Mervento 3.6-118 Recycling Rate

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Bachelor's Thesis

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BACHELOR'S THESIS

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Abstract

My Bachelor's thesis work has been to make an investigation of the recycling rate of Mervento Oy's new wind turbine Mervento 3.6-118. The study has been part of Mervento Oy's environmental management system ISO 14001. The Bachelor's thesis shows how the recycling rate has been determined through a material analysis and also the recycling methods that have been used and how the results were reported. According to the results, the part that cannot be recycled in the current situation consists mostly of the blades, which are constructed of glass reinforced plastic. The report highlights the alternative recycling methods that may be relevant for the recycling of glass reinforced plastics and the prospects of recycling methods.

Language: English Key words: wind turbine, wind power, recycling

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EXAMENSARBETE

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Abstrakt

Mitt examensarbete har varit att göra en undersökning av återvinningsgraden för Mervento Oy:s nya vindturbin Mervento 3.6-118. Undersökningen har varit en del av Mervento Oy:s miljöledningsystem ISO 14001. I rapporten redovisas hur återvinningsgraden har tagits fram genom materialanalys och vilka återvinningsmetoder som har användts samt redovisning av resultatet. Genom resultatet har det visats att den del som inte går att återvinna i dagsläget utgörs till stor del av bladen som är konstruerade av glasfiberarmerad plast. Rapporten lyfter fram de alternativa återvinningsmetoder som kan bli aktuella för återvinning av glasfiberarmerad plast samt återvinningsmetodernas framtidsutsikter.

Språk: Engelska Nyckelord: vindkraftverk, vindkraft, återvinning

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1. Introduction

Wind power is a renewable energy source that is becoming more and more widespread around the world. To take advantage of the energy contained in the wind is nothing new. As early as 4000 years B.C. the Egyptians had sails on their papyrus boats on the Nile. During the 10th century people used windmills to grind various grains in the Middle East and the U.S. began using windmills for pumping the water in the late 19th century. To take advantage of the wind for the generation of electricity started in the late 19th century and early 20th century, which has resulted in the current situation when there is a globally installed wind capacity of 238 GW. This is expected to increase up to a wind capacity of 500 GW in the year of 2016. /11/

The reason for the expansion of wind power today is that wind is a renewable energy source that will not cause any emissions during its operation time. Compared with other energy sources such as coal, oil and gas power plants that burn fossil fuels and contribute to a great greenhouse gas emission during their operation time, wind turbines only contribute to emissions during their time of manufacture, assembly and disassembly, and a small part in the service operations. A negative side that may be perceived of wind turbines is that a wind turbine changes the landscape because of its high altitude and large rotors. There have been many studies on how to proceed in order to assemble a wind turbine and to learn how it affects nature. However, it has not been investigated to the same extent how to do in the final stages of its lifetime. This thesis focuses on the final phase of a wind turbine, i.e. a material analysis of a wind turbine is made and its recycling rate is determined.

The report begins with a description of the company that placed this assignment, then the objectives and scope of the investigation, and the methods that have been used in the study. The report mentions various types of waste management methods and alternative recycling methods that can be applied to wind power. After a description of the wind turbine and its functions, the boundaries that have been made in the wind turbine are described. Some recycling prospects are mentioned and finally the result is presented, as well as an analysis and a discussion of the result.

2. The company

The company that this thesis work has been made for is Mervento Oy, which was founded in December 2008. The company was founded by Mr Martti Ala-Vainio and Mr Patrik Holm and with the investors of Power Fund II, managed by VNT Management Oy, Soldino Ltd and investors Mutual Pension Insurance Company Varma, AC Cleantech Growth Fund I Holding, EPV Energia Ltd and the company's own employees.

The company's business ideas are to develop, manufacture and deliver direct-drive wind turbines in the multi-megawatt class for placements on land, coastal and offshore. The market is initially directed to energy and power companies in Finland, Sweden, Norway, UK, Ireland and France.

Mervento has currently engaged position contractors for the manufacture of the components for the turbine, and most of the components are preassembled in Lovisa for later transport to the building site. Future plans are to build their own assembly hall on the west coast of Ostrobothnia.

