JSK2]: "lost through evaporation of amonia" ?

It should be noted that the loss of nutrients at the plant would be lower, if the compost is used before being mature, since a certain release takes place along with the decomposition of the material. Immature compost/digestate in the field may mean, however, that the loss merely takes place in the field instead of at the plant.

The methane yield is calculated as 10 m^3 per tonne of slurry and 60 m^3 per tonne of BMSW.
In the calculation model established for Aikan Agri (section 4.5), a mass balance is calculated with the given assumptions that are related more directly to the process at the plant. An example is shown in Figure 10 below. In this balance, the calculation uses 20,000 BMSW, but having 17 % of impurities, so it is a slightly different calculation than with an input of 20,000 tonnes. The below mass balance is balanced both for total fresh weight, organic and inorganic total solids, so that in and outbound masses are always in balance. This is done with respect for the analysis variation, since it will never be possible to have a balancing mass based on random sampling analyses. However, it has been ensured that there are no unrealistic inputs or outputs.

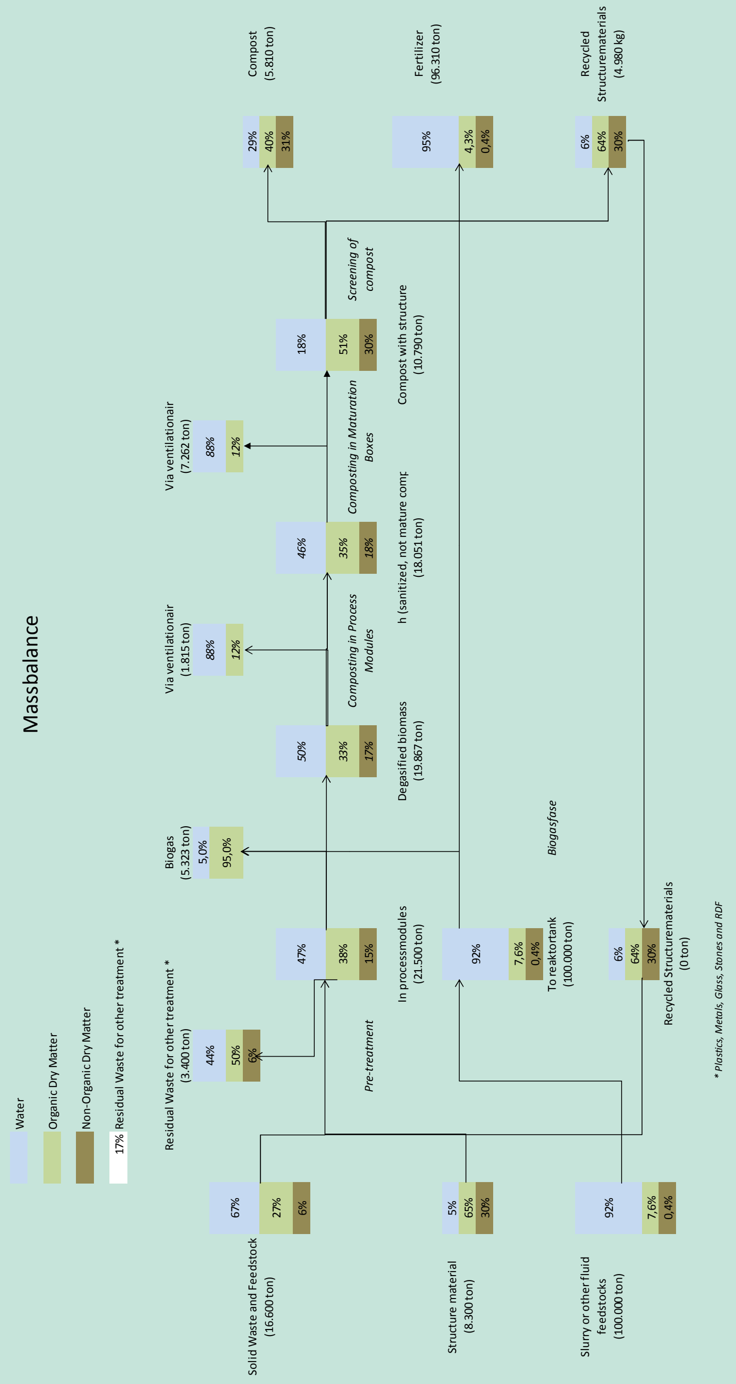


FIGURE 10

EXAMPLE OF MASS BALANCE CALCULATION FROM AIKAN AGRI CALCULATION MODEL. THE PERCENTAGES IN THE FIGURE REFER TO THE PROPORTION OF WATER, ORGANIC TOTAL SOLIDS AND INORGANIC TOTAL SOLIDS IN THE DIFFERENT FRACTIONS.

4.4.2 Energy balance

The energy consumption of the process consists of the following main sources:

- diesel for mobile equipment
- electricity for pumps, fans, motors, shredder etc.
- heat for sanitisation of leachate and heating of slurry

as well as transmission loss from pipes and heat loss from reactors and process modules.

A calculation of the total energy balance for an Aikan Agri plant based on 100,000 tonnes of cattle slurry and 20,000 tonnes of BMSW is shown in Table 5. In view of clarity the calculation uses combined power and heating generation, but it would also be possible to sell methane or biogas. The methane yield from cattle slurry and BMSW, respectively, is set at 10 m^3 and 60 m^3 of methane per tonne of fresh weight. The electricity efficiency rate is set conservatively at 35 % and the efficiency rate of the motor at 93 %.

