Reduction of Environmental Impact Effect of Disposing Wind Turbine Blades

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“Follow your inner moonlight; don't hide the madness”

Allen Ginsberg

To my professor, Richard Koehler

Abstract

Wind power industry is expected to be one of the fastest growing renewable energy sources in the world. The growth specially focuses on growing industries and markets, because of economical condition for wind power development besides political decisions.

According to growth of wind turbine industries, wind turbine blades are growing fast in both size and number. The problem that now arises is how to deal with the blades at the end of their life cycle. This Master Thesis describes existing methods of disposing wind turbine blades. Moreover, the thesis considers alternative method of disposing blades, based on environmental and safety consideration.

Key words: Wind turbine blade, Disposing methods, Environmental consideration.

Acknowledgement

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Contents

Chapter 1

Introduction

1.1 Background

During the past decade, a wind power industry has dramatic growth in the whole world. The total installed power capacity has increased dramatically from 2 percent in 2000 to 9.6 percent in 2010. For instance, since 1995 to 2010, EU's capacity has increased from 814 MW to 9,259 MW. This represents a yearly growth of 17.6 percent. Regarding growth of wind power industry, wind turbine blades are also growth in both size and numbers. The problem that now arises is how to deal with the blades at the end of their life cycle. It can be expected to have about 92,590 tons of blade materials from 2030 to 2035 which should be consider as disposing materials.

According to the fact that wind turbines are one of the most environmentally sound technologies for producing electrical energy, disposing phase of wind turbine blades has been one of the blind spot of environmental footprint of wind power industry.

In the last two decades the most environmental impact analysis concentrate on installation and operation phase of wind turbines and there is only limited information and practical experiences about disposal methods of wind turbine blades.

Wind turbine blades, as a component of wind turbine, usually are to be treated as waste materials after their life cycles. It is necessary to solve this problem and provide new methods and alternative ways regarding disposing wind turbine blades as useful resource materials. Available and suggesting methods for disposing wind turbine blades can be categorized in to four issues:

- *Land fill*: if we consider wind turbine blade as a waste material the first way to get rid of the waste material is disposing them in to the land fill.

- *Incineration*: waste materials can be can be consider as a resource to produce energy especially in the industries by treating as burning materials. Pyrolysis is another method which is suggested to use both thermal energy of incineration and using residual material from incineration process.

- *Recycling*: is a mechanical process to reuse wind turbine blades for other applications. To recycle wind turbine blades, they has to be crushed in to small particles an applied as a filler or primary material in other compositions.

- *Artificial reef*: a new suggestion to use wind turbine blades as an artificial reefs especially for offshore wind turbine with massive blades.

1.2 Objective

Wind turbine blades going to be one of the massive Fiberglass productions in this world. Lack of suitable method for disposing these materials after their lifecycle is an obvious obstacle throughout their development. Depending of our decisions, blade materials can be treated as waste or resource materials, after their life cycle.

The main objective of this work is to study available methods for disposing blades regarding environmental and ecological impact and providing a new method for applying them as the artificial reefs in sea as a resource material based on feasibility and technical concern.

1.3 Theory and Methodology

The main purpose of this Master Thesis is to describe available disposing methods of wind turbine blades and compare the strengths and weaknesses of these methods. This study is based on applying available method of disposing waste material for wind turbine blade and also suggests an alternative way of disposing wind turbine regarding using blade as a resource material, and consider the feasibility of applying this method for wind turbine blades after their life cycle.

The thesis is based on studying available literatures for disposing material throughout research and experimental works in this field.

The main source of research in this thesis is based on internet, literatures, interviews and observations methods.

This master thesis has written based on one year master course of "Wind Power Project Management" at Gotland University, Sweden.

1.4 Thesis over view

Chapter 1: Introduction

The Introduction part of this Master Thesis gives a general idea and basic information of this work regarding problem statement and clarification of subject.

Chapter 2: Wind Turbine Blades

This chapter gives an outline of wind turbine blades size and construction by describing the main factors of blades constructions.

Chapter 3: Life Cycle Assessment of Wind Turbine Blade

In this chapter main concept of Life cycle assessment are explained, Different ways of life cycle assessment of wind turbine blades discussed and estimation of wind turbine blade lifetime is presented.

Chapter 4: Disposing Methods of Wind Turbine Blade

According to information in Chapter 2 and Appendix A, this chapter deals with combination of available disposal method for wind turbine blades and aim to sum up with comparison of these methods based on their straight and weaknesses regarding wind turbine blades.

Chapter 5: Using Wind Turbine Blades as artificial reefs

This chapter introduces a new alternative method of disposing wind turbine blade regarding environmental and ecological factor and discus about feasibility, possibility and policy considering applying wind turbine blades for artificial reefs.

Chapter 6: Closure

This chapter is a summary of all methods and findings about disposing wind turbine blades and sum up with suggestion and future works in this field.

Chapter 2

Wind Turbine Blades

Wind turbine blades are long and slender shape with aerodynamically structures which sucked around when the wind is passing through them. They made from different kind of materials and components such as different kind of resins, epoxies and specially Fiber Glass Plastic materials. In 2001, over 5000 tons of finished fiberglass laminate was used for the production of wind turbine blades, and that worldwide production volume is increased to 2×10^6 ton in 2011. (Paul S. Veers et al. 2003). Figure (1) shows complete wind turbine blade constructions.

Figure 1 complete wind turbine blade construction

The blade is an aerodynamic body having special geometry mainly characterized by an airfoil cross section. Since wind turbine blades are one of the specific components of wind turbine, improvements in design, materials, manufacturing, testing and analyzing have been the main target of research and developments (Habalia and Saleh, 2000, Part I) Figure (2) shows the main part of blades structure which changed and improved rapidly in last decade based on production optimization.

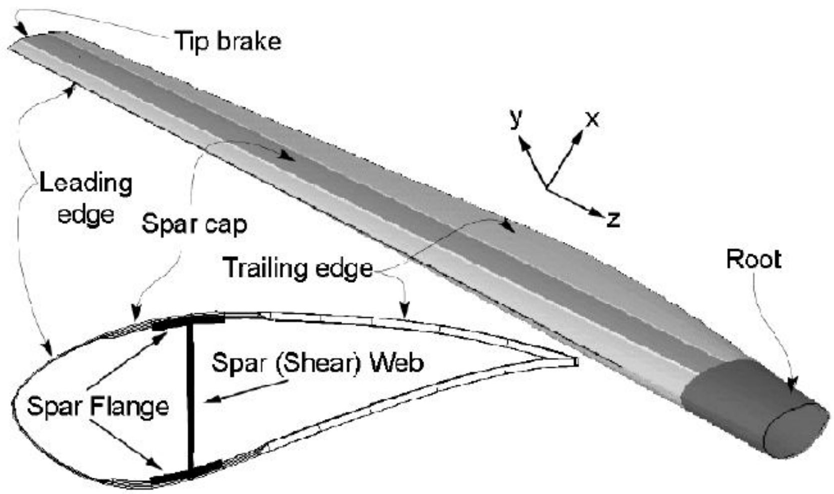


Figure 2 Wind turbine blade structure

2.1 Blade Materials

Wind turbine blades are designed to operate in the most unpredictably severe environmental conditions and still give satisfactory performances for the life time of the system (Habalia and Saleh, 2000, Part I) Blades should withstand in severe weather condition and turbulences[1] which create unpredictable loads and stresses on the blades. Blades material is one of the most important factors in blade manufacturing process which needs to fulfill all mechanical and chemical desires and should have a sufficient resistance during their life cycle.

