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UTILIZATION OF CAST SEAWEED AND WASTE FROM PECTIN PRODUCTION FOR ANAEROBIC DIGESTION

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SUMMARY: The paper describes a preliminary study on the environmental consequences of realizing a biogas plant using locally available biomass fractions in Solrød, Denmark. The biomass, which will be used at the plant, will consist of: cast seaweed (app. 20,000 tons year^{-1}), waste from pectin production (app. 80,000 tons year^{-1}) and manure (app. 50,000 tons year^{-1}) and other materials in lesser amounts. Methane potentials of the two "new" biomass fractions were measured to predict their contribution to the biogas production. Measured methane potentials were: Pectin waste: 370 to 460 ml CH_4 g VS^{-1} and cast seaweed (winter sample): 118 ml CH_4 g VS^{-1}. The predicted annual biogas production of the plant was 5.4 million m^3 CH_4. An environmental assessment concluded that a biogas plant using the aforementioned organic materials will reduce greenhouse gas emissions between 25,000 tons CO_2 year^{-1} and 40,000 tons CO_2 year^{-1} depending on the type of energy utilization. Reduction of nutrients in the coastal zone by removal of seaweed was found to be of high value.

1. INTRODUCTION

Expanding production of renewable energy has been high on the national and local political agendas in Denmark in recent years. In 2008, the Danish government assigned a working group of experts from various fields named the "Danish Commission on Climate Change Policy", to present a solution on how to phase out use of fossil fuels in coherence with the ambition of the European Union to reduce green house gas emissions by 80 to 95 % by the year 2050 compared to 1990. The working group presented their results in 2010, where after the Danish government presented their "Energy Strategy 2050" based partly on the recommendations made by the working group. Expansion of biomass use as a source of renewable energy is mentioned as a key part of transforming energy supply in Denmark away from use of fossil fuels. Among concrete, recent state initiatives to expand biogas production are: fixed electricity price from biogas above market price, state subsidy of biogas plant construction costs and making it mandatory for each

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Danish municipality to assign suitable locations for biogas plants.

The municipality of Solrød is situated 20 km south of Copenhagen, Denmark alongside the strait of Øresund. As a signatory of the Covenant of Mayors (an EU initiative to support local governments to reduce greenhouse gas emissions), the city council has passed a Strategic Energy Action Plan, where concrete actions and their projected effects were listed. The overall objective was to reduce total green house gas emissions in the municipality 50 % in 2025 compared to the baseline year 2007. One of the most important actions listed was construction of a biogas plant using locally available materials – including cast seaweed. The bay of Køge Bugt is, like many other coastal waters in Denmark, nutrient rich. This leads to a large amount of seaweed washing up on the shores of the bay each year. A thick "blanket" of decomposing seaweed sometimes extends 50 meters into the bay. Due to bad odor, and since the seaweed prohibits recreational use of the sandy beaches, local inhabitants have a strong wish to have the material removed from the beach and water. This is now being done, causing several thousands of tons of waste which needs to be treated each year.

This paper concerns a preliminary study carried out in 2009-2010 by the municipality in cooperation with universities, consultants and local businesses to define possible biogas plant concepts and assess these concepts environmental and economical consequences. The focus here is on the environmental effects.

2. PROJECT FRAMEWORK

2.1 Aims of the study

The overall aim of the study was to develop a bioenergy concept in a region with a relatively low amount of livestock, and thereby manure, by including "alternative" biomass fractions such as cast seaweed and organic waste from production of pectin and carrageenan. Specific aims included:

- determination of availability and suitability of organic materials for anaerobic digestion
- optimization of collection and pretreatment of organic materials
- development of technological and economical optimal incorporation of energy production in the local energy supply infrastructure
- environmental assessment
- evaluation of possibilities of utilization of degassed biomass

Figure 1. Beach cleaning at Solrød Strand, June 2011. Beach cleaning in the summer period produces several thousand tons of waste annually

2.2 Methane potential of seaweed and pectin waste

Use of seaweed for energy production has been the subject of several studies. Studies have concerned both cast seaweed, which washes up at beaches as in this study, or have focused on growing macro algae as an energy crop.