TABLE 5
EXAMPLE OF ENERGY CALCULATION FOR AIKAN AGRI PLANT WITH BMSW SANITISATION
(THE LARGE ENERGY CONSUMPTION FOR BMSW IS EXPLAINED BY THE REQUIREMENT FOR SANITISATION OF THE MATERIAL IN CO-DIGESTION WITH SLURRY)

Energy balance - Aikan Agri for 20,000 tonnes of BMSW and 100,000 tonnes of slurry				
Production; MWh	Electricity	Heat	Diesel	Total
From slurry	3,500	5,800	0	9,300
From BMSW	4,200	6,960	0	11,160
Consumption; MWh	Electricity	Heat	Diesel	Total
Pretreatment	91	0	168	259
For slurry	115	77	0	186
For BMSW	141	1442	83	1,666
Transmission loss	0	502	0	502
Balance; MWh	7,270	10,746	-251	17,847
Own consumption	Electricity	Heat		Total incl. diesel
Total, plant	**5 %**	**16 %**		**13 %**
Slurry fraction	3 %	10 %		7 %
BMSW fraction	6 %	28 %		22 %

In the calculation the heat exchange is found between in and outbound slurry and heat exchange in the exhaust air from composting. The heat consumption for heating BMSW is significant, but it should be mentioned that it might be lower in a concrete plant; the calculation uses a relatively low average temperature of inbound BMSW and savings for heating of the reactor tank have not been taken into consideration. The electricity consumption for BMSW is larger than for slurry - this is due to the fact that shredder (and screens) for pretreatment are electric. The diesel consumption does not include transport to and from the plant. Only internal operation has been included. If leachate from BMSW were hydrolysed continuously the energy consumption for heating would be higher, since 120,000 tonnes of leachate will actually be heated annually. In the below calculation the heat consumption has been added to the slurry fraction, since it is here the liquid leachate flows (apart from inbound slurry) are heated.

TABLE 6
EXAMPLE OF ENERGY CALCULATION FOR AIKAN AGRI PLANT WITH LEACHATE SANITISATION
(THE LARGE ENERGY CONSUMPTION FOR BMSW IS EXPLAINED BY THE REQUIREMENT FOR SANITISATION)

Energy balance - Aikan Agri for 20,000 tonnes of BMSW and 100,000 tonnes of slurry