Generally, wind turbine blade construction is based on Fiber Glass Plastic materials since they provide all technical and economical desires of manufacturing companies. Nowadays, by initiating disposal problem of wind turbine blade as major environmental concern of production, investigation and examination of possible alternative material come into view again.

[1] Non laminar wind streamline with several vortices

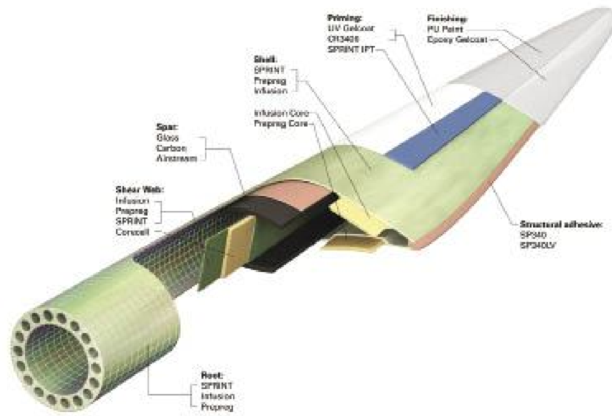


Figure 3 complete wind turbine blade construction

2.1.1 Glass Fiber Plastic

The most of wind turbine blades are made of Glass Fiber Reinforced Plastic. Indeed, GFRP is the main composite material which meets the entire objective for construction blades in manufacturing companies (Sutherland, 2000) Glass fibers are available in the form of textures and their construction is based on composition silicon materials.

The major databases in this field have come from the study of fiberglass composite which considers the material and loads for wind turbine blades the European FACT database De Smet, Bach 1994) and US DOE/MSU composite material fatigue database (Mandell and Samborsky 1997).

2.1.2 Carbon Fiber Plastic

According to increase in rotor size designers study other materials than glass composite for the blades. One of the materials which were successfully accepted was Carbon Fibers. Carbon fibers have several advantages over glass in blade structures: Higher modules, lower density, higher tensile strength, reduce fatigue sensitivity (Paul S. Veers et al. 2003). From disposal view point Carbon Fibers Materials are attractive for concrete and gypsums because of their superior chemical stability compare to glass fiber (Which tend to dissolve away in the alkaline environment of concrete or gypsums) (CHUNG 1994) Using carbon fiber material in blade structure can decline major concern of disposing blades.

The obvious disadvantages of Carbon Fibers are the huge difference in cost rather than Glass fiber materials. Table (1) shows a comparison between two kinds of Glass Fiber with carbon Fiber materials (Coverage of Science and Technology Having High Potential for Disruption and Analysis of plan, Polices and Technology to Enable Radical Improvement).

Table 1 Comparison of fiberglass and carbon fiber using blade structure

Capability	E-Glass Fiber	S-Glass Fiber	Carbon Fiber
Tensile Strength, MPa	3100~3800	4020~4650	3500~6000
Elastic Module, GPa	72.5~75.5	83~86	230~600
Elongation to break, %	4.7	5.3	1.5~2
Diameter of filament, mµ	6~21	6~21	5~15
Temperature of application, ˚N	-50~+380	-50~+300	-50~+700
Price, USD/kg	1.1	1.5	30

2.1.3 Other Materials

Search for other materials to have more efficiency in both aspect of design and economical is lead to study all old and new materials and compositions. Carbon/wood hybrid epoxies, E-glass and S-glass fibers are the most capable material for wind turbine blades.

S-glass fibers originally designed for marine applications, has significantly better property than E-glass, but the cost of these material has limited its use in blades.

Carbon /wood hybrids also offer distinctive material property suitable for wind turbine blades. The problems with these materials are providing a high-quality of surface finishing and also technical problem due to joint of hybrid materials.

The most important issue using other material in blade structure is cost of materials and also possibility of disposing them after their life cycle. Including this factor in manufacturing process of wind turbine blade can give a better perspective of disposing procedure in the future.

2.2 Blade Size

The number and size of wind turbines has increased significantly in recent years. In the last 25 years wind turbines have become considerably larger, from a rated power of 50 kW in 1970s to the multi-megawatt power plants of today, and it expected to continue for another decade. Figure (4) shows the growth of blade size and weight in recent years (Qin et al. December 2009) According to this figure with growth of blade length, blade weight is also increasing but this ratio is not linear. Consequently, blade weight is growing faster than length and the amount of blade material using in blade construction is increasing with the same ratio.

Even though, larger wind turbines are more expensive to install and operate than smaller ones, the total production cost per kilowatt hour of electricity produced has generally decreased with increasing wind turbine size (Environmental Research Web site).

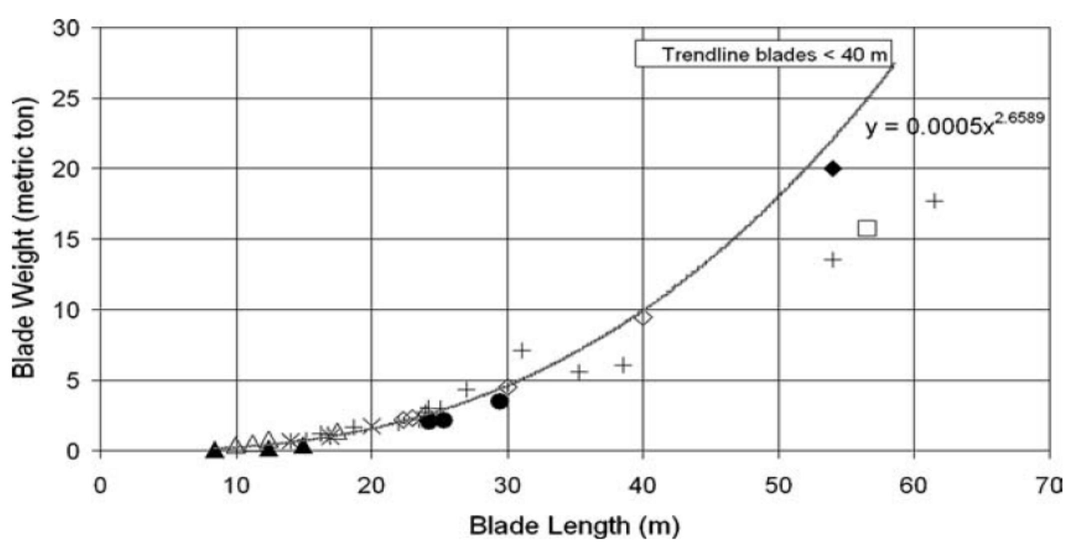


Figure 4 Development in rotor blade weight versus length

Chapter 3

Life Cycle Assessment of Wind Turbine Blade

This chapter will be considering the conception and description Life Cycle Assessment (LCA) of wind turbine blades. Although, Wind power technology has been developed since last century and became a major source of renewable energy production, there are still environmental impact from the manufacturing processes, Installation part and disposal process.