Hansen, 1982 studied macro algae species native to Scandinavian waters in fermentation studies. Measured methane potentials were 350-480 ml CH_4 g VS^{-1}. In the batch experiments, which were conducted at mesophilic temperature, the gas production was rapid, and almost completed after 12-15 days (Hansen, 1982). Chynoweth et al., 1987 reported measured methane yields of the species Macrocystis pyearifera (common name: Giant kelp) to be 290-350 ml CH_4 g VS^{-1}. In a recent study on methane potential from cast seaweed in southern Sweden, methane potentials of locally collected unspecified seaweed was measured to be 120 ml CH_4 g VS^{-1} (Nkema and Murto, 2010).

Reported measurements of methane potentials of pectin waste are sparse. However, Bafrani, 2010 reported yields of 360 ml CH_4 g VS^{-1} in batch experiments after 30 days of fermentation of citrus waste, which had undergone pectin recovery.

Evaluations performed for the pectin and carrageenan production facility, which have participated in this study, concluded that pectin waste is not usable as mono-substrate for anaerobic digestion. Pilot scale studies showed, however that co-digestion with manure is feasible. Since their waste materials have to be fed to a biogas reactor as part of a mix, the pectin and carrageenan production plant has decided not to proceed alone in energy utilization of the waste in spite of a promising measured methane potential.

3. METHODOLOGY

3.1 Availability assessment of biomass fractions

A local entrepreneur has collected cast seaweed along the entire 3.7 km coastline in Solrød Municipality in recent years. According to the entrepreneur, the amount collected in 2009 was 4,000 tons of material corresponding to 1080 tons km^{-1}. Three sampling campaigns were done to assess the composition of cast seaweed with regards to contents of dry solids (DS), volatile solids (VS) as well as content of total nitrogen, phosphorous and potassium. One of these campaigns were performed when the beach was being cleaned to evaluated the composition of material collected, as it was done in practice in Solrød at the time.

Interviewing the production manager at the local pectin and carrageenan manufacturer provided data on amounts and compositions of pectin and carrageenan wastes, which were available for anaerobic digestion.

The Danish Ministry of Food, Agriculture and Fisheries maintains a database on livestock covering every farm in Denmark. This data is publicly available, and was used to determine the number of pigs and cattle within a radius of 15 km of the proposed site of the biogas plant. Multiplying the number of cattle and pigs retrieved from the database (online at http://www.glr-chr.dk) with data from the same authority on average amount of manure per animal, a potential for pig and cattle manure for use for biogas production was found.

3.2 Methane potential measurements

Methane potentials of pectin waste, carrageenan waste and cast seaweed collected in Solrød in January, 2010, were measured in batch test according to principles described in Hansen et al., 2004. 1100 ml bottles fitted with butyl rubber lids were used for the tests. The bottles were flushed with nitrogen prior to addition of sample and inoculum. The inoculum used was sludge from a biogas reactor at Research Center Foulum. The bottles were kept at 35 ± 0.5 °C throughout the experiment. All tests were run in triplicate, and headspace concentrations of CO_2 and CH_4 were measured using gas chromatography.

A second measurement of methane potential of pectin waste was done at a different laboratory. Here 540 ml bottles were used with butyl rubber lids. The bottles were kept at 55 °C, and sludge from Snertinge Biogas plant was used as inoculum. Tests were run in triplicate.

3.3 Environmental assessments

As part of the project, three biogas plant concepts were developed, which differed in type of energy utilization: Use for process energy at the pectin and carrageenan production facility (Concept A), Biogas upgrade and supply to the natural gas grid (Concept B) and production of electricity and heat in a gas engine, where the heat energy is supplied to a local district heating grid. These plant concepts are illustrated in Figure 2.