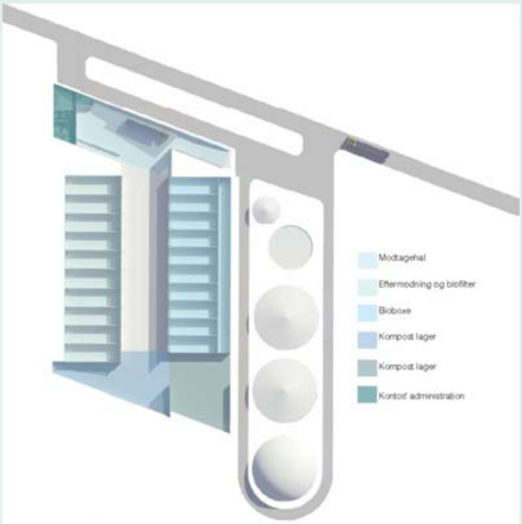
Production; MWh	Electricity	Heat	Diesel	Total
From slurry	3,500	5,800	0	9,300
From BMSW	4,200	6,960	0	11,160
Consumption; MWh	Electricity	Heat	Diesel	Total
Pretreatment	91	0	168	341
For slurry (and leach-ate)	115	4,823	0	4,939
For BMSW	141	70	83	294
Transmission loss	0	502	0	502
Balance; MWh	7,352	7,365	-251	14,467

Own consumption	Electricity	Heat	Total incl. diesel
Total, plant	**5 %**	**42 %**	**29 %**
Slurry fraction (and leachate)	3 %	92 %	58 %
BMSW fraction	6 %	8 %	9 %

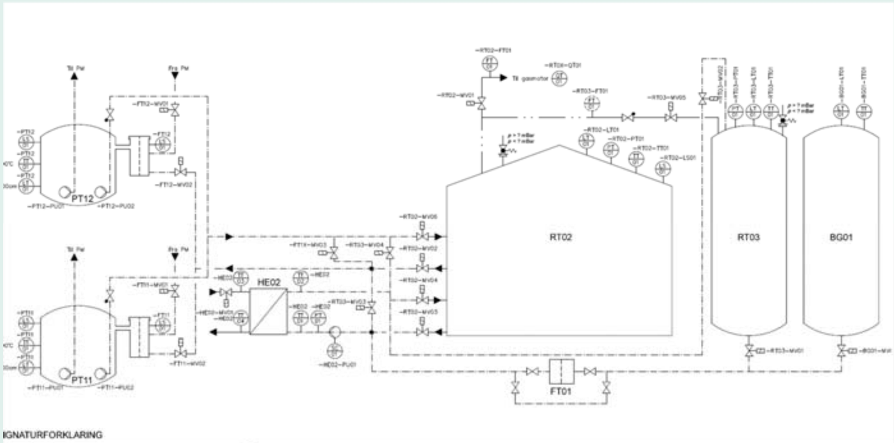
The above calculations depend somewhat on the efficiency of the concrete plant and the efficiency of heat exchangers and synergies in saved slurry heating etc. However, the trend is so clear that it is considered proven that sanitisation must take place prior to the process.

4.5 Aikan Agri – conceptual designs and operating economy

As mentioned, the aim was to combine the advantages relating to solid and liquid biogas generation and to adapt the Aikan Agri plant to the centralised biogas plant model for manure that is prevailing in Denmark. A standard model has been used as the basis for the conceptual design and operating economy calculations. It is the sequence of pumps, valves, throttles and measurement equipment controlled in the right manner that gives the operational advantage of Aikan Agri. This correlation can easily be adapted to a concrete biogas plant in connection with an extension. In practice, P&I diagrams and detailed design will always have to be adapted to existing components at a concrete plant. Construction drawings are in a similar manner prepared generically for the different elements (process modules, pipe ditches, reactor tanks etc.) and thus the combination can easily be adapted to the given situation. Below is shown an example of the design of an Aikan Agri plant at the energy company Thy Økoenergi; it is drawn by architects *Tankestreg* and consultants *Cowi* for the Danish Nature Agency and RealDania foundation.



Picture 5
Thy Økoenergi is an organic biomass plant that is being planned just outside the city of Thisted in Denmark; the plant will be based on solid biomass from agriculture supplemented with BMSW. The proposed design has been prepared by architects from Tankestreg in Thisted and Cowi.



Picture 6: P&I Diagram for a minor part of the Aikan Agri plant; it shows instrumentation for two process tanks connected with reactor tank, heat exchanger, reception silo and digester.

