TOP–NEST

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Value chain analysis of biofuels: Cambi

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Cambi describes themselves as 'a leading provider of technology to convert biodegradable material to renewable energy, with high quality in deliveries, competence and expertise.' Cambi was originally founded by Glommen Skogeierforening and has been involved in the development of environmental technology since 1989. In 1992, Petrol Holding AS took over as the main shareholder. After a capital increase in 1997, Cambi ASA established. Ownership structure was changed again in 2006 and major shareholders now include Petrol AS, PEBA AS, and Mallin Venture AS, in addition to the employees. Cambi is today a multi-national company with several plant operations in Europe and the US. Its main focus is on treatment of bio solids from municipal and industrial sludge. Nevertheless, it has also a growing business in connection with treatment of bio waste from organic leftovers, and is currently engaged in research programs related to treatment of biomass (bio renewables) from straw, wood chips, agricultural waste, animal by-products, sea weed and micro algae.

1. Basic input/output structure

1a. Main activities/segments

Feedstock provisioning

Cambi is primarily a producer of equipment for biogas extraction, and the main feedstock that its equipment relies on is biosolids, and to a lesser degree bio-waste and biomass[1].

Biosolids: Cambi's plants produce biogas mainly from what the wastewater industry calls 'biosolids.' 'Biosolids' are the solid "leftovers" after municipal and industrial sewage has undergone treatment to remove disease causing pathogens and volatile organic matter. This treatment process is usually carried out in an oxygen enriched environment at a wastewater treatment plant tank, where bacteria and other microorganisms digest the organic matter. The biosolids consist primarily of the remains of the microorganisms that have cleaned the sewage and can be processed further to create biogas and fertilizer.

Bio-waste: Some of Cambi's plants also produce biogas from bio-waste, e.g. organic leftovers such as food waste and slaughterhouse residues. It is able to process a wide range of organic leftovers, including categories II and III (high and low risk) animal by-products.

Biomass: Cambi also started up biogas production from bio mass, such as straw, wood chips, agricultural waste, animal by-products, sea weed and micro algae. Cambi's treatment of biomass (bio renewables) seems to be mostly at an experimental stage.

Processing

Cambi's plants produce biogas mainly from biosolids, and to a lesser degree bio-waste and biomass. The main processing step for all of these categories of organic material is anaerobic digestion, where the biosolids, biowaste or biomass is converted into biogas. Cambi's key technology is a patented 'thermo hydrolysis process' (THP) that pre-treat the organic material before anaerobic digestion and thereby increase the yield of biogas (or bio methane content). The thermo hydrolysis process is used in the processing of all types of organic material.

[1] Source: www.cambi.no & Cambi's Annual report 2008

Biosolids: Cambi's plants extracts biogas from industrial and municipal sewage in several stages[2]. In the **first stage**, the sewage usually goes through an 'aerobic activated sludge' process, where bacteria and other microorganisms digest the organic matter, in an oxygen enriched environment at a wastewater treatment plant tank. The result of this process is pollutant "free" water that can be discharged into rivers and biosolids which consist of solid leftovers and the remains of the microorganisms that have cleaned the sewage. In the **second stage**, the biosolids undergo a thermo hydrolysis pre-treatment, where the biosolids are first led into a 'reactor' that heats the bio solids to 165ºC before they are swiftly transported into a 'flash tank' with lower temperature (102º C) and pressure. The drop in pressure and temperature destroys cell structure/organic materials and dissolves naturally occurring cell polymers (a form of protein) into an easily digestible feed for anaerobic digestion and thereby increase yield of biogas. In the **third stage**, the biosolids undergo an anaerobic digestion process, in an air-tight tank where biogas is extracted from the biosolids. The biogas usually consists of about 45-85% methane (CH_4) and 15-45 % carbon dioxide (CO_2), in addition to traces of hydrogen sulphide, ammonia and nitrogen gas. A **fourth stage** is often needed when the biogas is used for vehicle fuel. In this fourth stage the biogas is upgraded to biomethane – which usually consists of at least 97% pure methane – through processes such as water scrubbing or pressure swing adsorption[3] (see model below).

