Dall Energy
New biomass technologies
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Date 09 May 2019

Journal no. 64011-0049

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EUDP Demonstration Project

EUDP
Energiteknologisk udvikling og demonstration

Final Report

Sustainable Biomass Heat & Power in Sindal, Denmark

1.0 CONTENTS

1.1 PROJECT DETAILS

Project title	Sustainable Biomass Heat & Power in Sindal, Denmark *(Original title: "Bæredygtig biomassekraftvarme i Sorø")*
Project Type	Demonstration
Project identification no. (program abbrev. and file)	Journal nr: 64011-0049
Name of the programme which has funded the project	Energiteknologisk Udvikling og Demonstrations Program (EUDP)
Project managing company/institution (name and address)	Dall Energy ApS. Dr. Neergaards Vej 3 2970 Hørsholm Denmark
Project partners	Dall Energy ApS. (EPC Contractor) Sindal Varmeforsyning A.m.b.A. (Client)
CVR (central business register)	30519787
Date for submission	May 9, 2019

Table 1 - Project details

Picture 1 - Sindal CHP Biomass Plant seen from above at the day of the official inauguration

1.2 SHORT DESCRIPTION OF PROJECT OBJECTIVE AND RESULTS

English description

The objective is to demonstrate a new innovative, cost-efficient, high-efficient, low-emission biomass Combined Heat & Power (CHP) plant in Denmark.

The demonstration plant is built in Sindal, Denmark and is based on the 3. generation of Dall Energy's award-winning and patented biomass multifuel two-stage gasification furnace.

For this project, Dall Energy have made several new and improved designs of the main parts of the plant resulting in a total plant concept with many advantages as shown in Table 2.

Dansk resumé

Formålet med dette projekt er at demonstrere et nyt innovativt og høj-effektivt biomasse kraftvarmeværk i Danmark som har meget lave emissioner.

Demonstrationsanlægget er bygget i Sindal i samarbejde med Sindal Varmeforsyning A.m.b.a. og er baseret på 3. generation af Dall Energy's prisbelønnede og patenterede multi-brændsel to-trins forgasningsovn.

For dette projekt har Dall Energy foretaget flere nye og forbedrede design af hovedkomponenterne i anlægget hvilket har resulteret i et komplet anlæg med mange fordele, som angivet i Table 2.

PARAMETER - *Parameter*	**ADVANTAGES - *Fordele***
Fuel flexibility *Brændselsflexibilitet*	Many low-grade biomass fuels *Biobrændsel af lavere kvalitet*
Moisture content in fuel *Fugtindhold I brændsel*	0-55 % (Up to 60% moisture possible) *0-55% (Op til 60% fugtindhold er muligt)*
Total energy efficiency *Total virkningsgrad*	110% (by use of air humidifiers) *110% (ved brug af luft befugtere)*
Solid fractions *Askefraktioner*	Only bottom ash and sludge from scrubber. (normally at least 3 fractions). *Kun bundaske og slam fra scrubber (normalt mindst 3 fraktioner)*
Costs *Omkostninger*	Cost effective heat and power production for medium sized plants *Kost-effektivt for kraftvarmeværker for mellem store anlæg.*
Load Turn down ratio *Lastregulering*	1:4 (also in power mode) - Load change from 25% to 100% in less than 30 minutes. *1:4 (også strømproduktion) - lastregulering fra 25% til 100% på <30 minutter.*
NO_X emissions - *NO_X emissioner*	<200 mg/Nm^3
CO emissions - *CO emissioner*	< 10 mg/Nm^3
Dust emissions - *Støv emissioner*	< 20 mg/Nm^3
Carbon content in bottom ash *Kulstofindhold i bundaske*	< 1%
Technological robustness *Teknologisk robusthed*	"No moving parts in hot zones" *"Ingen varme bevægelige dele"*

Table 2 - Main advantages of Sindal CHP Biomass Plant

1.3 EXECUTIVE SUMMARY

The Sindal CHP Biomass Plant is not just a traditional biomass plant. Dall Energy has developed and built a brand new type of biomass co-generation plant, which uses a newly developed gasification technology that supply the thermal energy to an Organic Rankine Cycle (ORC) turbine plant to make both heat and electricity.

This is the first time that such a plant is established in the world.

