Report

Selective hydrolysis of wastewater sludge

Part 1, September 2007

Model calculations and cost benefit analysis for
Esbjerg West waste water treatment plant,
Denmark

PSO-F&U project nr. 2006-1-6815

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0 Summary

0.1 Summary in English

This project ”Selective hydrolysis of wastewater sludge” is supported by EnergiNet.DK under the PSO-F&U projects having project number 2006-1-6815.

The projest constitutes the phase 1, a cost-benefit analysis of the possibilities to utilise the selective hydrolysis of sludge at waste water treatment plants to enhance the production of biogas based power and heat besides reduce the power consumption from handling and treatment of nitrogen and sludge at the treatment plants including for final disposal of the sludge.

The project is completed for EnergiNet.DK by company Eurotec West A/S in corporation with the municipality of Esbjerg, Risø National Laboratory, Rambøll, the Estate of Overgaard and SamRas.

The wastewater treatment plant Esbjerg Renseanlæg Vest is used as a model plant for the calculations of the benefits using selective hydrolysis of sludge as if established at the existing sludge digester system.

The Esbjerg Renseanlæg Vest is a traditional build plant base don the activated sludge concept besides traditional digester technology. The plant treats combined household and factory wastewater with a considerable amount of the wastewater received from the industries.

The wastewater shows unforeseen good settling capability. This implies that the amounts of primary sludge at the plant are quite high compared to what may be expected and to what is found at similar plants. Taking into account, that the efficiency of the selective hydrolysis is much higher for biological excess sludge than for primary sludge, this actual plant might not be optimal for the utilisation of the selective hydrolysis technology.

During the project period the Esbjerg Renseanlæg Vest undergoes considerable process changes, which has not yet finished. The most important part is the canges in the sludge handling, as the sludge retention time is under reduction from in the order of 40 to 70 days to an order of 20 days. This change may bring considerable to as well the amounts of biological excess sludge as to the constituents of the sludge. It is expected that the amounts may rise and the level of mineralisation may fall, why the total amounts of biological dry matter in the biological excess sludge may show a considerable enhancement. At the same time experiments using primary sludge for de-nitrification goes on, why it may be difficult to produce a safe calculation of the results of the changes including the changes of biological excess sludge amounts and constituents.

Thus the results included in this report mainly are based on the plant characteristics documented from historical data, and thus the data from the project may be objected as quite conservative relative to what actually may be obtainable.

The selective hydrolysis system is based on the fact, that an anaerobic digestion before a hydrolysis treatment enhances the hydrolysis efficiency, as the production of volatile organic components, which might inhibit the hydrolysis efficiency, are not produced to the same extent as may be the case for a hydrolysis made on un-digested material. Besides it is possible to separate ammonia from the sludge without utilising chemicals. The project holder has been able to show this for several

kinds of biomass; however it is experienced that it may be difficult to treat wastewater sludge, as the sludge seems to be difficult to treat in laboratory using simple equipment.

Risø National Laboratory has made experiments comparable to the full scale running characteristics, which not has been possible for the project holder. Thus the 2 parties has made parallel experiments to compare the obtained results.

The experience from the laboratory experiments show that the well controlled conditions at the Risø National Laboratory contributes to a very efficient hydrolysis treatment. This is the case as well for the conversion of organic matter to biogas as for the separation of ammonia from the sludge:

Based on the well documented Risø National Laboratory results the processing efficiencies in full scale may be expected as follows:

- hydrolysis efficiency on primary sludge 10 % or higher
- hydrolysis efficiency on excess biological sludge 40 %
- (ammonium + ammonia)-N reduction 50 %.

Thus the balances may be changed as follows at the plant as is:

- sludge dry matter reduction 230 tonnes of TS per year or 1.150 tonnes of dewatered sludge
- enhancement of biogas production 240 tonnes per year or 220.000 m^3
- nitrogen N reduction 45 tonnes per year or 7 % of the total N load at the plant

where it is especially interesting, that the dynamic load from this amount of nitrogen is higher, as the relative amount is not corrected for assimilated nitrogen or nitrogen, which passes unchanged through the plant to the final settling and pass out from the plant as dewatered sludge.

The energy balances are found to be influenced as follows:

- power demand for nitrification is reduced with 200 MWh
- diesel oil demand for transportation is reduced with 24 MWh
- power production from enhanced biogas is 220 MWh

and the heat consumption is enhanced with between 330 and 2.170 MWh depending on the establishment of heat exchangers to recover heat from the treated sludge.
Det skal noteres, at renseanlægget ikke kan afsætte overskudsvarme til omgivelserne; således er det ikke nødvendigvis økonomisk fordelagtigt at etablere denne varmevekslingskapacitet.

Power and energy reduction from reduced circulation of wastewater for de-nitrification, from reduced amounts of sludge for dewatering, for elimination of the consumption of methanol for de-nitrification are not included in the energy balances.

The hydrolysis processing also sanitises the sludge. If the energy consumption from a standard sanitising plant is included in the calculations to value this secondary benefit, the energy balances becomes even more advantageous.

As it is possible to describe the results of the changes of the sludge handling at the plant, it may be possible to describe the enhancement of the biological excess sludge amounts. This enhancement may have a positive effect on the energy balances. It is expected that it may be possible to measure the effect of the changes of the sludge handling by the end of this year.

The cost-benefit analyses show, that:

- the simple pay-back time under unchanged conditions is in the order of 10 years
- if primary sludge is used for de-nitrification the simple pay-back time is about 6 years
- if the value of sanitising is included the simple pay-back time is between 1,5 and 2,5 years.

These calculations do not take the ongoing changes of the sludge handling into account. Whatever the case the changes may result in further advantages from utilising the hydrolysis system relating to as well sludge as nitrogen amounts.

Based on the obtained results the participants of the project may recommend the phase 2 initiated and the hydrolysis plant established as an experimental full scale at the Esbjerg Renseanlæg Vest waste water treatment plant.

Eurotec West A/S thanks goes to the Esbjerg Kommune, Esbjerg Renseanlæg Vest and the rest of the project parties for a fruitful corporation during this phase 1 of the project looking forward to fulfil the expectations to project part 2.

0.2 Summary in Danish

Dette projekt har modtaget støtte fra EnergiNet.DK under PSO-F&U ordningen med projektnummeret 2006-1-6815.

Projektet udgør fase 1, en cost-benefit analyse af mulighederne med udnyttelse af selektiv hydrolyse af slam på renseanlæg for forøget produktion af biogasbaseret kraft og varme samt reducerede energiomkostninger til håndtering af kvælstof og slam på renseanlæg samt til slutdisponering af slam.

Projektet er fuldført for EnergiNet.DK af Eurotec West A/S i samarbejde med Esbjerg Kommune, Risø National Laboratory, Rambøll, Overgaard Gods og SanRas.

Projektet benytter Esbjerg Renseanlæg Vest som modelanlæg til beregning af benefits ved etablering af selektiv hydrolyse af slam på renseanlægget, som indpasset i det eksisterende rådnetank anlæg.

Esbjerg Renseanlæg Vest er et traditionelt opbygget renseanlæg baseret på aktiv slam teknologi og rådnetank teknologi. Anlægget behandler spildevand fra boligbebyggelse og væsentlige industriområder i Esbjerg By.