The company has a certified management system according to the requirements in ISO 9001 and ISO 14001. In the environmental management system there are objectives and targets that provide guidelines on how to meet the goals set up by the company, presented below.

3. Goal and extent

Mervento Oy has a certified environmental management system according to the requirements in ISO-14001. This thesis is part of the management system. The task was to make a study of Mervento’s new prototype Mervento 3.6-118 wind turbine. The investigation is the second target that Mervento has included in its objective: minimising the environmental impacts of the Mervento wind turbines during their life cycle, which can be seen later in this chapter.

The goal of this work is to conduct a material analysis of the turbine and according to that determinate the recycling rate with the methods used commercially in the current situation. Another goal has been to locate the materials that are the most difficult to recycle in the wind turbine to provide the opportunity to consider other options of material selection.

Mervento’s Environmental Programme 1,

Objective:

Minimising the environmental impacts of the Mervento wind turbines during their life cycle.

Targets:

1. Investigation on the suppliers´ environmental performance

2. Investigation on the recycling rate of the Mervento 3.6-118

3. A waste management plan for the erection work of the prototype.

4. Investigation on the energy-pay-back for the Mervento 3.6-118

4. Course of action

Wind power is a relatively young industry, and there are few documented examples of how the dismantling and recycling are done for a wind turbine. Wind turbines are generally very complex designs involving many different types of materials and components. The biggest problem nowadays is what to do with the used rotor blades, which consist of mostly glass-reinforced plastics (GRP) mixed with different support materials.

The recycling rate of a product can be defined as the part of the product that is recycled. The recycling rate is expressed in percentage. /24/

To define the recycling rate of Mervento 3.6-118 turbine, it was necessary to determine the total weight and the kinds of materials that had been used in the wind turbine parts.

This information was taken out of part lists, which include descriptions of the types of material, their weights, and the amount. The results from the part lists were afterwards updated, because some information of the parts was not included in the part lists. The applications were based on discussions with the personnel of Mervento, who gave more precise values of each material.

After the weights and the different material types had been identified, the recycling rate of each material was made. Recycling is a relatively complex topic. There are many different methods developed for handling waste. There are, for example, no books nor standards that describe what the best method is. To determine the recycling rate, literature from the Internet, recycling company websites, the legislation and different reports that include different waste management systems were used. An interview with Mr Leif Åkers, CEO at Stormossen Oy in Vaasa, and a visit to Nordic Composite Engineering in Jakobstad, were also made. E-mails were also used to collect more information, but with less success. This was perhaps because this work was made during the summer holidays.

5. Largest components and their materials in a wind turbine

Figure 1. The four largest components in a wind turbine. /17/

In figure 1 the largest components in a common wind turbine can be seen. They are foundation, tower, nacelle and rotor.

The function of the foundation is to give the tower a solid base to stand on and to keep the tower stabilized using its own weight. The foundation is constructed of reinforced concrete, and in the center of the foundation is a metal cap where the tower is fixed.

The tower is a conical tube constructed of steel. The tower is wider in the bottom and narrow in the top. Inside the tower there is usually a ladder or an elevator to facilitate the service of the wind turbine.

Placed on top of the tower is the nacelle, also called the turbine housing. Inside the nacelle there are a generator, a control system, the yaw system, a break, a cooling system and in most cases a gearbox. Covering the nacelle is a shell made of glass-reinforced plastics (GRP). Other materials used in the nacelle are steel, cast iron, copper and aluminium. There is also a significant amount of electronic components that consist of a number of different materials. (see 6.4.4)

Fixed to the nacelle are a hub and blades, which together are called a rotor. In the current situation the most common rotor is a three bladed rotor. In the hub there is a pitch system that turns the blades in the right angle against the wind. A cone made of GRP covers the hub. The blades are made of GRP and a small amount of metal in the bearings. In chapter 6.6 some methods on how GRP can be recycled are described. In the current situation GRP is a difficult material to recycle. /14/