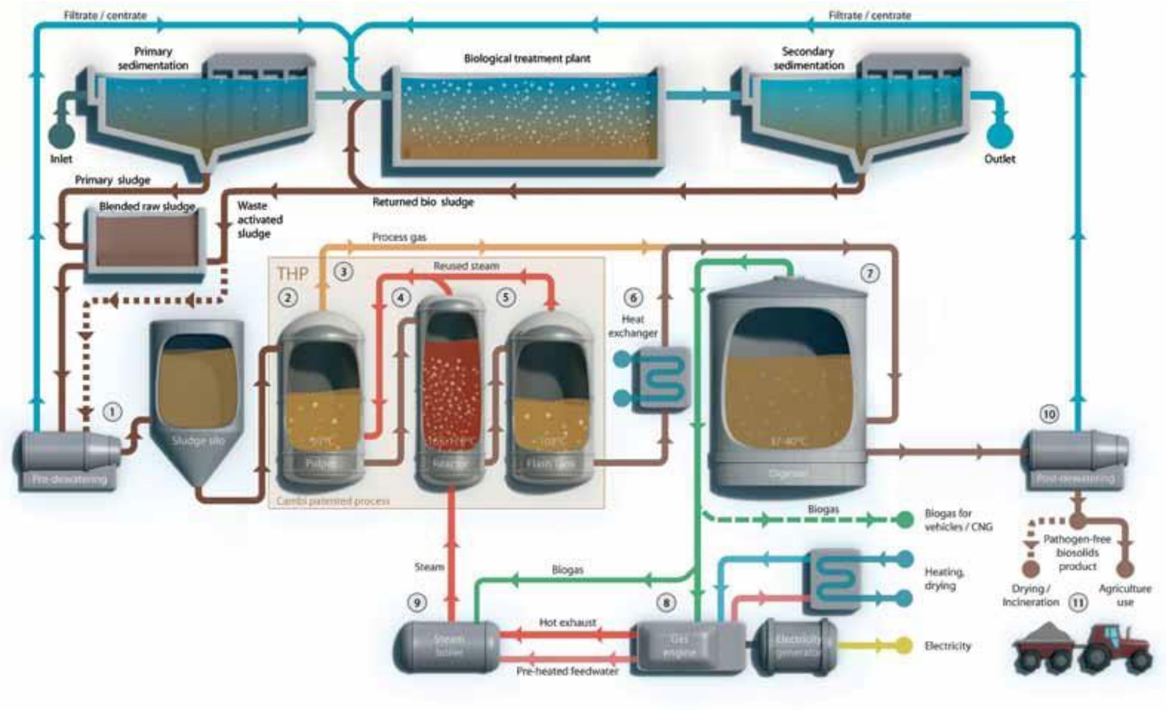
Bio-waste: Cambi extracts biogas from biowaste in much the same way as biosolids. The only difference is the first stage – where the biowaste is cleaned of non-organic material and rather being put through an 'aerobic activated sludge' process. The biowaste then goes through the same processing stages as the biosolids.

Biomass: Cambi also extracts biogas from biomass in much the same way as biosolids, although the first stage is again different. Cambi's treatment of biomass (bio renewables) is mostly at an experimental stage.

[2] See Seadi et al. (2008) and Jørgensen (2009) for an explantion of biogas extraction methods and www.cambi.no for the company's technological solutions

[3] See Peterson & Wellinger (2009) for an explanation of biogas upgrading technologies.

Model of Cambi's processing plant of biosolids*:



* Source: www.cambi.no, Biosolids brochure

Use of waste products

Biogas production is in itself based on waste products – namely biosolids, biowaste and some types of biomass (biorenewables). Nevertheless, the extraction of biogas from biosolids, biowaste and biomass leads again to new waste products – namely heat and sludge.

