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INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems ANNEX XI

38th IEA Topical Expert Meeting

Material Recycling and Life Cycle Analysis (LCA) of wind turbine

Roskilde, March 2002

Organised by: Risoe

FOI
SWEDISH DEFENCE RESEARCH AGENCY

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Topical Expert Meeting

IEA Topical Expert Meeting

MATERIAL RECYCLING AND LIFE CYCLE ANALYSIS (LCA) OF WIND TURBINES

INTRODUCTORY NOTE

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1. Background

Preliminary studies have demonstrated that electricity produced from wind turbines is one of the most environmentally sound ways of producing electricity. However, the future prospects of wind energy with it's accelerating market growth call for a proactive attitude from both industry and society in order to prevent or reduce future problems with waste and it's disposal after served lifetime. World Energy Council has predicted that global coverage of wind power over the next 20 years could expand to between 180.000 MW and 470.000 MW.

Material recycling offers a reduction of the environmental impact. Life cycle analysis is a systematic tool that can be used for analysing and assessing the environmental impact of a product throughout its entire lifecycle from cradle to grave. The methodology of LCA is used in different industries as a decision making tool in the design of new products. It is also used for bench marking of the environmental impact of alternative products and services, both when seen from the industry's and from the society's point of view.

Until now only a few LCA-studies involving wind energy have been carried out, but a growing awareness is emerging. Studies in Canada, USA, Austria, Holland, Germany and Denmark related to this item have been reported, and a couple of projects partly financed by the Danish Government are being carried out.

2. Objectives

It is proposed to carry out an expert meeting with the aim of establishing an overview of the status of activities in this field among IEA members, and to obtain a basis for definition of a possible annex on these matters under the IEA Wind Agreement.

Potential items for discussion:

- Procedures and processes for disposal and recycling of materials and components for wind turbines.
- Requirements by national authorities, international standards and market pull.
- To identify LCA based methods and to evaluate and transform them into a common frame of methodology that can be applied in the wind energy sector.
- Inventory of all materials and all processes and services that are involved. Also the dismantling, possible reuse and disposal of all items and materials after the served life of the wind turbine should be considered.
- Bench mark environmental impact of global wind energy production for future scenarios with and without LCA.
- Prepare guidelines for applying LCA in the area of wind energy.

3. Means

Information from practical results of LCA work in the wind energy sector and in comparable industrial sectors from which experience can be extracted and used for the present case.

Establishing of contacts between ongoing projects and the industry should be made in order to help selling the idea of LCA as a design method.

Contacts to national authorities to gather information about possible planned incentives to support greener production.

The various methods and practical results should be evaluated and a systematic method developed.

The steps in performing a LCA should be outlined and the method subsequently tested on a chosen wind turbine by participants in the annex.

4. Approach

The expert meeting is held in order to identify the member countries interest and to decide upon the primary research objectives that could constitute a possible annex.

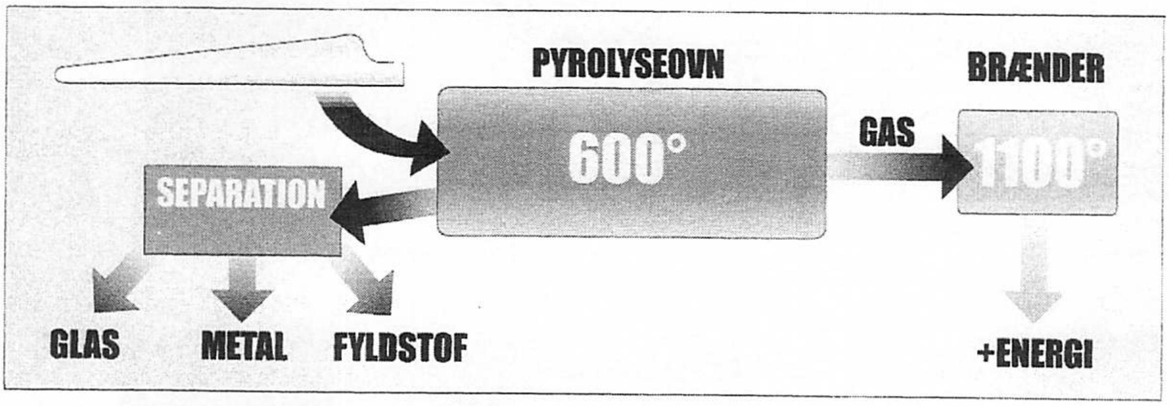
5. Intended audience

Experts from the industry and from the scientific society who are applying or investigating Life Cycle Assessment methods in relation to design, construction and manufacturing of Wind Turbine Systems. Also persons working with planning and standardization in the area of "cradle to grave" requirements to Wind Turbine Systems should participate.

2001-12-12, EB

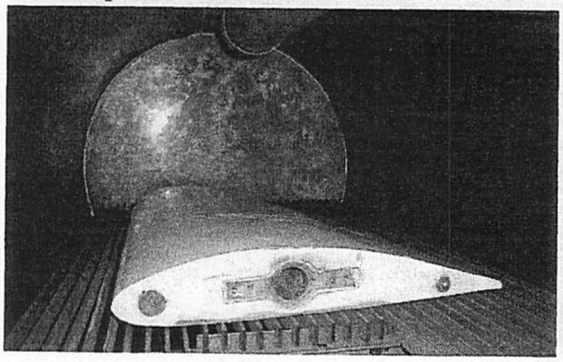
Two-stage combustion of Plastic Composites – A short technical presentation.

Fibreglass-blades contains almost 50 % polyester- or epoxy-plastic.
When the pastic part is removed in a pyrolysis oven at 500 - 600 °C we obtain residual products, that are easily separated in pure material flows for recycling. The gas is burned safely and environmentally correct in a separate oven at 1000 – 1200 °C.
Full size blades can be processed without cutting them into shorter parts.

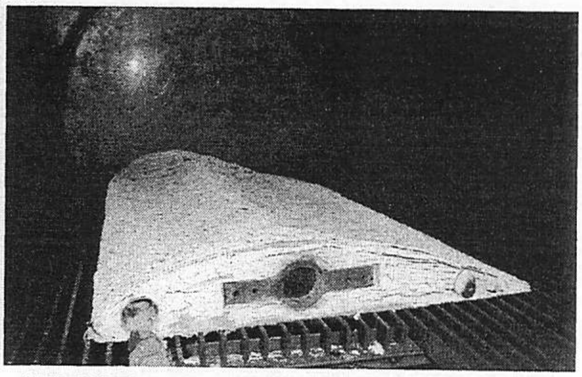


In our test plant, the pyrolysis-oven has an internal diameter of 1 m and a length of 6 m.

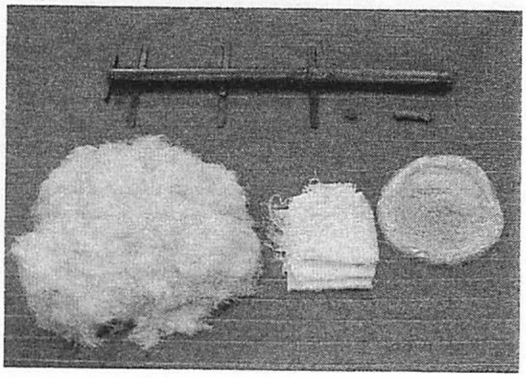
Bladetip from 55 kW Vestas Wind Turbine.



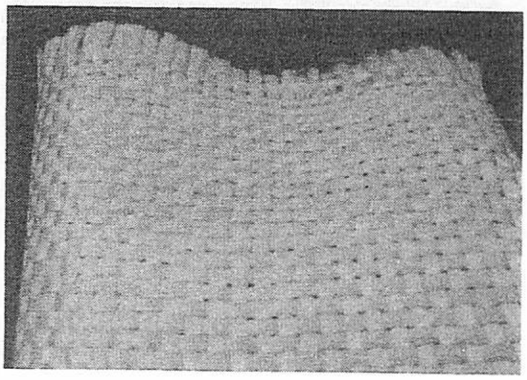
AEROSTAR 7.5 m Bladetip before pyrolysis.



AEROSTAR 7.5 m Bladetip after pyrolysis.



Glassfibres, fabric, powder and stainless steel separated.



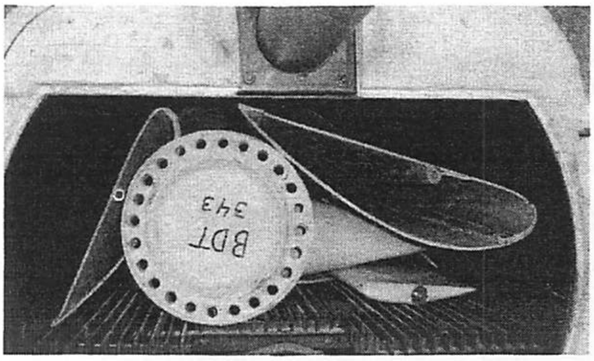
Fabric in close up – intact.