Despite the fact that, wind energy is one of the most environmentally sound technology, disposing and removal phase has been identify as a vague phase of environmental impact issue of wind power system.

3.1 Life Cycle Assessment

According to ISO 1997a, the definition of life cycle assessment can be written as: *"Environmental life cycle assessment (LCA) is the calculation and evaluation of the environmental impacts associated with the life cycle of products, material or service"* (ISO 1997a)

In fact, life cycle assessment is a tool for analyzing the environmental impacts of a given products (Borup and Andersen). According to the fact that all the products have their own life cycle, from when they are produced by raw material and then manufacturing process till the last phase of disposal process. In each phase of life cycle of products they may have environmental impacts which can be define and improve by using life cycle assessment (Qin et al. December 2009).

3.2 Life Cycle Assessment of wind turbine blade

The method and procedure of Life cycle assessment that mentioned above is used to assess wind turbine blade life cycle. According to the fact that wind energy is one of the most environmental friendly systems to produce energy, it is important to reduce the effect of decommissioning of the wind turbines after their life cycle. The large composite blades represent a big problem in the case of LCA; indeed, about 20% of recycled materials from blades can be used successfully in other products (Bjerregaard and Thor March 2002).

Life Cycle Assessment is a tool for analyzing the Environmental Impacts of certain product. In the case of wind turbine blade the main environmental impact can be written as:

- Possibility of dismantling, carrying and removal for the expected industry without any problem.
- Knowledge of development of process.
- Environmental concern of disposing Fiber glass or Carbone fiber plastics materials.
- Decreasing greenhouse effect during process

Figure (5) shows a result of study which has done by Mads Borup and Per Dannemand Andersen in removal and recycling workshop. This figure demonstrates how much uncertainty is there for wind turbine blades with respect to handling and recycling process (Borup and Andersen).

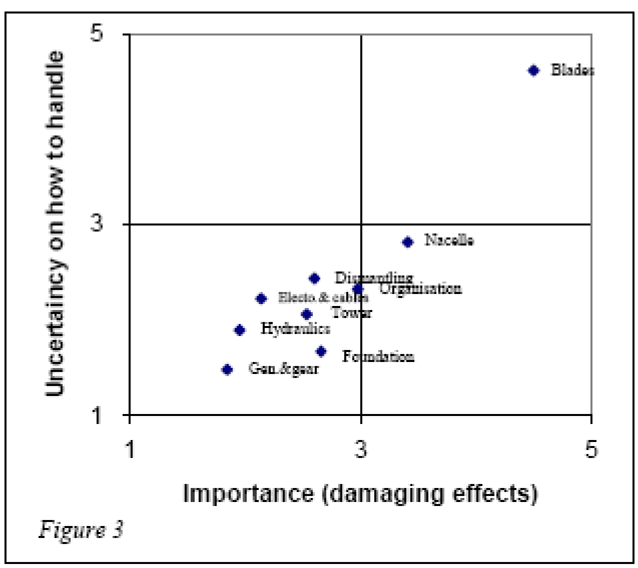


Figure 5 the blades are a major problem in removal and recycling phase

Considering the structure and material of current wind turbine blades, they are designed for an expected lifetime of about 20 years (Tong, Chapter 13). This is the period of time that blade manufacturing companies can guarantee the operation of wind turbine blades. After their Lifetimes blades can be disposed or sold in second hand market. The second hand market of wind turbine blade is not suggested because of two reasons:

- Wind turbine blade is the most important part of wind turbine and it is not suggested to use them after their cycle due to mechanical fault such as cracks and fatigue defects and also corrosion of stiffness parts.
- According to improvement of aerodynamic design and material, and also increase in size of blades, it is not suitable to use second hand blade for wind turbine.

Chapter 4

Disposing Methods of Wind Turbine Blades

Wind turbine blades typically made of different kind of reinforcement resins, such as Glass Fiber, Carbon Fiber and different kind of polymers such as polyurethane, polyester, Poly Vinyl Chloride (PVC). Prof.Henning Albers estimated that for each KW installed wind turbine, 10 Kg of blade material is needed. So, for 5 MW wind turbine, it would be 50 tons of blade material (Albers et al. February 2009).

According to increasing the size of wind turbine blades in recent years, the amount of blade material which should be disposed after their lifecycle is increasing. Figure (6) shows increase of the diameter of the rotor blade versus the mass of produced wind turbine blade.(Wind Energy 2000)

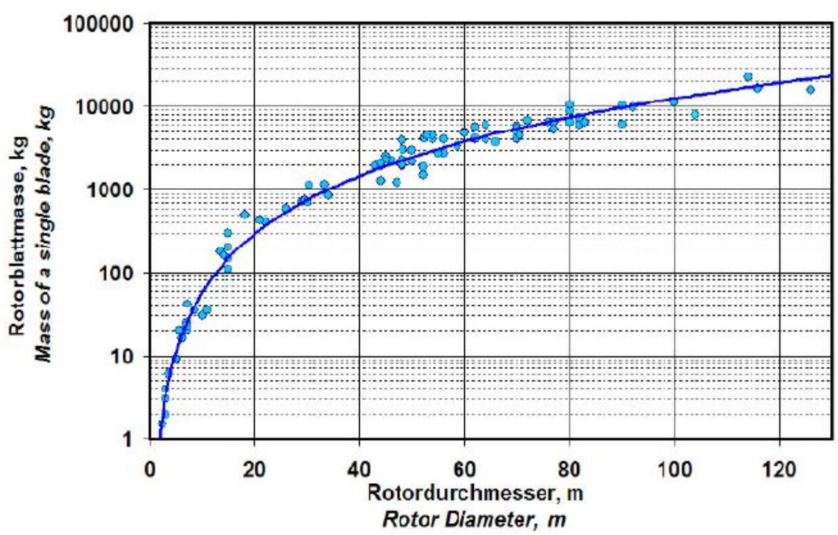


Figure 6 both size and mass of wind turbine blade are increasing

Based on estimation of Prof.Henning Albers, in 2008, that expressed for each MW installed wind turbine 10 ton blade material is needed. For instance, Sweden the share of electricity production by wind power is increase rapidly. In fact, since 2005 to 2008 installed capacity doubled from 500 MW to 1021 MW. According to estimation of Swedish Wind Energy Association, Sweden will need to increase its installed capacity to 6 - 9 GW in order to reach the 2020 target, of which 2-3 GW could be offshore wind power. This means that the amount of blade material used in wind turbine increase in a same rate of installation. Figure (7) shows increasing amount of wind turbine blade material in Sweden which should be dispose after their lifecycle (Global Wind Energy Council).