The conversion rate of biosolids, biowaste and biomass to biogas is far below 100%. The conversion rate of biosolids to biogas for instance is usually somewhere between 40 and 60%. The implication of this is that biogas production leaves a lot of waste products – usually called sludge (or treated biosolids) – that needs to be disposed of[4]. This sludge can be incinerated or buried in landfills, but these options are costly and add no value. Using the sludge as soil on farmland or converting it to fertilizer are other options. These options are more costly, but they provide some value added for society. The production of biogas also produces a lot of heat. This heat can be channeled back into the production process or be used to produce electricity or combined power and heat.

There are many potential technologies on the horizon that might increase the use of (or reduce) waste products from biogas extraction – some of these include nutrient capturing technologies to make better fertilizers and other include technologies such as molecular manipulation that improve the conversion rate of biosolids to biogas[5].

[4] See Seadi et al. (2008) and Jørgensen (2009)
[5] See Peterson & Wellinger (2009)

Integration with other energy production technologies

Since bio-methane (upgraded biogas) is chemically identical with natural gas (fossil-based gas), it can use the same transportation infrastructure and be used for the same applications as natural gas, such electricity generation, water heating, space heating, cooking and vehicle fuel. The biogas can also be turned into electricity through the use of fuel cells, combustion engine or gas turbines and transported as electricity over the electricity grid or as combined power and heat if the infrastructure is available.

End use

Biogas needs to be upgraded to biomethane to be used as fuel for vehicles[6]. Biogas frequently contains toxic gases such as hydrogen sulphide and volatile siloxanes that are damaging to engines and often have too high a content of (non-combustible) carbon dioxide content to effectively propel vehicles. Biogas is usually upgraded to biomethane through either one of two technologies – water scrubber technology or pressure swing adsorption technology. Once the biogas is upgraded to biomethane, it usually consists of at least 97% pure methane and can be used as a substitute for natural gas. (Although natural gas usually has a slightly higher energy output because it also contains higher hydrocarbons such as ethane, propane and butane.)

Biomethane can be used to power both fuel-cell and internal combustion (both petrol and diesel) based vehicles. To make use of biomethane (and natural gas) in existing combustion based vehicles, they need to be fitted with new fuel tanks that can store biomethane in a compressed form. Further modifications, however, are few and usually not very costly, and the vehicle can also be turned into flexifuel vehicle that can run on both biomethane and petrol/diesel. There are also vehicles produced specifically to run on biomethane/natural gas, which provide an environmentally friendly alternative to petrol/diesel based vehicles with a longer range than for instance electric cars. Biomethane can also be used to power fuel-cell based vehicles, although this technology seems to be more at an experimental stage now. When these fuel-cell based vehicles arrive, they will most likely be hybrids, which carry both methane tanks and battery, since the fuel cells need to be warmed up to function properly. In addition, fuelling station need to be equipped with tanks that can store biomethane in a compressed form.

Distribution, marketing and sales

Cambi primarily produces plants and provide operational support. It is usually municipalities that are responsible for distribution, marketing and sales of the biogas/biomethane.

[6] See for instance Aebiom, European Biomass Association's 'A Biogas Road Map for Europe' for further explanations on this issue.

Biogas from the facility in Oslo is used in public busses and renovation trucks in the Oslo municipality

Source: Klitkou

1b. Main supporting activities

Cambi is undertaking a large number of research projects on converting biomass to energy and fertilizer. Many universities in Europe and USA are engaged with analysis of Cambi thermally pretreated lignocellulosic material. A number of PhD students are working on optimization of pretreatment conditions, maximizing nutrient value of biofertilizer and perform life cycle assessments on sustainability with the Cambi process. Cambi have invested in several test rigs enabling flexible and advanced pretreatment of various feedstocks, e.g. straw, wood chips, agricultural waste, animal by-products, sea weed and micro algae.

Cambi has since 1995 been involved in several Norwegian Research Council funded research projects involving development of pre-treatment processes, adoption of new feedstock and production and use of bio pellets.