1.3.1 TIME LINE OF THE PROJECT

2012-2015:
Initially the Demonstration plant was meant to be built in Sorø, with SEAS-NVE as host. However for various reasons SEAS-NVE decided not to built the plant. Hereafter was the project moved to Farum. Dall Energy and Farum district heating company tried to develop the project, but Farum could not obtain a building permit for it.

2016:

Sindal became the official host of the project in 2016. The design and engineering of the demonstration plant was done during 2016. Also in 2016 the design of the building and the tender document was made and submitted, and all permits for the plant was obtained.

2017:
In January 2017, was the contract between Sindal and Dall Energy effective. All the hardware components was purchased. The building was build, but roof was to be mounted after Dall Energy had installed its main equipment.

2018:
In January 2018, was the main equipment installed, and during the spring was the total plant erected.

First fire was in June. The plant worked well and in July was the plant handed over to the client.

On September 15, was official opening made by the Minister of Energy: Lars Christian Lilleholt and Chairman of EUDP: Thea Larsen.

1.3.2 RESULTS

The plant has performed well and the objectives of the project has been meet. Main results are:

- Dust: 10 mg/m3
- CO: 0 mg/m3
- NOx: 100-200 mg/m3
- Total efficiency: 110 %
- Power efficiency (18% gross, 16% net)
- Stable operation

Also a test with SNCR – NOx reduction technology has been made. Hereby was NOx reduced to 25 mg/Nm3.

1.3.3 UTILIZATION OF THE PROJECT

The project has been a major project for Dall Energy in its ambition to become a global leading provider of biomass plants.

The project was the first project for Dall Energy as turn key contractor, and Dall Energy have hereby gained a lot of experience which will be used in coming projects.

The project has become internationally known and recognized.

The IEA Task 32 has acknowoledged the results and named the project a "bioenergy succes story":

http://task32.ieabioenergy.com/wp-content/uploads/2019/03/Environmentally-friendly-fuels.pdf

Potential clients are interested in the technology built in Sindal. Currently (Spring 2019) Dall Energy is having dialoge with clients in Denmark and Germany of follow up projects.

Hower: A new energy law was put into force in Denmark January 2019. This law is preventing district heating plants to use biomass a resource for its heating. The law require district heating plants to use electricity as energy source for its heating.

Thus is the new law preventing the further utilization of the tehcnology in Denmark.

1.4 PROJECT OBJECTIVES

The project is a technical demonstration plant of a new biomass CHP concept, where several different fuels will be used to provide CO_2-neutral heat and power with a very high overall efficiency and very low emissions.

The demonstration plant for the project is built in Sindal, Denmark (Sindal CHP Biomass Plant) and has a total budget of approx. DKK 65 million.

Overall, the project has following main objectives:

- to demonstrate an innovative, cost-efficient, high-efficient, low-emission biomass Combined Heat & Power (CHP) plant in Denmark.

1.4.1 THE TECHNOLOGY OF SINDAL CHP BIOMASS PLANT

The new plant in Sindal includes the following innovative parts:

- A multi-fuel low-emission two-stage gasification furnace
- A combustion afterburner for NO_X reduction
- A thermal oil system for low dust flue gas
- A highly efficient gas cooling system
- An Organic Rankine Cycle (ORC) Turbine
- An innovative system for particle management