P&I diagrams and construction drawings are made with AutoCad. Parts lists with TAG numbering are ordinary word format. Manuals and functional descriptions are also in ordinary word format.

The different elements, components and procedures (for construction and operation) are entered into the Aikan calculation system containing investments and depreciations, operating costs and payback period. The system has been designed in a way that it gives easy access to specifying a concrete plant based on concrete requirements. The product of the system is a concrete calculation containing:

1. Mass balance; in respect of the concrete composition of raw materials
2. Technical outline; containing design, components, area and product yield
3. Financial and technical estimates; taking both CAPEX and OPEX into consideration
4. Revenues and expenses - forecast (10-year horizon)
5. Assumptions behind the calculation; concrete choices taken for the calculation
6. Construction costs (i.e. investment in plant); price of today's date of the plant based on detailed components

The model is comprehensive; it consists of 40 excel sheets with formulas and calculations, and it can produce estimates in several languages. Thus, the model contains a complete business model calculation for the plant, including operating expenses.
Two calculations based on the Aikan calculation model have been made for scenarios with 100/300 (x1000) tonnes of slurry and 20/100 (x1000) tonnes of BMSW (including structural materials), respectively. In Figure 11 and Figure 12 revenues, expenses and earnings before taxation, depreciation and amortization (EBITDA) are shown graphically for the two scenarios. It is clearly seen that earnings for the large plant are best. So there is an economy of scale to be had. The calculations do not take into account transport costs for collection of the slurry. This may lead to major changes in the financial situation, and the economy of scale may be outweighed by longer transport distances.