1c. Type of companies involved in each segment

Feedstock provisioning

Feedstock provisioning for biogas production is usually carried out by municipalities. To produce biogas from biosolids economically, the biogas plants needs to be located near wastewater treatment facilities and the wastewater treatment facilities need to process a fairly large amount of sewage. Cambi states that it can build biosolid plants for populations upwards from 150,000. Since these wastewater facilities are usually operated by municipalities, the municipalities are primarily responsible for feedstock provisioning. The same is the case for biowaste, since municipalities are usually responsible for waste management.

Processing (biosolids and biowaste treatment)

Cambi has operations in many other countries including Norway, Denmark, UK, Poland and the US. At the end of 2008, there were 17 Cambi plants were operating in different markets and three further plants under construction. Most of Cambi’s activities are related to treatment of bio solids. But Cambi is increasing its activity with regards to biowaste treatment as well. Cambi states that they have set up several test rigs in relations to its research activities on treatment of biomass (see Geographical scope).

1.d. Lead firms

Since the municipalities take on an important role as supplier of feedstock, producer and potential user of biogas, it is difficult to determine the lead firms in the biogas industry/ wastewater industry. Cambi provides equipment for one type of wastewater treatment where the sludge is turned into biogas, but other options exist where the sludge is simply disposed of on landfills or incinerated. In this sense, the Cambi is part of a wider industry that competes against companies providing other type of wastewater solutions.

2. Key technologies

2.a. Technologies for main and supporting activities

Cambi produce biogas mainly from biosolids, and to a lesser degree bio-waste and biomass. The main processing technology used for all of these types of organic material is anaerobic digestion – in which the biosolids, biowaste or biomass is converted to biogas in an oxygen depleted environment. Anaerobic digestion is not a new technology or a technology unique to Cambi. Cambi's key technological innovation is its patented 'thermo hydrolysis process' (THP), which pre-treat the organic material before anaerobic digestion and thereby increase the yield of biogas (or bio methane content). Cambi uses the thermo hydrolysis process is used in the processing of all types of organic material and gives the following description of the technology:

> "Cambi THP is the high-pressure steam pretreatment of municipal and industrial sludge and biowaste before anaerobic digestion. The Cambi process disintegrates and liquefies cell structures and other organic materials, which become more readily available for biodegradation. The THP therefore yields significantly more biogas over conventional anaerobic digestion[7]."

The Cambi claims that its THP plants are highly energy efficient with low operating costs and that they generate significantly more energy than they consume. Cambi also points out that THP was ranked the best available sludge treatment technology in two independent papers presented at the 13th European Biosolids & Organic Resources Conference, Manchester, November 2008[8].

2.b. Assessment of technological development stage

Anaerobic digestion is a process that occurs naturally in nature (swamps) and it has been used by humans since the mid-1800s to produce biogas (the first anaerobic digester was allegedly built by a leper colony in Nombay, India, in 1859). Anaerobic digestion itself can be described as a mature technology, but it is still possible to improve the process in terms of yield.

Cambi's thermo hydrolysis process (THP) for pre-treatment of organic material is a younger technology. But it has been in use since the mid-1990s and is described by Cambi as a proven and reliable technology.

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[7] Cambi's Annual report 2008
[8] www.cambi.no

2.c. Is the technology disruptive or path-following/incremental?

Cambi's thermo hydrolysis process (THP) provides increased yield of biogas from organic material. It does not provide a qualitatively different product or constitute a radically different process of producing biogas. It can therefore best be described as incremental.

2.d. Market characteristics

Cambi's market is complex. Cambi provides equipment and operational support for plants that can convert biosolids and biowaste into biogas. In terms of its primary market as a supplier of wastewater treatment and waste management equipment, it competes against supplier of other solutions that does not necessarily involve production of biogas.

Cambi is also indirectly dependant on the market for biogas, and the market for biogas crosses into the market for other energy carriers. Since bio-methane is chemically identical with natural gas (fossil-based gas), it can be used for the same applications as natural gas – such as electricity generation and vehicle fuel. And untreated biogas can also be turned into electricity through the use of fuel cells, combustion engine or gas turbines and transported as electricity over the electricity grid or as combined power and heat when the infrastructure is available. In this sense, the demand for biogas coincides with the demand for natural gas, electricity and combined power and heat.