Spildevandet, der tilføres anlægget, er specielt ved at udvise overordentlig gode bundfældningsegenskaber. Dette medvirker til, at mængden af primærslam på anlægget er aldeles høj i forhold til, hvad der er fundet på tilsvarende renseanlæg. Taget i betragtning, at hydrolysesystemets effektivitet er betragtelig højere på overskudsslam fra aktiv slam anlægget end på primærslam, har det vist sig, at netop dette renseanlæg ikke er optimalt for udnyttelse af selektiv hydrolyse teknologien.

Esbjerg renseanlæg Vest undergår i forsøgsperioden væsentlige procesmæssige ændringer, der ikke er afsluttede med projektperioden. Væsentligst er der tale om en ændring af slamhåndteringen, således at slamalderen reduceres til under halvdelen fra i størrelsesordenen 40 til 70 døgn mod i

størrelsesordenen 20 døgn. Denne ændring vil medvirke til en betydelig ændring af såvel mængderne som sammensætningen af biologisk overskudsslam, idet det forventes, at mængderne vil stige og mineraliseringsgraden falde, således at den samlede mængde tørstof med biologisk overskudsslam kan stige betydeligt. Idet der samtidig med disse ændringer laves forsøg med anvendelse af primærslam til de-nitrifikation, vil det være vanskeligt at udføre en sikker beregning af ændringerne af slammængder og slamkarakteristika.

Resultaterne med dette projekt er derfor i alt væsentligt baseret på den eksisterende situation, og resultaterne må derfor betragtes som ganske konservative i forhold til det generelt opnåelige.

Systemet til selektiv hydrolyse af slam benytter sig af, at en udrådning forud for en hydrolyse medvirker til en forøget hydrolyseeffekt, idet dannelsen af flygtige organiske forbindelser, der indvirker hæmmende på hydrolysen, ikke kan dannes i samme omfang, som det er tilfældet, dersom hydrolysen foretages før en udrådning. Der ud over er det muligt at udskille ammoniak fra slammet uden anvendelse af kemikalier. En lang række laboratorieforsøg udført af projektholderen har eftervist dette, dog således at erfaringerne med spildevandsslam har været varierende, da spildevandsslam er en vanskelig råvare at behandle i laboratoriet under simple forhold.

Risø National Laboratory har udført forsøg, der svarer til forholdene i fuld skala, hvor dette ikke er muligt på samme niveau i projektholderens laboratorium. Af samme grund er der lavet sammenlignende forsøg de 2 laboratorier imellem.

Laboratorieerfaringerne viser tydeligt, at kontrollerede forsøgsomstændigheder medvirker til en effektiv selektiv hydrolyse. Dette er tilfældet hvad angår såvel indvirkningen på omsætning af organisk stof til biogas som på afdampning og isolering af ammoniak fra slam.

Med Risø National Laboratory forsøgene er det vist, at følgende kan opnås:

- en hydrolyseeffekt på 10 % eller bedre på primærslam
- en hydrolyseeffekt på omkring 40 % på biologisk overskudsslam
- en udskillelse af flygtigt kvælstof som ammonium og ammoniak på mere end 50 % af den tilførte mængde.

Disse ændringer medvirker til, at balancerne på renseanlægget forventes ændret som følger:

- en reduktion af mængden af slam tørstof på 230 tons TS per år, svarende til 1.150 tons afvandet slam
- en forøgelse af biogasproduktionen på 240 tons per år eller 220.000 m^3
- en reduktion af belastningen med flygtigt kvælstof på 45 tons per år eller 7 % af den totale N belastning på anlægget

hvor det er særlig interessant, at den dynamiske belastning fra denne N-mængde er betydeligt større, da den relative mængde ikke er korrigeret for assimileret kvælstof eller organisk kvælstof, der passerer uændret igennem renseanlægget til efterklaringstankene og ud fra anlægget med afvandet slam.

Anlæggets energibalancer er påvirket som følger på årsbasis:

- elforbruget til nitrifikation er reduceret med 200 MWh
- dieselolie forbruget til transport er reduceret med 24 MWh
- elproduktionen fra forøgelsen af biogasproduktionen er på 220 MWh

og varmeforbruget er forøget med mellem 330 og 2.170 MWh afhængigt af, om der etableres varmeveksleranlæg til genvinding af termisk energi fra behandlet slam.

Det skal noteres, at renseanlægget ikke kan afsætte overskudsvarme til omgivelserne; således er det ikke nødvendigvis økonomisk fordelagtigt at etablere denne varmevekslingskapacitet.

Reduktionen af elforbruget til recirkulering af spildevand til de-nitrifikation, til afvanding af mindre slammængder samt til fjernelse af forbruget af metanol til de-nitrifikation er ikke indregnet i beregningen af el- og energiforbrug med energi balanceberegningerne.

Med hydrolyseprocessen opnås der en grundig hygiejnisering af slammet. Dersom energiforbruget til en standardmæssig hygiejnisering er indregnet for at værdisætte denne fordelagtige effekt, bliver energibalancerne yderligere fordelagtige.

Når effekterne af omlægningerne på renseanlægget kan eftervises ved de forventede forøgelser af mængderne af biologisk overskudsslam, forventes det, at energibalancerne forbedres yderligere. Det forventes, at effekten af disse omlægninger kan slå igennem på produktionen og sammensætningen af biologisk overskudsslam indenfor dette år.

Cost-benefit analysen viser, at:

- den simple tilbagebetalingstid under uændrede forhold er i størrelsesordenen 10 år
- dersom primærslam er benyttet til de-nitrifikaion er den simple tilbagebetalingstid omkring 6 år
- dersom værdien af et hygieniseringsanlæg inkluderes er den simple tilbagebetalingstid mellem 1,5 og 2,5 år.

Disse beregninger tager ikke højde for de ændringer, der nu forløber på renseanlægget. Det forventes, at ændringerne resulterer i yderligere fordele med udnyttelsen af selektiv hydrolyse på renseanlægget, når der ses på mængderne af såvel produceret slam som belastning med kvælstof.

Baseret på de opnåede resultater anbefaler projektdeltagerne, at projektets fase 2 iværksættes og at der etableres et forsøgsanlæg til selektiv hydrolyse af slam på Esbjerg Renseanlæg Vest.

Eurotec West A/S sender sin tak til Esbjerg Kommune, Esbjerg Renseanlæg Vest of de øvrige projektdeltagere for et frugtbart samarbejde med projektets fase 1 og ser frem til at kunne omsætte erfaringer til virkelighed med fuldførelsen af fase 2.

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1 Introduction

This report constitutes the report phase 1 of the project:

"Selective hydrolysis of sludge, Part 1"

PSO-F&U project nr. 2006-1-6815

substituted by EnergiNet DK and with company Eurotec West A/S as project holder.

The project participants are:

- Eurotec West A/S: Project holder, project management, laboratory scale experiments and plant supplier

- Municipality of Esbjerg, Esbjerg Renseanlæg Vest: Model wastewater treatment plant

- Risø National Laboratory: Laboratory scale experiments

- Rambøll Danmark A/S: Consultant

- SamRas ApS: Consultant

- Estate of Overgaard: Laboratory scale experiments

The part 1 project includes the specification of:

- conditions at the Esbjerg Renseanlæg Vest wastewater treatment plant
- mass balance for sludge production at the plant
- laboratory experiments with primary sludge and excess sludge from the plant including anaerobic treatment of sludge in laboratory scale digesters and mass balance analyses
- combining anaerobic hydrolysis with ammonia stripping
- full scale hydrolysis plant specification
- cost benefit analysis
- model calculation program to calculate mass balances for similar wastewater treatment plants
- interviewing a number of wastewater treatment plants especially related to digester functioning and possibility to incorporate hydrolysis systems at the plants
- model calculation for a mean size wastewater treatment plant

and this report describes the results of the project.