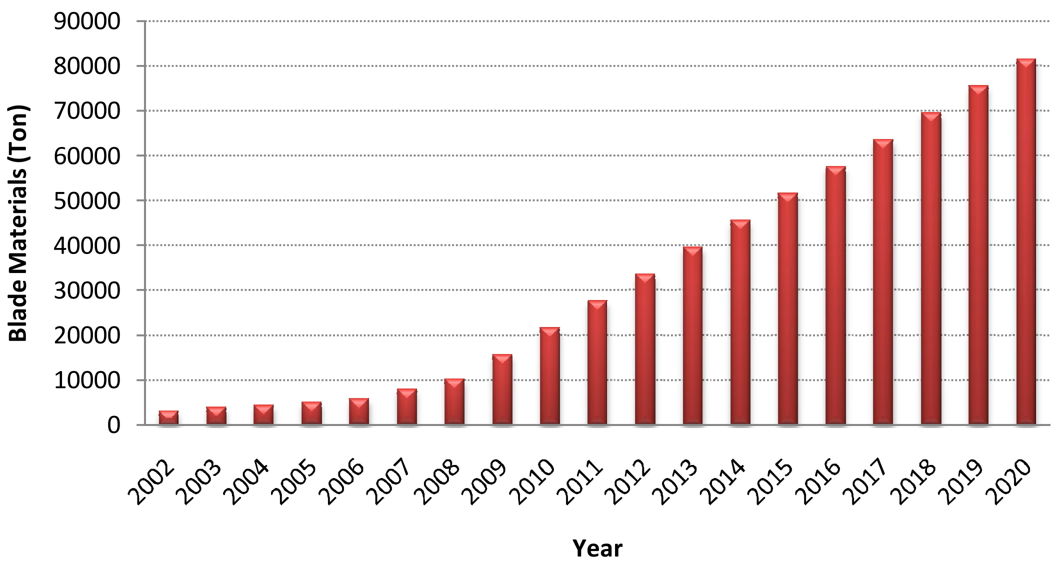


Figure 7 prediction of amount of blade material in Sweden from 2002 to 2020

Although, the amount of disposing blade materials is still small, but it will increase significantly in next decade. If we make comparison between annual Municipal Solid Waste (MSW) generations per person in Sweden which is about 400 Kg per year (in 2009) (See Franssons Recycling Machines for references) the amount of blades material is equal to 137,500 Swedish resident in the same year.

Considering LCA of wind turbine blades, which is between 20 to 25 years, it is necessary to develop a method to handle these amounts of material after their life cycle. In order to dispose blade material, they can be considering as a waste material from wind turbine or wind farm. Base on information from “Appendix A” waste material can be handling with three different methods.

4.1 Land Filling of Wind Turbine Blade

Considering wind turbine blade as a waste material, Landfill is the first alternative for disposing them. This means that to dump wind turbine blades in to huge hole in the ground, which contains several considerations according to policy, environmental and technical issues. Regarding this thesis, Sweden is the country which taken in to account for this issue.

Figure 8 land filling of wind turbine blade

4.1.1 Policy

Using landfill for disposing material provide several consideration such as legitimacy issue regarding land acquisition , waste material classification, Environmental laws, permission process, taxes and grants and etc. For instance, Germany banned landfilling of GRP in June 2005 due to their high (30%) organics content such as wood epoxies (Larsen January/February 2009).

In Sweden Environmental Protection Agency (EPA) has the main role in the development of Swedish environmental law and it is responsible to provide the guidance of Environmental Code, which consist of recycling and conservation of resource, for other agencies.

In Sweden the land filling of combustible material has been prohibited since 2002, and in 2005 it was extended to organic waste, due to resource conservation and reduces environmental impacts.

According to the land fill tax act, from January 2000 all the materials entering land fill is taxed. The current price is 435 SEK per ton. The reason of this act is to reduce land filling due to environmental concern (Swedish Environmental Protection Agency).

4.1.2 Environmental Concern

Even though, Landfilling of blade materials do not have special concern in global warming due to absence of gas emission such as CH_4 and CO_2, But there is an Environmental concern regarding land filling Plastic material special in case of thermoplastic or thermoset materials which have high resistance of decomposition. In fact, it is not suggested to landfill plastic materials with high heat capacity and also the materials which might have recycling potential.

Although, there are about 160 landfill site operate in Sweden, the number of landfills has decreased dramatically during last ten years, consequently, the amount of industrial waste in landfills in not more than half percent compared to 1994 (Swedish Environmental Protection Agency). In the case of taxes, the tax of land filling has been raised from SEK 250 per ton in 2000 to SEK 435 per ton in 2005 (Ekstrand and Wänn April 2008).

4.1.3 Feasibility Study

Feasibility study is determining the possibility and assessing the cost and benefits associate with the business opportunity and identifying the problems dealing with the projects during the business process (Hoagland and Williamso October 2000).

There are several consideration that should taken in to account regarding landfilling process such as quantity of wind turbine blades, land acquisition, transportation and labor cost, management and surveillance issues. In addition, it should also be considered that landfilling of blade material does not have any profits for project developers. In fact, Disposing wind turbine blades can be an extremely expensive project and also there is not any benefit in it, except to get rid of blades materials, which cannot be a suitable method regarding Policy and Environmental concerns. So, it is necessary to study other methods of disposing materials.

4.2 Incineration of Wind Turbine Blade

The second possibility of disposing wind turbine blades is incineration and it means burning blades to achieve thermal energy. Heating or thermal energy is used to produce electricity and also it is the main source of energy in many factories such as cement factories.

Heating content or thermal capacity of Fiber Glass Plastic is the primary issue which should be evaluate before using them as fuel energy. As roll of thumb, thermal capacity of 9 tons of Fiberglass is equal to 3 tons of Oil (See ReFiber ApS October 2007 for references) According to growing price of Oil, especially these days, due to Middle East crisis, Fiberglass waste material can be more or less an alternative to support a part of incineration material in factories. Indeed, the caloric values of blades is about 11000-14000 KJ/kg which can be found interesting when compare it with another source of energy. Table (2) shows caloric value of some important fuels.as you can see in this table caloric value is an important factor for burnable material and it has reverse direction with its quantity. It means that for the material with high caloric value less material is needed to reach higher heating energy. (Tools and Basic Information for Design)

Table 2 Comparing caloric values of different flues

Fuel	Caloric Value (KJ/Kg)
Alcohol, 96%	30,000
Carbon	34,080
Coal	15,000 - 27,000
Gasoline	47,300
Methane	55,530
Petrol	48,000
Wood (dry)	14,400 - 17,400
Wind Turbine Blade	11,000- 14,000
Natural gas	43,000 (KJ/ m^3)
Heavy fuel oil	41,200 (KJ/ m^3)

The major concern is not only the thermal capacity of Fiberglass materials but also the residual ashes after incineration process which are mostly contain calcium oxide, which comes from the calcium carbonate, boron, and other oxides in the glass and can react promptly with water or water vapor and it can be dangerous for eye and lungs (See Sponberg in refrences). Figure (9) shows a polluted areas according to Deposited slags from incineration-plants(See ReFiber ApS October 2007 for references)

Figure 9 Residual ashes from incineration process

Co-incineration[1] can be an alternative for burning wind turbine blades but there will be several consideration based on policy of environmental and ecological effect.

4.2.1 Policy

In Sweden aforementioned law and policy issues in Appendix A should be consider regarding incineration or co-incineration process of wind turbine blades. In fact, these policies illustrate the possibility of burning wind turbine blades in incineration plant and can be written as: (Ekstrand and Wänn April 2008).

- *European Parliament and Council directive 2000/76/EC of 4 December 2000 on waste incineration*
- *European Parliament and Council directive 2006/12/EC*
- *Environmental Code Chapters 2, 9, 15*
- *Ordinance (1998:899)*
- *Ordinance (2001:1063)*
- *Ordinance 2001:512 on Deposing of Waste*

[1] Co-incineration is a method refers to incineration of other types of waste together with MSW.