6. Waste management and recycling methods

6.1 History of waste and waste legislation

Waste management has improved a lot during the past few decades. When waste management arose, it was not with the same intent as today. The disposal of waste was first identified as a sanitation problem in the cities. In the absence of proper rules how waste should be handled, waste was just thrown out on the streets and stored in basements. In the 19th century the first joint management laws in Finland appeared, stating that every house owner in the cities should regularly sweep his part of the street. In the late 19th century the first healthcare law in Finland came, which declared that the waste should regularly be carried out of the cities to landfills located in worthless classified lands. During that time sorting waste started to arise, people used and saved useful materials such as metals, wood, leather etc. This waned in the 1930s due to the fact that people started to have a better life standard after World War I. After World War II sorting waste took speed again, and even the recovery of waste. In the 70s recycling of metals, paper and waste oil was a normal thing in Finland. In year 1979 the first Waste Management Act in Finland appeared, and thanks to that environmental issues started to be recognized. This act declared, among other things, that every property in the urban areas should have access to waste transportation. Most of the waste was then transported to landfills. However, the problem was that almost all of the landfills were unguarded at that time, which led to the fact that all kinds of waste were carted to the landfills. Some of the waste was directly polluted. A new Waste Act came in 1994, which is still today a guideline on how to handle waste. After Finland had joined the EU, new ways of thinking followed. After the new Waste Act investigations and settlements of the old unattended landfills began. Today landfills are well controlled with proper constructions and regular checks, so that no pollutant substances are released into the nature. The waste act is about to get renewed again, but the new act is not yet in force. /10/

6.2 What is waste?

Waste is often regarded as something undesirable, something that the owner would like to or need to get rid of. Depending on how one looks at a product or material, waste occurs when the owner considers it waste, and that can depend on time, place and cultural context.

Waste has many names, such as rubbish, scrap, debris or residue. Depending on how it is called, it gets a different nuance when deciding what should be considered as waste.

According to the Finnish legislation waste is: a substance or object which a holder discards or intends or is required to discard. /2/

The new waste act that is still in the progress of getting renewed will allow waste to cease as waste.

Waste occurs from all different stages of a product´s lifecycle, from primary production up to the demolition of the actual product. However, the best waste management system is to strive to a situation where no waste occurs. /3/

6.3 Waste management

Getting a functional society to recycle is an important task. If we did not have a recycling system, it would lead to a lack of raw materials in the end, and the society would overflow with garbage. The amount of disposed municipal waste in year 2010 was an amount of 557 000 ton, which is a growth of almost 20 percent from the year before. The total amount of waste is increasing every year and so is the raw material consumption. The waste should therefore be regarded as a resource of material and be properly disposed of. There is a simple logic for the environmental prosperous: that it is better to reuse the material several times than to throw it away and refine new raw materials from the nature. Recycling will not only reduce the processing of new raw materials, it also saves a substantial part of energy and reduces the environmental load if the waste is utilized. /22/

Aluminium is a very good example of energy saving. The use and melting of aluminium scrap for new raw materials saves up to 95 % energy, instead of processing new raw materials. /30/

To obtain a satisfying quality of the raw material from waste it is necessary that the materials are sorted into right fractions. Categories that the sorting in companies can be divided into in the area managed by Stormossen Oy are:

- Kitchen waste
- Combustible waste
- Paper waste
- Cardboard waste
- Scrap metal
- Glass waste
- Hazardous waste
- Bulky waste
- Construction waste /23/

During the past few decades recycling has gone in a positive direction, probably because of new policies, such as subsidies and taxes that have provided incentives for recycling. Generally defined with recycling is that virgin material is replaced with the collected materials.

Some market economists are against recycling. In accordance with market economy rules, recycling is not profitable in many cases. With the exception of metal it is cheaper to produce new raw materials than to reprocess the materials from waste. This is because the economy measuring Gross National Product (GNP) does not measure the environmental aspects. GNP measures only what is measurable in money, and it counts all turnover as plus.

Without legal or management control, that is, if market forces could prevail until such a time that it would be profitable to recycle, it would lead to a shortage of raw materials. Environmental problems would increase in terms of eutrophication, greenhouse gases etc. and the control of the spread of heavy metals and other persistent toxic substances to nature would be lost.