2.e. Energy and environmental performance

Unlike the natural gas, the methane extracted by Cambi is part of the natural methane cycle and does not add to greenhouse gases to the atmosphere.

Although Cambi does not provide any systematic statistics of environmental performance, it does state that its thermo hydrolysis process (THP) ensures:

- 50-65% of the organic matter (Volatile Solids – VS) in sludge converted to biogas
- High quality biogas, rich in methane, low in H2S
- Ideal for green electricity, as renewable vehicle fuel, or substitute for natural gas

3. Geographic scope

Although Cambi is a Norwegian company, it has operations in many other countries as well, including Denmark, UK, Poland and the US. In the annual report for 2008, Cambi's operations were summarized in the following way:

> "*At the end of 2008, 17 Cambi plants were operating in different markets with a further 3 plants under construction. These plants treat biosolids and waste from more than 10 million people or approx. 300.000 tons dry solids (DS) a year. All together the plants produce 660 GWh renewable thermal energy every year which is equal to 220 GW h green electricity. This renewable energy production replaces 220,000 tons fossil CO2-emission from fuel each year.*"

Most of Cambi's activities are related to treatment of bio solids. But Cambi is increasing its activity with regards to biowaste treatment as well. Currently there are only three plants that treat bio waste, in Verdal, Lillehammer and Oslo. Cambi states that they have set up several test rigs in relations to its research activities on treatment of biomass, but it does not state where these test rigs are located. The following table shows Cambi's operations around the world:

Cambi Plant Locations*:

Country	Locations	Treatment
Norway (Cambi AS):	Verdal	Biowaste/Biosolids
	Hamar	Biosolids
	Lillehammer	Biowaste
	Drammen	Biosolids
	Oslo	Biowaste
Demark (Cambi Denmark):	Fredericia	Biosolids
	Næstved	Biosolids
UK/Ireland (Cambi UK Ltd.)	Aberdeen	Biosolids
	Chertsey	Biosolids
	Dublin	Biosolids
	Milton Keynes	Biosolids
	Tees Valley	Biosolids
	Whitlingham	Biosolids
	Cardiff	Biosolids
	Afan	Biosolids
	Davyhulme	Biosolids
	Riverside	Biosolids
Poland (Cambi rep. office)	Bydgoszcz	Biosolids
US (Cambi Inc.)	Washington DC	Biosolids

* Source: www.cambi.no

4. Governance

The governance structure is complicated since the municipalities take on an important role as supplier of feedstock, producer and potential user of biogas.

5. Institutional context

Since the introduction of a ban on biodegradable waste (such as paper, tree waste and food waste) being placed in landfill sites in July 2009, several municipalities in Norway have introduced or are about to introduce more environmentally friendly forms of waste treatment that turn organic waste into energy, biogas and fertilizer.

EU's landfill directive (Council Directive 1999/31/EC) includes ever stricter thresholds for the phasing out of biodegradable waste to landfills. The directive aims to utilize the waste resources in a better way and to reduce the emissions of harmful greenhouse gases from disposal. The consequences of this directive are increased demands for treatment capacity in Europe.

EU´s "Animal By-Products Regulation". One key factor of this directive is the requirement that waste from slaughterhouses and food producers have to be treated under high temperature for a specific time in order to avoid the spread of disease (different temperatures for different classifications).

Cambi received the internationalization prize by "Skaperkraft" in 2011.

Key figures

Cambi AS:

Income statement*	2010	2009	2008	2007	2006
Total revenues	211 298	103 978	174 349	194 210	89 177
Operating results	28 020	13 413	8 949	10 614	5 438
Profit before tax	24 072	11 689	13 015	13 151	6 843
Profit	17 485	7 489	9 859	9 786	5 107
Salery	29 532	25 197	20 753	12 860	10 802

* 1000 NOK

References

Al Seadi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., Volk, S., & Janssen, R. (2008). *Biogas handbook: BiG>East Biogas for Eastern Europe*. Esbjerg: University of Southern Denmark.

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