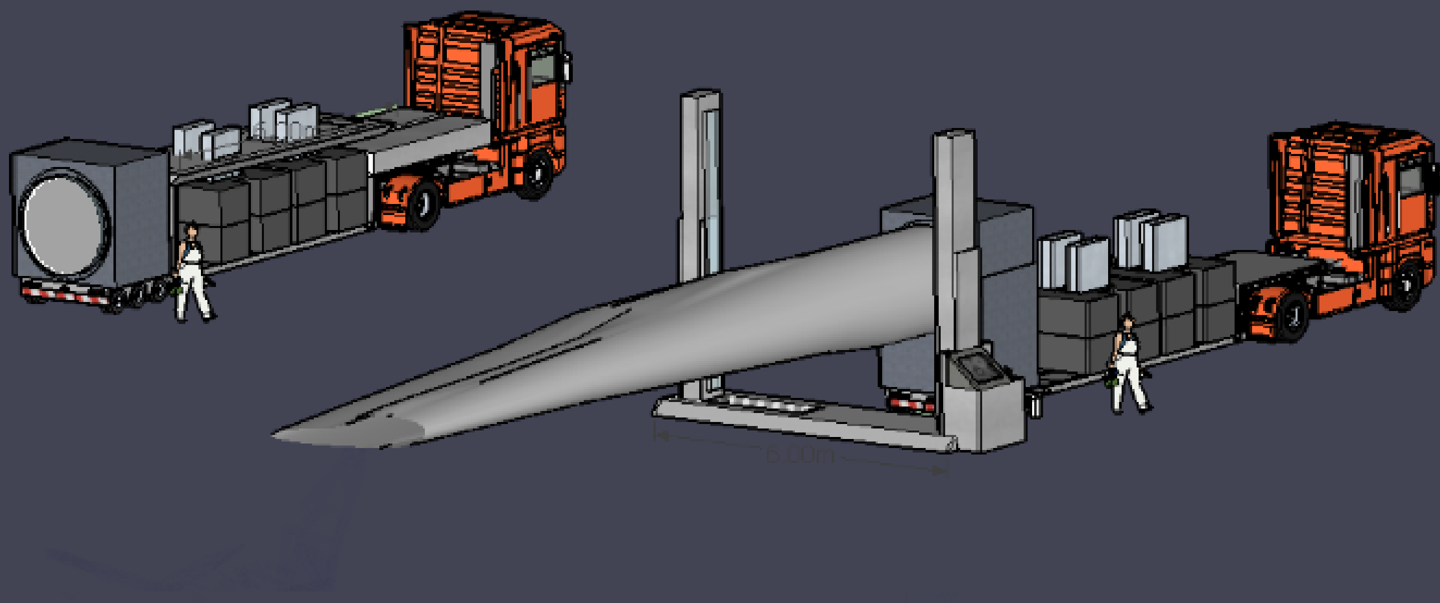

Manufacturing Scanner

Business report

Course
Experts in Teams - F-EIT5-U02

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" - It detects failures in all types of blades, for both manufacturers and owners, at a fixed low cost"

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Executive Summary

The complete business report acts as proposal ending with a decision on whether the idea is viable or not. A positive conclusion will lead to a suggestion of further investigation within this field.

Present day wind turbine faces plenty of maintenances, issues and blade failures, all these problems together are difficult to handle and thereby very costly. That is why this report aims to come up with an idea solution to detect manufacturing errors and faults before installing the wind turbine blades.

This business report aims to investigate whether a Manufacturing Scanner has the ability to detect errors and faults in new wind turbine blades. In addition the business report examines if the idea based on a Net Present Value calculation along with a budget is economically beneficial.

The business report includes a technical description of an x-ray scanner, materials in wind turbine blades and software detection of anomalies.
A business plan is conducted to determine whether the Manufacturing Scanner is a viable business opportunity. The business plan consists of a market analysis, which includes a supply chain, positioning, pricing and customer segments, and furthermore a budget, including a Net Present Value and business case.

Based on the investigated areas and the final conclusion, the idea seems viable. The scanner is possible to produce at a reasonable price, the project is economically beneficial and there is a present market potential.

Contents

1 Problem Statement

1.1 Formulation of objectives

Does a large x-ray scanner have the ability of detecting flaws and errors in wind turbine blades? What type of flaws do we focus on? Why is a x-ray scanner a necessity in order to detect flaws and errors in turbine blades? Why is it constructed the way it is? How does the scanner detect the flaws? Is the x-ray scanner a profitable investment? How does the scan of turbine blades affect the environmental aspects?

1.2 Specification of requirements

This project includes a dissemination of the following problems and questions:

- An explanation of x-rays and wind turbine blades in general. In addition the materials that are used to manufacture them.
- A technical documentation of x-ray scanners including interacting between x-rays and turbine blades?
- General software for analyzing turbine blades.
- A market analysis regarding competitors, customer segments, positioning and pricing.
- An economic overview including a Net Present Value (NPV) calculation and budget.
- A description and discussion of the environmental aspects.

2 Introduction

The Danish government is committed to have a completely renewable energy system without non-renewable energy sources as coal, oil and natural gas by 2050.[2] Therefore the Danish renewable energy sources need to produce at least the danish energy consumption in energy supply and in the transportation sector. In Denmark 2015, 42.1% [1] of the Danes electricity consumption were produced by wind turbines and these numbers increase every year. These numbers and governmental goals show that wind energy in Denmark is a part of the future energy system, and that is why we need to produce the most reliable wind turbines with the lowest defect rate as possible. Basically wind turbines don't have any cost after being installed, there is minor maintenance and inspections, however sometimes wind turbines experience malfunction due to wear and tear, lightning or manufacturing errors.These malfunctions can prove to be very expensive because the repairs or a brand new wind turbine blade is expensive especially when the wind turbine is off-shore. So due to this problem we tried to generate a solution which could decrease the amount of malfunctions.
We have generated an idea for an x-ray scanner, and this business report aims to investigate the following aspects of the idea:

- The idea
    - Underlying description of x-ray scanners
    - Environmental aspect
    - Software perspective
- Business plan
- Budget

The purpose with this business report is to investigate whether or not the idea is feasible, if it got an economical potential and create a business proposal.
The content will be a physical explanation of the x-ray scanner solution in regards of how it will locate eventually manufacturing defects on and within the wind turbine blades. Further how software algorithms and AI based on data collecting will predict how these defects will affect the wind turbine in the future.
Regarding x-rays, the report also considers environmental aspects and working conditions. An analysis of the idea to determine if it is feasible or not is carried out in the business plan with a market analysis and in the end a budget for the idea.

3 Idea, Technology and Design

3.1 Idea description

In the idea generation process we came across the problem that when buying wind turbine blades from the manufacturer, you could potentially end up buying blades with internal flaws that is undetectable on the surface. In order to solve that problem we came to the conclusion that it would make sense to work with the construction of a manufacturing scanner.