To have a properly working waste management system, a few functional elements are needed. These are logistics, infrastructure, products, materials, marketing, economics and ideas. /10/

6.4 Recycling methods today

6.4.1 Reuse

Reuse principles are based on taking a used product or material and use it for new purposes without making any major changes in the design or choice of materials. Reuse is the most environmentally sound method to handle used products, and is given priority in most cases.

An example of reuse is retread tires. The old structure is reused, but the worn surface is removed and replaced with a new one. A prerequisite for the reuse method is that the used product is in good condition when taken out of use. Reuse is suitable to all materials and products that do not constitute any harm to humans or the environment. /5/, /10/

6.4.2 Recycling

If reuse is not suitable for a product, then recycling is the next priority of method. The method means that you to take advantage of the material in a product by destroying it, mainly by melting. Obtained is then a material of equal quality or a material of lower quality, e.g. metals keep the equal quality but plastics get a lower quality. The most recycling friendly materials today are metals and can be recycled from scrap metal and electronic scrap. Metals can be recycled over and over again without losing their characteristics. Many metal recycling facilities today produce raw material exclusively from scrap metal. Also steel mills that produce raw materials from ore need scrap metals in their process in order to cool the molten in the furnace. /24/

6.4.3 Energy recovery

Combustible types of waste that are not suitable for recycling as material can be recycled as energy. The primary method of energy recovery is to use the combustion of waste as a fuel. The bulk of the fuel is combustible waste from households and residues from the industry. Incineration plants are usually equipped with either grate boilers or fluidised boilers, or a combination of both. Grate boilers are more robust boilers and require less pretreatment of fuels. The waste is fed into the combustion chamber on a grate and forms a burning bed. Fluid boiler requires that the fuel is finely crushed by a crusher before it is fed into the boiler. That is because the fuel is blown into the combustion chamber. The heat generated by the combustion process in an incineration plant shall be recovered as well as it is possible in practice. /21/, /10/

6.4.4 Electronic waste and producer responsibility

All of the electronics we come in contact with in everyday life are electronics that belong to a group of products with so called producer responsibility. It means that the manufacturer is obliged to dispose of the electronic products when they are scrapped. Nowadays the price of the electronic products includes a fee covering the handling of a product when it is taken out of use. /2/

The first step of recycling electronic waste is to manually handle it in order to isolate hazardous waste, metals, plastics etc. from the product. The materials are then separated for reuse, recycling, energy recovery or landfill. Electronic waste mostly contains a small amount of hazardous waste that must be handled and disposed of properly so that they don’t do any harm for humans or the environment. /28/

The electronic waste has lately become a popular resource, because it contains several metals such as copper, aluminium, lead and several precious metals such as silver and gold.

The requirements for the recycling of electronic waste are determined by the waste electrical and electronics equipment directive (WEEE). /27/

6.5 Other waste treatment methods

6.5.1 **Landfill**

Waste that can´t be recycled or energy recovered will be transported to the landfill. There are three different kinds of landfills, depending on the waste type that is deposited. Waste that is deposited is inert waste, plain waste, and some hazardous waste. Today landfills are well managed, and there is also a good control of the different waste types that are deposited to landfills. From the landfills today energy is extracted in form of landfill-gas that has been formed inside the landfill. The gas is then burned for heat or electricity production. Although landfills in Finland are fairly well controlled today, there is still the option of waste management to be chosen as a last resort. It is only those materials that can't be recycled or burned that one should choose to deposit.
The reasons why one should avoid the deposit of waste to a landfill are that a landfill requires a lot of space, the materials can eventually break down and even in a well managed landfill this may cause environmental problems. Landfilling is a waste of material resources. /10/, /20/

6.6 Recycling methods for composites

Today the wind power industry has not many options regarding what to do with the used rotor blades and nacelle covers that mostly consist of GRP and metals or wood as support materials. As said earlier in the report, the GRP waste is a problem for the recycling of a wind turbine, and today all GRP is added to landfills in Finland.

In the figure below some alternatives for what to do with the used rotor blades and nacelle covers are presented.