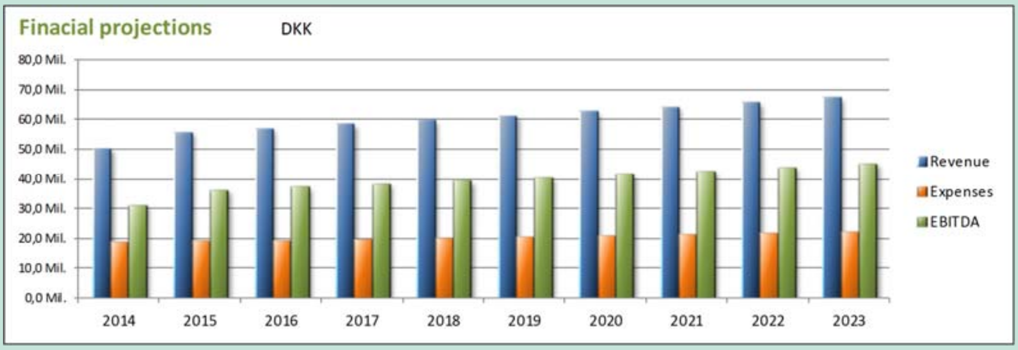


FIGURE 11
KEY FINANCIAL FIGURES FOR AN AIKAN AGRI PLANT BASED ON 50,000 TONNES OF BMSW AND 300,000 TONNES OF SLURRY

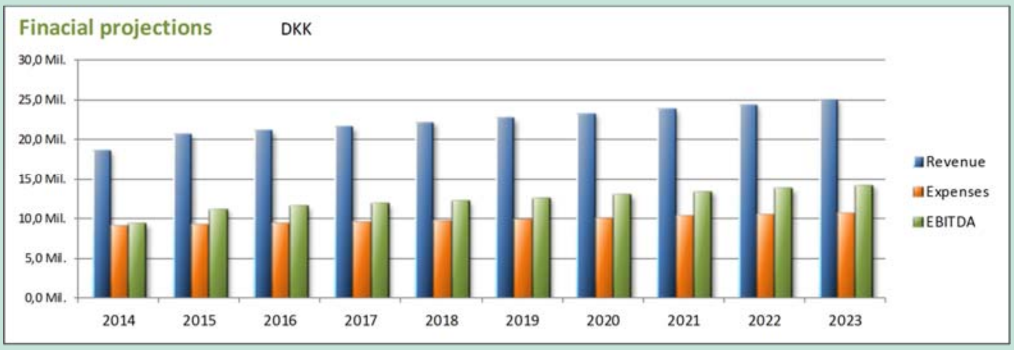


FIGURE 12
KEY FINANCIAL FIGURES FOR AN AIKAN AGRI PLANT BASED ON 20,000 TONNES OF BMSW AND 100,000 TONNES OF SLURRY

In Figure 13 and Figure 14 the payback period and Internal Rate of Return (IRR) for the two plants are shown. Both calculations use the same framework conditions. In practice, the gate fee for waste would probably be lowered to make the larger plant more competitive than the smaller one. If the gate fee is lowered by DKK 100/tonne of BMSW (from 450 to 350) the payback period increases from 1.6 years to 2.4 years.

Returns to Equity

IRR	After Tax	Pre Tax
5 years	33,7%	51,8%
10 years	33,6%	51,6%

Payback on Equity Investment		
Payback on Equity Investment	1,6 år	1,3 år

FIGURE 13
PAYBACK PERIOD AND INTERNAL RATE OF RETURN (IRR) FOR AN AIKAN AGRI PLANT BASED ON 50,000 TONNES OF BMSW AND 300,000 TONNES OF SLURRY

Returns to Equity

IRR	After Tax	Pre Tax
5 years	6,9%	10,6%
10 years	17,4%	26,8%

Payback on Equity Investment		
Payback on Equity Investment	6,0 år	5,4 år

FIGURE 14
PAYBACK PERIOD AND INTERNAL RATE OF RETURN (IRR) FOR AN AIKAN AGRI PLANT BASED ON 20,000 TONNES OF BMSW AND 100,000 TONNES OF SLURRY

The key figures rest on concrete assumptions from the demonstration plant in Holbæk, Denmark. Naturally, in a new plant there will be many specific issues that may be different.

The framework conditions are decisive for the operating economy of all energy and fertiliser producing plants. The framework conditions are, generally, market driven, but a better climate and environment behaviour normally needs support by incentives, orders or other statutory measures. It is well-known that framework conditions vary from one country to another. In Table 7 the most decisive framework conditions in our calculation are shown.

TABLE 7
FRAMEWORK CONDITIONS FOR AIKAN AGRI PLANT DESCRIBED IN THIS REPORT

Parameter	DKK per unit
Sales price per Nm^3 methane	4.50
Gate fee per tonne of BMSW	450
Gate fee per tonne of slurry	0
Settling price digested per tonne of slurry	0
Settling price per tonne of compost	0
Incineration gate fee per tonne of reject suitable for incineration	450

The sales price of methane cleaned from biogas is higher than the price of natural gas due to the subvention structure for renewable energy replacing fossil fuel. Due to the low energy prices the subvention has a major impact on the profitability of a plant.

To assess how changes in the framework conditions affect the business model calculation, these were changed for both plants as shown in Table 8. The gate fee for BMSW was reduced, the sales price for methane was reduced and marketing costs for both compost and digested slurry were set at DKK 30 per tonne/m^3.

For the large plant these changes mean that the payback period before taxation increases from 1.3 year to 7.9 years while for the small plant it reaches more than 10 years against 5.4 years.

It is clearly seen what framework conditions mean for the profitability of the plant.

TABLE 8
FRAMEWORK CONDITIONS IN ALTERNATIVE SENSITIVITY CALCULATION

Parameter	DKK per unit
Sales price per Nm^3 methane	4.00
Gate fee per tonne of BMSW	400
Gate fee per tonne of slurry	0
Settling price digested per tonne of slurry	- 30
Settling price per tonne of compost	-30
Incineration gate fee per tonne of reject suitable for incineration	450

5. Discussion

One of the purposes of this project was to optimise the pretreatment of source-separated BMSW in the Aikan Agri system. Source-separated BMSW always contains some amount of impurities in the form of plastics, metal, glass, wood etc., which cannot be decomposed in the digestion process. These impurities will be a nuisance for the digestion process or undesired in the useful residual materials - compost and digested slurry. In traditional biogas plants the technical tolerance for impurities is very low due to the risk of clogged pipes, filters and pumps. This means that the impurities must be removed before the biogas process. The pretreatment techniques we know today either generate large quantities of wastewater that must be disposed with the residue or through the sewer or up to 50 % of the biogas potential is segregated with the residual waste. In the simple mechanical pretreatment stages tested in this project waste with a small share of impurities (under 15 %) collected in biodegradable packaging can be handled directly without preseparation in Aikan Agri. Naturally, this gives an optimal opportunity for exploitation of the biogas potential. From waste with larger shares of impurities (more than 15 %) only large items are removed in the initial stage. This gives the highest possible share of organic matter through the system, and the impurities are segregated in the end by screening the compost.