- *Ordinance 2002:1060 on Waste Incineration*
- *NFS 2002:28*
- *NFS 2006:6*
- *NFS 2004:4*

Moreover, the most important factor for incineration wind turbine bale is "*Swedish Environmental Standard*" for gas emission during incineration or co-incineration process. Based on this standard there is a limitation of dust and gas (SO2, NOx…) emission which is a major obstacle on the way of incitation process. (Ekstrand and Wänn April 2008).

4.2.2 Permission

Permission process is another considerable issue regarding incineration wind turbine blades which can be another difficulty of this process. Permission procedure time can took several weeks or month to be confirm by responsible centers which can be Consultation and Environmental Impact Inventory and EIA.

4.2.3 Feasibility study

Another subject which should be considered is the feasibility of burning wind turbine blades. In fact, there are several considerations which can take in to account burning wind turbine blades. For instance, after dismantling blade in the site and collecting them. There should be special permission for transporting to the crushing place and if it happens in the site there should be another concern about the dust emission and collection of small particles. Blade materials should be crushed in to small parts and it needs to be treated in two or three steps.

Based on these issues incineration of blades can create several problem during process and also expensive project for the companies who wants to burn wind turbine blades after their life cycles

4.2.4 Alternative ways

4.2.4.1 Incineration blades in Cement Industry

There could be an alternative way to use wind turbine blade as a fuel in other industries. For instance, in cement companies they can be used as fuel and the ashes also can be use again in cement material as an additive material. In this case, there will have a close cycle process from blade manufacturing company to the cement company. In May 2010, the first disposal blade has been processed in the new plant built by Zajons in Melbeck and utilised in the Lägerdorf cement plant (See Dr. Schmidl Erwin for references).

Figure 10 wind turbine blades beak down to use as fuel in cement companies.

This process was consisted of several steps:

1- The blades break down on site (or in storage place) to avoid special permission for transportation
2- Dust and small particles collected and return in to material flow of blades.
3- About 10 m wind turbine blade particles are collected and transported to the treatment plant by train or lorry without special permission.
4- In pre-crushing area blades crush down in to smaller pieces (1 m in length) by automotive saw.
5- Two specific shredder machines crush the blades in an encapsulated system into pieces with an edge length of < 50 mm.
6- In separation process ferrous or non-ferrous metal are separated with magnet and eddy current.
7- Residual materials transported to the cement company.

In this process thermal energy content of wind turbine blades is use for calcinations process and the ashes react with raw material in 1450˚C to form specific mineral component.

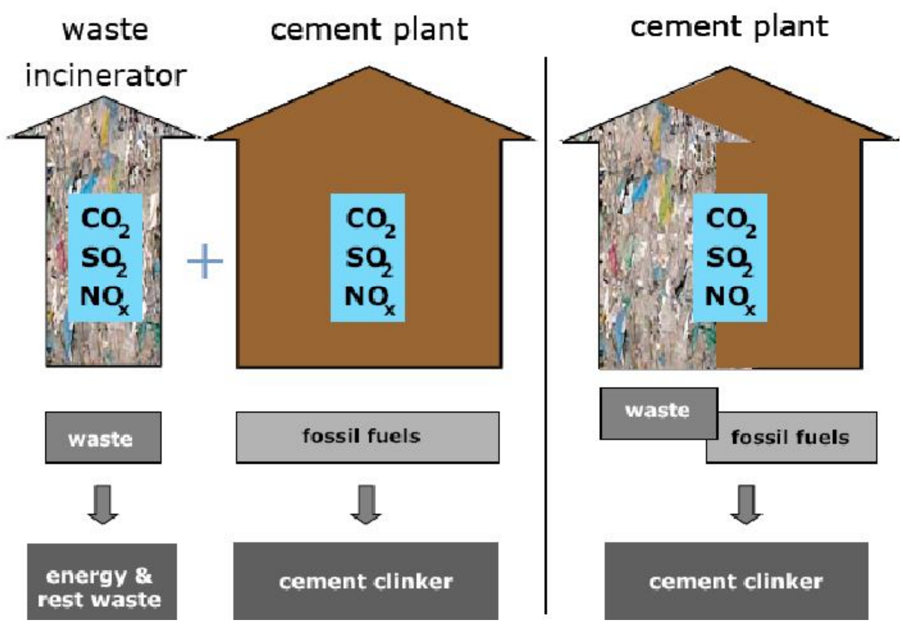


Figure 11 Incineration waste material in Cement Co.

Cementa Company which located in Slite, Sweden can use wind turbine blade as an incitation or filler material in cement. In the case of filler material, the most important issue is that the blade materials should not be alkali because they could have chemical reaction with water or other substance in cement.

In the case of incineration, there is not any major concern in Cementa Company except the amount and transportation and also crushing process (for massive blades) are the issues which can be expensive project. In this case, there is not any concern about gas emission in the company because there is a filtration system in the exhaust tower.

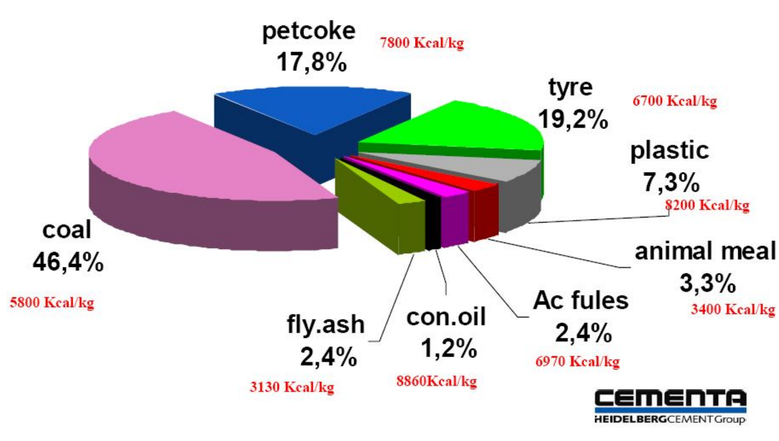


Figure 12 Percentage of fuel used in Cementa Company

The most important factor for using wind turbine blade as a fuel in Cement Company is the final cost of blades. For instant, the cost of transportation and also crushing blades will be expensive especially for offshore wind turbine blades. In fact, due to increase the size of blades the cost of dismantling, storage, transportation, etc. will increase. On the other hand the feasibility of grinding or crushing wind turbine blades with about 100m length will be another big obstacle on the way of using blade as fuel in cement companies and can have a major effect on their total cost.

4.2.4.2 Pyrolization

The other possibility of disposing wind turbine blade is Pyrolization and gasification which is done by ReFiber ApS in Denmark. Based on their experience it is possible to pyrolis blade in an oven in 500 ˚C. In this case, wind turbine blade materials can transformed in to energy saving heat insulation-wool. Figure (13)

Figure 13 insulation-wool in Refiber company

Unfortunately, based on governmental decision wind turbine companies have permission to dump worn out wind turbine blades and other fiber glass scrap on landfills or burn them in the incineration plants. So the companies have authority to dump scrap on very cheap, but still controlled, landfills in Denmark (See ReFiber ApS October 2007 for references).