Results from pyrolysis:

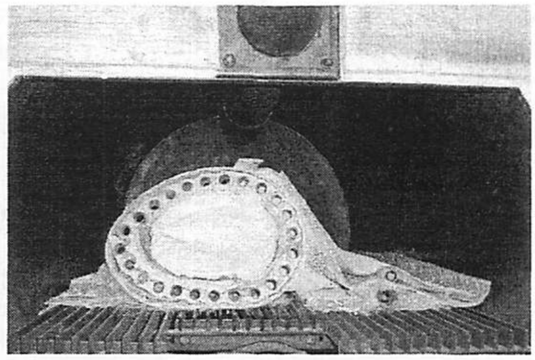
Glassfibre fabric and CSM mat	2.7 kg	15.9 %	Recyclable
Glue-fillers and colour pigments	2.0 kg	11.8 %	(Recyclable)
Stainless steel parts	4.0 kg	23.5 %	Recyclable
Pyrolysed polyester etc.	8.3 kg	48.8 %	Energy resource
Initial weight of tip	17.0 kg	100.0 %	

The heat-energy dissipated substitutes 5.7 litres of gas oil.

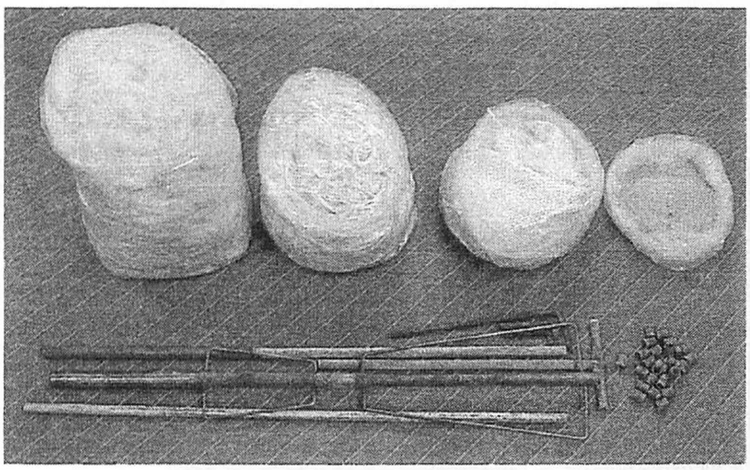
Blade from 30 kW Turbine.



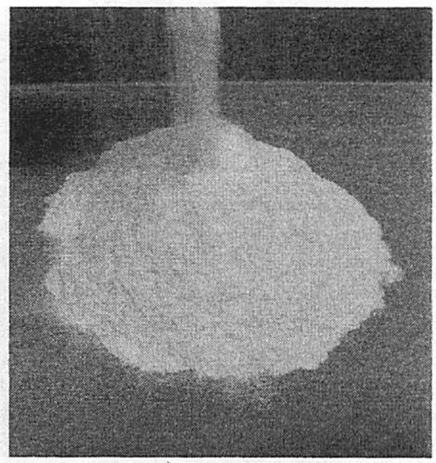
5 m Blade before pyrolysis.



5 m Blade after pyrolysis.



Glassfibres, roving, glassfabric, powder and steel-parts separated.



Glasspowder 50 – 100 µm.

Results from pyrolysis:

Glassfibres (fabric, roving, mat)	21.7 kg	33.9 %	Recyclable
Glue-fillers and colour pigments	1.2 kg	1.9 %	(Recyclable)
Stainless steel parts	5.9 kg	9.2 %	Recyclable
Steel 37/52	5.1 kg	8.0 %	Recyclable
Pyrolysed polyester etc.	30.0 kg	47.0 %	Energy resource
Initial weight of Blade	63.9 kg	100.0 %	

The heat-energy dissipated substitutes 20.6 litres of gas oil.

The measured calorific value of matrix-materials was 30 MJ/kg.
This value is 70 % of the calorific value of gas oil and 20 % higher than the calorific value of coal.

The Energy content of a typical 3 ton Blade thus substitutes 1 ton of gas oil or 1.7 tons of coal

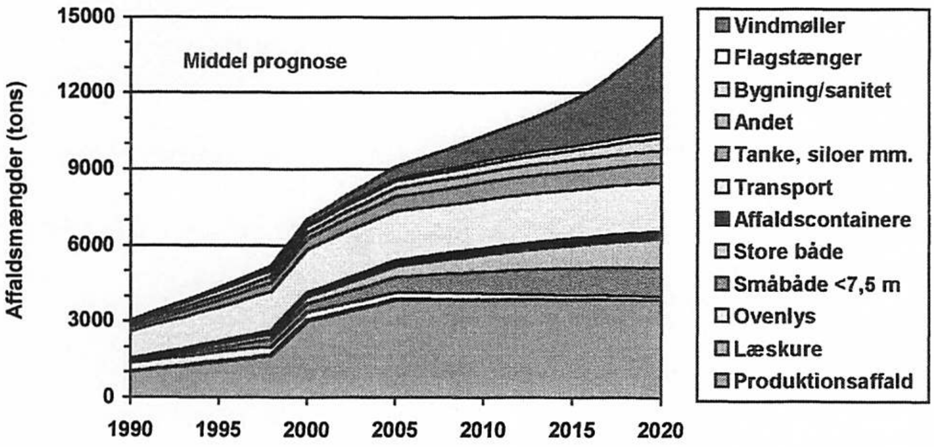
The steel-content can be recycled as scrap iron in the iron industry. The glass should preferably be recycled in the glass industry as a new raw material. Another option is to use the glass in powder form as a pure filler material in the plastics or concrete industry.
The current project has developed a method of converting the glassfibres to a powder state.

Markets (in Denmark only)

In the year 2010 the annual amount of composit-waste is expected ca. 10.500 tons.
The Energy-content herein equals ca. 3.500 tons of gas oil.

Below a mean value prognosis for the total amount of composit-waste is cut from a report of the Danish Environmental Protection Agency : "Armeret epoxy- og polyesterplast, forbrug og affaldsmængder"

Prognose for samlede mængder af kompositaffald 2000-2020 (middel prognose for udtjente produkter).
Der er antaget en stigning i mængderne af produktionsaffald på 5% pr. år i perioden 2000-2005.
Bygning/sanitet omfatter ikke polyesterbeton og kunstmarmor.



Dark blue = Wind Turbines. Red = Production waste. Light blue = Transport sector.
Green = Boats.

Depositing of combustible waste, including plastic based composites, were banned by July 1st 2001, following the EU directive 399-L-0039 (The Landfill directive).

Opportunities

- By purchasing the patented rights, it wil be possible for an operator to perform an environmentally sound processing of worn out composit parts and production waste.
The end products are thermal energy and materials ready for recycling as new raw materials.

- The proces can handle big as well as small glass fibre parts, production waste, grinding dust, not cured epoxy-prepreg, cured or not cured polyester- or epoxy-spilllage.

- Pyrolysis gas can be burned in existing power plants world wide.

- Recycling Facilities can be produced as turnkey-plants, and sold to markets that buy or produces major amounts of glass fibre products. (Wind Turbine Blades etc.)

- Thus there is a possibility to equip major windfarm projects with a "Cradle to Grave" solution as regards the fibre glass parts.

Using LCA in the design of Wind Turbine Rotor Blades

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M.C.C. Lafleur † K. Molenveld ♣ W. Teunissen ♣ A.M. van Wingerde +

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Abstract

This article contains information on the use of structure effectiveness indexes in relation to the environmental impact of the structure during it's life cycle. This project is partly funded by the E(conomy), E(cology) and T(echnology) EET-programme of the Dutch ministry of Economical Affairs.

1 INTRODUCTION

The BLADECO project is performed within the Ecology Economy and Technology programme (EET) of the Ministry of Economic Affairs, by the following partners:

+ TUD – WMC-Group,
* KEMA b.v.,
† ECN – Wind Energy/DEGO,
♣ ATO-DLO,
AERPAC b.v.,

The project started in 1997 with a foreseen duration of approximately 4 years. For successful completion, the project was to be followed by a demonstration project. The project did however not finish as expected due to the bankruptcy of AERPAC.

The main motivation for this project is the increasing size of rotor blades, which makes them harder to transport, and increases the waste problem after their service life, also considering the growing production numbers.

The demands with respect to environmental impact and recycling possibilities are getting more important for product development. The analysis required to determine the environmental impact, a **Life Cycle Analysis**, is usually performed after the product has been developed. This is, however, not a sound methodology because changes to the product, proposed due to the outcome of the LCA are rather expensive to incorporate afterwards.

The objective of this project was the development of a new generation of large wind turbine rotor blades which would meet the following requirements:

- manufacturing by new automated process;
- cost price reduction of approximately 20%;
- use of environmentally friendly materials
- rotor blades should be (re)/(down)-cycled.

The size problem should be tackled by producing rotor blades in smaller parts, which can be easily transported and probably produced in an automated production process and assembled near the site where the wind turbines are installed. This will require the development of models for joint design.