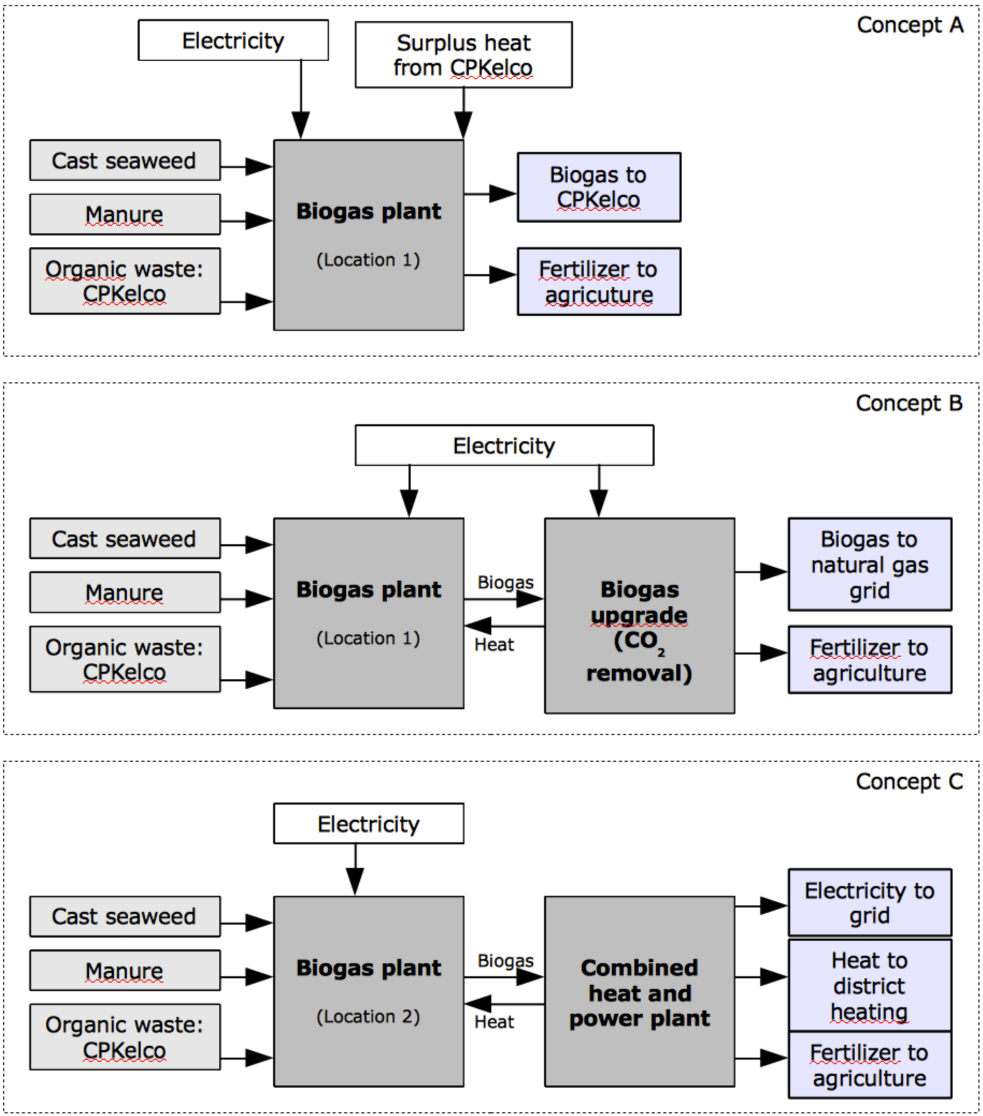

Figure 2. Conceptual models of utilization of cast seaweed, manure and organic waste (mainly waste from production of pectin) for biogas production

To evaluate the effects on green house gas emissions of each of the three plant concepts, the baseline method was used where positive and negative effects were quantified in case of constructing a biogas plant compared to the present situation. Positive effects included in the calculations were substitution of fossil fuel use, substitution of fertilizer with degassed biomass, and reduction of methane emissions caused by anaerobic decay of seaweed and other biomass fractions. Negative effects included electricity use at the biogas plant, and transport of biomass to and from the biogas plant. With regards to evaluation of green house gas effects, the following values were used:

- CO_2 emission from transport of biomass to and from biogas plant: 0.721 kg CO_2 tonkm^{-1}
- CO_2 emission from use of natural gas: 0.204 kg CO_2 kWh^{-1}
- CO_2 emission from use of heating oil: 0.266 kg CO_2 kWh^{-1}
- CO_2 emission from the local electricity grid: 0.490 kg CO_2 kWh^{-1} (DONG, 2010)
- CO_2 emission from production of fertilizer: 7.031 kg CO_2 kg N^{-1} and 1.052 kg CO_2 kg P^{-1} (Wood & Cowie, 2004)
- Uncontrolled release of methane from anaerobic decay of biomass: 0.053 kg CH_4 kg biomass^{-1} year^{-1} = 1.113 kg CO eq. kg biomass^{-1} year^{-1} (DMU, 2009)

4. RESULTS AND DISCUSSION

The amounts of locally available organic materials suitable for anaerobic digestion were quantified. The available amounts were: pectin waste (77,000 tons year^{-1}), carrageenan waste (2,400 tons year^{-1}), cast seaweed from Solrød and neighboring municipalities (22,200 tons year^{-1}), manure from pigs and cattle (52,800 tons year^{-1}) and horse manure and grass cuttings in lesser amounts. Chemical analysis showed that the content of heavy metals and other compounds will allow for use of the degassed material as fertilizer. However, in one sample of cast seaweed, the content of cadmium was above allowed concentrations, which means that it’s possible that not all collected seaweed can be used at the biogas plant. Methane potentials were used to predict the biogas plants production of gas, assuming that 75% utilization of the methane potential will be achieved (Deublein & Steinhauser, 2008).