6.6.1 Mechanical recycling

The principles of mechanical recycling revolve around the size reduction of the waste component through shredding or crushing, for reincorporation into another material. This method has been a common method for glass fibre materials. For example, different projects have shown that composite materials can be successfully fed into a cement kiln. Approximately two thirds of the material are transferred into raw materials for cement and one third, the organic part, is burnt and this generates energy. /4/

6.6.2 Pyrolysis

Pyrolysis can be explained in an easy way as baking buns backwards, to put the finished buns into the oven and take out the ingredients. The process is about to expose the material to a very high temperature in an environment affected by oxygen depletion. Hence a decomposition of organic volatile components occurs which can then be condensed. The pyrolysis technique is under constant development for the application of composite products, for example tires and blades from wind power. The problem with the method is that when composite materials are exposed to high temperature, the tensile strength is considerably reduced and leads to the fact that the recycled composite's usability decreases. Therefore different projects for recycling of used rotor blades have begun to develop pyrolysis with microwaves. Microwave pyrolysis has several advantages when the heating of the material does not occur by heat conduction. Heating by microwaves distributes heat energy more evenly over the material and it is possible to use much lower temperatures than in the conventional pyrolysis. The materials that arise when applying pyrolysis and microwave pyrolysis for composite materials result in two fractions, organic fraction and inorganic fraction. The organic fraction is liquid and consists of styrene, toluene, benzene and other poly-aromatic substances. The organic substances have a high energy value and can be used for energy recovery or converted into synthetic gas. The inorganic fraction is fiberglass and that can be used for secondary products or added to the landfill. /3/, /24/, /26/, /29/

Figure 2. Wind turbine blade part before pyrolysis. /16/

Figure 3. Wind turbine blade part after pyrolysis. /16/

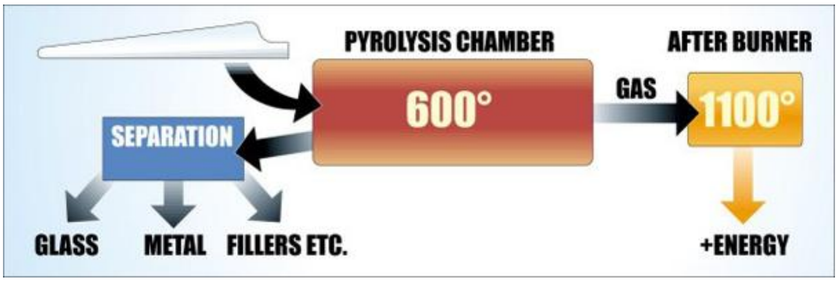

Figure 4. Process scheme of pyrolysis. /16/

6.6.3 Fluidised bed

This method involves feeding shredded composite materials into a bed of sand. The sand is fluidised with a hot stream of air at 450-550°C which breaks down the polymers so that they vaporize. The fiber and filler materials are then released and carried out in a gas stream. The fiber and filler are then separated and the resin products are fully oxidized in a combustion chamber, where the heat can be recovered. With this method glass fibers lose about 50 % of their tensile strength, but they retain their stiffness when processed at 450°C, which is sufficient to remove polyester resin. At higher temperatures more strength is lost. A particular advantage of the fluidised bed process is that it is very tolerant of mixed and contaminated materials. /15/

6.6.4 Solvolysis

Solvolysis is a chemical reaction in which the solvent, such as water or alcohol, is one of the reagents and is present in great excess of that required for the reaction. Solvolytic reactions are usually substitution reactions, reactions in which an atom or a group of atoms in a molecule is replaced by another atom or group of atoms. The solvents act as or produce electron-rich atoms or groups of atoms that displace an atom or group of atoms in the substrate molecule. At high temperatures or in the presence of strong bases, some solvents act as eliminating agents, producing alkenes from alkyl halides. It is common practice to name solvolysis reactions after the specific solvent, such as “hydrolysis” when water is the reagent. A project that aims to develop the solvolysis method is the European EURECOMP project, which started in May 2009 and will last for 36 months. This project has shown that this method could retain the fiber length and strength better than other recycling methods. /7/, /19/