In order to look inside the blades, we wanted to use the same kind of technology that is already being used for scanning cargo containers, where large x-ray scanners are used to give images of the content inside. We wanted to do the same thing with a wind turbine blade thus allowing to see possible air pockets or other construction failures inside the blade. To improve the possibility of detecting errors we also wanted the scanner to be able to use the same kind of technology that is used in CT-scanners, where the scanner rotate around the object being scanned. That would allow us to make a 3D model of the blades internal structure, and further improve the possibility of detecting structural problems caused by misfolded layer of fibres.

We wanted to make the manufacturing scanner mobile, so it could be transported to the blades and not the other way around. This was achieved by constructing a scanner system that was mounted on a truck trailer.

The final problem of allowing the scanner to rotate around a trailer was countered by a design that allowed the wind turbine blade to rotate instead, while the scanner remained stationary.

3.2 Material Composition of Blades

In order to justify the use of a x-ray scanner to look through wind turbine blades, a certain amount of knowledge about there material composition is needed.

Modern wind turbine blades are constructed using composite materials, that means several individual materials are combined in order to maximize their strengths and minimize their weaknesses. The shell of a blade is made of layers of weaved fibre materials. They are made of synthetic carbon fibres, glass fibres or natural plant fibres that have been processed. The fibres are incorporated in a matrix of either polyester resin or epoxy resin to make up the main part of the blades. Balsawood is used for additional structural benefits in the sandwich layer and different polymer based foams are used to fill the void inside the blades. The blade itself is build up around a structural beam of carbon fibre, which extends through most of the blade.

The blades of a wind turbine will go through as many as 10 million cycles in their 20 years lifespan. Each time the blade passes the tower it has been subject to a cyclic load that is know as “fatigue”. Any object that bends back and forth for a large number of times will sooner or later collapse due to structural damage in the material. This can be illustrated by bending a spoon back and forth until it ends up breaking.

It is important that the blades are made of materials that withstand fatigue. This is achieved by using fibre reinforced plastic, the fibres allow the stress at one point of the wing to spread out through the length of the fibre and the matrix of polymeric resin allows the load to distribute from one layer of fibres to the next, thereby minimizing the load on the wing.

Fibres:

Different types of fibres are used to enforce the wind turbine blades. Test have been conducted using plant fibres for blade construction, but they lack the strength needed when the blades reach a certain length, and therefore is not very widely used. However the chemical composition of plant fibres is mostly cellulose. Cellulose is a polysaccharide made of large numbers of glucose units bound together through β(1,4)-glycosidic bonds and is composed of carbon, oxygen and hydrogen.

Glass fibres are often used for blade construction, as it is a rather inexpensive material. It is made of melted stone that is extruded into low diameter “fibre hairs” which are then spun and woven into fibre mats. For blade manufacturing E-glass fibre is the most commonly used. Like all natural minerals it is a compound made of several different oxides joined together. Silicon oxide, calcium oxide and aluminum oxide constitute the majority and smaller amounts of magnesium oxide and boron oxide are also present.

SiO_2	52-56 %
CaO	16-25 %
Al_2O_3	12-16 %
MgO	0-5 %
B_2O_3	5-10 %

Table 1: Chemical composition of E-glass

Carbon fibres are often used for the larges blades, as the fibres are lighter than those of glass fibre products. When a wind turbine blade gets longer it is preferred to lower their weight. An increased weight contributes to fatigue as the stress on the blade is increased. Carbon fibres do contribute with more stiffness than glass fibres, which ensures that the blade does not bend as much. Carbon fibres are made from heat-treated polymers that are spun and woven. Unfortunately the treatment leads to carbon fibres being more expensive than the glass counterpart, which mean that they are only used when necessary. Carbon fibres are made of single sheets of graphite that are wrapped together, and therefore they mainly consist of carbon.

Resin:

The matrix that keeps the fibres in place is made of polymers. It has been common to use polyester compounds, but it has gradually been taken over by epoxy resin. Epoxy resin has its name from the functional group that makes the compound reactive; this part of the molecule is named “epoxide”. Due to internal strain in epoxide molecules, between to carbon atoms and a single oxygen atom, they are very reactive and when mixed with different compounds known as “hardeners” the molecules will react and form crosslinks between the individual molecules. The hardeners may be different organic substances such as amines, and in order for the process to work; each molecule needs two functional groups. This allows each compound to react with two other molecules, and thereby creating an enormous web of entwined molecules. As both the epoxy and hardeners are organic compounds, they are made of carbon, oxygen, nitrogen and hydrogen.

Balsawood:
Balsawood is used to add strength to the blade in the “sandwich” section. Before the lumber is cut down, it contains a lot of water, but after drying the space that the water took up is filled with air instead. This makes the balsawood very light and gives the material a large strength to weight ratio. As most plant materials it contains large amount cellulose, and therefore the wood is composed of carbon, oxygen and hydrogen, with small amounts of minerals being left in the plant cells.

Foam:
Structural foams are added to fill the voids inside the blade. Different type can be applied, such as PVC-foam or foams containing polystyrene. Common for them all are they consist mostly of organic materials. So it is expected to be mainly carbon, oxygen and hydrogen, and in the case of PVC also chloride.
To sum up, the molecules we need to scan through consist of a relatively large amount of light atoms such as hydrogen, nitrogen, oxygen, and carbon. Blades with glass fibres contain minerals with silicon and calcium as the largest part, which are a bit heavier, but still in the lighter end of the periodic table.

3.3 Errors in Blades

Typical errors in turbine blades can be narrowed down to the following areas.
Wear:

- Leading edge erosion
- Missing or worn paint/forefront tape
- Lost or broken gurney flaps and ect.

Operating Errors:

- Ligtning damage
- Handling damage from mountning

Manufacturing defect:

- Dents in the laminate
- Delamination
- Air inclusions

- Balsa cracks or overlap
- Inadequate adhesion of glue joints

The errors we want to detect are placed in the last category manufacturing defects. Manufacturing defects are especially hard to detect because the defects are sandwiched between the layers of the blade, which means that they are very hard to detect. When the blade is being produced a lot of measures are being taken to prevent faults, but because of the lack of methods for detecting these errors many of them end up in the finished product. Because of the lack of knowledge within this area of errors, it is also very hard to determine which type of manufacturing errors end up causing faults.

3.4 X-ray Imaging Method

From the material composition and error description written above there is nothing preventing us from scanning a turbine blade. The next question is what technique is the best for detecting the kind of errors explained in the chapter above. In the following chapter the two most popular x-ray scanning methods are examined as possible solutions and the pros and cons of all will be compared and best solution will be implemented in the design process.

3.4.1 Underlying techniques of planar imaging

Planar x-ray imaging is the most simple method of creating images from x-rays, and was also used to create the world's first x-ray image in 1895.

Figure 1: X-ray image - 1895

This method is very similar to the way overhead projectors work. A source creates diverging beam of x-rays that is shined through a given object and on the is a planar sheet of material, able to capture the intensity of x-rays. If this sheet is a image sensor, like that of a regular camera, the data can be used to create a greyscale 2-dimensional image of the object, where the dark spots, as seen in Figure 1 represent lower x-ray transmission intensity and therefore thicker, or heavier, material.