Our kind acknowledgement goes to EnergiNet.DK for subsidising the project.

2 Description of the hydrolysis system by Eurotec West A/S

The hydrolysis system is developed by Eurotec West A/S with company Carl Bro A/S as consultant. The development is based on many years of experience with anaerobic systems, especially with the digestion of animal manure.

The basic rights for the system are owned by the Danish company BioCircuit ApS.

The system is based on the understanding, that hydrolysis of untreated organic matter is inhibited by the produced hydrolysis products as long as the hydrolysis is based on biology. As such the hydrolysis should be optimised by a first digestion of constituents making up an inhibition potential to the hydrolysis. Thus the hydrolysis system is based on the following fundamental set-up:

- a preliminary or step 1. digestion of the biomass, preferably using digestion in the mesophilic temperature interval
- a hydrolysis process at a super-thermophilic temperature level
- a final or step 2. digestion which may find place within a temperature range of 35 to 55°C.

As such the hydrolysis system demands a 2 step digestion.

The temperatures in the different steps are controlled by as well internal heating units in the tanks as by using heat recovery in a specially designed sludge to sludge counter-current heat exchanger. The main purpose of the heat exchanger is to cool the mass from the hydrolysis tanks to the temperature in the step 2. digester.

The flow in the system is preferably a sequencing batch system.

The system set-up may be adapted to 1 of the 2 following demands:

1. Hydrolysis of the biomass, including controlled sanitation of the biomass
2. Hydrolysis of the biomass, including ammonia stripping and controlled sanitation of the biomass.

At wastewater treatment plants ammonia oxidation and de-nitrification by far is the most energy consuming processes, why a stripping of ammonia from the digested sludge introduces as well a reduction of running costs at the plant as a possibility to utilise evaporated ammonia as fertiliser in agriculture as a nitrogen source.

3 Esbjerg Renseanlæg Vest wastewater treatment plant

3.1 Overall description of the wastewater treatment plant

The Esbjerg Vest wastewater treatment plant is owned and run by the municipality of Esbjerg.

The plant is designed for the following load:
- organic load: 290.000 PU
- nitrogen load: 192.000 PU
- phosphorous load: 168.000 PU.

The plant design is based on the activated sludge process including nutrients removal based on the recycling principles for de-nitrification besides precipitation for phosphorous removal.

Sludge from the plant is digested in 4 digesters, and the produced biogas is used for heat and power production.

The wastewater treatment plant receives wastewater from as well industrial sites as from private households.

The incoming wastewater shows indeed very good settling characteristics, why the main part of the organic matter entering the plant is found in sludge from primary settling.

The result is that the amount of primary sludge without utilising settling chemicals by far exceeds the commonly expected amounts; thus the ratio between primary sludge / activated sludge quite much higher than normally expected and found.

The implications from this deviation from a normal situation are described below, as it results in unforeseen deviations of sludge characteristics compared with general experience.

3.2 Wastewater treatment processes

Wastewater entering the plant undergoes the following processing:
- pumping and metering station to lift up the wastewater
- screen station
- flow metering station
- combined aerated sand and fat trap
- primary settling – if the concentration of P is high, iron salts are added for P precipitation
- activated sludge de-nitrification
- activated sludge nitrification with simultaneous P precipitation
- secondary settling of biological sludge, non-bacterial SS and precipitated P
- outlet metering and sampling station.

The demands to the outlet are as follows:
- SS ≤ 30 mg/l
- BOD-5 ≤ 15 mg/l
- total-N ≤ 8 mg/l

- total-P ≤ 1,5 mg/l

In general the outlet demands are kept.

3.3 Sludge treatment processes

Sludge is produced as follows:

- primary sludge is produced during the primary settling or primary precipitation process
- biological excess sludge is produced during the activated sludge and simultaneous P precipitation process.

The produced sludge undergoes the following treatment:

- settling and / or precipitation of primary sludge
- concentration of primary sludge in concentration tanks
- settling by precipitation of biological excess sludge
- polymer addition
- belt dewatering by gravitation
- pumping stations to pump sludge to the digesters
- 2 step mesophilic digestion in 2 parallel lines, one line having 2 digesters á net 2.200 m^3 the other line having 1 digester á net 2.200 m^3 and 1 á net 2.000 m^3
- digested sludge intermediate storage tank
- digested sludge dewatering by belt press.

All the produced sludge is digested in the anaerobic digesters. Sludge is to some extent received from external sources. This amount is of minor importance.

The sludge is dewatered to a TS concentration of about 18 to 22 % TS; as a mean about 20 % TS.

The produced and dewatered sludge is used for agricultural purposes as fertiliser.

The sludge is stabilised, not sanitised.

It ought to be mentioned, that the hydraulic retention time in the digester tanks is quite long, about 35 days, and that the digestion process finds place in 2 steps. Thus the mineralisation level may be quite high, and somewhat higher than commonly expected during digestion, where the hydraulic retention time typically is in the order of 20 to 25 days.

3.4 Sludge balances and biogas production

As a yearly mean the sludge balances are as follows:

- primary sludge	210 – 220 m^3 / 24 h at 5 – 6 % TS	= about 11.800 kg TS / 24 hours
- excess biological sludge	40 – 50 m^3 / 24 h at 3,5 – 4 % TS	= about 1.700 kg TS / 24 hours
- sum amounts	250 – 270 m^3 / 24 h at 5 – 5,3 % TS	= about 13.500 kg TS / 24 hours

The production of biogas is as follows as a general level:

	Primary sludge	Excess sludge	Sum / mean
M^3 biogas / m^3 sludge	22	7,5	19,5

M^3 biogas / t TS	400	190	375
M^3 biogas / kg TS digested	0,75	0,65	-

These observed biogas production values are within a generally expected level.

On the other hand the data shows that in general the amount of primary sludge is 4 times higher than the amount of excess biological sludge, giving a ratio of primary sludge / biological excess sludge as 4 / 1. In general this ratio is in between 1 / 1 and 2 / 1.

The Esbjerg Vest plant buys high amounts of easy digestible C to nourish de-nitrification. By bypassing a certain amount of the primary sludge to the de-nitrification step, the de-nitrification may find the necessary amounts of C for de-nitrification from the primary sludge. Such a change may reduce the amount of primary sludge available for digestion, but on the other hand pass SS to the activated sludge plant which, at least partly pass more or less untreated to the secondary settling.

Thus there may be a reduction of the biogas production from establishing such a bypass; on the other hand the amount of excess sludge may rise thus bringing a biogas potential from excess sludge to the digester system.

Chapter 3.5 further evaluates the consequences of such a proposed change-over.

3.5 Sludge utilisation

The de-watered sludge produced at the Esbjerg Vest wastewater treatment plant is used as fertiliser in agriculture.

In general the levels of heavy metals and environmental priority pollutants are below the limit values, why the utilisation of the sludge in agriculture is regulated under the "slambekendtgørelsen" the sludge statutory provisions.

As a mean the sludge is handled as follows according to information from the plant:

- transported 35 km for storage
- stored for several months
- transported 15 km for final utilisation as fertiliser at a farm
- transported 5 km at the farm for transport to the fields and spreading.

The transport distance at farms is not verified. This distance is evaluated as being a likely level.

The actual transport running distance is about 2 times the distance, as the vehicles has as well the turn as return tour. In general it cannot be expected to have return fright running with wastewater sludge.