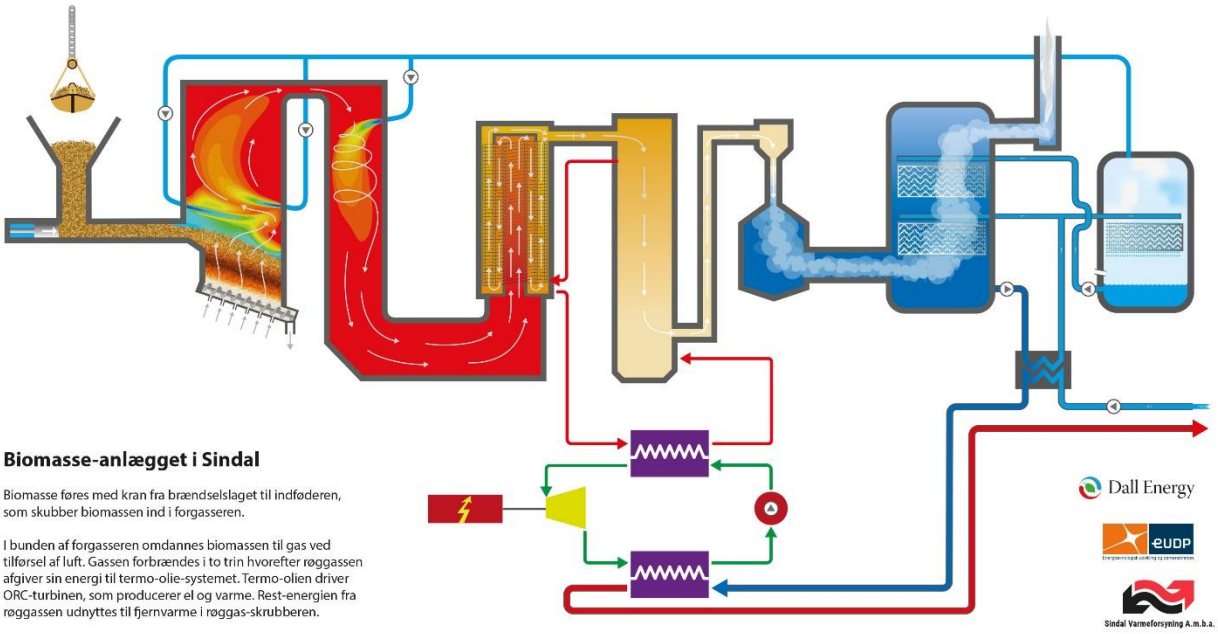

Figure 1 - Overall process diagram

Before the flue gas is passed through the thermal oil heater, the temperature of the flue gas is about 950 degrees Celsius. After giving its energy to the thermal oil plant, the temperature is about 185 degrees Celsius. From the thermal oil plant,

the heat can be directed to district heat exchangers or to the ORC plants turbine that produces electricity and heat.

In the quench the flue gas is cooled to 60 degrees Celsius, and in the flue gas condenser the flue gas is cooled further, and the final energy is extracted. When the flue gas is led to the chimney, the temperature is as low as 40 degrees Celsius.

The current project adds several new features to the Dall Energy concept. In the following the new designs and advantages are shortly described.

Multifuel Gasification Furnace & Afterburner

So far, Dall Energy has three gasification reference plants in operation, two in Denmark and one in United States of America.

The previous Dall Energy Furnaces have integrated gasification and gas-combustion. Hereby can ultra-low dust and ultra-low CO emissions be achieved, and the NO_X level is also very low.

In this project a new generation of the gasification furnace was demonstrated:

- Above the gasification zone the gases are partially combusted (oxidized).
- In a new separate reactor (the Afterburner) the gasses are burned.

With this new design several advantages are achieved:

- Ultra-low NO_X emissions
- Possibility to use gas for various purposes.

Picture 2 - Main hall at Sindal CHP Biomass Plant

Highly efficient flue-gas cooling

Standard gas coolers lower the flue gas to about 5 °C above the return temperature of the district heating water. Typical temperatures of the flue gas in the stack is 45-50 °C

Dall Energy low temperature flue gas cooler lowers the flue gas equal to or below the return temperature of the district heating water. This results in an increase of energy efficiency of the total plant of about 5-10% and a flue gas temperature out of the stack of 35-40 °C.

Particle management

Standard biomass systems have 3 particle handling systems: Bottom ash, fly ash and sludge from scrubber system.

The Dall Energy system have only 2 particle system: the bottom ash and sludge from scrubber system.

The main reason for this it the low dust emission of the gasification furnace and therefore the plant does not have any need for cyclones or electric filters.

Another reason is that the Dall Energy have developed a new particle management system in combination with the flue gas condensation system:

Particles are captured in the Quench which are hereby removed from the scrubber system, thus avoiding clogging of the heat exchangers and injection nozzles.

Beside removing the particles of the flue gas without extra expensive cleaning equipment, the flue gas condensation system also increases the thermal efficiency by 25%.

ORC system integration

Normally biomass heating plants in the size range of 5-15 MW are heat only. There have been several attempts to develop CHP systems with high power efficiencies such as with gasification. These systems are still very expense and/or not reliable, thus not yet ready for market implementation and export.

The ORC system has proven to be reliable and cost-effective. The ORC technology for biomass systems is growing fast. So far more than 150 plants have been built in Europe. The leading manufacturer "Turboden" have a growth rate of 20% and have sold more than 30 ORC-units in 2011. All these systems were sold in connection with grate fired biomass furnaces.