Measured methane potentials were: Pectin waste: 370 to 460 ml CH_4 g VS^{-1}, and cast seaweed (winter sample): 118 ml CH_4 g VS^{-1}. The first test of pectin waste was done at mesophilic temperature and yielded 370 ml CH_4 g VS^{-1} which is close to the value reported by Bafrani, 2010 (360 CH_4 g VS^{-1}). The second test, which was done under thermophilic temperature, yielded a somewhat higher result: 460 ml CH_4 g VS^{-1}. To estimate the biogas production, the average of the two values was used in the calculations. The methane potential of cast seaweed (118 ml CH_4 g VS^{-1}) was in the low range compared to other studies (see section 2.2). An explanation for this can be that the sample used was collected in January, which meant that most of the seaweed had been deposited at the beach many months before sampling, and had probably undergone partial decay.

Table 1 shows the predicted gas production, based on methane potentials of the different waste fractions. The bulk of the biogas production will be caused by digestion of pectin waste, which is due to a relatively high methane potential, high material availability and a high content of volatile solids (VS: 98-99%). Analysis of collected cast seaweed using the method used now suggested that most of the dry matter was inorganic (sand). In the calculations of predicted methane production it was therefore assumed, that a large fraction of the material was sorted before anaerobic digestion, and the sand fraction was returned to the beach. If the seaweed supplied to the biogas plant is on average more recently washed on shore than the January sample analyzed, it may cause the actual biogas production from seaweed to be higher.

Table 1. Expected biogas production based on methane potentials of materials and availability assessment of the materials

Biomass fraction	*Supply* [tons year^{-1}]	*Dry matter* [tons year^{-1}]	*Methane potential* [$m^3CH_4tonDS^{-1}$]	*Expected biogas production* [$m^3CH_4year^{-1}$]
Cast seaweed	22,200	13,054	21.5	210,741
Pectin waste	77,000	12,335	409.4	3,787,518
Carrageenan waste	2,400	563	71.6	30,222
Pig manure	49,700	3,380	370.0	1,250,452
Cattle manure	3,100	288	260.0	74,958
Horse manure	330	158	400.0	63,360
Grass cuttings	85	26	400.0	10,540
Total	154,815	29,804	227.2	5,427,790

Based on the projected energy production described above, and taking into account the factors described in section 3.3, net reduction of greenhouse gas emissions were calculated for each of the three plant concepts illustrated in Figure 2.

Table 2. Reductions of green house gas emissions by implementing each of the three plant concepts. Negative values denote increase in emissions compared to the baseline

Cause of decrease or increase in greenhouse gas emissions	*Plant concept A (substitution of natural gas use at pectin production facility)* [tonsCO_2eq. year^{-1}]	*Plant concept B (Upgrade of biogas to the natural gas grid)* [tonsCO_2eq. year^{-1}]	*Plant concept C1* (Production of electricity and heat)* [tonsCO_2eq. year^{-1}]	*Plant concept C2** (Production of electricity and heat)* [tonsCO_2eq. year^{-1}]
Production of electricity	0	0	12,502	20,666
Production of heat	4,630	13,936	6,374	6,374
Substitution of natural gas use at pectin production facility	12,266	0	0	0
Electricity use	-379	-2,595	-379	-379
Substitution of use of fertilizer	2,962	2,962	2,962	2,962
Reduction of methane emissions	11,921	11,921	11,921	11,921
Transport of biomass	-944	-944	-1,402	-1,402
Net reduction	30,460	25,280	31,980	40,140

* Substitution of mixed electricity production; ** Substitution of coal based electricity production

Assessments of net reduction of green house gas emissions suggest that production of electricity combined with production of heat for supply to the local district heating grid will result in the highest net reduction in greenhouse gas emissions. As seen in Table 2, two scenarios were analyzed with regards to electricity production: "C1", where it is assumed that produced electricity substitutes production with the average associated greenhouse gas emission as it is today. For "C2" it is assumed that production substitutes coal powered production, which will correspond to the Danish Energy Strategy mentioned in the introduction, where fossil fuel based energy sources are phased out, and supply of renewable energy (such as biogas) is increased. The least favorable plant concept is upgrade of biogas for injection to the natural gas grid. This is partly due to a considerable electricity use of the upgrade process.