3.6 Nitrogen load

The nitrogen load at the nitrifying and de-nitrifying plant is as follows as a mean of 3 months values. Data are in kg per 24 hours:

	Inlet water	+	anaerobic sludge reject water	=	nitrogen load	+	Settled primary sludge
Tot-N	1870	+	410	=	1750	+	530
Amm-N	910	+	260	=	1170	+	-

The data shows, that the reject water total nitrogen and ammonia nitrogen accounts for between 20 and 25% of the nitrogen load at the nitrifying and de-nitrifying processes.

This implies, that a reduction of the ammonia load at this part of the plant may lead to a visible reduction of the power consumption for the necessary nitrogen treatment.

3.7 Ongoing changes and plans for the plant

3.7.1 De-nitrification

As the plant works now with a very efficient primary settling a high part of the available carbon is settled in the primary settling tanks. Relative to the demand for C to fulfil the necessary de-nitrification this leaves insufficient amounts of C for the de-nitrification. Thus it is necessary to add C to the de-nitrification phase. The amount is big, nearly 100 tonnes of C as methanol is added every year for de-nitrification.

If pumping a part of the primary sludge to the de-nitrification, this input of C may be reduced or even stopped.

To calculate the need for primary sludge for de-nitrification, the following presumptions are used:

- consumption of methanol C about 100 tonnes / year
- primary sludge 5% total solids
- primary sludge volatile solids 70% of total solids
- TOC / VS ratio about 0,30
- COD / VS ratio about 0,95
- bio-available VS / total VS ratio about 0,7
- COD – de-nitrification demand 7 to 9 kg COD / kg nitrate-N
- COD of methanol 1,5 kg / kg VS
- TOC / VS of methanol 0,375

This implies that the amount of primary sludge TS for de-nitrification is in the order of 700 to 800 tonnes primary sludge TS a year.

For control 100 tonnes of methanol C corresponds to 270 tonnes of methanol as VS or 400 tonnes of COD. The COD of 700 to 800 tonnes primary sludge TS is 500 tonnes using the above ratios, which is in the same order of magnitude, and may indicate acceptable presumptions.

According to chapter 3.4 the daily amount of TS from the primary settling is 11 to 12 tonnes. Thus the need for primary sludge for de-nitrification corresponds to between 15 and 20 % of the total amounts of primary sludge.

3.7.2 Excess sludge production from using primary sludge for de-nitrification

The change in the amounts of biological excess sludge from using primary sludge for de-nitrification may be estimated using the following presumptions:

- nitrate de-nitrification yield g VSS / g COD about 0,3
- VSS / TSS about 0,85
- COD / VS ratio about 0,95
- VS / TS ratio about 0,7

- Primary sludge TS for de-nitrification 700 to 800 tonnes per year

where it is expected, that the sludge production from nitrification and de-nitrification is unchanged.

This brings a production of excess sludge of 165 to 190 tonnes of excess sludge TS per year.

The inert part of the primary sludge may pass more or less unchanged through the aeration system. It is expected, that this accounts for about 50% of the above production or about 90 tonnes per year.

Thus the total sludge production may be in the order of 255 to 280 tonnes per year. Thus this implies that using 700 to 800 tonnes of primary sludge TS for de-nitrification results in an effective sludge reduction of the primary sludge added the de-nitrification of about 65%.

3.7.3 Revised sludge balances and biogas production

As a yearly mean the sludge balances are as follows:

- primary sludge	165 – 200 m^3 / 24 h at 5 – 6 % TS	= about	9.800 kg TS / 24 hours
- excess biological sludge	55 – 65 m^3 / 24 h at 3,5 – 4 % TS	= about	2.200 kg TS / 24 hours
- sum amounts	220 – 265 m^3 / 24 h at 5 – 5,3 % TS	= about	12.000 kg TS / 24 hours

The production of biogas is as follows as a general level:

	Primary sludge	Excess sludge	Sum / mean
M^3 biogas / m^3 sludge	22	7,5	18,4
M^3 biogas / t TS	400	190	360
M^3 biogas / kg TS digested	0,75	0,65	-

Comparing with the data in chapter 3.4 the biogas production may be reduced about 5 to 6 % using the proposed amounts of the primary sludge for de-nitrification.

Taking into account that the costs of buying nearly 100 tonnes of methanol C may be in the order of 0,9 million Danish crowns, this change-over may be quite profitable as the gross value of the reduced biogas production may be between 0,3 and 0,4 million Danish crowns.

3.7.4 Changes to the sludge age of the aerated and de-nitrifying plant

Until the beginning of this year the aerated and de-nitrifying part of the wastewater treatment plant has run with a high sludge age. The sludge age might have been in the order of 40 to 70 days.

Having a sludge age at this level, the sludge may have poor settling characteristics besides being quite mineralised.

During the last part of the project period the sludge age has been reduced, and it is stated as the goal to reach a sludge age of about 20 days. This may imply that the sludge changes towards:

- reduced sludge volume index
- higher sludge production, thus higher amounts of biological excess sludge
- lover mineralisation level of biological excess sludge, and thus
- higher content of organic matter in biological excess sludge, which implies
- higher biogas potential from biological excess sludge.

It is not possible to foresee the influence on the amounts and contents of the sludge.

The final stabilisation of the aerated and de-nitrifying part of the plant takes place during the coming few months, why it may be possible to state the changes within the autumn of 2007.

3.8 Corresponding sludge data for other wastewater treatment plants

In general the load and wastewater contents of wastewater received at wastewater treatment plants differ much, mainly as the influence from factory wastewater differs.

A row of interviews at wastewater plants similar to Esbjerg Renseanlæg Vest shows the differences between the plants. Below the main conditions for sludge production, digestion and management are given. For further details see appendix 4.

Yearly data	1	2	3[1]	4	Esbjerg R. V.
Primary sludge m^3 / % TS	22.300 / 5	55.115 / 4	78.475 / 1	-	78.500 / 5,5
Excess sludge m^3 / % TS	5.100 / 6,1	22.010 / 5	32.850 / 1	39.819 / 5,3	16.500 / 3,8
Ratio E / P, m^3 / m^3, TS / TS	0,23 / 0,28	0,4 / 0,5	0,42 / 0,42	-	0,21 / 0,15
Digesters m^3	2100	2 á 2.500	2 á 1.600	1.500	3 á 2.500 1 á 2.200
H. R. T., days	28	2 x 11,8	33	13,7	33
Biogas m^3	474.100	-	410.000	-	$1{,}7 – 1{,}8 \times 10^6$
Biogas m^3 / kg TS	0,33	-	0,35	-	≈ 0,37

Note: 1. Primary and excess sludge is concentrated in a common concentration tank bringing a dry matter content of 3,4 % before digestion.

Relating to this report the most important figures are the relative amounts of primary and secondary sludge at as well a volume ratio as at dry matter ratio. The table shows, that the Esbjerg Renseanlæg Vest has a low ratio between wet sludge amounts and an unforeseen low ratio on sludge dry matter amounts. On the other hand the high relative amounts of primary sludge contribute to a high dry matter specific biogas production.

4 Laboratory scale experiments

4.1 Materials and methods

4.1.1 Risø National Laboratory

Excess biological sludge is received from the Esbjerg Renseanlæg Vest wastewater treatment plant for fed batch experiments.

Digestion step 1 is performed as a fed batch digestion at 35°C. Hydrolysis is performed at 80°C. Digestion step 2 is performed at as well 37°C as 52°C to describe possible differences between mesophilic and thermophilic digestion.

Hydrolysis is performed with or without agitation. The headspace of the hydrolysis tank is flushed with N_2.

For details see appendix 1 and 2.