The materials selection process has been quite exhaustive, looking to the common material combinations of

- glass/epoxy or glass/polyester but also to
- aluminium (primary and partly recycled)
- steel;
- wood;
- carbon/epoxy;
- flax/epoxy;
- etc.

Part of the work performed aimed to develop a methodology to use LCA data early in the product development cycle. This article shows a procedure to select materials early in the design process, based on performance indicators for materials in relation to the design driving failure mode(s), [1].

Rotor blades for wind turbines are loaded statically and dynamically and stiffness is gaining importance as a design driving parameter for large sections of the blade. For some of the failure modes the performance indicator is derived in an example design problem.

2 ENVIRONMENTAL IMPACT IN ONE NUMBER, THE ECO-SCORE

In the last decade, environmentally driven product development is coming more in the focus of interest. This development, sometimes called Life Cycle Engineering (LCE), is aimed at the design of products which have the lowest impact on the environment without reducing the functionality of the product. Essential for the LCE process is the judgement and trade-off of the different environmental effects. The environmental impact is determined by summing the use of raw material, use of energy and resulting emissions and waste of the product over the life cycle, which is considered to last from manufacturing till end of life. For each of these Environmental impacts a *score* is determined. This methodology is called Life Cycle Analysis.

A detailed LCA tends to be expensive, in cost and time. The result of LCA's performed for different design options are difficult to interpret and to compare. In the design process, time and uniformity in the parameters used in the comparison are essential. That is why the LCA methodology in itself is not very suitable in the product development process. To simplify this process, the LCA scores for each individual process are weighted and summed into the ECO-indicator score (mPt), see e.g. url : www.pre.nl/eco-indicator99

The ECO-indicator method is developed by a panel of international organisations, universities, research institutes, government officials and consultants, in total 365 persons. Still the weigthing of the different effects is considered to be the most controversial step in the ECO-indicator method.

A number of environmental effects are incorporated in the ECO-indicator:

- depletion of resources;
- green house effect;
- deterioration of ozon layer;
- smog;
- water pollution;
- heavy metals;
- carcionogenic effects;
- etc.

For each of these LCA scores the weighting factor has been established. The weight factors are determined on the basis of the so called **Distance to Target** principle.

This principle can be explained as follows:
The seriousness of an environmental effect is determined by the distance between the current level and the target level for this effect. In Europe these two values are specified for each environmental effect. For example the amount of green house gasses emitted to the atmosphere is known and the target level is determined. This target level, i.e. that level of emission which will not show any demonstrable effect, is determined by an international committee of experts. The distance between the current level and the target level is the measure for the weighting factor. The scores for a certain environmental effect are multiplied with these weighting factors en summed to a single number: the ECO-indicator in mPt (milli Point).

Some examples of the ECO-indicator score are shown in the table below.

Materials Production	ECO-ind. mPt	unit
Primary aluminium	22	/kg
100% recycled aluminium	1.8	/kg
Primary copper	85	/kg
20% recycled steel	4.3	/kg
PVC	4.2	/kg
PP	3.3	/kg
Processing		
Electrolytic galvanising both sides by 0.001 mm	22	$/m^2$
cutting steel	0.42	/kg
extrusion of alumium	2.0	/kg
Energy use		
Average European electricity production	2.1	/MJ
Heat from oil	0.15	/MJ
Mechanical heat	0.17	/MJ

Table1: *ECO-indicator values conform the ECO-indicator 95 for the production of some materials and processes.*

This table shows the ECO-indicator for the production and processing of some raw materials and the use of different sources of energy.

Such tables are created for a large amount of (raw) materials and production processes. The end-of-life scenario, recycling or down cycling, is not taken into account in tables like this. The administrative character of the work shown makes it very suitable for computer application.
The work presented here is performed with the computer program SimaPro 4.

3 MATERIAL PERFORMANCE BASED ON THE ECO-SCORE

The BLADECO research showed that using materials which have a low ECO-indicator per unit of mass does not automatically result in a design in compliance with the Life Cycle Engineering ambition, i.e. a low overall environmental impact. This is caused by the low(er) mechanical performance of these materials in the structure, which necessitates the use of much more material to create a rotor blade fit for purpose.

Therefore, a parameter which does not only indicate the environmental impact score but also the technical performance of the material is needed.

There are many performance or effectiveness parameters available for construction materials, see [2]. For example, in case of a bar or shell structure loaded in pure tension one can easily determine the structure effectiveness indicator for stiffness, $\frac{E}{\rho}$ and for strength $\frac{\sigma_{strength}}{\rho}$. In which E is the modules of elasticity, ρ is the density and $\sigma_{strength}$ is the breaking stress of the material.

For the BLADECO project a catalogue,[3] of technical/environmental structure effectiveness index is created for a number of promising materials. This index, **LCA-effectiveness** index has been created for static strength, fatigue strength and stiffness for a rotor blade section. The methodology can be easily expanded to different effectiveness indicators like e.g. cost effectiveness or a buckling criterion.

4 ECO-SCORE FOR WIND TURBINE ROTOR BLADES

Wind turbine rotor blades can be constructed from many material combinations. In the BLADECO project, all kinds of materials have been investigated, like glass/carbon or flax fibres, different kinds of epoxy, PVC and polyurethane matrix materials.

To show the value of the **ECO-effectiveness** index, a case study will be presented for a section of a rotor blade with a load carrying "nose cap"

This section, see figure 1, is loaded by a static and lifetime equivalent fatigue bending moment.

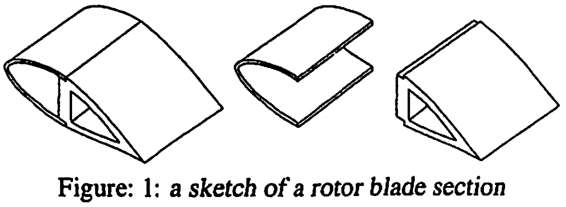

Figure: 1: *a sketch of a rotor blade section*

M_{static} = 0.230 MNm
$M_{fatigue}$ = 0.159 MNm

The geometry of the so called load carrying nose is ellipsoidal and the wall thickness has to be determined in such a way that this part has sufficient resistance in strength, fatigue and stiffness.

The required bending stiffness EI of this section can be determined from

$$EI = \frac{My}{2 \cdot \epsilon_{allow.}}$$

In which M is the bending moment, y de height of the profile and $\epsilon_{allow.}$ the allowable strain. The profile height is assumed to be 0.38 m.

An approximation of the bending stiffness for the nose section is

$$EI = 0.0017 \cdot t \cdot E$$

In which t is the wall thickness.

The influence of the tail on the stiffness is neglected. The mass of the nose section is approximated by

$$m_s = 0.89 \cdot t \cdot \rho$$

The main assumption is that the remaining parts of the structure, the tail section, are made in such a way that they do not restrict the design w.r.t. the maximum strains or flexibilities.

The chosen construction materials for the determination of the ECO-score are:

- glass/epoxy 80% uni-directional 20% cross-plies,
- carbon/epoxy 80% uni-directional 20% cross-plies and
- aluminium 70% recycled.

The designer has to solve the following question: with which material can we create the rotor blade section with the lowest ECO-indicator score, which still meets all functional requirements (in this example mainly mechanical properties)?

Looking at the ECO-indicator per unit of mass, see table 2, glass epoxy seems to be the best choice, and especially carbon epoxy seems to be a bad choice. However is this also true for the rotor blade section considered?

The main assumptions used are:

- the choice of material will not influence the environment during the operational life of the rotor blade;

		Glass/Epoxy 80/20	Carbon/Epoxy 80/20	Aluminium 70% recycled
Primary raw materials	$[mPt/kg]$	5.8	19.5	22
Recycling	$[mPt/kg]$			-14.1
Total Eco-indicator	$[mPt/kg]$	5.8	19.5	7.9
density	$[kg/m^3]$	1780	1412	2800
Youngs Modulus	$[MPa]$	31476	95460	72000
$\epsilon_{stat.}$	[%]	0.342	0.193	0.593
$\epsilon_{fat.}$	[%]	0.358	0.242	0.388
stiffness s.e.c	$[MPa/kg/m^3]$	17.68	67.61	25.71
fatigue s.e.c	$[MPa/kg/m^3]$	0.06	0.13	0.15
stiffness specific ECO-indicator score	$[MPa/mPt/m^3]$	3.07	3.47	3.26
strength specific ECO-indicator score	$[MPa/mPt/m^3]$	10.48	6.69	19.30
fatigue specific ECO-indicator score	$[MPa/mPt/m^3]$	10.97	8.39	12.63

Table 2: Material properties and ECO-indicator score for 3 design options en their specific performance index

- end-of-life scenario, recycling or down cycling is not taken into account.