This project will be the first project where an ORC system is combined with a Dall Energy Furnace and a highly efficient energy recovery system.

This project will hereby break many records within the industry of CHP from biomass with ORC. Among the records to be broken are emissions, fuels flexibility, total efficiency.

Low grade fuels

One of the benefits of the gasification solution is that Sindal can use low grade fuel. The gasification technology can handle fuel with up to 60 percent moisture content, as well as dry fuel.

The plant can use a combination of local and cheap fuels in the form of garden waste and other residues that cannot normally be used elsewhere, which therefore are very cheap and help keeping fuel costs down.

In addition, the gasification process ensures that the flue gas has a very low content of dust, CO and NO_X.

Instead of a relatively fast combustion of solid material, the reaction to gas occurs in a slow gasification process, and hereafter the gasification gas is burned. Due to low speed of gas and a good mix of gas and air are the level of dust, CO and NO_X very low after the gas combustion. Therefore, no flue gas filters are installed, which are otherwise required for other types of biomass plants.

CFD Study

In 2016 a CFD study of a new CHP plant for Sindal was made in order to obtain low emissions of 100 mg NO_X/m3 or below.

Together with FORCE technology (CFD) Dall Energy investigated if such low NO_X could be achieved by stage dividing the gas combustion further.

According to the CFD model of Force it seems like such low NO_X can be achieved without SNCR (Injection of urea or ammonia): when part of the gas is partially oxidized at 900 °C and having a retention time of about 1 second - then the total NO_X will be below 100 mg NO_X/Nm^3.

1.4.2 TIME SCHEDULE AND MILESTONES

In the spring of 2016, Sindal Varmeforsyning was approved as host for the new demonstration plant and after all necessary approvals from the authorities was in place, the contract was finally signed in February 2017.

Dall Energy then began the detailed engineering and procurement of all components for the plant which continued throughout 2017.

The erection phase for Dall Energy, which began in the beginning of January 2018, was implemented and completed within the time schedule and according to the milestone agreed upon between the client and Dall Energy.

The new plant was commissioned in the summer of 2018 - with official opening on September 15th by the Minister of Energy in Denmark.

Operational handover of the plant to client was achieved after just 15 days of operation after successful demonstration all the warranty data of the plant.

The final handover of the plant was achieved approx. 3 weeks ahead of the time schedule.

1.4.3 RISKS ASSOCIATED WITH THE PROJECT

The following risks was identified for the project:

- The new plant in Sindal is the first project in which Dall Energy has turn-key responsibility.
  Being a turn-key supplier is a major risk, and in order to handle a project of this size & complexity, Dall Energy hired five experienced employees to ensure a successful completion of the project.

1.4.4 UNEXPECTED PROBLEMS

Generally, the project did not experience any major unexpected problems with regard to the scope of supply from Dall Energy.

Although, shortly after the contract was signed with the client, the project had to be delayed due to a delay attributed to the civil works contractor. This postponed the project time schedule by 3 months and a revised time schedule had to be implemented.

Beside this delay in the time schedule, the project "only" experienced the typical "child diseases" which must be expected with a demonstration plant.

1.5 PROJECT RESULTS AND DISSEMINATION OF RESULTS

The Sindal plant was put into operation in June 2018. But due to the low demand for district heating throughout the summer and fall of 2018, the plant was only operating on low-medium load in this periode (10-50% load).

Full load was obtained in December 2018.

1.5.1 RESULTS FROM SINDAL CHP BIOMASS PLANT

The results of the plant show that key parameters in table below have been accomplished.

The key parameters of Sindal CHP Biomass Plant are as follows:

- Input power: 5.5 MW
- Electricity production: 800 kW
- Heat production: 5.0 MW
- Moisture in fuel: 20-60%
- NO_X emissions: 100-200 mg/Nm^3
- Dust emissions: <20 mg/Nm^3
- CO emissions: <20 mg / Nm^3
- Load regulation: 20% -100%
- Fuel types: Wood chips, green wood waste
- Overall plant efficiency: 110 %
- Carbon content in bottom ash: < 1%

Fly ash

After 3 months of operation the plant was shut down for a week of planned inspections. An inspection of the furnace, afterburner and the thermal oil heater showed a very low accumulation of fly ash, which confirmed the great advantage of the gasification process and relating low-dust emissions.