This method is relatively easy to carry out and fast, because it only uses one image. The problem with this method is that it takes a 3D object and creates a 2D image, this means that it could be hard to detect and differentiate errors therefore, the computerized tomography method has been developed.

3.4.2 Underlying techniques of CT-scanning

The CT scanner, or computerized tomography scanner, function almost like a planar x-ray scanner. The only difference between the two is that the CT-scanner takes a series of photos around the scanned object and renders a 3D model of the object with the possibility of seeing inside the object. CT-scanners are currently being used in hospitals all around the world and looks like the following.

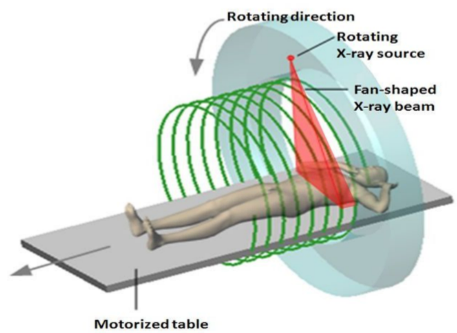

Figure 2: CT-scanner

In general the x-ray emitter and receiver are placed on opposite sides of the object and are spun around the object taking x-ray pictures at certain degrees, see Figure 2. When the emitter reaches a full revolution, the patient is moved further into the machine and the process starts over. The pictures are then assembled into a 3D model by a computer.

The best thing about this method, for detecting errors in turbine blades, is that it can create a full 3D model of the turbine blade, which could then be analyzed with great precision. This method increases the error detection margin which must be very large to detect the kind of errors these blades could contain. Another positive thing about the CT-scanning method is that it is possible to differentiate between the bottom of the blade and the top. This also makes the error detection job much easier, because the object is not shadowing parts of itself. But with greater error detection also comes larger data. The size of the data generated by one CT-scanning of a blade would be the number of pictures taken in one rotation larger than the planar method. And on top of that the 3D model would be even larger. Another negative side is the amount of extra time it takes rotating the emitter and receiver around the blade, for each scanning step.

3.4.3 The Design

Because of the size of turbine blades creating a CT-scanning of each blade would be a huge task, and the amount of data storage and analysis required would be beyond the scope of this project, the blade scanner must be able to locate important errors by using a combination of both planar and CT-scanning. As mentioned before, the kind of errors the scanner is supposed to detect is typically located in the following parts of the blade.

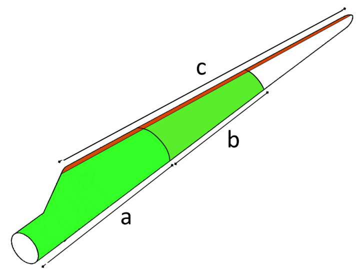

Figure 3: Blade divided in sections.

Here the lengths **a** and **b** is where the manufacturing errors typically show up, and the length **c** is where the blade is glued together. So, the scanner should focus of these parts with the CT-scanning and the rest can be scanned with standard planar imaging.

Another important requirement from a logistic point of view is that the scanners must be portable. It is by far more desirable for a company to be able to have the scanner delivered to them when they need it, instead of shipping the turbine blades to the scanner location. With this in mind the following design proposition has been made.

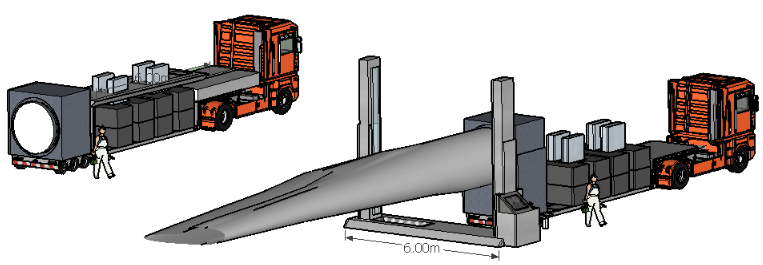

Figure 4: Manufacturing Scanner with and without blade mounted.

The image shows the x-ray scanner when it's packed and ready to drive and when it is in use. In this design a truck can carry all the necessary parts for scanning a turbine blade. The modular design of the system also makes it easier to replace broken parts. The scanner consists of emitter and receiver pillars, a base-plate for the pillars, a rotatable mount for the blade and counterweights. The whole scanner can be packed together on a truck bed. When the truck has arrived at the costumer, the scanner can be unpacked, here the receiver and emitter, located in separate pillars, can be connected to a base-plate.

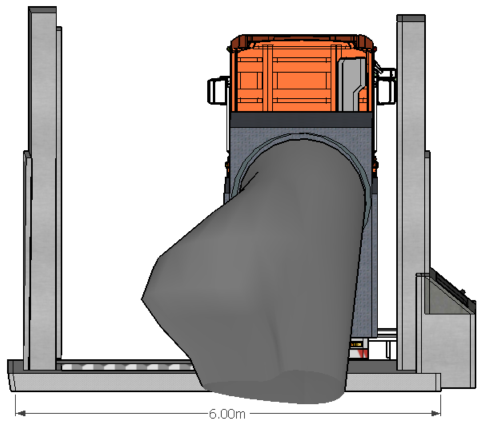

Figure 5: Manufacturing Scanner from behind.

The turbine blade can then be mounted horizontally onto the truck where a motorized system can rotate the blade along its horizontal axis.

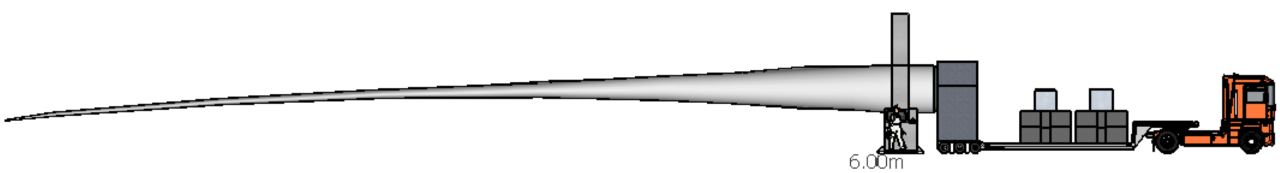

Figure 6: Manufacturing Scanner from the side.

The truck can then drive back and forth so that the blade is moving relative to the emitter and receiver, this can be used to create the planar image of the blade. If the blade spins along its horizontal axis while the truck is moving a CT-scanning can be made.

4 Software Analysis

The x-ray scan of an object in a 2-dimensional space would result in an image as shown on Figure 7. This image could then be viewed by a technician or it could be processed by image analysis algorithms. If known structures are common, then image analysis would be able to distinguish the anomalies from the common structures. An example would be the bone shown in Figure 7. The common structure would be the bone - the bone would have a brighter contrast compared to the tissue surrounding the bone differentiating the bone for analysis. The white bone contrast can then be analyzed further. Different algorithm can be taken into use based on what exact anomalies are wished discovered. Particularly for the bone in Figure 7 a 'crack' algorithm would yield a preferable result. This image analysis would discover the darker contrast - representing a crack - on the white bone contrast.