The end-of-life treatment will have quite some influence on the total ECO-indicator score. Recycling and energy recovery can have a positive influence on the result, i.e. reduce the ECO-indicator score. The idea behind this is that by recycling input of primary material is reduced. Especially for a metal like aluminium this effect on the ECO-indicator score is high. However, the possibilities of recycling depend for a large part on the possibility to separate the individual components.

In the example the wind turbine rotor blade section with an aluminium nose is not an optimal choice w.r.t. recycling. To get a positive influence on the ECO-indicator score the aluminium part has to be separated from the plastic tail which, depending on the chosen adhesive joint, will have a negative influence on the outcome. In this case, due to the fact that aluminium has a high scrap value and the amount is high, percentage wise, used in this kind of construction it will be worthwhile to separate the parts and reuse the aluminium. A recycle percentage of 70% is probably not unreasonable.

		Glass/Epoxy 80/20	Carbon/Epoxy 80/20	Aluminium 70% recycled
t	[mm]	24	14	6
$mass_{section}$	[kg/m]	38	18	15
ECO-ind.	[mPt/m	218	342	119

Table3: *Wall thicknesses t and ECO-indicator scores*

In table 3 the results of the example design are presented. The wall thickness is determined taking the highest values needed to get sufficient static or fatigue resistance. For all materials the static strength appears to be the design driving failure mode. The resulting mass per unit length is shown and the ECO-indicator score which is the multiplication of the mass times the specific ECO-indicator per unit of mass.

The ratio's between the actual ECO-indicator scores are inversely proportional to the ratio's of the ECO-indicator for static strength in table 2. This shows that the ECO-indicator s.e.c. is a useful index for the choice of a construction material.

5 CONCLUSION

From the BLADECO research the following conclusion have been drawn:

- it is possible to use the ECO-indicator in the (pre-)design of a rotor blade;
- the ECO-effectiveness index gives designers a better insight in the environmental effects of the choice for a certain material;

References

[1] Beukers A. and E. van Hinte. *Lightness, The inevitable renaissance of minimum energy structures.* 010 publishers, Rotterdam, 1998.

[2] Tooren M.J.L., J. Sinke, and H.E.N. Bersee. "Composites: Materials Structures & Manufacturing Processes.". Dictaat LR-32, TUD, July 1993.

[3] Zwart G. "BladEco pre-design; The search to a rotor blade with a low environmental impact.". BLDPV-080 -080, AERPAC, July 1999.

7th March 2002

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of Wind Turbine Rotor Blades

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K. Molenveld ♣ W. Teunissen ♣ A.M. van Wingerde +

March 7/8 2002

Presentation is based on results obtained in the BLADECO project, performed by the following partners:

- \+ TUD – WMC-Group,
- * KEMA b.v.,
- † ECN – Wind Energy/DEGO,
- ♣ ATO-DLO,
- AERPAC b.v.,

slide 1

ECN

7th March 2002

1. INTRODUCTION

Project objectives were to develop a new generation of Wind Turbine Rotor Blades which meet the following requirements:

- manufacturing by new automated process;
- cost price reduction of approximately 20%;
- use of environmentally friendly materials;
- rotor blades can be (re)/(down)-cycled.

slide 2

ECN

Many materials have been investigated on the usefulness for the production of large rotor blades and evaluated on the basis of

- technical performance, like
  - static strength,
  - fatigue strength,
  - stiffness.
- economy,
- environmental impact.

ECN

Some material(combination)s that have been investigated are:

- glass/epoxy or glass/polyester;
- aluminium (virgin and recycled to a high extend);
- steel;
- wood;
- carbon/epoxy;
- flax/epoxy;
- etc.

ECN

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For each of these materials a LCA scores is determined using the ECO-indicator method.

The ECO-indicator method is based on the determination of a certain score for an environmental impact.

These environmental impacts can be:

– depletion of resources;	– heavy metals;
– green house effect;	– water pollution;
– deterioration of ozon layer;	– smog;
– carcionogenic effects;	– etc.

slide 5

ECN

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Problem how to balance or weigh effects against each other?

The weight factors are determined on the basis of the so called **Distance to Target** principle.

For each environmental effect the current level and a target level (for Europe) is determined by a group of international experts.

This distance is the basis of the weighting factor.

slide 6

ECN

2. ENVIRONMENTAL IMPACT IN ONE NUMBER, THE ECO-SCORE

- Environmentally driven design (Life Cycle Engineering) is more in the focus;
- target is design with lowest impact on environment;
- problem is how to use LCA data early in the design process to prevent costly changes at the end.

ECN

In aircraft engineering one is used to technical performance or structure effictiveness criteria, which are mainly focussed on weight reduction.
Examples are of such s.e.c. are for simple tension bars
designed for stiffness $\frac{E}{\rho}$
or
designed for strength $\frac{\sigma_{strength}}{\rho}$

The ECO-indicators are usually expressed in mPt./kg, see table for some examples:

ECN

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Materials Production	ECO-ind. mPt	unit
Primary aluminium	22	/kg
100% recycled aluminium	1.8	/kg
Primary copper	85	/kg
20% recycled steel	4.3	/kg
PVC	4.2	/kg
PP	3.3	/kg
Processing		
Electrolytic galvanising both sides by 0.001 mm	22	$/m^2$
cutting steel	0.42	/kg
extrusion of alumium	2.0	/kg
Energy use		
Average European electricity production	2.1	/MJ
Heat from oil	0.15	/MJ
Mechanical heat	0.17	/MJ

The ECO s.e.c. is defined as the: *technical s.e.c. divide by the ECO-score.*
Target is to get a high ECO s.e.c number!

slide 9

ECN

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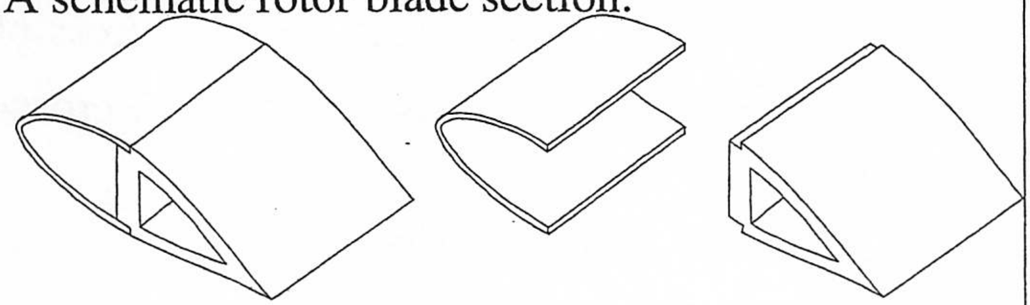
3. Example

A schematic rotor blade section:



with the following loading

$$M_{static} = 0.230 \text{ MNm}$$
$$M_{fatigue} = 0.159 \text{ MNm}$$

slide 10

ECN

The design formulae are:

$$EI = \frac{My}{2 \cdot \epsilon_{allow.}}$$

$$EI = 0.0017 \cdot t \cdot E$$

$$m_s = 0.89 \cdot t \cdot \rho$$

The chosen construction materials for the determination of the ECO-score are:

- glass/epoxy 80% uni-directional 20% cross-plies,
- carbon/epoxy 80% uni-directional 20% cross-plies and
- aluminium 70% recycled.

The material data needed for the design is:

7th March 2002

		Glass/Epoxy 80/20	Carbon/Epoxy 80/20	Aluminium 70% recycled
Primary raw materials	$[mPt/kg]$	5.8	19.5	22
Recycling	$[mPt/kg]$			-14.1
Total Eco-indicator	$[mPt/kg]$	5.8	19.5	7.9
density	$[kg/m^3]$	1780	1412	2800
Youngs Modulus	$[MPa]$	31476	95460	72000
$\epsilon_{stat.}$	[%]	0.342	0.193	0.593
$\epsilon_{fat.}$	[%]	0.358	0.242	0.388
stiffness s.e.c	$[MPa/kg/m^3]$	17.68	67.61	25.71
fatigue s.e.c	$[MPa/kg/m^3]$	0.06	0.13	0.15
stiffness specific ECO-indicator score	$[MPa/mPt/m^3]$	3.07	3.47	3.26
strength specific ECO-indicator score	$[MPa/mPt/m^3]$	10.48	6.69	19.30
fatigue specific ECO-indicator score	$[MPa/mPt/m^3]$	10.97	8.39	12.63

slide 13

ECN

7th March 2002

The result:

		Glass/Epoxy 80/20	Carbon/Epoxy 80/20	Aluminium 70% recycled
t	[mm]	24	14	6
$mass_{section}$	[kg/m]	38	18	15
ECO-ind.	[mPt/m	218	342	119

All design option were driven by the static strength criterion.