4.1.2 Eurotec West laboratory

Excess biological sludge is received from the Esbjerg Renseanlæg Vest wastewater treatment plant for batch experiments.

Digestion step 1 is performed as batch digestion at 35°C. Hydrolysis is performed at 80°C. Digestion step 2 is performed at 40°C.

Hydrolysis is performed with agitation. The headspace of the hydrolysis tank is flushed with atmospheric air.

The step 2 batch is inoculated with fermenting sludge from either Esbjerg Renseanlæg Vest or Viby Jylland wastewater treatment plants. In each case a test and a standard reactor is used for the digestion experiments.

Produced biogas is collected and metered in lab gas domes.

Analyses of sludge contents are performed by accredited Laboratory Eurofins A/S. Besides Eurotec West A/S themselves performs dry matter analysis using Mettler UV measurement equipment.

4.2 Results

4.2.1 Risø National Laboratory results

Hydrolysis efficiency for primary and excess biological sludge

Primary sludge

The below table shows data for dry matter conversion and methane production for primary sludge from concentration tank.

	Step 1	Step 2	Hydrolysis efficiency
Temperature ºC	35	52	-
Ml gas/g liquid	10,8	1.0	9,2$
ml/g TS	359	47.0	13,1$
ml/g VS	491	79.4	16,2$
% methane	73	72	-

$: The efficiency is not corrected for the evaporation of water during the hydrolysis.

The water evaporation has not been stated, why the actual efficiency from the hydrolysis cannot be calculated. It is expected, that the step 2 biogas production adds at least 10 % methane and biogas to the step 1 digestion taking the dry matter conversion in the first step into account.

The table shows, that the methane content is high, over 70%. This is higher than commonly found, but still within the general range.

For further information see appendix 2.

Biological excess sludge

The below table shows data for dry matter conversion and methane production for excess biological sludge.

	Step 1	Step 2	Hydrolysis efficiency
Temperature ºC	37	52	-
TS at start [g/100 g]	4,04	2,78	-
TS at end [g/100 g]	2,80	2,24	-
VS digested [g/100 g]	1,26	0,56	44 %
Produced methane l/kg TS	170	100	40 %
Produced methane l/kg TS or VS digested	545	496	-

The hydrolysis efficiency calculation includes the correction for dry matter conversion and water evaporation throughout the experiments.

It may be expected, that the methane content of the biogas is in the order of 65%. Using this figure the biogas production as l/kg TS or VS digested are 838 for step 1 and 763 for step 2. These figures are within the stoichiometrical levels of digestion of organic matter in general.

For further information see appendix 1.

Ammonia stripping on primary and biological excess sludge

Primary sludge

There is not yet received data for ammonia stripping from hydrolysis of primary sludge. Data will be incorporated into the report later.

Biological excess sludge

The table below shows data for ammonia production from organic nitrogen besides ammonia stripping from biological excess sludge. The experiment has found place without agitation and headspace flushing of evaporated ammonia.

	pH	NH_3, g/l	Organic N g/l	Total-N, g/l
Biological excess sludge	7.6	1.5	1.4	2.9
Step 1,.37°C	7.95	1.15	1.35	2.5
Hydrolysed sludge	7.65	1.4	1.1	2.5
Step 2, 52°C	7.8	1.65	0.95	2.6

The table shows a certain reduction of nitrogen through the step 1 digestion. A reduction like this is not commonly found unless the sludge has a content of nitrate corresponding to the reduction. As the concentration of nitrate in biological excess sludge is expected to be below the outlet demand, this cannot be the case.

The table below shows data for ammonia stripping under the same fundamental conditions, now with agitation and headspace flushing.

Component	Before hydrolysis, g/kg	After hydrolysis, g/kg
Ammonia + ammonium-N	1,30	0,65
Nitrogen total	2,70	2,00
pH	7,63	9,07

The table shows a market rise of the pH value besides a powerful evaporation of ammonia nitrogen.

The evaporation of water is not given, why the concentration corrected for evaporation of water contributes to an evaporation exceeding the stated 50% evaporation of (ammonia + ammonium)-N.

For further information see appendix 2 and 3.

4.2.2 Eurotec West laboratory results

Hydrolysis efficiency for primary and excess biological sludge

Primary sludge

There is not made hydrolysis experiments with primary sludge. On the other hand primary sludge by far constitutes most of the sludge produced at the plant.

For further information, see chapter 3.4, “Sludge balances and biogas production”.

Hydrolysis of the digested sludge adds a step 2 biogas production of 44 l/kg TS. As the biogas production in general is 400 l/kg TS, and the evaporation of water is 22,4 %, this biogas production adds about 5 % more biogas to the step 1 biogas production.

Still this figure may be evaluated as rather uncertain estimation.

Biological excess sludge

The below table shows data for dry matter conversion and biogas production for excess biological sludge.

	Step 1	Step 2	Hydrolysis efficiency
Temperature ºC	40	52	-
TS at start [g/100 g]	3,95	3,23	-
TS at end [g/100 g]	2,70	-	-
VS digested [g/100 g]	1,15	-	-
Produced biogas l/kg TS	190	70	25 %
Produced biogas l/kg TS or VS digested	0,65	-	-

The table shows that there is a market biogas production from step 2. Correcting for a water evaporation of 16,4 % during the hydrolysis, the biogas production from step 2 adds 25 % more biogas to the step 1 biogas production.

As a curiosity it may be mentioned, that a step 2 digestion at 40°C brings on a biogas production similar to the biogas production at 52°C.

Ammonia stripping on primary and biological excess sludge

Primary sludge

There is not made digestion experiments with primary sludge. On the other hand the primary sludge accounts for most of the sludge produced, why digested sludge from the plant digesters may show a level of efficiency of the ammonia stripping efficiency on primary sludge.

The table below shows data for ammonia production from organic nitrogen besides ammonia stripping from digested sludge from the plant.

Component	Before hydrolysis, g/kg	After hydrolysis, g/kg
Ammonia + ammonium-N	0,87	0,75
Nitrogen total	1,96	1,81
pH	7,65	7,36

The evaporation of water during the stripping process is 22,4 %. Taking this into account the evaporation of (ammonium + ammonia)-N is 33%.

Biological excess sludge

The table below shows data for ammonia production from organic nitrogen besides ammonia stripping from biological excess sludge.

Component	Before hydrolysis, g/kg	After hydrolysis, g/kg
Ammonia + ammonium-N	1,48	1,24
Nitrogen total	2,92	2,43
pH	7,6	8,0

The evaporation of water during the stripping process is 16,4 %. Taking this into account the evaporation of (ammonium + ammonia)-N is 30%.

4.3 Conclusion on laboratory scale experiments

The laboratory experiments performed by Risø National Laborarory and Eurotec West A/S differs to some extent, as the Risø results in general shows higher efficiencies than the Eurotec results.

The reason for these deviations are not known; whatever it may be clear, that the experimental conditions at the Risø laboratory are well controlled, where the Eurotec laboratory is more simple.