Figure 14 Pyrolization of wind turbine blades

In the case of pyrolization, there is not enough experience, and also there is a lot of blind spot according to the feasibility of doing this process for different size of wind turbine. In fact, in this process also needs to crush the blades in to the small parts and it can be an expensive project in the field of pyrolization of Fiberglass plastic.

4.3 Recycling of Wind Turbine Blade

Although, Glass Fiber Materials are normally not recycled, but for wind turbine blade it can be the best way due to environmental and ecological concern and can be discussed as a "material recovery" issue which consider both aspect of recycling and reusing materials with the scope of further using or using in other industries. Figure (15)

Feasibility study of recycling blade is the most important factor to evaluate the possibility of process for different size and material of wind turbine blades.

Wind turbine blades are made of different material such as different kinds of epoxies and resins, Figure (3). In this case, level of accuracy is an important issue in separation process. In fact, the type of materials which gain at the end of recycling process should define precisely to indentify recycling process and type of operation and treatment on wind turbine materials.

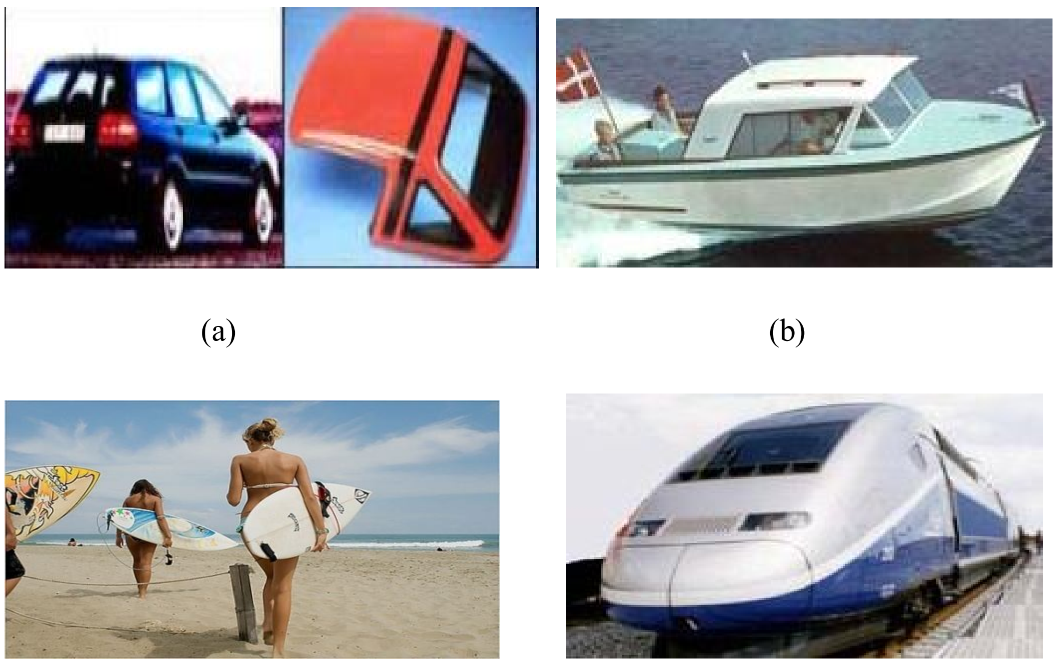
Crushing wind turbine blade in recycling process like other mentioned methods is inevitable. According to size and material of wind turbine blades three problem arise:

1- Lack of proper crusher machine base on dimension of blades

2- Remarkable tool abrasion during crushing process

3- Health and safety concern due to formation of dust during process (Albers et al. February 2009)

There will be another concern for residual stress in small particles due to crushing process of blades which can have major influence of producing cracks or other faults in new coming products. Residual stress and mechanical glitch have a direct effect on possibility of using recycling blade material in manufacturing companies.



(a) (b) (c) (d)

Figure 15 different application of fiberglass material (a) automotive industries, (b) Boat industries (c) Sport (d) Train construction

On the other hand, whether it is possible to recycle blade materials the cost of these material is another important issue compare with raw material. So, possibility of purchasing recycling material to use in blade production process is an important issue.

Some companies such as Seawolf (See SeaWolf Company in references) which is the first company that invented how to recycle most FRP and natural fibers and reincorporating into products, tries to recycle wind turbine blades with their own techniques, but unfortunately they are not successful because of special materials[1] which are used in blades structures.

Today there is not any evidence regarding possibility of recycling blade materials, regarding aforementioned factors at the moment, recycling wind turbine material is not major problem for blade manufacturing companies and still there is not sufficient investigation on it, but it will be a primary concern in next few years.

4.4 Using wind turbine blades in building constructions

Joel H. Goodman, have worked on architectonic reuse of wind turbine blades and suggest several different architectural design with wind turbine blades especially for buildings and solar collectors. Figure (16) (See Goodman for references)

Using wind turbine blades in building constructions after their life cycle should have special surveillance base on technical issue. Fatigue loads have major effects on wind turbine blades during the operation and can cause several mechanical faults such as cracks and residual tensions in their structures which cannot be identify easily but it can destroy the whole construction of blades. According to this fact it is not suggested to use blades in the permanent construction due to safety issues.