The ratio's of the ECO-ind are equal to the ratio of the static strength specific ECO-indicator.

slide 14

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4. Conclusion

From the BLADECO research the following conclusion have been drawn:

- it is possible to use the ECO-indicator in the (pre-)design of a rotor blade;
- the ECO-effectiveness index gives designers a better insight in the environmental effects of the choice for a certain material;

slide 15

ECN

LIFE CYCLE ASSESSMENT OF WIND TURBINE BLADE MATERIALS

IEA R&D WIND EXPERT MEETING, RISØ 7.-8.3.2002

VTT

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2

TECHNOLOGY FOR IMPROVED MANUFACTURE OF BLADES FROM ENVIRONMENTAL RESOURCES (TIMBER)

- EU JOULE project 1997-1999
- Partners
  - KEMA & Aerpac (The Netherlands), Inasco Hellas (Greece), VTT (Finland)
- Tasks
  - Material selection (including LCA)
  - Material production and testing
  - Joint types
  - Blade design
  - Prototype manufacturing
  - Prototype testing
- other

VTT PROCESSES

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3

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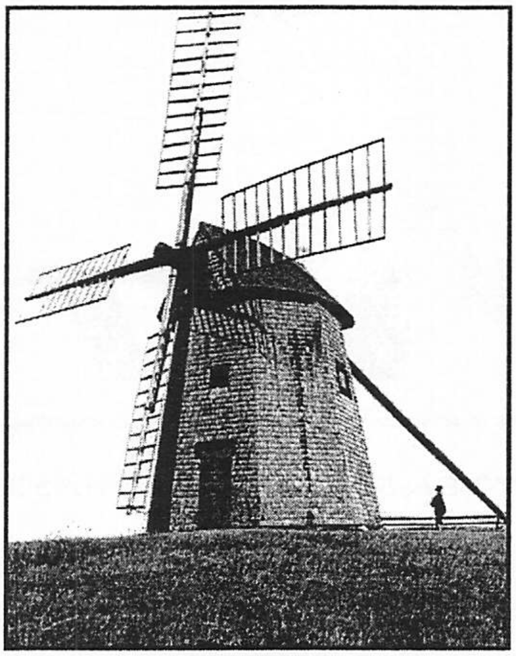

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4

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GOAL AND SCOPE

- Development and implementation of materials for wind turbine blades which combine **environmental** and **economic advantages** without any adverse effects on mechanical properties
- Design of wind turbine blades with emphasis on the use of **environmentally friendly materials, ease of manufacturing** and the **possibility of local assembly and disassembly**
- Development and implementation of **innovative jointing techniques** for wind turbine blade components

VTT PROCESSES

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SYSTEM BOUNDARIES

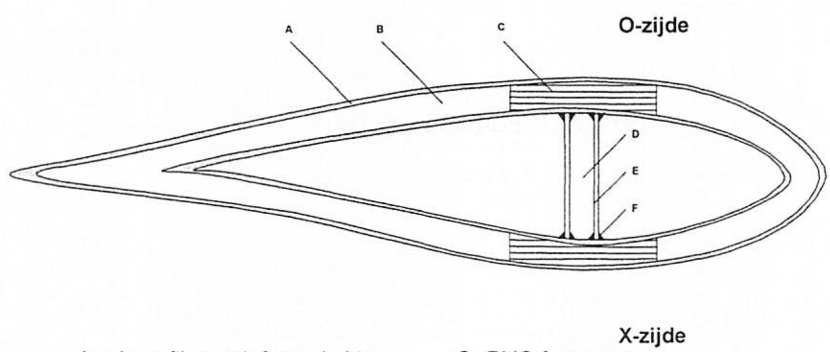
- Different materials for shell&stiffener; material production, transports, waste treatment
- Comparative study, simplifications:
  - mould for blade manufacturing
  - pitch regulation, lightning protection
  - metal studs for bonding, coatings
  - electricity consumption of manufacturing process
  - transports, maintenance
- Functional unit: electricity produced by WT

[System boundaries, flow chart]

COMPARED SYSTEMS

- APX 33L, standard glass-fibre epoxy
- wood-epoxy systems
  - APX 33W, a prototype manufactured and tested in the project
  - TIMBER 33, a theorethical design containing more wood than APX33W
- AOC 38, a conventional wood-epoxy (upgraded from 7m to 16.25 m)

SCHEMATIC CROSS-SECTION OF THE BLADE



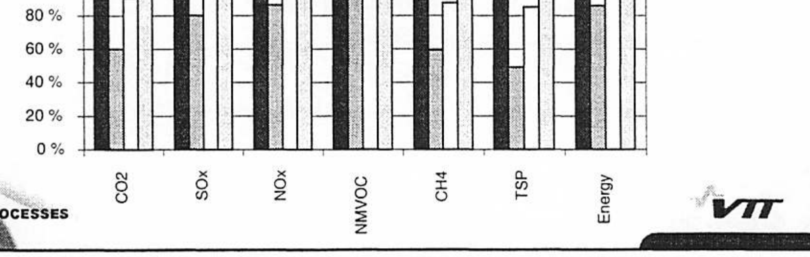
A. glass-fibre reinforced skin	C. PVC foam core
B. PVC foam core	D. glass fibre reinforced skin
C. Glass fibre reinforced girder	E. epoxy adhesive

COMPARED SYSTEMS

Weights of materials in different systems [kg]

MATERIAL	APX33L	APX33W	TIMBER	AOC
Epoxy	408	340	205	466
Glass-fibre	308	266	30	34
PVC and/or PS foam	29	19		86
Wood		432	905	1026
PF glue		18	39	
TOTAL	745	1075	1179	1612

ENERGY CONSUMPTION AND SOME AIR EMISSIONS



Primary energy consumption and energy produced

- Primary energy consumption 0,1-0,3% of the total electricity produced by the turbine
- Primary energy consumption for the entire life cycle of one blade end energy production in the blade incineration

	Consumed energy	Produced energy	
	Primary energy	Heat	Electricity
	[GJ]	[GJ]	[kWh]
APX33L	53	-	860
APX33W	55	7,1	700
TIMBER	46	14,9	400
AOC	65	16,2	1080

LCA FOR WOOD MATERIALS

- Laminated veneer lumber (LVL9
  - difference in tensile strength: 0,8 kg LVL is equal to 1 kg gluelam
  - contains PF glue (8%)
- Glued laminated timber (gluelam)
  - contains RF glue (3%)
- composite veneer
  - with epoxy glue (15 and 20%)
  - with RF glue (15%)

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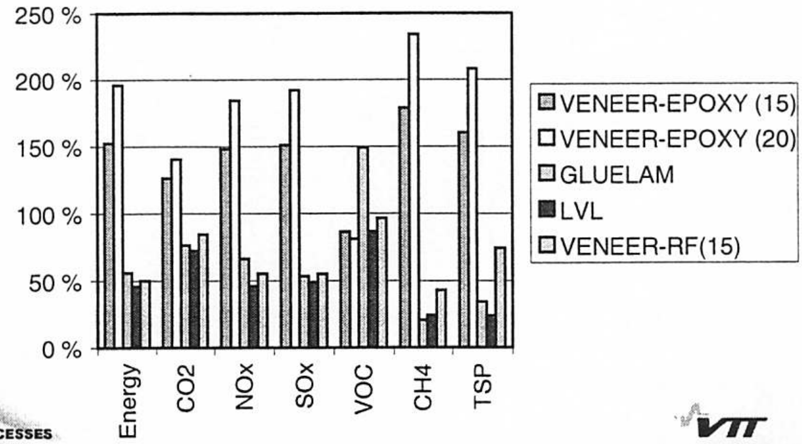
AIR EMISSIONS AND ENERGY CONSUMPTION FOR WOOD MATERIAL MANUFACTURING

100 % = MEAN VALUE



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IMPACT ASSESSMENT (LCIA)

- Inventory analysis -> Impact assessment -> Normalisation/Grouping/Weighting
- LCIA is used to better understanding inventory analysis results
  - Inventory results are assigned to impact categories (global warming, acidification, eutrophication, resources consumption, etc)
  - Indicator results are calculated
- Valuation (weighting) is a subjective step and methods are not comparable with each other.
- 4 Methods used (EPS, Ecoscarcity, Effect category,Eco-indicator)

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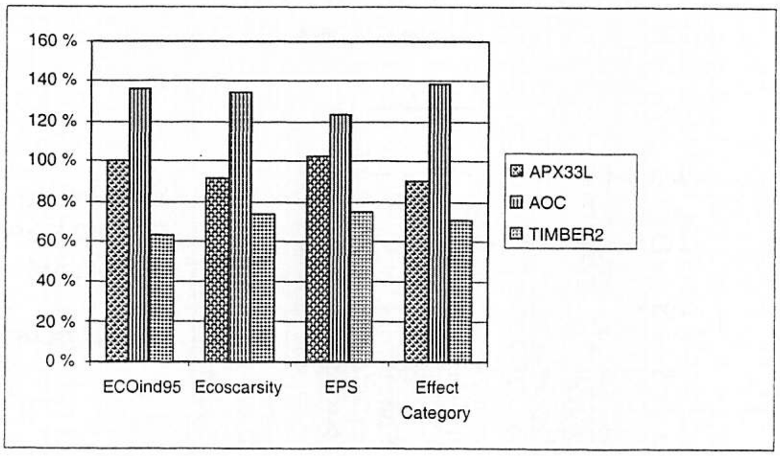
COMPARISON OF VALUATION RESULTS