Figure 7: X-ray scan of a bone in 2D space. [4]

The project is based on x-ray scanning wind turbine blades. Different approaches can be taken into use for image analysis and thereby AI (artificial intelligence), or more specifically, machine learning is a possibility. What is machine learning and why is it relevant? Machine learning is the concept of teaching a computer to do tasks normal workers would do, however, the machine would learn from its results based on a defined goal. Say the goal was to predict whether or not an anomaly on the blades would need further manual inspection after installation. The machine learning algorithm would look at previous conclusions or a set of learning data - provided by humans - to determine if a blade would need further inspection in the future or not. The goal could then be expanded by guesstimating when the blade would need the inspection if any.

A database backend to store the x-ray images and machine learning data would be needed. Possibly deploying all the AI machine learning logic on a server backend. Thus allowing smaller computers to process complex algorithms on large datasets. The server- and database backend would be accessible from any location including off-shore networked device or computer handling the x-ray scans of blades.

A relevant subject to consider is the data size of the scans as this will have a big effect on the process time and storage requirements. Say an entire 50 meter long turbine blades was CT-scanned and the scan captured sections of 20 centimeters. That would result in 250 sections. Each section would consist of 36 images rotated around the blade. Let's estimate a high resolution X-ray image is about 2.5MB in size. Following equation can be formulated.

$$\frac{5000}{20} \times 36 \times 2.5MB = 22.5GB \tag{1}$$

Thus the size of scanning a blade will result in a 22.5GB collection of images. This data size is a realistic size to process, however, a powerful computer might be needed in order to give live feedback. The most recommended option for storage is to store the data to a portable storage device and physically bring it home to the central storage unit.

Global maritime satellite internet is provided by a couple of different companies allowing for the possible of running networked devices while operating off-shore. Thus making it possible to access the server- and database backend while doing inspection off-shore. With this opportunity follows the possibility of developing a mobile application - or similar - to transfer any feedback to the AI system on the fly.

5 Work Environment

5.1 Legal requirement for work safety and other law issues.

X-ray systems are subject to special legislation, which is found in *"Bekendtgørelse om industrielle røntgenanlæg m.v."*.[3]The announcement is there to insure the wellbeing of the people and the operators of the x-ray systems in general. In order to justify our use of a x-ray scanner we are going to give an introduction to the things that need to be considered before we can start our business. By ensuring we comply with the rules, we avoid unpleasant surprises later. It can be a costly affair if the business is closed by the authorities simply because there is no track of current law.

The text distinguishes between open and closed x-ray systems. As our x-ray scanner will be mounted on a truck trailer it will of course be an open system, and therefor is covered by specific rules for these.

Before any new or modified x-ray system can be used, it is required that the Health Authority *"Sundhedsstyrelsen"*[1] has been notified and that they subsequently approves the facility. It is required that a given x-ray system have a designated operation manager whose qualifications should be approved by the Health Authority. It is required that the person have adequate training to be responsible for operation and it is emphasized that knowledge of radiation risk and radiation protection must be among the person's competencies.

The operation manager is responsible for making sure that the people who operates the x-ray system is aware of the legal requirements needed to work with the x-ray apparatus and the safety that follows. It must be ensured that the required radiation safety equipments are present at the workplace, and measuring instrument are available for the employees, as they are not allowed to start working without it. Finally the operation manager is responsible for inspecting the x-ray system at least once a year, despite this, the systems also needs to be inspected by the Health Authority at least once every five years.

The legal text also contains a number of requirement specifications for the technical design of the system.

- The frame of the scanner is to be connected to the object being scanned (the wind turbine blade).
- A mobile system needs to have equipment to block off an area around the unit so that unauthorized persons are prevented from getting close to the radiation.
- The x-ray system needs to be equipped with movable screening that is strong enough to stop the residual radiation from the unit.
- There need to be a red lamp that lights or flashes while the system is in operation.

[1] The Danish health authorities.

- It is required that the control unit can be locked, to ensure that the system can not be started by strangers with bad intentions. Finally there needs to be a written manual in Danish.

We as a company should ensure that a operation manager of the facility is appointed and the Health Authorities gets a chance to approve the x-ray system, during an inspection as soon as possible. It is important that our employees receive the necessary training and therefore the authorities should be contacted for more detailed description of what they expect from our operation manager. Finally the legal text uses the phrase "x-ray examination should be performed on a specially designed photography space", this unclear formulation should be investigated and documented, to ensure that we actually have permission to move our scanner unit from customer to customer.

6 Business Plan

Before the explanation of a more thorough business plan consisting of; supply chain, market positioning, customer segments, competitors and budgets are presented, Alexander Osterwalder's Business Model Canvas (BMC) was made (See Appendix C). The BMC is initial thoughts of various business elements, without further explanation. These elements work as building blocks and direction for the business plan. Chosen elements, the challenging ones, are then investigated and elaborated in the actual business report under *Market Analysis*. While the *Market Analysis* concerns the chosen elements, the BMC gives an overview and acts as the common strategy of the idea.

6.1 Market Analysis

6.1.1 Supply Chain

In order to make a thorough strategy and plan for how to launch the product and enter the market in the best way, it is of highest importance that the actual market and its patterns are investigated carefully. The electricity market is a little different to other markets because it involves both public and private companies as well as interests. The specific legislation in this field secure that the companies are committed to their promised obligations. Due to the market structure, it is tough to enter this market, especially when you introduce a new business model and link in the supply chain. The figure below is a visualization of the actual supply chain of the wind power market, with the additional new link marked with the label "US".

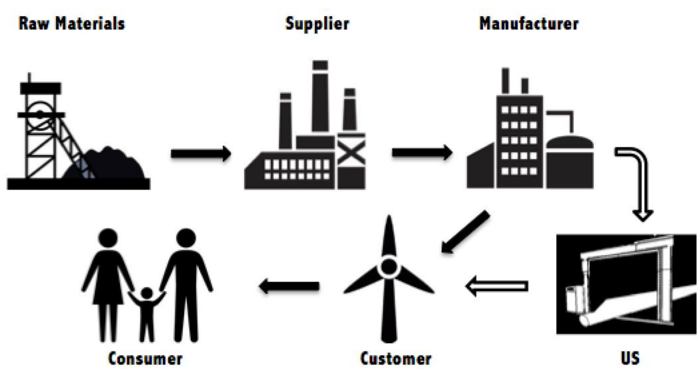

Figure 8: Supply Chain of Wind Power production.

The first step in the chain is the mining and extraction of *Raw Materials* such as iron ore, carbon, tree etc. When these are extracted they are passed on to the next link, *the Suppliers*. *The Suppliers* process the raw materials and make them into all kinds of materials including steel, processed balsa tree, epoxy and glass fibre that are all used in the production of wind turbines. The third link in the chain are *the Manufacturers*. It is companies as Siemens, Vestas or blade manufacturers as LM Wind Power. All mentioned companies produce the core elements of the wind turbines.