The conclusions from the experiments may be as follows relating to the efficiency on the biogas or methane production:

- treating primary sludge with hydrolysis adds about 5 % or more biogas relative to the stated common production level according to the Eurotec West A/S results
- treating primary sludge with hydrolysis adds about 10 % or more biogas relative to the stated common production level according to the Risø National Laboratory results
- treating biological excess sludge with hydrolysis adds about 25 % or more biogas relative to the stated common production level according to the Eurotec West A/S results
- treating biological excess sludge with hydrolysis adds about 40 % or more methane relative to the stated standard production level according to the Risø National Laboratory results

The conclusions from the experiments may be as follows relating to the efficiency on (ammonium + ammonia)-N stripping:

- treating primary sludge with hydrolysis strips about 33 % of the (ammonium + ammonia)-N according to the Eurotec West A/S results
- treating biological excess sludge with hydrolysis strips about 30 % of the (ammonium + ammonia)-N according to the Eurotec West A/S results
- treating biological excess sludge with hydrolysis strips at least 50 % of the (ammonium + ammonia)-N according to the Risø National Laboratory results

The Risø results are obtained under well controlled conditions most comparable to full scale running conditions. Thus the results of these experiments are used for the below described mass balance calculations. These calculations refer to the expectations to the performance of the sludge digestion at the Esbjerg West wastewater treatment plant.

5 Mass balances

5.1 Presumptions

The cost benefit analysis is based on the following presumptions:

- sludge amounts according to chapter 3.4
- hydrolysis efficiency data according to chapter 4.2.1
- ammonia evaporation according to chapter 4.2.1
- unchanged de-watering characteristics
- handling and transport according to chapter 3.5

As the report is written, the changes in sludge amounts and contents originating from the chapter 3.6 ongoing changes at the plant are not yet described. The implications of the changes might be estimated within this year.

5.2 Dry matter balances

The mass balances with and without hydrolysis plant may be as stated below according to chapters 3.4 and 4.2.1. All data are at a yearly basis.

Without hydrolysis

Primary sludge	+	Biological excess sludge	+	Water	=>	Biogas	+	Digested sludge
4.300 t TS	+	620 t TS	+	200 t	=>	1.960 t TS	+	3.160 t TS

With hydrolysis

Primary sludge	+	Biological excess sludge	+	Water	=>	Biogas	+	Digested sludge
4.300 t TS	+	620 t TS	+	210 t	=>	2.200 t TS	+	2.930 t TS

Changes

Primary sludge	+	Biological excess sludge	+	Water	=>	Biogas	+	Digested sludge
0 t TS	+	0 t TS	+	10 t	=>	240 t TS	+	- 230 t TS

The biogas amounts correspond to 1.850.000 m^3 biogas produced without hydrolysis and 2.070.000 m3 produced with hydrolysis, an enhancement of 220.000 m^3 per year or 12%. At a methane content of about 65 % and 10 kWh per m^3 methane this corresponds to an energy production of 1.400 MWh per year.

The low rise in biogas production is a result of the fact, that 87% of the sludge is primary sludge; this is a much higher part than commonly found.

The wastewater treatment plant biogas production corresponds to the level found in the laboratory. On the other hand the calculated sludge amounts are double up the amounts leaving the plant according to the yearly statements. As the amounts of primary and excess biological are verified, this deviation is not understood. A main reason for the deviation may be the very high sludge age for the nitrification and de-nitrification plant. See chapter 3.7.4.

The reduced sludge production contributes to reduced sludge pumping costs as well as polymer and power consumption for de-watering. These changes are not included in the calculations of the reduced power consumption and reduced sludge handling costs.

5.3 Nitrogen balances

The change of the nitrogen load at the nitrifying and de-nitrifying plant may be as stated according to chapters 3.6 and 4.2.1. All data are at a yearly basis as tonnes per year.

The reduction is given as rounded figures, and the evaporation of water in not taken into account. Thus the actual values of ammonia stripping might be until 5 % points higher than indicated.

Without hydrolysis

	Inlet water	+	anaerobic sludge reject	=	nitrogen load	+	settled primary sludge
Tot-N	680	+	150	=	640	+	190
Amm-N	330	+	95	=	425	+	-

With hydrolysis

	Inlet water	+	anaerobic sludge reject	=	nitrogen load	+	settled primary sludge
Tot-N	680	+	105	=	595	+	190
Amm-N	330	+	50	=	380	+	-

Changes

	Inlet water	+	anaerobic sludge reject	=	nitrogen load	+	settled primary sludge
Tot-N	0	+	- 45	=	- 45	+	0
Amm-N	0	+	- 45	=	- 45	+	-

Thus the reduction of nitrogen onto the nitrification and de-nitrification may be at least 45 tonnes per year. This corresponds to 14% of the (ammonium + ammonia)-N load or 7% of the total nitrogen load at the plant. As a part of the nitrogen load is assimilated in the sludge produced during the nitrification and de-nitrification and as a part of the organic N passes unchanged through the plant to the excess sludge, the dynamic load from the evaporated N at this part of the plant actually surpass the given percentages.

The reduction in the (ammonium + ammonia)-N load reduces the power consumption for the oxidation of the substances to nitrate. Besides it also reduces the necessary recirculation rate for nitrified wastewater to the de-nitrification tanks, reduces the amounts of sludge and thus the sludge de-watering costs. As the (ammonium + ammonia)-N oxidation by far is the most power consuming of these operations, only the reduced power consumption from the reduction of the amount of (ammonium + ammonia)-N is used for calculating the reduction of the power consumption.

6 Energy balances

6.1 Hydrolysis plant energy production

The produced biogas is converted to heat and power in 2 Caterpillar gas engines. The characteristics of the gas engines are as follows at full load:

- input effect 530 kW per engine
- power yield 33 % or 175 kW per engine
- heat yield 45 % or 240 kW per engine

One of the engines has wrecked. As the engines are quite old, it might be convenient to change to a modern gas engine based construction. A Jennbacher 312 has been evaluated. This might change the effect production as follows at full load:

- input effect 1.500 kW
- power yield 40 % or 600 kW
- heat yield 38 % or 570 kW

As the caterpillar engines might be replaced, the energy conversion calculations are based on the Jennbacher data using 8.000 hours or more running at full load, as part load running at an input effect of 90 % or more might not influence the power and heat efficiencies to any extent.

Element	Without hydrolysis	With hydrolysis	Change
Biogas production m^3 / year	1.850.000	2.070.000	220.000
Energy production MWh / year	12.030	13.460	1.430
Power production MWh / year	4.810	5.380	570
Heat production MWh / year	4.570	5.110	540

Again it ought to be mentioned, that the sludge amounts from the aeration and de-nitrification plants are unforeseen small, and that they may rise during the coming time leading to a marked rise of the hydrolysis efficiency. See also chapter 3.7.4.

6.2 Hydrolysis plant energy consumption

The energy consumption for the hydrolysis plant is estimated as follows:

Position	MWh / year
Consumed power………………………………………………..	350
Consumed heat…………….……………………………………….	2.370
Sum, consumed energy………………………………………….	2.720

The reason for the high heat consumption is, that the step 2 digested sludge is not cooled in a counter current heat exchanger counter current to untreated sludge to step 1. The reason is, that the Esbjerg Renseanlæg Vest cannot supply heat to the district heating network. If the mentioned heat exchanger is established the investment may be about 600.000 DKK excl VAT, and the heat gain about 1.500 MWh per year.

The energy consumption for a sanitation plant under similar running conditions is estimated to the following amounts:

Position	MWh / year
Consumed power……………………………………………………..	240
Consumed heat……………….……………………………………….	1.490
Sum, consumed energy…………………………………………….	1.730

Thus everything else equal the sanitation plant consumes about 40 % of the power and 63 % of the heat consumed by the hydrolysis plant. If establishing the above mentioned heat exchanger, the relative heat consumption of the sanitation plant may rise.