[1] urea formaldehyde

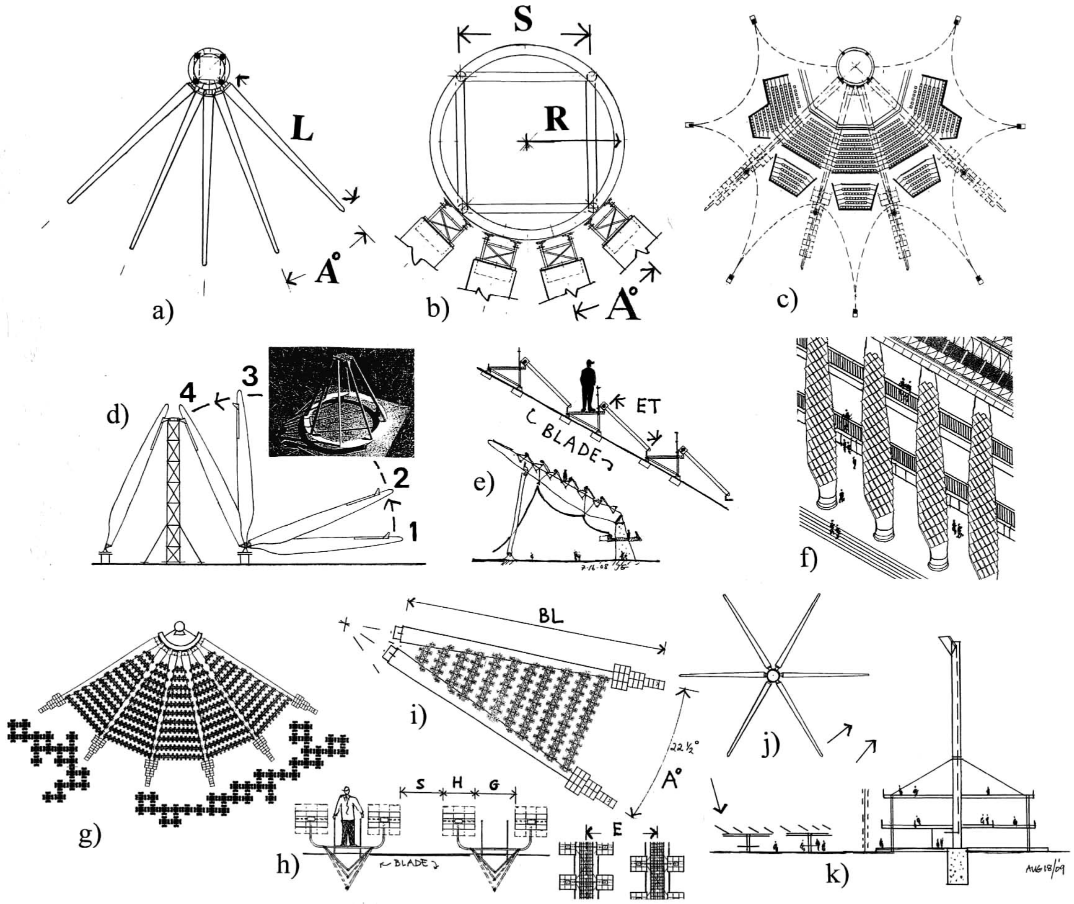


Figure 16 Architectonic used blade configurations: a-c) Open air theatre with tensioned tent roof hanging from four radiating blade beams; d) teepee type frame; e) blade beams supporting; f) blade colonnade with PV; g-i) receiver on tower and small heliostats; j-k) restaurant on a tower-receiver with horizontal radiating blade beams.

On the other hand, from aesthetic point of view, social acceptant is a discussable issue using wind turbine blades in architectural construction. In this case, the positive or negative aspect of social attitudes can illustrate the possibility of this method and it is critical point for decision making of this achievement.

Table (3) shows a comparison between different available methods of disposing wind turbine blades. It shows the strength and weaknesses of each method base on technical, economical and environmental issues.

Table 3 Comparison of different methods of Disposing wind turbine blade

Disposing Methods	***Strength***	***Weakness***
Land Fill	- Very simple process - Fast method	- The highest level of Environmental and ecological concern - Depend on policy, Taxes and governmental decisions - It is not affordable
Incineration	- Achieve thermal energy as main source of energy - Less environmental Impact than land fill - Easier process rather than Recycling	- Roughly low heat content - There is not enough experience for the process - Blades needs to be crushed
Recycling	- The most environmental sound method - Ability to use or sell material after the process	- Lack of technical experiences - Expensive project - complicated process - Blades needs to be crushed

Chapter 5

Using Wind Turbine Blades as Artificial Reefs Constructions

Blades materials can be consider as resource after their lifecycle using in valuable structure in the sea. In fact, it can be possible to use blade materials as an artificial habitat for marine life. So, It would be remarkable issue in the field of reusing wind turbine blades. This chapter discuss about the feasibility of using blades as an artificial reefs considering economical, technical, environmental and ecological issues.

5.1 Artificial Reefs

Definition of artificial reef can be varying by different policies or laws in different countries but according to artificial reefs guidance it can be written as:

"*An artificial reef is a submerged structure deliberately constructed, placed, or left on the seabed to emulate some functions of a natural reef such as protecting, regenerating, concentrating, and/or enhancing populations of living marine resources."*(London protocol. 2nd Meeting 19. 23 May 2008 Agenda item 5)

Artificial reefs can be made of different materials such as concrete, metal or plastic and they can be placed or built for variety of purposes. The main purpose of building or placing artificial reefs is reproduction or protection marine life, but there is also other purposes like environmental and ecosystem management, managing marine resource for biodiversity and special species, promoting of tourism and leisure activity like angling, Scientific research and education (London protocol. 2nd Meeting 19 . 23 May 2008 Agenda item 5).


(a) (b)


(c) (d)

Figure 17 different kinds of artificial reefs (a) Multi-purpose concrete reef (b) ship wreck used for SCUBA diving (c) Tire reefs (d) Motor Cycle.

5.2 Historical and global use of artificial reefs

Although, fisheries science is quite young and the science of artificial reef is even younger of that. However, traditional fishermen from many years ago know that fishes congregate around solid structures on the seabed such as rocks, logs and shipwrecks. It is known that fisherman from 3000 years ago start to develop near shore fishing by placing rocks, brush, coconut shells and even ruins of ancient Greek temples in the Mediterranean Sea. (Dan Wilhelmsson 2009)

Today, artificial reefs are using worldwide to manage fisheries, protect marine environment, support recreational and reproduction marine life and help tourism attraction based on coastal management. About 10% of Japan's coastal sea floor is covered by artificial reefs and with the scope of commercial fishing around 170 000 modules of artificial reefs have been used at 75 sites in Taiwan. For instance, increasing biomass of filter feeders and harvesting mussels growing on artificial reefs are the sample of purpose in the Baltic Sea (Dan Wilhelmsson 2009).

5.3 Using wind turbine blade for artificial reefs purposes

5.3.1 Structure

Wind turbine blades have an aerodynamic shape and hollow structure. Figure (18) shows the construction of blades, the root of wind turbine blades have circular shape with different diameter base on size of blade, and it is the only inlet in to the blade. The tip of blades is closed at the end of the blade and it is much thinner than other parts of blade.

It has been pointed out that the significant contribution of structural complexity to fish abundances, community composition, diversity and biological productivity on artificial reefs, mainly based on enhancement of shelter availability. Depend on variety of sizes, wind turbine blade can create a safe environment for fishes, larvae, roes, algae and also it can be a place to protect crustaceans near the seashore Dan Wilhelmsson 2009).

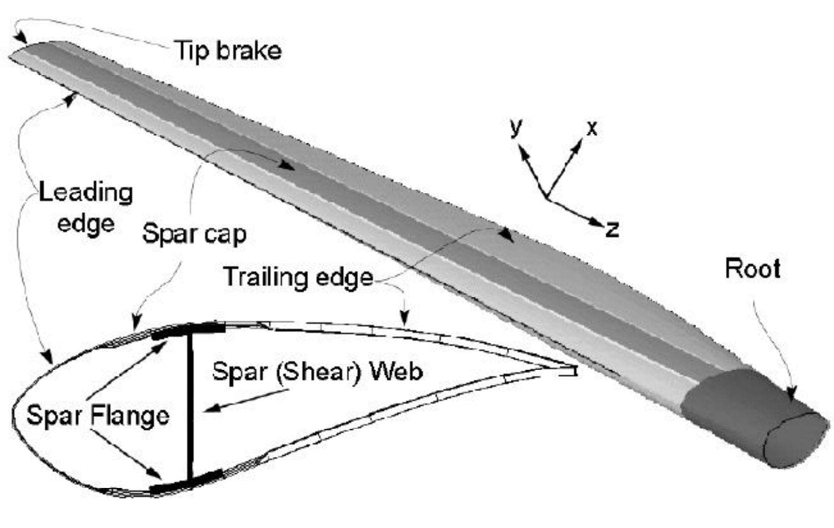


Figure 18 Wind turbine blade structure

To get positive effect on fish abundance, the scale of artificial reef should match the size of the fishes (Global Wind Energy Council). Depending on artificial reef design and purposes it might be vital to change the structure of blades, For example cutting the tip of blades or making holes in different part of it. Applying small changes in blade structure is based on artificial reef purposes and the ways of using them in different water depth for different marine types.