After *the Manufacturers* we want to add an additional link. This is where the mentioned business is placed. This link contains our company who secures that the manufactured blades are of a high and acceptable quality, before they are sold on. Materials, overall dimensions and jointing are all quality checked and scanned thoroughly, to secure there are no production errors. Next link is *the Customers*, it consist of huge companies as Dong, Vattenfall, EON and plenty more. They work as contractors for the government and buy foundations from manufacturers and wind turbines from others, to become owners of wind turbine farms and thereby distributors of power to the consumers. The last link in the chain is *the Consumers*; it is more or less everyone, from big companies to private families. They are the end users, who use power and electricity every day for multiple machines and devices. The consumers pay for the exact amount of electricity they are using, the payment covers charges, taxes as PSO, VAT, transport of electricity and the electricity price itself.

6.1.2 Positioning

The strategy of how to launch the product and engage the market is very important in order to achieve success. Since this company acts as a completely new business in the market, they turn out as a first mover, which of course bring several competitive advantages. The first mover role gives time to establish great brand recognition and customer loyalty. The extra time provides a longer learning curve for the company, who can scale over a way more time than normally, because there is no immediate pressure from competitors. A first mover has to act fast, in order to establish customer relations before possible competitors enter the market, but at the same time calm to obtain strong relations and provide exceptional service.

In section 6.1.1 Supply Chain, it is described where the business will be placed, in between the already existing and competitive markets of *Manufacturers and Costumers*. Plenty already well-established business acts in these markets, but the additional market as “product-controller” seems very open. Our Business seeks to aim for both the previous and the following link in the chain. The business will thereby deal with two customer segments. The first segment that consists of companies who produce and manufacturers the blades and wish to make the best products possible and the second segment, the buyers and owners of these performance products, who wants them to be without failures. The owner of the blades and turbines, for instance Vattenfall, will also gain the ability to put forward supplier demands. Now they will actually get to know the product they have bought and be able to secure whether it is of the desired and agreed quality or not.

6.1.3 Competitor Analysis

At the moment there are no direct competitors. It has been mentioned several times in the last two sections that this business aims for an unused market, as an additional link in the wind power supply chain. But since this is not a core link there will be an opportunity to “skip” this link in the chain. The business is seen as an optional extra help to the already existing companies, both manufacturers and customers/owners of blades and turbines. Because this is optional, the market penetration will be low in the beginning and it will probably newer reach the high end, since there is always the possibility to skip this step and save the money in either end.

Nevertheless, a similar company operates in Spain. The company is called HeliTechnics®[5] and deal with aerial and terrestrial services on, i.a. Wind turbines. They perform cleaning of wind turbine blades from helicopter and aerial drone inspection with high-resolution cameras.
HeliTechnics® are protected from a patent[6] through the international patent systems PCT and WIPO[7], which allows them to be the only ones who perform wind turbine cleaning from helicopter via a special developed "cleaning-apparatus". The patent covers a long list of countries including Denmark, Norway and Sweden, although they are not doing business in any of these countries at the moment.

Figure 9: Helitechnics® cleaning wind turbine blade with water canon.

Our business works only on new blades that are to be installed either on- or offshore, while HeliTechnics®' services regards maintenance of already installed wind turbines. The reason why they are still a competitor is because their business are placed in the same market as ours, in between the links of the *manufacturers and customers/owners*. Despite the fact HeliTechnics® is a service company hired for cleaning and maintenance, they are just dealing with one customer segment, the customers and owners, for instance Dong, Vattenfall or EON. It is more likely to say that they are a supplement to the customer and owner link, than in the previous link where our business is placed.
Our business shall be seen as a checkpoint the blades pass after they have left the production, but before they reach the owner, hired by either one. Since HeliTechnics® is only hired by the owners to perform maintenance instead of them, they are not seen as direct competitors. The services these two companies offers cannot replace or cover each other, both are dealing with a new business model as service companies in the wind turbine field, but the hiring one does not eliminate the other.

6.2 Budget and Net Present Value

6.2.1 Introduction

The general idea of a Net Present Value (NPV) is to check if an investment is profitable attractive or not. In a NPV there are three scenarios:

1. Present value of inflow > present value of cash outflow
2. Present value of inflow = present value of cash outflow
3. Present value of inflow < present value of cash outflow

If the present value of inflow is higher than the present value of the cash outflow **(1)**, the NPV is positive and the investment would be attractive.
If the present value of inflow is equal to the present value of cash outflow **(2)**, then the NPV would be zero which means that the investment is neither attractive nor unattractive.
The third scenario is when the present value of inflow is smaller than the present value of cash outflow **(3)**. When that is happening the investment would be financially unattractive.
When the NPV is found the internal rate of return (IRR) is calculated and is compared to the minimum attractive rate of return (MARR). The difference of the IRR and the MARR is how big the profit is of the investment. Both the IRR and the MARR is explained later on.

6.2.2 Assumptions

In order to calculate the NPV a lot of assumptions must be made. The investment is based on facts from the business Nuctech but the rest of the assumptions are based on qualified guesses in collaboration with sundry webpages.

The assumptions consist of investment, paychecks, transportation, rent, maintenance, electricity, scrap value and annual income. Figure 10 represents the different values and secondary a description of each assumption.

Values for X-ray Scanner:	Value:	Unit:
Lifetime	20	Years
Minimum attraktive rate of retur	5%	

Income:	Price:	Unit:
Annually income start	kr. 5.000.000,00	DKK

Cost:	Price:	Unit:
Investment cost	kr. 20.000.000,00	DKK
Annually Pay	kr. 2.520.000,00	DKK
Annually Transport fuel	kr. 45.571,00	DKK
Annually Rent	kr. 72.000,00	DKK
Electricity	kr. 56.925,00	DKK
Annually Maintenance	kr. 75.000,00	DKK
Scrap value	kr. 50.000,00	DKK

Figure 10: NPV assumptions

The lifetime of the x-ray scanner is set to be 20 years and the rate (MARR) of the investment is set to be 5%.

The Investment:
The investment is based on the x-ray scanner and a truck to transport it. We have contacted the firm Nuctech which has estimated that the scanner probably would cost between 10 and 25 million. In addition we assume that the scanner has a cost of 18 million DKK and the truck 2 million DKK. 20 million DKK in total.

The Annual Pay:
The annual pay is a sum of all the payments to those we believe are necessary in order to get the scanner to function. That is including the salesman, the project manager, the driver, the x-ray projectionist and two analysts.

By checking at ug.dk the employees will get the following salary:

- Driver: 27.000 DKK
- X-ray projectionist 33.000 DKK
- Two analysts 66.000 DKK
- Salesman 34.000 DKK
- Project manager 50.000 DKK

The sum in DKK/year: 2.520.000 DKK

The Transport:
It has been decided that the head office is located in Kolding because most wind turbines is manufactured in Jutland and because several offshore wind farms are located near Jutland.