The assessment shows that reduction of uncontrolled methane emission results in app. 30% of the net reduction of green house gas emissions. The calculations behind these figures are, however, based partly on rough estimates.

A valuable environmental benefit is the removal of nutrients from the coastal area caused by removal of cast seaweed. From assessment of amounts and measured nutrient content of the collected seaweed it was found that collection of seaweed from Køge Bugt can remove 120 tons N year^{-1}. The entire input to Køge Bugt of nitrogen including both natural and anthropogenic sources is estimated to be app. 1,800 tons N year^{-1} (Danish EPA, 2010). An action plan to reduce the nutrient load to Køge Bugt is presently in the hearing process. The action plan lists initiatives that will reduce the nitrogen load to Køge Bugt by app. 86 tons N year^{-1} at a yearly cost of 5.7 million €. The cost of collecting and pre-treating cast seaweed for production of biogas is estimated to be app.1/10 of that, and furthermore result in revenue due to energy production.

Based on the findings of the preliminary study described in this paper, the City Council of Solrød has decided to proceed in constructing a biogas plant based on the mentioned waste fractions. A formal agreement between the municipality and the pectin and carrageenan production facility has been signed, ensuring that pectin waste will be supplied to the biogas plant. Economic evaluation of the concepts showed that a biogas plant using the described mix of organic material can be built and operated with a sound economic performance. The next steps towards realization of the bioenergy concept include testing the mix of materials in a pilot scale digester, preparation of a final, detailed plant design, securing contracts with biomass suppliers and energy companies, securing necessary permits and establishing a bioenergy company, which will be responsible for building and operating the biogas facility.

5. CONCLUSIONS

A bioenergy concept was developed for Solrød Municipality, where cast seaweed (app. 20,000 tons year^{-1}), waste from pectin production (app. 80,000 tons year^{-1}) and manure (app. 50,000 tons year^{-1}) will be used to produce biogas (5.4 million m^3 CH_4 year^{-1}). Waste from pectin production was found to be of high value for anaerobic digestion. Several positive effects of realization of the biogas plant were identified: net CO_2 reduction (25,000 to 40,000 tons CO_2 year^{-1}), utilization of nutrients from cast seaweed and pectin waste, income from energy production, improving conditions for recreational use of the local beaches and removal of considerable amounts of nutrients from the local coastal waters, which suffer from eutrophication.

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REFERENCES

Bafrani, M.P. (2010). Citrus Waste Biorefinery: Process Development, Simulation and Economic Analysis. Ph.D. thesis. Chalmers University of Technology.

Chynoweth D.P., Fannin K.F. and Srivastava V.J. (1987) Biological gasification of marine algae. In Bird K.T., Benson P.H. (eds). Seaweed cultivation for renewable resources. Elsevier, Amsterdam: 285-295

Cooperative Research Centre for Greenhouse Accounting. For IEA Bioenergy Task 38. Accessed at http://www.ieabioenergy-task38.org/publications/

Danish EPA. (2010). Forslag til vandplan. Hovedopland 2.4 Køge Bugt. ISBN: 987-87-92668-54-7. Report (in Danish)

Deublein D. and Steinhauser A. (2008). Biogas from waste and renewable resources – An introduction. ISBN: 978-3-527-31841-4: Wiley-VCH Verlag Gmbh & Co

DMU, 2009. Denmark's National Inventory Report 2009. Emission Inventories 1990-2007 – Submitted under the United Nations Framework Convention on Climate Change. Århus University

DONG, 2010. General Dekleration 2009 - Eastern Denmark.

Hansen G. (1982). Methane production from marine, green macro algae. Resour. Conser., 8, 3, 185-194

Hansen T.L., Schmidt J.E., Angelidaki I., Marca E., Jansen J.l.C., Mosbæk H., Christensen T.H. (2004). Method for determination of methane potentials of solid organic waste. Waste Management, 24, 4, 393-400

Nkemka V.N., Murto M. (2010). Evaluation of biogas production from seaweed in batch tests and in UASB reactors combined with the removal of heavy metals. J. Environ. Manage. 91, 7, 1573-1579

Wood S. and Cowie, A. (2004). A review of greenhouse gas emission factors for fertilizer production. Research and Development Division, State Forests of New South Wales.