6.3 Reduction of power for nitrification

The power consumption for nitrification is based on the following assumptions:

- 2 moles of oxygen to oxidise 1 mole of ammonia
- power specific oxygen transfer rate 0,8 kg O_2 per kWh

why the power consumption to oxidise 1 kg of ammonia is 4,5 kWh. This implies as follows:

Yearly amount of ammonia stripping 45 tonnes á 4,5 MWh / tonnes equals <u>200 MWh / year.</u>

It is expected, that the stripped ammonia has a value as fertiliser that makes it possible to supply it free of charge for farmers at the gate.

6.4 Energy consumption for transport of sludge

The energy consumption is based on the actual handling of the sludge and on general figures from the transport sector for transport and reload of sludge.

The basis is as follows:

- 20 % total solids in the dewatered sludge
- 35 km transport distance from wastewater treatment plant to sludge storage
- 15 km transport from sludge storage to farm
- 2 km from storage area on farm to fields
- diesel consumption 2,5 litres / km for transport
- diesel consumption 0,25 litres / ton of sludge for loading onto truck
- 30 tonnes of load for transport on road
- 8 tonnes of load for transport at farm
- empty return
- energy content 10 kWh / l diesel.

This brings on the following diesel consumption in m^3 / MWh per year:

Element	Without hydrolysis	With hydrolysis	Change
WWTP to sludge storage	14,7 / 147	13,7 / 137	- 1,1 / 11
Sludge storage to farm	6,3 / 63	5,9 / 59	- 0,5 / 5
Farm to field	4,0 / 40	3,7 / 37	- 0,3 / 3
Reload sludge storage	3,9 / 39	3,6 / 36	- 0,3 / 3
Reload farm	3,9 / 39	3,6 / 36	- 0,3 / 3
Total consumption	32,9 / 329	30,5 / 305	- 2,4 / 24

The table shows, that even if the ratio of primary to excess sludge at the plant is uncommonly high, there is a reduction of the diesel consumption of 2,4 m^3 per year. All other things equal a more common sludge ratio would reduce the consumption to a much higher extent.

6.5 Energy balances

Based on the above results the energy balance may be as calculated below. All values are in MWh per year:

Incoming energy:		
Power production	570	
Heat production	540	
Power savings from reduced nitrification	200	
Power savings from reduced transport	24	
Sum, incoming energy	1.334	1.334 MWh
Outgoing energy:		
Power consumption for hydrolysis plant	350	
Heat consumption for hydrolysis plant	2370	
Sum, outgoing energy	2.720	2,720 MWh
Net energy production:		- 1.386 MWh

The reason for the high heat consumption is, that the step 2 digested sludge is not cooled in a counter current heat exchanger counter current to untreated sludge to step 1. If this heat exchanger is established the investment may be about 600.000 DKK excl VAT, and:

Secondary recovered heat in MWh per year:	1.500	1.500 MWh
Net energy production		114 MWh

Taking the benefit from the sanitation into account, the balance may be a follows:

Sanitation plant power consumption	240	
Sanitation plant heat consumption	1.490	
Sum, energy demand of sanitation plant	1.730	1.730 MWh
Net energy production		1.844 MWh

Again it has to be stated, that the production of biological excess sludge at the Esbjerg Renseanlæg Vest is uncommonly low. As the ongoing running characteristics are finalised the amounts of biological excess sludge may rise, making visible changes to the mass balances and thus to the energy balances.

The balance shifting from using primary sludge for de-nitrification is not calculated. It has not yet been possible to find a proper data basis for this calculation. It may be quite clear, that such a change too may be quite beneficial for the energy balance.

7 Cost benefit analysis

7.1 Establishment costs for hydrolysis plant and connections

The establishment costs for the plant are given below. The costs are based on a detailed going through of the plant, possibility to connect to the existing installations besides experience from similar project. All costs are excl. VAT.

The establishment costs are specified as follows:

Element	Cost
Soil and concrete works	100.000
Buildings	200.000
Hydrolysis tanks including equipment	750.000
Mechanical equipment, pipes including mounting	2.300.000
Heat exchangers including mounting	1.400.000
Power and signal cables installation	300.000
Air / gas handling and treatment installations	600.000
Scada system	300.000
Sum 1. Establishment costs………………………..	………………………5.950.000
Consultancy	800.000
Sum 2. Total establishment costs………………….	………………………6.750.000
Risø National Laboratory	1.550.000
Eurotec West project work, following up	1.500.000
Unforeseen costs, rebuilding costs et cetera	1.000.000
Sum 3. Total project costs………………………	……………………...10.800.000

Thus it is found, that the establishment costs for the plant are 6.750.000 DKK excl. VAT. The costs for following up, further development and control of plant functioning are 4.050.000 DKK excl. VAT including outlays, buffer for further development of the plant, rebuilding buffer et cetera.

Thus using round figures the investment costs for a 250 m^3 per day sludge treatment hydrolysis plant may be expected to be about 7 million DKK excl. VAT.

As the hydrolysed sludge is sanitised to a very high level of sanitation, it may be of interest to face the alternative costs for establishing a sanitation plant that sanitises the sludge according to the demands to controlled sanitation.

These establishment costs are sketched to the following level:

Sanitation plant including 2 parallel sanitation tanks:……………………….4.800.000 DKK

Thus the costs for establishing a sanitation plant amounts about 70 % of the costs of the hydrolysis plant. It should be mentioned that sanitation not contributes to the other benefits of the hydrolysis.

From a legal veterinary point of view this makes the sludge digestion plant comparable with the plant including the hydrolysis system.

7.2 Benefits from establishing hydrolysis plant

7.2.1 Qualitative benefits

The qualitative benefits from establishing hydrolysis system are as follows:

- the sludge is sanitised; the efficiency is quite much better than the legal demands to controlled sanitation which especially implies a profound effect on viability of some temperature resistant vira, spores and parasite eggs
- the need for power at the waste water treatment plant is reduced.

Besides the project has contributed to propose an alternative handling of the primary sludge by:

- utilising a minor part of the primary sludge the need for buying and to transport methanol to the plant for de-nitrification is eliminated.

The energy demands for the production, transport and handling of methanol are not included in the energy calculations.

7.2.2 Quantitative benefits

The values of establishing the hydrolysis system are:

Position	DKK / year
Produced biogas / power…………………………………………..	340.000
Produced biogas / heat…………………………………………….	0
Reduced sludge amounts……………….…………………………	445.000
Reduced power consumption for nitrification……………………..	110.000
Sum, quantitative benefits	895.000

Besides the project has contributed to propose primary sludge as an alternative to buying ethanol:

Position	DKK / year
Eliminated methanol costs………………………………………….	900.000
Reduced biogas production………………………………………	- 350.000
Net reduction from using primary sludge for de-nitrification………	550.500

As such the utilisation of primary sludge as an alternative to methanol reduce the biogas production somewhat more than gained from the efficiency of the hydrolysis plant. Whatever the financial benefit is clear.

7.3 Costs for running hydrolysis plant

The costs for running the hydrolysis system are:

Position	DKK / year
Power consumption………………………………………………....	195.000
Heat consumption…………………………………………………...	0
Maintenance and repair of machinery equipment…………………..	40.000
Yearly running and maintenance costs……………………………...	235.000

It ought to be mentioned, that the sales price for power is 600 DKK / MWh while the price for buying is 550 DKK / MWh.

Besides and to compare the system sanitation rate the alternative cost for running a sanitation plant treating sludge according to the demands to controlled sanitation:

Position	DKK / year
Power consumption…………………………………………………	135.000
Heat consumption………………………………………………...	0
Maintenance and repair of machinery equipment…………………...	30.000
Yearly running and maintenance costs……………………………...	165.000

Thus the energy costs to run a sanitation plant amounts about 70 % of the similar costs for the hydrolysis plant.