If it is assumed that the truck is driving 100 kilometers (km) a day and a working week is five days, it will drive 23.000 km in one year (six weeks of vacation is taking into consideration).
In addition the truck is driving 4,29 km/l and the fuel price is 8,5 DKK/l. The truck will therefore use the following price in DKK on fuel:

$$\frac{2300km}{4,29km/l} = 5.361liters \rightarrow 5.361l * 8,5\frac{DKK}{l} = 45.571DKK \tag{2}$$

The Rent:
The rent of a 100 square metre apartment in Kolding for office has a price of 6.000 DKK/month which will be 72.000 DKK/year. Including everything.[8]

The Maintenance:
The maintenance on the x-ray scanner is estimated to be 75.000 DKK/year. The price is an estimate of sundry costs to the truck such as tires and mechanical parts and to the x-ray scanner.

The Electricity - 3D-scanning:
The electricity price of the x-ray scanner is calculated by several parameters. The calculation is based on a full 3D scan of a 50m long blade.
First the numbers of blades scanned in one week the first year should be calculated:

$$\frac{250blades}{46weeks} = 5,5\frac{blades}{week} \tag{3}$$

The next value which is calculated is the hours it takes to perform a 3D scan of a 50m long blade. The x-ray scanner is able to scan 20cm at the time and is estimated to take 1,2 minutes. The following calculation is based to the given values and will calculate the hours it will take to scan a blade.[9]

$$\frac{\frac{500cm}{20cm} * 1,2minutes}{60minutes} = 5hours \tag{4}$$

When the previously two results have been found it is placed in the next calculation. In addition the numbers of working weeks, the energy consumption of the scanner and the electricity price have been added.

$$5\frac{hours}{blade} * 5,5\frac{blade}{weeks} * 46\frac{weeks}{year} * 20kW * 2,25\frac{DKK}{kW} = 56.925\frac{DKK}{year} \tag{5}$$

The electricity price is therefore 56.925 DKK/year when it is only 3D scanning. If it only where 2D scan is would cost around 2.000 DKK/year. A minimum of two third of the blade is scanned in 3D and the 2D scanning price have therefore been neglected in this NPV.

The Scrap Value:
The scrap value is estimated to be 50.000 DKK/year.

The Annual Income:

The annual income is calculated from the costs. If a NPV is performed without any income it would have a deficit of 5.000.000 DKK/year based on ≈ 3.000.000 DKK to sum of all costs and 2.000.000 DKK to the repayment of the investment cost the first year. From data collected[10] it is known that there is an average production of 250 wind turbines a year. Each turbine has three blades and if we are taken into consideration that we are a new business, it would be natural that all blades aren't scanned. Therefore we estimate that we are scanning around 30% of all wind turbines the first year and the following years we have an increase of 2,5% in the income from the year before.

The first year the income pr. scan would be:

$$\frac{5.000.000 DKK}{250 blades} \approx 20.000 \frac{DKK}{blade} \tag{6}$$

6.2.3 Calculations and Results

The NPV formula is the following:

$$NPV = I + SC * (1+i)^{-N} + A * \frac{(1+i)^N - 1}{i * (1+i)^N} \tag{7}$$

I = Investment, SC = Scrap Value, i = MARR, A = Annuity and N = lifetime.

When the annual income for the project is changing, the NPV is calculated using excel in order to see the net cash flow, present value and the accumulated value for each year.

With the investment, the costs and the income plotted into excel, the table will look like figure 11.

Year	Investment & scrap value	Annually profit	Net cash flow	Present value	Accumulated
0	kr. 20.000.000,00	0	-kr. 20.000.000,00	-kr. 20.000.000,00	-kr. 20.000.000,00
1		kr. 2.230.504,00	kr. 2.230.504,00	kr. 2.124.289,52	-kr. 17.875.710,48
2		kr. 2.286.266,60	kr. 2.286.266,60	kr. 2.073.711,20	-kr. 15.801.999,27
3		kr. 2.343.423,27	kr. 2.343.423,27	kr. 2.024.337,13	-kr. 13.777.662,15
4		kr. 2.402.008,85	kr. 2.402.008,85	kr. 1.976.138,62	-kr. 11.801.523,53
5		kr. 2.462.059,07	kr. 2.462.059,07	kr. 1.929.087,70	-kr. 9.872.435,82
6		kr. 2.523.610,54	kr. 2.523.610,54	kr. 1.883.157,04	-kr. 7.989.278,78
7		kr. 2.586.700,81	kr. 2.586.700,81	kr. 1.838.319,97	-kr. 6.150.958,81
8		kr. 2.651.368,33	kr. 2.651.368,33	kr. 1.794.550,45	-kr. 4.356.408,36
9		kr. 2.717.652,54	kr. 2.717.652,54	kr. 1.751.823,06	-kr. 2.604.585,30
10		kr. 2.785.593,85	kr. 2.785.593,85	kr. 1.710.112,98	-kr. 894.472,32
11		kr. 2.855.233,70	kr. 2.855.233,70	kr. 1.669.396,01	kr. 774.923,69
12		kr. 2.926.614,54	kr. 2.926.614,54	kr. 1.629.648,48	kr. 2.404.572,17
13		kr. 2.999.779,90	kr. 2.999.779,90	kr. 1.590.847,33	kr. 3.995.419,50
14		kr. 3.074.774,40	kr. 3.074.774,40	kr. 1.552.970,01	kr. 5.548.389,51
15		kr. 3.151.643,76	kr. 3.151.643,76	kr. 1.515.994,54	kr. 7.064.384,05
16		kr. 3.230.434,85	kr. 3.230.434,85	kr. 1.479.899,43	kr. 8.544.283,47
17		kr. 3.311.195,72	kr. 3.311.195,72	kr. 1.444.663,73	kr. 9.988.947,20
18		kr. 3.393.975,62	kr. 3.393.975,62	kr. 1.410.266,97	kr. 11.399.214,17
19		kr. 3.478.825,01	kr. 3.478.825,01	kr. 1.376.689,19	kr. 12.775.903,36
20	kr. 50.000,00	kr. 3.565.795,63	kr. 3.515.795,63	kr. 1.325.066,40	kr. 14.100.969,76

Figure 11: NPV calculations

The calculation for the annual profit and present value in excel are listed below:

- Annual profit:

$$Annual\,profit_{year1} = Income - Sum\,of\,costs \tag{8}$$

$$Annual\,profit_{year2} = Annual\,profit_{years1} * 1,025 \tag{9}$$

- The present value:

$$Presentvalue = \frac{Net\,cash\,flow}{(1+MARR)^{year}} \tag{10}$$

The NPV of our project is **14.100.969,76 DKK** and proves that our x-ray scanner is a financially attractive project.
The break-even point is after 11 years which means that the investment is paid off after 11 years which can be seen in figure 12.