7. Used materials in Mervento 3.6–118

7.1 Sections of used materials

Confidential

7.2 Short description of parts and their materials in Mervento 3.6-118

Confidential

7.3 Total weight

Confidential

7.4 Boundaries

The foundation has not been included in the calculations. The foundation is below ground level and does not constitute any danger to humans or the environment after the wind turbine has been dismantled. Nor is there anything in the Finnish legislation on how to deal with the area where a wind turbine has been standing. Restoration of the site can be compared to tearing down a house. It is required that the area is cleaned up so that no leftovers can form any danger to the ambient environment, such as constructions where it is possible to climb up and fall down. It is the landowner´s duty to see to it that these requirements are performed at demolition. However, it is possible to reuse the foundation if it is in a good condition, e.g. to place a new wind turbine on it or use it for another purpose. /32/

In case of removal of the concrete, there are two opportunities in the current situation. One opportunity is to crush the concrete and separate the reinforcements from the concrete, and then use it as filler material. The other possibility is to crush the concrete and separate it from the reinforcement and then transport the concrete to the landfill for final disposal. /31/

In electronics there are some small amounts of precious metals and other materials. Due to poor statistics of how much these represent, they have not been divided and specified according to their share of the total weight. The same goes for the small amounts of lead, wood, and glass in the electronics. These are included in the estimated recycling rate of electronic waste.

8. Recycling rate of Mervento 3.6–118

A wind turbine is a very complex construction with many different materials and alloys. Theoretically the recycling rate could be of a very high percentage, but it would be a very costly process and could be a more harmful method to the environment than the commercial methods available today. This is because it might require long transport distances to be able to use the right methods, or it could result in a high usage of energy if you want to separate the materials and alloys.

The recycling rate has been determined using the methods available in the current situation. These methods are the ones used in a commercial way today in Finland. In order of preference according to the waste legislation, they include the following: reuse, materials recycling, energy recovery and finally landfill.
All metals in the calculations have been estimated to have a full recycling rate of 100 %, with the exception of metals that are included in the electronic parts. They are included in the estimated recycling rate of electronic parts.

A recycling rate of the total amount of the electronic parts was decided and the rate is 78 %. This rate is taken from a statistic diagram from the recycling company Stena Technoworld Oy, found in Appendix A.

All glass reinforced plastics in the calculations are considered to be landfilled.

The calculation of the total recycling rate with the methods that are used commercially in the current situation of Mervento 3.6-118 resulted in a recycling rate of about 94 %.

In table 4 can be seen the calculated percentage of materials recycled in different ways, as well as the amount landfilled. For further detailed information about the materials and the recycling methods that have been used, see Appendix B.

There are other alternatives to increase the recycling rate. One of these alternatives is for example to burn the organic part in the blades. Later on in the report, in chapter 8.2, there is a calculation on the recycling rate if the blades are added to incineration.

Table 4. The total recycling rate used with the commercial methods that are used in the current situation. In this calculation all GRP was added to landfill.

Reuse	Recycled	Energy recovery	Landfill	
1,17 %	92,46 %	0,04 %	6,33 %	%
	Recycling rate		93,67 %	%

9. Recycling prospects

9.1 General improvements of recycling

In the future it would be a necessity to see waste as a resource of material and not as junk. According to the EU Sixth Environment Action Programme the quantity going to final disposal (landfill) should be reduced to 50 % of the total amount in year 2050, which will result in an expanded waste mass for recycling and energy recovery. /9/

According to Mr Leif Åkers at Stormossen Oy, the most comprehensive change of waste handling will be that of plastic waste. Within 10 years energy recovery will be the dominating method for plastic waste, until a proper recycling method has been developed. In the future plastic waste might be handled with a pyrolysis technique which separates the organic, liquid fraction from the solid material.

According to Mr Åkers there are also projects that are developing intelligent plastic packages. It means that a chip assembled into the packaging tells what kind of material the packaging is when added to the recycling process. As the development of recycling methods proceeds, sorting waste will become a more increasingly important part of the recycling process. The intelligent packaging products would perhaps be a step on the right way towards getting a working sorting method for commercial recycling.