Constructing artificial reefs is costly and logistically difficult (Seaman and Sprague 1991). Hence, changing blade structure (creating holes, cutting down and crushing) is critical issue and needs to have spatial planning for constriction and deployment in the water base on technical and economical factors.

5.3.2 *Blade Materials*

Blade materials are made from FGRP and they are inert material, it means that they do not have any chemical reaction with the seawater. Moreover, blade materials are absolutely solid and do not have any chemical leakage in the sea. The weight of wind turbine blades is much less than other kind of artificial reef such as concerts or metal and it can reduce the transportation cost especially for offshore wind turbine blades but in contrast, it can make a problem regarding stability issue on the sea bed.

Blade materials does not contain hazardous material compare with ship and boats like radioactive materials, heavy metals and also they have much more durability due to using different resins materials on their surfaces.

Ability of attraction of marine life regarding food availability is the major concern regarding blade materials. Indeed, they should provide food for fish through epibiota, such as algae, hydroids, bryozoans, bivalves, corals, and mobile invertebrates associated with the sessile biota (Dan Wilhelmsson 2009).

For instance, Dan Wilhelmsson et al. provide a study about the effect of artificial reef on fish assemblage in cold water and realized that only ten fish species totally attracted to the non complex experimental reefs (Dan Wilhelmsson et al. 2006)

5.3.3 Technical Concern

Possibility of using wind turbine blade as artificial reef is completely based on technical issues. In fact, placing wind turbine blades in different depth of the sea by different water temperatures in one hand, and suitability, stability and monitoring process of blade on the other hand needs to have special concern regarding technical concerns.

- *Suitability:*

This project should be done by monitoring the effects of the reefs on marine environment in short, medium and long term process. The monitoring should be considering environmental effect of reefs. If a reef does not meets its objectives or have a negative effects on environment and marine life should be dismantle and remove from sea bed. Removing project can be as complex as placing, and it is depend on position of reef and bathymetric characteristic of sea bed (London protocol. 2nd Meeting 19. 23 May 2008 Agenda item 5).

Size and complexity of blades structure is another factor in fish assemblage. On the large reefs, species should be less likely to go extinct from accidental events than on small reefs, and thus larger reefs should have more species (Dan Wilhelmsson 2009). According to the size of blades in offshore wind farms, they can meet this objective and also they can provide a suitable shelter for different marine life.

- *Durability and stability:*

Regarding the fact that it takes some years for reef to be colonized by biological communities, in meanwhile they should be stable and durable in different weather conditions to achieve the main objectives. Base on this aspect weight of blades are one the important issues in this project. As rule of thumb, it is suggested that the weight of the reef is at least double that of the specific gravity of seawater, or, otherwise, that the structure is actually anchored to sea bed (London protocol. 2nd Meeting 19. 23 May 2008 Agenda item 5).

5.3.4 *Feasibility:*

Application of blades for artificial reefs should be based on possibility of acquiring, transporting, handling and deploying in safe and cost effective ways. According to booming of wind turbine blade manufacturing industries in all around the world, procurement factor for blades will not be a major concern in next few years.

There are also some studies and experiences based on optimization of transporting and handling blades in a cost effective ways, especially for offshore wind farms which are already located in the sea by project developer companies.

Some major issue like insertion or placing optimization on the sea bed based on durability and stability in severe weather conditions and suitable depth and location, needs to be consider before initiating the project. For instance, Larvae of different fish species have different vertical distributions during the pelagic stages and it can be vary with depth (Dan Wilhelmsson 2009).

5.3.5 Policy and Framework

The United Nations Law of the Sea Convention (UNCLOS) provides general framework for the guideline of marine environmental activities. At present time, there is not special framework or international instrument regarding artificial reefs but there several act and protocol which can be used indirectly for regulation frameworks for artificial reefs.

- *The London Convention and London Protocol:* Consider prevention of pollution marine environment by dumping of waste material.
- *Basel Convention:* Regarding controlling cross-borders movement of dangerous waste and eliminating guidelines. This convention also considers the technical guidelines for environmentally sound management (ESM) of the full and partial dismantling of ships.
- *OSPAR Convention:* The main Objective of this convention is to protect marine environment of North-East Atlantic.
- *Barcelona Convention:* the protocol is for protection marine environment and coastal region of the Mediterranean Sea. Moreover, this convention extended to the general issues such as integrated coastal zone management and sustainable development.

Marpol protocol: Is an International act to prevent pollution from ships. This protocol also contain environmental impact rules for dumping ships in the sea (Act to prevent pollution from ships Dec. 29, 2000)

In this case, it is necessary to study all short term and long term environmental effect of blades in the sea and also carrying out some experimental studies to explore the amount of marine attraction on the blades. This can be done like an investigation of Dan Wilhelmsson et al. (Dan

Wilhelmsson et al. 2006) regarding the effect of high-relief structures on fish assemblages in cold climates.

In Table (4) the advantages and disadvantages of using blade for artificial reef are listed which can illustrate the concept of proposing this method regarding disposal wind turbine blades.

Table 4 Advantages and disadvantages of using wind turbine blades as artificial reef constructions

	Advantages	**Disadvantages**
Using Wind Turbine Blades as Artificial Reefs Constructions	- Easy and simple method - Fast process - Blades should not be crushed - Less environmental impact rather than common methods - Support marine life reproduction - Cheap method due to elimination some extra costs like taxes	- There is not sufficient theoretical and practical experience in this field

Chapter 6

Closure

6.1 Discussion

Disposing wind turbine blade process should be based on several considerations such as Environmental and Safety, Economical, Technical and logistic issues. To meet this objective there should be a long term planning and management to study the feasibility of applying available methods in different companies or countries.

It is suggested to initiate a study project regarding disposing blade in Research and Development part of manufacturing companies to optimize risk and cost of this process.

6.2 Conclusion

This Master Thesis has present available method of disposing wind turbine blades and investigated feasibility of their applications due to environmental and ecological considerations. It has also provided a new method for disposing blades as an artificial reef in the sea regarding marine construction policies and frameworks.

The problem which now arises is that there is a lack of experimental knowledge of applying these methods for wind turbine blades after their life cycle. Some of these methods such pyrolysis have a successful practical experiences but some of them such as artificial reef and burning in cement industries needs to have more experiences to establish the feasibility.

Although, there are several methods for disposing blades, but it still is a blind spot of wind power development. Depend on size of wind turbine blades we can use different method of disposing. For instant, it can be suggested to use artificial reef method for massive and offshore blades, and incineration in cement or other industries for small and onshore wind turbine blades. But applying these methods is still depending on feasibility of transportation, policy, and technological factors.

6.3 Future Work

Using wind turbine blade for artificial reefs construction needs to have special concern due to Environmental and Ecological issues. The most effective design of blade concerning attraction of different marine species needs to be demonstrated through experimental works.

Identifying feasibility of using blade as artificial reefs regarding policy and frame work and technical issues in this field can create further discussion and work throughout this subject.

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