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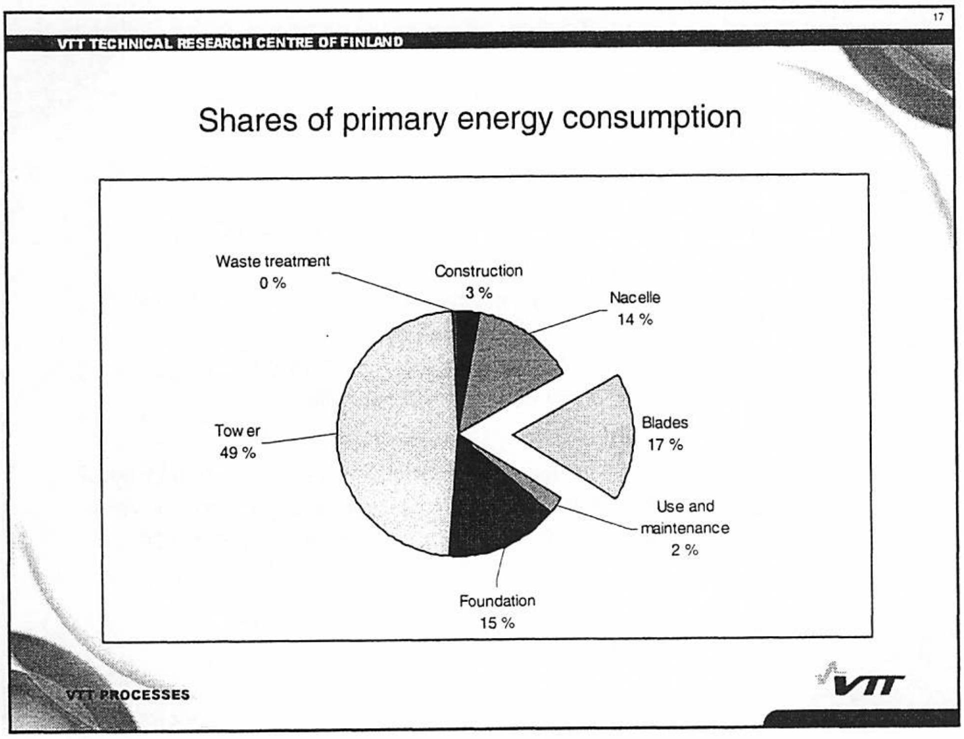
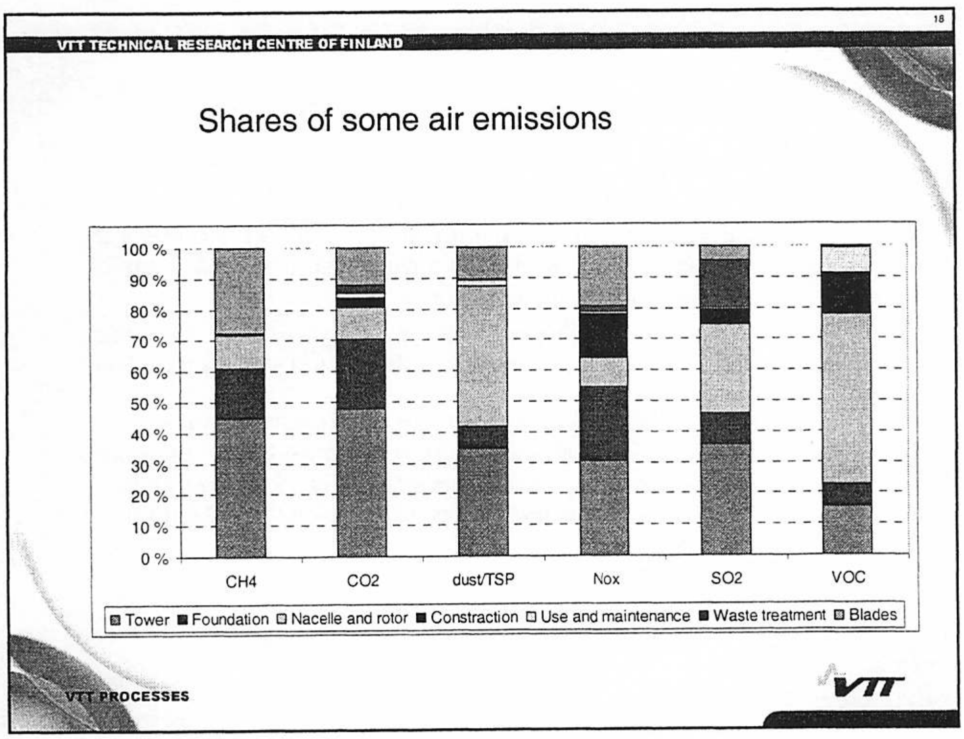

17
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Shares of primary energy consumption
Waste treatment
0 %
Construction
3 %
Nacelle
14 %
Blades
17 %
Use and
maintenance
2 %
Foundation
15 %
Tower
49 %
VTT PROCESSES
VTT


18
VTT TECHNICAL RESEARCH CENTRE OF FINLAND
Shares of some air emissions
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
CH4
CO2
dust/TSP
Nox
SO2
VOC
Tower
Foundation
Nacelle and rotor
Constraction
Use and maintenance
Waste treatment
Blades
VTT PROCESSES
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CONCLUSIONS

- Replacing glass-fibre epoxy with wood can reduce environmental burdens:
  - 60-88% of air emissions (CO2, SOx, NOx, VOC, CH4, TSP)
  - appr. 95% of the primary energy consumption
  - 75-86% of the net energy consumption
- The amount of epoxy is critical to the results
- LCA proved to be a good tool for judging sustainability of materials and products from environmental point of view. Other tools are needed for economical and technical evaluation.

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20

...CONCLUSIONS

- Blade manufacturing from biodegradable materials is a good way to improve the environmental performance of a wind turbine, so why not to...?
  - Manufacturing processes are designed to produce glass-fibre blades -> modifications required also in production lines
  - money, money, money.... If new materials are not economically advantageous, the changes are not going to happen (e.g. labour intensity)..., even if they are both environmentally and technically better than traditional solutions

VTT PROCESSES

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21

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OR?

VTT PROCESSES

COMPOSITES AND THE ENVIRONMENT

- Recycling of composite waste
  - Life cycle analysis

Definitions

- Recycling = Reuse + Recovery

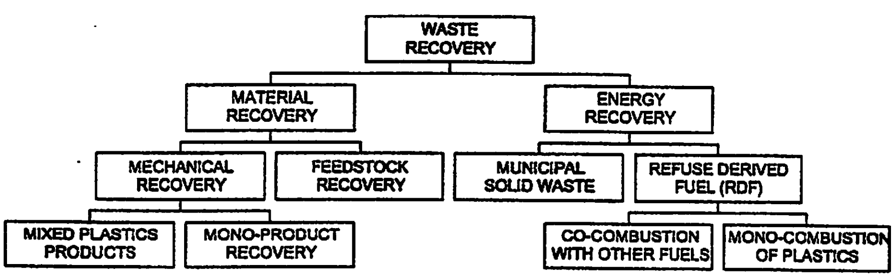
- Reuse = Reuse of products in similar or different applications (Sv. Återanvändning)
- Recovery = material recovery + energy recovery (Sv. Återvinning)

RECYCLING CLASSIFICATIONS

PRIMARY	REUSE AS A NEW PRODUCT WITH SIMILAR PROPERTIES
SECONDARY	REUSE AS A NEW PRODUCT WITH LESS DEMANDING PROPERTIES
TERTIARY	CONVERTING WASTE INTO BASIC CHEMICALS BY PYROLYSIS, GASIFICATION OR HYDROLYSIS
QUATERNARY	WASTE INCINERATION TO RECOVER ENERGY CONTENT AS HEAT

Source: Rusch. K., Recycling of Automotive SMC - the Current Picture, 48th Annual Conference, SPI 1993 3

WASTE MANAGEMENT OPTIONS



DRIVING FORCES FOR THE RECYCLING OF COMPOSITE WASTE

- Landfill disposal will no longer be allowed because of legislation
- Regulatory and economic constrains are directing the waste management
- Customer and public demands

COMPOSITE WASTE TYPES

1. PRODUCTION WASTE AND REJECTED PRODUCTS	•SHORT LIFE-TIME •EASY TO COLLECT AND SORT •NO CONTAMINATION
2. END-OF-LIFE DISCHARGED PRODUCTS CONTAINING COMPOSITE COMPONENTS	•MEDIUM LIFE-TIME •COLLECTING, DISMANTLING, SORTING AND CLEANING •CONTAMINATION POSSIBLE •TRANSPORTED WITH OTHER WASTE COMPONENTS
3. END-OF-LIFE DISCHARGED SINGLE COMPOSITE PRODUCTS	•LONG LIFE-TIME •STRUCTURE DOWNSIZING NEEDED FOR TRANSPORTATION