The recycling methods of for example glass and metals will be the same after 20 years, according to Mr Åkers. The methods that are developed in the current situation are working methods, although there will maybe be a higher recycling rate of the total produced amount. Thanks to a better control of the circulation of material a more effective recycling rate will be seen in the future. /31/

9.2 Recycling prospects of wind turbines

In the wind power industry a growing amount of used rotor blades is emerging. All composite materials that are difficult to recycle are currently added to the landfill in Finland. Due to their high 30 % organics content in general, such as resin and wood, a better solution would be to burn them in order to get electricity or heat. The problem is the high percentage, 60 % of the ashes that emerge from the burned scrap. Due to the presence of inorganic loads in composites, this ash is pollutant, so the post-treatment has to be adapted so that the pollutions don't harm the environment. /18/

A calculation on the recycling rate of Mervento 3.6-118 was made where the blades were added to energy recovery. The calculations of organic compounds of the nacelle covers and blades can be seen in Appendix C. The recycling rate would then be as in table 5 below. If this table is compared to table 4, one can notice the higher percentage with energy recovery instead of landfilling. If GRP could be recycled, the total recycling rate would be as high as 96 %.

Table 5. In this calculation all GRP was added to energy recovery.

Reuse	Recycled	Energy recovery	Landfill	
1,17 %	92,46 %	2,43 %	3,94 %	%
	Recycling rate		96,06 %	%

Regarding to GRP, the biggest problem today is not the material itself, but the lack of volume that makes recycling financially difficult.

"*There are now technologies available to reuse fiber-glass and blades from wind turbines and other components in cars. The problem is not technologies, but, that there is not enough scrap, so it is not commercially viable to put a plant that could use only these blades* – Per Dannemand Andersen, 2009"

In a study made by Professor Henning Albers from the Institut für Umwelt und Biotechnik, Hochschule Bremen, there are predictions about how the development of composite materials will increase in the future. The study shows that in 2034, approximately 225 000 tons of used blades are discarded annually worldwide. Another study predicts that in 2040 the number will be 380 000 tons. /13/

With the increasing amounts of discarded blades, it could be viable to build a pyrolysis plant near the areas where most wind power parks are planned. To ease up the transportation the blades could be crushed. Then it would be more economical to transport blades longer distances. /18/

10. Discussion

According to all the collected data, the final result of the recycling rate of Mervento 3.6-118 is 93.67 %. When the blades and nacelle covers were added to incineration, the recycling rate increased up to 96.06%. As the situation is today, if increasing the recycling rate further according to composite materials, it would maybe be necessary to use another material in the blades and nacelle covers. However, that could result in a reduction of the blades' properties and a more expensive outcome. To get a more thorough recycling rate of the wind turbine, it would be necessary to look up the electronic parts and cables more carefully, due to their mixed composition.

The recycling rate does not tell the whole story of how environmentally sound the wind turbine is. To get a bigger picture of how the turbine affects the environment, it will be important to see how much energy the different recycling methods require. To try to reduce the total weight of the wind turbine with other materials or constructions could result in a more environmentally sound turbine. When material optimization is discussed, durability aspects and the economy must be considered.

Due to the low age of the wind power industry, there are no good examples to compare this result with, a "guideline" of other wind turbines' recycling rates. The dismantling and recycling of wind turbines are an arising topic and more and more studies are made of the possible routes of used turbines.

If further work is done on the recycling rate calculations, my thesis could work as a foundation for continued research on the materials that affect the recycling rate the most.

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/31/ Interview with Mr. Leif Åkers, Stormossen Oy 20.7.2011

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STW Process Stena Metall 2010

	Recuperation (%)	Recycling rate (%)	Energy recovery (%)	Landfill (%)	
refrigeration	99.37	91.72	7.65	0.63	%
other large household appliances	81.7	81.7	0	18.3	%
small appliances	88	68	20	12	%
Monitors	96	93.8	2.2	4	%
other information and telecommunications	99	92	7	1	%
TV	96	92.5	3.5	4	%
Other consumer electronics	75	73	2	25	%
lamps, excluding filament light bulbs	96.5	96.5	0	3.5	%
lighting equipment	81	71	10	19	%
Electrical and electronic tools	8.82	91.17	7.65	1.18	%
toys, leisure and sports equipment	78	78	0	22	%
medical equipment and supplies	78	78	0	22	%
monitoring and control equipment	78	78	0	22	%
ATMs	80	80	0	20	%

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