Bottom ash

An initial sample analysis of the bottom ash shows that all measured values are below the limits acc. to the Danish legislative requirements for bio ash (BEK nr 818 af 21/07/2008 – "Bioaskebekendtgørelsen"). The bottom ash can based on this result also be utilized as a fertilizer in the agriculture and in forests in Denmark.

1.5.2 RETURN ON INVESTMENT

The budget of 65 million DKK (9 million €) makes the investment the largest investment in Sindal and the project has attracted a lot of attention in the town in the north of Denmark.

The investment will pay back as the heating price can be lowered, as the new biomass plant is both highly energy efficient and fuel flexible.

90 percent of Sindal's heat demand can be covered by the new plant, so from now on Sindal will only use their traditional gas engines or gas boiler at peak load. At the same time, the new plant can function from 15% to 100% power and maintain both its energy efficiency and the very clean combustion.

1.5.3 DISSEMINATION OF THE RESULTS

The project has become internationally known and recognized.

The IEA Task 32 has acknowoledged the results and named the project a "bioenergy succes story":

http://task32.ieabioenergy.com/wp-content/uploads/2019/03/Environmentally-friendly-fuels.pdf

Also a number of articles has already been written including:

2018:

July: Energy Supply: " Dall Energy bag positive emissioner i Sindal"

September: Forskning i Bioenergy "Forgasserovn redder økonomien i nordjysk varmeværk"

September: Energy Supply: "Dall Energy bag positive emissioner i Sindal"

October: IEA task 32: "Bioenergy for heat – the hot cases"

2019:

January: Bioenergy International "Sindal pushes boundaries of small scale CHP"

Also a number of oral presentations has been made by Dall Energy and Sindal has received visitors from Denmark and abroad including USA, France, Germany.

1.6 UTILIZATION OF PROJECT RESULTS

The project results will be utilized by Dall Energy to further improve the gasification process and the design of the multi-fuel furnace.

1.6.1 MARKETING AND BUSINESS PLAN

The multi-fuel & multi-product system will be marketed by Dall Energy.

The marketing plan of Dall Energy is a very dynamic plan, as the company is young and still needs sufficient references to credible in the market.

Based on the results of the first 3 Dall Energy plants will start marketing the heat-only system outside Denmark. Part of this marketing will be announcing this current demonstration project and the advantages it gives, and hereby we prepare the market for the technology.

In 2018 Dall Energy won a Horizon 2020 project and within this project a Marketing and Business plan is currently being developed.

1.6.2 TARGET GROUPS

The target group for the technology is district heating companies globally. Further target groups are industrial costumers which have a need of heat and power.

District heating companies

The district heating companies have a main purpose to supply end-costumers with cheap and reliable heat. In most countries there is a national regulation that regulate the conditions of the of district plants. In Europe these national regulations must apply with EU regulations.

The EU regulations say member states must make initiatives, so CHP and biomass can be exploited.

The end costumers will use the Dall Energy technology mainly due to the fuel flexibility, the high efficiency and the low maintenance costs.

Due the low emissions of The Dall Energy technology the awareness of biomass as a green technology will increase, and hereby the market may open even further.

As this plant will generate heat at a higher temperature (thermal oil at 300C) than in normal district heating plants (hot water at 100C) the solution opens for other thermodynamic machines such at high efficiency absorption chillers and water purification systems by distillation.

Also, the fact that the furnace can use various types of biomasses will have a positive effect on the end-user and eventually in farmer and forest organizations.

Heat supply for industrial customers

A secure and cheap heat supply is important for many industries. In some industries the energy costs can exceed the costs of the raw project and even the

costs of labor. Therefore, the multi-fuel & multi-purpose plant is considered a big market in the industry.

1.6.3 MARKET POTENTIAL

The Danish market of the new fossil free heating plants is estimated to be 50-100 plants:

The market potential is partly related to a fuel switch of the more than 650 natural gas fired CHP plants in industry and in district heating sector, and partly related to an "upgrade" of the more than 200 biomass heat only plants that are in operation today.

Hower: A new energy law was put into force in Denmark January 2019. This law is preventing district heating plants to use biomass a resource for its heating. The law require district heating plants to use electricity as energy source for its heating.

Thus is the new law preventing the further utilization of the tehcnology in Denmark.