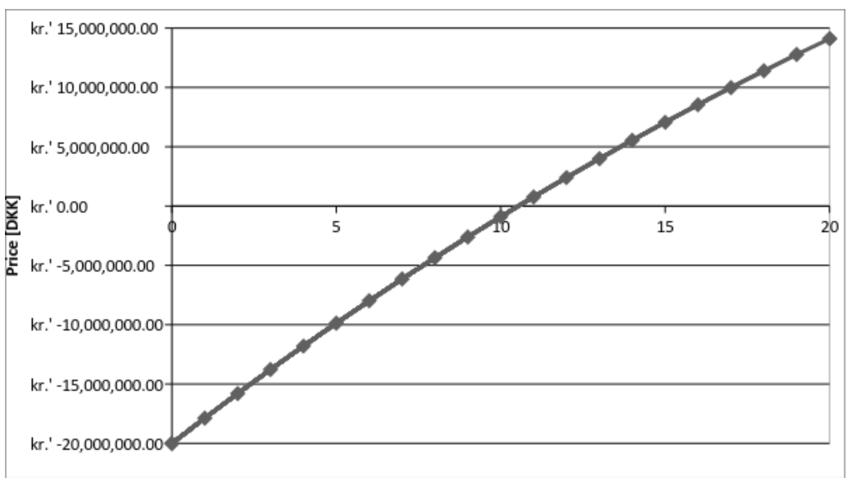

Figure 12: NPV shown graphically.

The IRR is the rate where the NPV goes to zero. By subtracting the MARR from the IRR. The higher a project's IRR is, the more desirable it is to undertake the project. The IRR is found by a tool in excel called "goal-seeking"[11] and is 11,5 %. The gap is therefore 6,5 % and is a sign of a healthy investment.

6.3 Blade price compared to a scan price

As written above the price of a 2D/3D scan is 20.000 DKK and a new wind turbine has a price of approximately 1,2 mio. DKK[2] and that is without any expense for dismounting the defect blade. The 20.000 is 2 % of the total blade price. In addition it would have a price of at least 250.000 to repair a minor defect on an offshore wind turbine blade due to the fact that the turbine among other things has to be stopped. It would furthermore be

[2] Rikke from Vattenfall

a security for an eventual buyer to have a guarantee of a well-functioning blade or at least to be informed if it has any defects by scanning the blade.

In order to elaborate the above results, a case from Anholt off-shore windfarm is explained in the next section. The case elaborates whether the price determination of a blade scan is viable.

6.4 Anholt Case

In order to justify whether the idea is feasible and have market potential, a case study was made. Based on the above sections with cost-calculations and market positioning, the group found it relevant to figure out if the scanner could actually save companies any money.
The case was built on a real-life offshore wind farm, *Anholt Havmølleparkv*[12], consisting of 111 wind turbines with a blade length of 60 meters. The idea was to calculate what the price would have been, if all turbines were scanned in advance back in 2011. These scans should be able to find all hidden and potential productions failures, which could and still can strike the blades further on.
The group categorized these failures as either minor or major failures. Since there is no evidential record saying how many failures occur on the basis of poor production, the group predicted the failure rate.
Minor failures was set to 10%, these failures are small and can be repaired either on ground before installation or offshore by maintainers. Major failures was sets to 0.5%, these failures are too big to repair and would therefore result in blade replacement. If major failures were found by scan, and thereby before installation, the buyer could claim a new blade free of charge.

Onshore (Scan):
Minor failures reparation cost 75.000 DKK/blade. (See Appendix B)
Blade manufacturer replaces major failures.

Offshore:
Minor failures reparation 250.000 DKK/blade.
Major failures include: Cost of new blade is 1.2 million DKK, rent of crane vessel 250.000 DKK and labour of 2 maintainers for 4 hours 10.000. (See Appendix B)

6.4.1 Case Calculations

The price of a scan is 20.000 DKK and there are 333 blades.

Offshore:
Minor: 333·0,1·250.000 = 8.325.000
Major: 333·0,005·(1.200.000+250.000+10.000) = 2.431.000
Minor + Major = 10.756.000

Onshore (Scan):
Minor: 333·0,1·75.000+(20.000·333)= 9.157.500
Major: The blade manufacturer covers major failures.
Savings: 10.756.000 - 9.157.500 = 1.598.000

The calculations show that if the predicted failure rates of both minor and major failures are legit, the owner of the wind turbines at *Anholt Havmøllepark* saves 1.598.000 DKK. This result gives the indication that the calculated price is reasonable and that the idea in general is feasible.

7 Conclusion

Throughout the project the written problem statement has been carefully answered.

The first two problems regarding large x-ray scanners and their ability to detect flaws and errors, which types of flaws that are in focus and why x-ray scanners are a necessity in order to detect those flaws, have been meticulous explained and thereby reached the following conclusions. The x-ray scanner has the ability to detect manufacturing errors and with a combination of planar and CT-scanning. The parts of the blade which typically experience manufacturing errors can be scanned with CT so a higher error detection precision is achieved. The rest of the blade can be scanned with a planar x-ray scanner. This reduces detection resolution but decreases scanning time.

The problem regarding software for analyzing turbine blades has been investigated and illustrated. The software analysis includes a description of an x-ray image in 2D and the introduces the idea of artificial intelligence, it has been concluded that the data size of scanning a wind turbine blade is estimated at 22.5GB. The size is realistic to process however a powerful computer might be required in order to give live feedback.

As the previous technical problems have been finished, the market analysis including supply chain, competitors, customer segments, positioning and pricing were explained. Through the market analysis the supply chain has been examined and the new link “US” has been implemented. From the market analysis is can be concluded, that there is an open spot for launching the Manufacturing Scanner. The few competitors in the service business give the product an opportunity to act as firstmover and thereby benefit from the ensuing advantages.

As the market analysis is finished an NPV including a budget was carried out. From the chapter it is clear that the investment of 20.000.000 DKK is an economically beneficial investment. This has been concluded from the NPV calculation and the IRR calculation. The IRR gives a result of 6.5%.

When all problems from the problem statement have been answered, calculated, explained and analyzed the idea of an x-ray scanner scanning a wind turbine blade, must be concluded to be a good idea. Straight from the ability of the x-ray scanner to detect very tiny errors to the investment which appears to be a good investment, taken all our assumptions into consideration, our idea has been proven to be both realistic and economically beneficial.

Since it has been concluded that the idea is economically beneficial and there seems to be a great market potential. The group recommends that this business should be further investigated.

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Appendices

A Group Contract

Cooperation Agreement - Group 5 EiT - Vattenfall.

General:

1. Everyone should be on time. Rather 5 minutes too early than 5 minutes late.
2. Project work days are usually Wednesday, but if necessary more days will be scheduled.
3. If a group member is running late they are required to inform another group member either by Facebook or mobile.
4. If a group member cannot attend the scheduled project workday, they are required to give notice asap. Every third time a group member is more than 5 minutes late, they must bring cake for the group, the next project workday.

Preparation:

1. The work material to be prepared before a project workday is agreed upon on the previous project workday. (In special cases, Facebook can be used to coordinate work material).
2. Group members are required to complete any task given to them, by the agreed upon deadline.
3. Group members needing help with their task should make sure to seek help from other members as soon as possible.

Agreement:

1. All decisions are decided by simple majority.
2. If the group members cannot get an agreement, they will seek the help of their adviser.

Teambuilding:

1. The work pace should not be grueling, as there should be time to have fun and team build. That said, the work should be completed within the deadlines.
2. If a group member is working and you're taking a break, it is expected that you don't do anything to break their concentration. (Loud topic discussions, music etc.)
3. Breaks can be coordinated within the group, or short breaks can be taken individually.