It cannot be expected, that a sanitation plant may have any influence on the biogas production or change nitrogen balances, why it is not comparable to the hydrolysis plant from a processing point of view.

7.4 Fees for handling of sludge

Esbjerg Renseanlæg Vest uses a contractor to take care of the produced sludge. As long as the sludge keeps the demands to content of organic priority pollutants and heavy metals the sludge is used for fertiliser.

For the calculations we assume, that all sludge is used for fertiliser. The costs to handle the sludge are 285 and 100 DK per tonnes for contractor and farmer receiving the sludge. This implies that the costs without and with hydrolysis plant are as follows having amounts according to chapter 5.2.1 de-watered to 20% dry matter:

Position	Without hydrolysis	With hydrolysis	Change DKK / year
Fee for contractor	4.505.000	4.175.000	330.000
Fee for farmer	1.580.000	1.465.000	115.000
Total fee	6.080.000	5.640.000	445.000

Referring to chapter 5.2.1 there is a marked deviation from the mass balance digested sludge amounts to the yearly quantified amounts. This deviation might become reduced during the ongoing changes in the plant running characteristics as noted in chapter 3.7.

7.5 Payback calculations

7.5.1 Standard conditions

The simple payback time based on the above calculations may be as follows excl. VAT:

Investment, DKK 6.750.000

Yearly balance in DKK / year:
Power production 340.000

Reduced power consumption for nitrification	110.000	
Reduced fee for sludge disposing	445.000	
Sum, ingoing	895.000	895.000
Power consumption	195.000	
Maintenance and repair	40.000	
Sum, outgoing	235.000	235.000
Yearly balance excl. man-hours		660.000
Simple payback time		10,2 years

Taking man-hours into account this simple payback time might be at the limit of acceptable.

7.5.2 Standard conditions with power consumption covered by own power production

The simple payback time based on the above calculations may be as follows excl. VAT:

Investment, DKK		6.750.000
Yearly balance in DKK / year:		
Power production sold	130.000	
Reduced power consumption for nitrification	110.000	
Reduced fee for sludge disposing	445.000	
Sum, ingoing	685.000	685.000
Power consumption	0	
Maintenance and repair	40.000	
Sum, outgoing	40.000	40.000
Yearly balance excl. man-hours		645.000
Simple payback time		10,5 years

Taking man-hours into account this simple payback time might be at the limit of acceptable.

7.5.3 Plant using primary sludge for de-nitrification

The simple payback time based on the above calculations may be as follows excl. VAT:

Investment, DKK		6.750.000
Yearly balance in DKK / year:		
Power production	- 10.000	
Reduced power consumption for nitrification	110.000	
Reduced fee for sludge disposing	445.000	
Value of methanol	900.000	
Sum, ingoing	1.445.000	1.445.000

Power consumption	195.000	
Maintenance and repair	40.000	
Sum, outgoing	235.000	235.000
Yearly balance excl. man-hours		1.210.000
Simple payback time		5,6 years

Taking man-hours into account this simple payback time may be objected as quite acceptable.

7.5.4 Plant added the value of sanitation

The simple payback time based on the above calculations may be as follows excl. VAT:

Investment, DKK		6.750.000
Investment in sanitation plant		4.800.000
Marginal investment for hydrolysis plant		1.950.000
Yearly balance in DKK / year:		
Power production	340.000	
Reduced power consumption for nitrification	110.000	
Reduced fee for sludge disposing	445.000	
Value power consumption for sanitation	135.000	
Sum, ingoing	1.030.000	1.030.000
Power consumption	195.000	
Maintenance and repair	40.000	
Sum, outgoing	235.000	235.000
Yearly balance excl. man-hours		795.000
Simple payback time		2,5 years

Whatever this simple payback time is quite acceptable.

7.5.5 Plant using primary sludge for de-nitrification and added the value of sanitation

The payback time based on the above calculations may be as follows excl. VAT:

Investment, DKK		6.750.000
Investment in sanitation plant		4.800.000
Marginal investment for hydrolysis plant		1.950.000

Yearly balance in DKK / year:

Power production	- 10.000	
Reduced power consumption for nitrification	110.000	
Reduced fee for sludge disposing	445.000	
Value power consumption for sanitation	135.000	
Value of methanol	900.000	
Sum, ingoing	1.580.000	1.580.000
Power consumption	195.000	
Maintenance and repair	40.000	
Sum, outgoing	235.000	235.000
Yearly balance excl. man-hours		1.345.000
Simple payback time		1,4 years

Whatever this simple payback time is quite acceptable.

8 Conclusion

The Esbjerg Vest waste water treatment plant deviates from other waste water treatment plants in having a very low ratio of excess biological sludge to primary sludge. This deviation has profound implications on the efficiency of the hydrolysis system, as the dry matter conversion efficiency from treating biological excess sludge is about 4 times higher than the efficiency from treating primary sludge.

For the time being the plant undergoes principal changes to the sludge handling, as the sludge age is under a profound reduction from between 40 to 70 days towards about 20 days. Besides experiments with using primary sludge for de-nitrification, as an alternative to methanol are under way. These changes may have profound influence on the amounts of biological excess sludge, as the amounts may rise and the mineralisation level may fall.

It may be possible to measure the changes on the amounts of sludge within this year. In any case it is expected, as mentioned, that the biological excess sludge amounts may rise and that the sludge may become much more suitable for hydrolysis and enhanced energy production.

The results included in this report are based on the existing conditions at the wastewater treatment plant, why the results may be objected as quite conservative.

Based on the well documented Risø National Laboratory results the processing efficiencies in full scale may be expected as follows:

- hydrolysis efficiency on primary sludge 10 % or higher
- hydrolysis efficiency on excess biological sludge 40 %
- (ammonium + ammonia)-N reduction 50 %.

Thus the balances may be changed as follows at the plant as is:

- sludge dry matter reduction 230 tonnes of TS per year or 1.150 tonnes of dewatered sludge
- enhancement of biogas production 240 tonnes per year or 220.000 m^3
- nitrogen N reduction 45 tonnes per year or 7 % of the total N load at the plant

The energy balances are found to be influenced as follows:

- power demand for nitrification is reduced with 200 MWh
- diesel oil demand for transportation is reduced with 24 MWh
- power production from enhanced biogas is 220 MWh

and the heat consumption is enhanced with between 330 and 2170 MWh depending on the establishment of heat exchangers to recover heat from the treated sludge.

Power and energy reduction from reduced circulation of wastewater for de-nitrification, from reduced amounts of sludge for dewatering, for elimination of the consumption of methanol for de-nitrification are not included in the energy balances.

The hydrolysis processing also sanitises the sludge. If the energy consumption from a standard sanitising plant is included in the calculations to value this secondary benefit, the energy balances becomes even more advantageous.

The cost-benefit analyses show, that:

- the simple pay-back time under unchanged conditions is in the order of 10 years
- if primary sludge is used for de-nitrification the simple pay-back time is about 6 years
- if the value of sanitising is included the simple pay-back time is between 1,5 and 2,5 years.

These calculations do not take the ongoing changes of the sludge handling into account. Whatever the case the changes may result in further advantages from utilising the hydrolysis system relating to as well sludge as nitrogen amounts.

Based on the obtained results the participants of the project may recommend the phase 2 initiated and the hydrolysis plant established as an experimental full scale at the Esbjerg Renseanlæg Vest waste water treatment plant.