Studies of the residual fraction of the BMSW showed that the decomposable organic material sticking to the impurities corresponds to 10-12 % of the gas potential of the unseparated waste. Since only a minor part of the impurities are removed in the preseparation (= shredding and segregation) the benefit from not segregating or washing the reject will be rather low. The variations of the yield results in full scale tests show that other factors than separation play a significantly larger role for the total yield (Figure 6). So there is hardly much to be gained from not preseparating; and this stage also has positive effects. Through shredding and removal of the largest items the exposure to decomposition of the organic material is increased and the percolation is improved since large plastic bags are removed. The advantage of treating BMSW in Aikan Agri, totally, is that more biogas per tonne of BMSW is produced since only a small share of the potential is removed. Over time other pretreatment methods may prove even more efficient, but today the relatively low-key and cheap solution is also the most efficient.

Through the development of Aikan Agri the aim was, among others, to find the best way of using the process modules for attaining biogas from BMSW without having to pump impurities contained in the BMSW into the reactors. With a long dwelling time in the reactor it is admittedly possible to attain a high biogas yield per tonne of organic material input from BMSW in systems with so clean BMSW that it can be fed directly. This will to some extent balance the loss happening in the segregation of potential during pretreatment. The requested long dwelling time is primarily due to the hydrolysis process, which in direct feed must take place in the reactor in parallel to the methane production. A long dwelling time is rarely profitable when at the same time large volumes of slurry are to be treated with a relatively constant flow in the reactor. In the Aikan Agri concept it is possible to extend the dwelling time of the solid material in the process modules and still preserve the same flow of liquid readily decomposable masses (slurry and leachate from the process modules). Thus, the process modules add some extra treatment options to the conventional, liquid biogas plant. This opens up for development perspectives for exploitation of a larger part of the potential in different raw materials. The hydrolysis in the process modules may in the future be extended so that heavily degradable organic materials can also be transformed into biogas. For example, it may be possible in the future to treat straw or other solid crop residues. They may contribute with a biogas yield and also be used subsequently as a fertiliser. This is an area where work is ongoing.

In the Aikan process digested liquid is pumped from the reactor tank to the process module where it percolates through the waste. The purpose is to wash hydrolysed, readily decomposable organic material that is pumped back in the reactor tank for digestion. In section 4.3.2 it is described how digested slurry from the digestion tank is filtered and used for percolation. The filter residue is mixed with the solid waste and used in the process module. Digested slurry will be the best decomposed liquid that is available at a slurry-based conventional plant, while leachate from Aikan plants without slurry has the added value that it does not contain any particles (fibres) and can therefore be used without filtration. The use of slurry as a percolation liquid is associated with two problems. One of the problems was that the fibres clogged the nozzles; the other was that the slurry left a fibre layer on top of the waste, preventing after a short while the liquid from entering the mass. It is realistic that applicable technical solutions for the clogging problems can be developed by watering unfiltered slurry in the process module under higher pressure than what is done today. A similar process is used in practice with fertiliser placement of slurry under pressure directly on the field. In this method the slurry is pressurised and injected into the soil using this pressure (Morken & Sakshaugen, 1998, Nielsen 2002). It would be possible to investigate this solution in more detail.