But the big market potential is related to export. Turboden (ORC manufacturer) estimate that the Global market potential for ORC Units for Biomass CHP in 2013 is about US$ 100 million.

The price of the ORC unit is (more or less) the same as the price of the biomass system, so the market potential for Biomass manufacturers who deliver the biomass plant is also about US$ 100 million.

Below is the district heating market in Europe, Russia and China described as these are considered the main markets. The district heating market is the largest market for the technology to be demonstrated, but there is also a considerable market in the industries with a heat and/or cooling and/or electricity demand.

This market potential is not described further.

Europe

From abstract of District Heating and Cooling, Country by Country 2007 Survey:

"With more than 5000 District Heating and about 100 District Cooling systems in Europe the sector accounts for about 10% of the heat and 2% of the cooling markets. About 1 EJ of district heat is annually delivered to customers in the former EU-15 for a total value of about 11-12 billion €. Further 1 EJ is annually delivered in the twelve new EU member states to a value of about 6-7 billion €.

District Heating continued to grow in Austria, Italy, Iceland, Norway, and Sweden at high expansion rates."

1.6.4 COMPETITION

Competition related to fuels and technologies

Before 2019 was the main competitor the Danish law: The law was favouring natural gas fired plants.

After 2019 is the main competitor the Danish law: The new law is favoring electricity consumption for production of district heat via electrical driven heat pumps.

Competition with other manufacturers

For the medium sized biomass plants (5-15 MW thermal input) there are no global companies. Companies in this size-range is typically national manufactures of biomass-based systems that operate in a certain country.

Dall Energy's strategy is to form partnerships with companies that operate locally, who know the language, the rules and regulations, the political system etc.

Competition with other biomass CHP technologies

Steam cycle biomass CHP systems and biomass gasification systems are competitors to ORC plants. Today, steam cycle systems are too expensive below 20 MW_{TH} and biomass-gasification systems are either too expensive or not reliable enough.

1.6.5 PATENTS

A key part of Dall Energy business strategy is to patent the technologies Dall Energy develop to avoid other companies from copying the innovations.

Dall Energy already holds several patents.

A new patent application was submitted during the project. The new patent application is protecting Dall Energy against copying of the "Sindal technology".

1.6.6 ENERGY POLICIES

Denmark has a strategy for research, development and demonstration of biomass technology for combined heat and power production from 2003: "in Danish: Strategi for forskning, udvikling og demonstration af biomasseteknologi til el- og kraftvarmeproduktion i Danmark" - (hereinafter named "FUD strategy").

The current project is very much in line with this FUD-strategy.

Quotes from the FUD-strategy:

- "According to a report on energy policy the F&U effort on a long-term basis must contribute to developing useful and environmentally friendly technologies, which are as competitive as possible when we need them: e.g. because we eventually wish to replace our domestic oil and gas production. Such effort will continuously base on Danish strength positions, and it will be relevant to focus on technologies with an international perspective too".
- "F&U specifically prioritizes an effort aiming at:
  - better fuel exploitation
  - better process understanding

- reduction of the burden on the environment, including less emission
- recycling of waste
- optimization of thermal production for biomass, possibly through re-thinking with other industrial processes
- inclusion of further biomass resources to promote a flexible use of fuel
- better understanding of fundamental conditions in terms of biogas processes and micro-flora, including increased awareness about stress factors and inhibitors"

1.7 PROJECT CONCLUSION AND PERSPECTIVE

EUDP has been very supporting to the development of the Dall Energy low emission fuel flexible biomass technology.

The current project was the first project with electricity production, which was one of the key objectives for Dall Energy when the concept was first developed in 2009.

It can now be concluded – after 10 years of development that Dall Energy (with support from EUDP have developed a unique biomass technology that can

- Can provide CO2 neutral energy at low cost
- Can use various types of low grade fuels
- Has little environmental impact (low emissions)
- Is stable to operate
- Has low maintenance costs

The perspective is more difficult to describe

One hand should the perspective in Denmark be good as Danmark wants to be CO2 neutral but on the other hand wants the politicians to "electrify" Denmark, which has led to new energy laws that eliminate the market for the Dall Energy technology in Denmark.

In order to open up for the Low-emission technology there is an urgent need to modify the energy laws in Denmark.

The perspective globally are very positive, but it will be difficult for Dall Energy to develop a company without a market in Denmark.