Level of ambition:

1. It is expected that every group member's ambition level should be high.
2. The ambition level can under special circumstances (deadlines, etc.) be changed, as long as the group agrees.

Learning:

1. It is up to the individual group member to take responsibility for his/her own learning.

Work Culture:

1. Group members should be respectful of each other. (Let them speak and listen to their points of view)
2. If a problem should occur between group members (academically or personally), it should be addressed as soon as possible.
3. Work problems should be solved by groups of two where possible.
4. The work tasks of the day should be clear and thought out beforehand.
5. At the end of the project workday, the results should be evaluated and the work tasks for next time should be planned.
6. In case of serious violation of the cooperation agreements, the advisor will be contacted.

B Mail Correspondences

B.1 Morten Saldern; Mail Correspondence

Svar fra Morten:

Som jeg kan ikke udlevere finansielle data fra Vattenfall! Men jeg vil gerne være behjælpelig med nogle estimater på spørgsmål 1-6.

Jeg har tidligere arbejdet ved DONG Energy og været involveret i vinge kampagnen på Horns Rev 2, og kender derfor en del til de overvejelser der er gjort i forbindelse her med.

Det er meget afhængigt af hvilken størrelse mølle i tænker på, Horns Rev 2 møllerne er relativt små og kan derfor klares med et lille jack-up kranskib, hvis vi det er større møller stiger prisen på kranskibet betragteligt.
Nedenstående svar tager udgangspunkt i Horns Rev 2

1. Omkostninger i forbindelse med afmontering af vingerne på en Off-Shore mølle.

- Forberedelse af mølle til demontering af vinger ca. 4 timer for 2 mand 10.000

Kranskib leje 250.000 pr døgn + mobiliserings omkostninger

Special løfteåg til enkelt vinge hejs kan kun lejes ved Siemens, kender ikke prisen.

Vinge rack monteret på skib til transport af vinger kan lejes ved Siemens kender ikke prisen

Havnearbejderne i Esbjerg tager sig rigtig godt betalt for at løft vinger fra skib til kajen! Regn med 10.000 pr vinge

2. Omkostninger i forbindelse med leje af skib til transport af mandskab og vinger.

- Et lille kranskib koster ca. 250.000 kr. pr døgn + fuel

3. Omkostninger til transport af møllevinger på land.

- Kommer lidt an på hvor langt de skal men jeg vil gætte på ca. 10.000 kr pr vinge pr transport

5. Omkostninger til reparation af skader i fibermatrixen. Både hvis det foretages på land eller til havs.

- Det kommer meget an på hvor meget der skal repareres, hvis det kun er overflade skader kan det klares hurtigt for måske 75.000 kr på land, men her til kommer omkostninger til fabrikshal eller telt med varme og udsugning.

Offshore kan prisen blive meget høj, da der er mange vejrligsdage over en sæson på Horns Rev 2 kan det være op til 50%. Der kan være vejrlig på af regn, lav temp. tordenvejr, højvind og høje bølger. Man kan let bruge 250.000 pr vinge, selv uden de helt store skader

6. Omkostninger for mandskab til maling af mølle vinger til havs.

- Jeg har ikke hørt om nogle der har gjort dette på en hel vinge offshore. Men det vil blive dyrt et rope access team (2 mand) koster ca. 175 euro pr time!

Overflade arealet på en Siemens B45 vinger, der sidder på horns rev 2 er ca. 220 m2. arealet skal vaskes for salt, fugle klatter og andre urenheder, slibes ned, primes og males. Det er et kæmpe arbejde fra reb.

Vi er også meget interesserede i at vide, hvad den begrænsende faktor for en vindmølles levetid er. Vi ved selvfølgelig at vingerne nok oplever den største slidtage, men at de generelt kan repareres.

Hvornår har en vindmølle udtjent sin cirka. 20-25 års levetid. Er det når gearkasse og generator er slidt op?

Ja alt kan repareres og vedligeholdes og møllerne kunne i princippet køre længere end de 20-25 man typisk estimerer. En af grundene er at økonomien ikke er for god når først tilskuddet er væk. Så er afregnings prisen pr KWh = markedsprisen, og den ligger vel omkring 20 øre desuden kan prisen være negativ i perioder med for meget strøm på elmarkedet!
Men jeg vil mene at det for det meste er gearet er fejler og giver ældre møller dødsstødet.

Det var lidt de store overskrifter, men det er vanskeligt og tidskrævende at komme med estimater, specielt når det ikke er mere konkret.

B.2 Rikke Juul Balle; Mail Correspondece

Hej Emilie,

Super, det er en god ide at sikre vingerne er i orden før montering. Vi ser flere forskellige typer fejl under drift og de kan deles ind i alm. slid (forkant erosion, manglende/slidt maling/forkanttape, tabte/knækkede VG'er, gurneyflaps ect.), drifts fejl (lyn skader, håndteringsskader fra montering) og produktions fejl (buler i laminat, delamineringer, luftindeslutninger, balsa revner/overlap og mangelfuld vedhæftning af limsamlinger) – det er denne gruppe af fejl i evt. vil kunne finde ved hjælp af x-ray.

Fejlene fra sidste gruppe ses oftest:
Balsa – første 1/3 af vingelængden i balsa områderne (primært bagkantbalsa)
Laminatskader – midterste 1/3 af vingelængde i det styrkebærende laminat
Limsamlinger – hele vejen langs bagkanten

Det er svært at sige noget om en gennemsnitspris for en vinge, men en 55-60 meter lang vinger koster ca. 1.2 mio. kr. Det bliver så væsentligt dyrere når det er erstatningsvinger der er tale om da disse typisk ikke længere er i serieproduktion. Det kan være helt op til 2 mio. kr. for en ca. 45 meter lang vinge som ikke længere er i serieproduktion.

Håber det besvarer dine spørgsmål ellers er du velkommen til at ringe/skrive igen.

Med venlig hilsen / Best regards

Rikke Juul Balle

C Alexander Osterwalder's Business Model Canvas

Key Partners	Key Activities	Value Propositions	Customer Relationships	Distribution Channel
Vattenfall *Dong* *LM Wind Power* *Siemens* *Vestas* *EON* *Nuctech*	X-ray scanner system with possibility of generating 3D images. Data storage and algorithms for error detection. Well trained personnel for operating the scanner. **Key Resources** X-ray scanner Great location of the scanners Transportable scanners Great costumer service Package solutions	Detecting future error. Major savings in future maintenance. The condition of the blade before mounting. The Manufacturing Scanner detects failures in all types of blades, for both manufactures and owners, for a fixed low cost.	Service partnership. Continously monitoring. Planning maintenance. Data collecting from different blades/customers to improve service and detecting future errors.	Business to busines. Fairs . Direct contact/sales. Service agreements.

Cost Structure	Revenues Streams
Investment of the x-ray scanner. Transpotation of the device. (Truck). Fascilities. Labour.	Direct sales (scannings) - Suppliers/Manufacturers Direct sales (scannings) -Owners/Power suppliers Servic agreements - customers