The gas potentials in the two primary substrates of Aikan Agri, BMSW leachate and slurry, were measured in a number of tests. The results showed that the gas potentials are comparable with potentials obtained in tests conducted elsewhere. One of the hypotheses of the project was that different types of inoculum may have different effects on the digestion of either BMSW or slurry. The reasoning is that the microbial composition of inoculum from a reactor tank containing the more complex BMSW leachate might have a positive (synergy) effect on the gas yield from slurry. The opposite might also be the case if the specialised microorganisms in inoculum from slurry reactor tanks might work positively on the digestion of leachate from BMSW. There was no clear effect of inoculum, neither on BMSW leachate nor on cattle slurry. The random variation was high, and it is more likely to be the substrate type (BMSW or slurry) that is decisive for the magnitude of the gas yield. It is also logical that with a relatively long digestion period the substrate's microbial community will adapt to the feedstock (slurry, BMSW etc.). Knowledge about how the microbial community in the substrate changes and at which rate may contribute to refining the process control further.

Also with respect to compost production, Aikan Agri differs from other biogas systems. It is well-known that the composting process turns even heavily decomposable organic materials into stable organic material. The aerobic decomposition, which is controlled in Aikan Agri through active aeration, is naturally occurring in nature, but over a much longer period. In the composting nutrients bound to the material are made accessible to plants. In the composting also a certain evaporation of nutrients takes place; primarily nitrogen in the form of ammonia. Nitrogen would possibly also be lost in the more passive decomposition in nature since, alternately, the nutrients are mobilised and immobilised during the decomposition process. The difference in loss of nitrogen during the spread of manure, digested slurry and compost would be relevant for a more detailed study. It is a general rule that fertiliser must be spread in a way that it is accessible when the plants need it. Compost, which is more stable, retains the fertiliser and the time of spreading may be less important; however, this calls for more detailed surveys and must be related to crop and cultivation system - and the compost must be adjusted subsequently. This project has quantified the loss during composting, but no work has been done to optimise the process in order to retain the largest possible quantity of nitrogen. The loss in direct spreading of digestate without composting and the rate of exploitation of nutrients were not part of the project. The use of organic residues, in other words, is a complex dynamic system that involves both what takes place in the field and at the plant. It may be important to conduct a project in view of identifying a good, environmentally benign practice.

As described, the Aikan Agri concept keeps solid and liquid waste separate. Thereby, the biogas process is physically divided into several stages (hydrolysis and methanogenesis take place in several places). The biogas yield from the same quantity (input) and type of waste is the same for Aikan Agri and for conventional liquid biogas solutions. The methane potential in BMSW is approximately the double as what is realised so there is scope for improvement for both concepts. In Aikan Agri it is possible to treat several different types of waste in different ways and to compost the solid fraction. This gives good development options, but it also makes the process control more complex. The Aikan Agri process control is designed in a way that it is relatively easy to adjust through the SCADA system. So the complexity will not be remarked in a given plant, but it is a feature it will be possible to exploit in the further practical process development.

Through the project the Aikan technology has improved its export potential in general. Interest has been shown from several countries where waste management systems are being developed. This interest is due to the flexibility of the concept; many types of waste can be treated separately and differently due to the design in batches. Also, the investment needs for the technology are moderate, for instance compared with incineration, and the plant generates both energy and fertiliser (compost). The Aikan Agri concept supports the flexibility by expanding the treatment options for solid and liquid agricultural raw materials. The largest challenge for export today is that by 2013 only one Aikan plant is in operation. It is a huge advantage that this plant (BioVækst) has been in operation continuously and without suspension of operations for ten years, but many international tender specifications have a requirement for at least three reference plants. This challenge is faced by many innovative technologies: getting through what is sometimes referred to as “the Death Valley”. In other words, the step from development to commercial operation. Overcoming “the Death Valley” requires the courage to invest in the first plants. Aikan has shown its strength by having BioVækst surviving on current market conditions, but in Denmark the general interest in investing in waste treatment has been very limited in the private sector. This is first and foremost due to relatively unilateral public investments in incineration technologies and the associated district heating network. In addition, there have been a few unfortunate, unsuccessful projects regarding biological waste treatment that have been discontinued and created a barrier to future investments. Originally, public investments in incineration plants made sense since the purpose was to divert organic waste from landfill. Today, focus is on resource recovery from waste and in this context Aikan Agri is a good and well-proven technology that may gain a stronger foothold in the Danish waste model.

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