6

EU STRATEGY FOR WASTE MANAGEMENT

- PREVENT WASTE
- REUSE PRODUCTS
- RECOVERY OF MATERIALS
- ENERGY RECOVERY
- LANDFILL IS RESTRICTED

Source: EU Comission 1996

ENVIRONMENTAL PRODUCT DESIGN

- Minimize consumption of materials
- Select compatible polymers
- Ensure easy identification and collection within the likely recovery system
- Simplify disassembly and material segregation

METHODS FOR RECYCLING OF COMPOSITE WASTE

- ***Material recovery:*** Mechanical particle size reduction of the cured composite with direct reuse of the resulting ground fractions
- ***Energy recovery:*** Incineration of the composite waste together with other fuels
- **Material recovery with energy recovery:** Energy recovery of matrix by incineration, reuse of inorganic ash in suitable products
- ***Chemical recycling:*** Decomposition of the matrix resin through hydrolysis or pyrolysis to basic raw materials

MATERIAL RECOVERY OF COMPOSITE WASTE

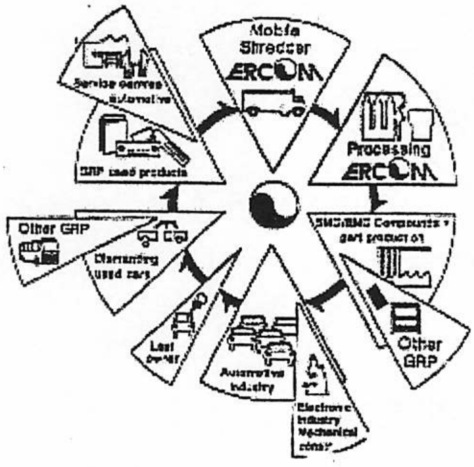
- Mechanically ground fractions of recycled composites are used in new products
- Recycled composite is mixed with virgin material as filler or reinforcement
- Up to 5 - 15 % by weight of recycled fractions can be used in the virgin material

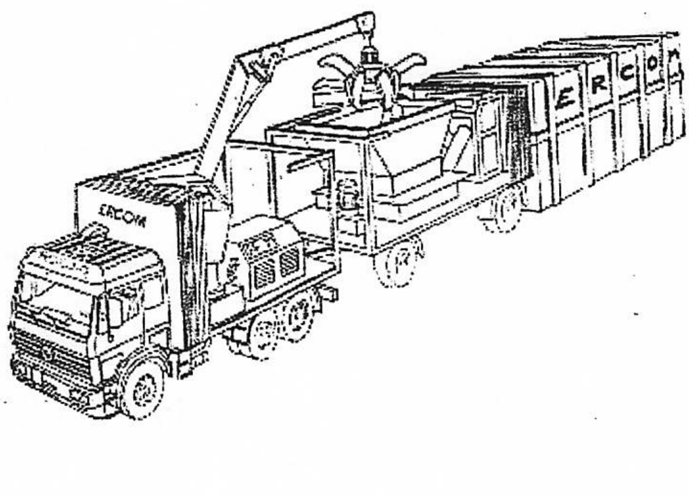
REQUIREMENTS FOR MATERIAL RECYCLING

- Logistic system for collecting, sorting and dismantling
- Quality system for producing ground fractions free from contamination
- Feasible process technology and applications for recycled materials

ERCOM - a concept for material recycling

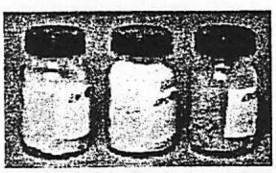
Material circulation Ercom GmbH

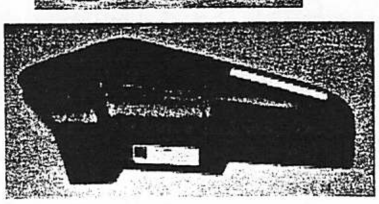




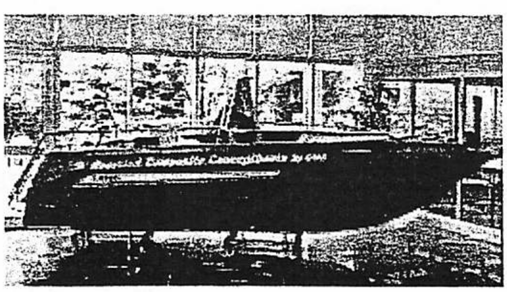
CASE I: AUTOMOTIVE APPLICATIONS

- Mechanical recycling of SMC parts from the automotive industry has been done commercially by ERCOM in Germany since 1992
- Over 2 million parts have been recycled
- In France Mecelec Composites et Recyclage offers a similar process
- Potential for increase of SMC recycling rate (currently < 1 % of SMC production in Europe)
- Cost of recycled SMC higher than virgin SMC at present volumes





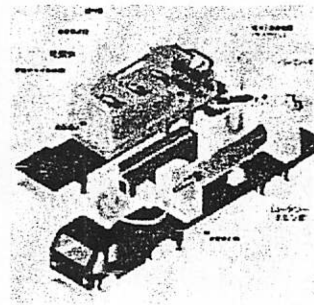
CASE II: CONCEPT-BOAT CONTAINING 20 % RECYLED MATERIALS BASED ON TOTAL WEIGHT



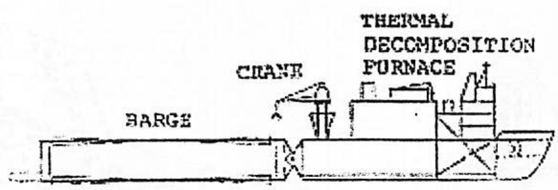
- Layer of recycled laminate between layers of virgin laminate
- Ground, recycled fractions are mixed with virgin material
- Application by special spray-up equipment
- Cost and performance similar as for conventional boats

CASE III. CONCEPTS FOR MATERIAL RECYCLING IN JAPAN

Mobile incinerator for GRP waste

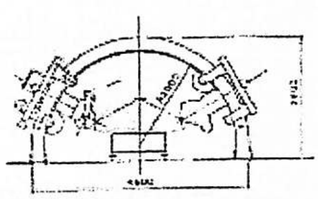


CASE III. CONCEPTS FOR MATERIAL RECYCLING IN JAPAN



Collecting system for GRP boats

Systems for dismantling



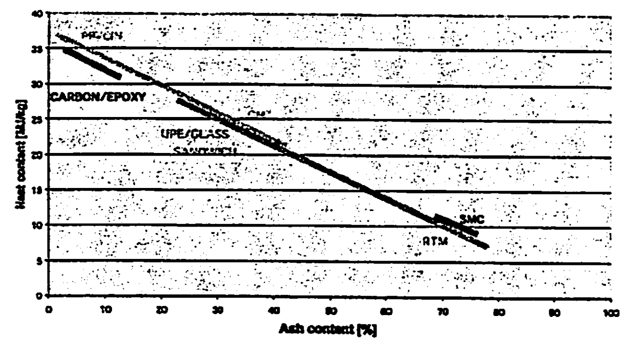
CHEMICAL RECYCLING

- Chemical or feedstock recycling by pyrolysis has been proven technically possible
- Gas and oil is generated, inorganic fraction can be used as a filler
- Investment costs for pyrolysis plants are however currently too large for economical feasibility

ENERGY RECOVERY BY INCINERATION

- The most important replacement for landfill
- Energy recovery is generally accepted in Europe
- Is already implemented at several incineration plants for household waste in the Nordic countries
- Energy content of composite waste depends on the amount of inorganic fibers and fillers
- Incombustible residue from the glass reinforcement and the filler

Energy content depends on the filler and reinforcement content in the composite



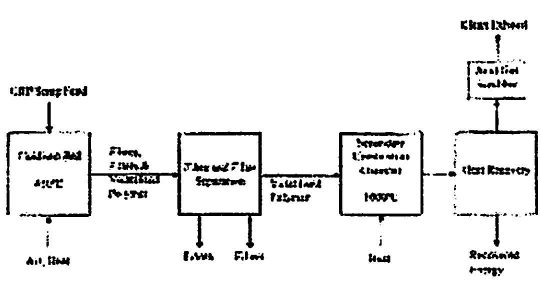
Ash content and heat content for different composites

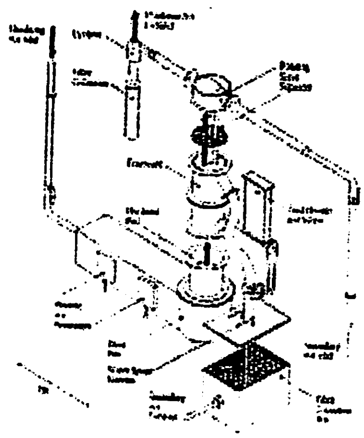
Energy recovery and material recycling

Some examples:

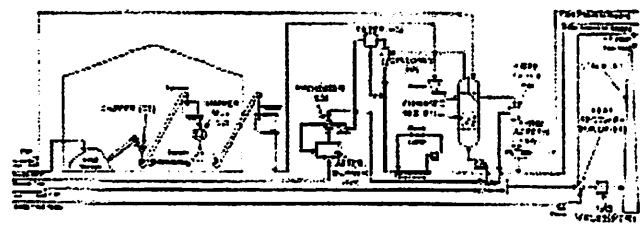
- Composite waste can be used as an energy resource in the manufacture of cement
- Co-combustion of coal and composite waste reduces sulphur emissions
- Glass fiber recovery from the incineration process

RECOVERY OF GLASS FIBRES FROM THE INCINERATION PROCESS





Proposed plant

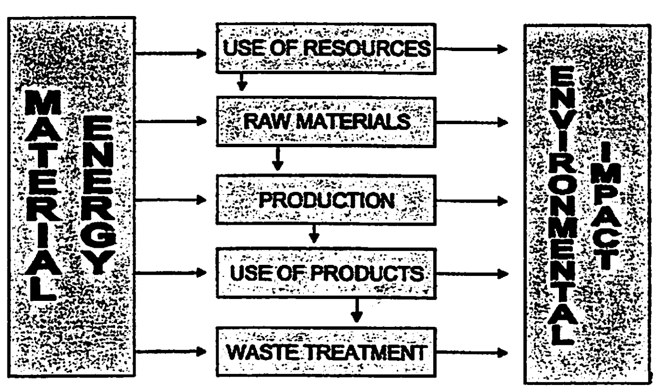


Separated fibres from the incineration process can be used to make moulding compounds, with a recycled fibre content up to 50 wt-%

Life cycle analysis

A tool for evaluating the total environmental impact of a product or a service from cradle to grave

LCA ESTIMATES THE TOTAL ENVIRONMENTAL IMPACT



Use of LCA

- Identify phases in a products life cycle that account for the main environmental impact
- Compare different raw materials, production methods, energy-supply and transportation systems
- Use obtained data to select the material combinations with the lowest environmental impact

Life cycle analysis EPS

Environmental Priority Strategies in Product Design

- Manufacturing
- Product use
- Waste handling

How are these phases affecting the environment?

Life cycle analysis EPS

Environmental load =

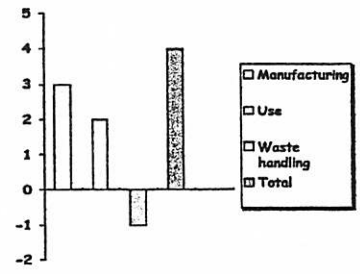
Environmental load index X amount

ELU (Environmental Load Unit)

Life cycle analysis EPS

General example

The different phases in the life cycle are added.
This gives the total environmental load



Example: Liquid gas bottles

Material options:

	Weight
Composite	*6.6 kg*
Aluminium	*7.1 kg*
Steel	*12.1 kg*

Use environment:

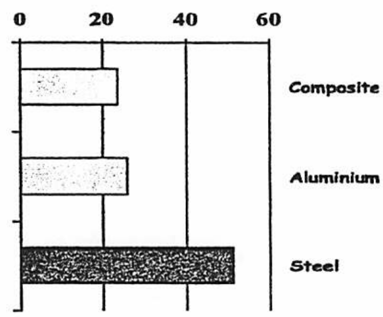
Non corrosive - corrosive

Stationary use - mobile use

LIFE CYCLE ANALYSIS EPS

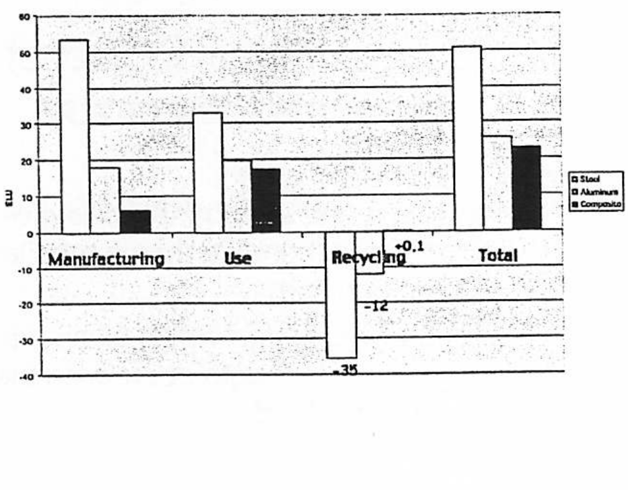
Liquid gas bottle

Normal environment
Stationary use

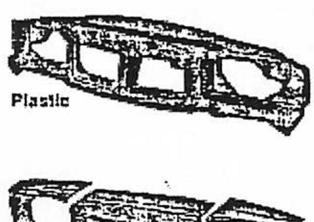


LIQUID GAS BOTTLES

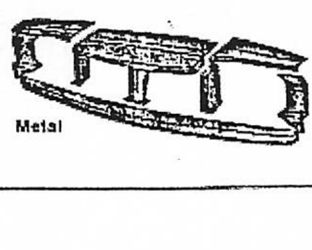
Stationary use, normal environment



Which front end is most environmental sound

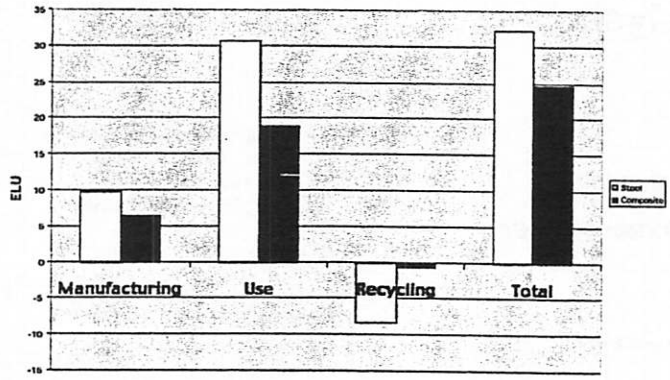


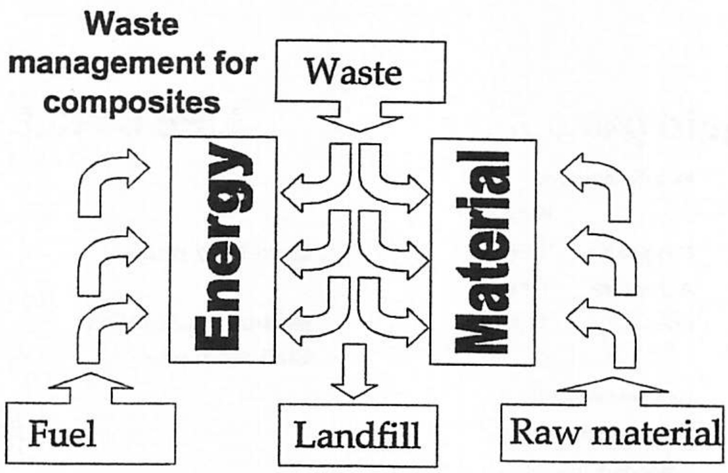
GMT-composite
Material consumption: 4.0 kg
(0.3 kg scrap)
Component weight: 3.7 kg



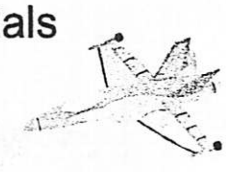
Galvanized steel
Material consumption: 9.0 kg
(3.0 kg scrap)
Component weight: 6.0 kg
Painted area: 0.8 m²

Front for passenger car

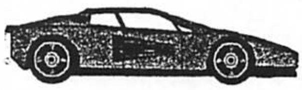




Environmental benefits with composite materials



- Low weight
- Long life-length
- High stiffness
- High strength
- Corrosion resistant
- Design freedom



Environmental impact of products - summary

- Low weight and strong materials give environmental benefits during mobile use and transportation
- Materials and design which gives the product long life length decreases the environmental load

Vattenfall's work on LCA

LCA for wind mills (data from a 500 kW wind mill). This study was carried out 1996 and the results are included in a larger study (see below).

LCA for 10 different electric power production system - based on inventory data (life cycle inventory) - carried out 1996 - followed Nordic guidelines.

A brochure based on the reports mentioned above.

Certified Environmental Product Declaration (EPD) - e.g. Lule river and Forsmark.

http://www.vattenfall.se/om_vattenfall/var_verksamhet/var_produktion/livscykelanalyser/

Database called SPINE - owned by Vattenfall.

IEA Topical Expert Meeting
Material recycling and LCA of wind turbines
7th and 8th of March 2002

Tech-wise
energy environment knowledge

LCA of offshore and onshore wind farms
Prepared in co-operation with Vestas

Henriette Hassing
Tech-wise A/S

IEA Topical Expert Meeting
Material recycling and LCA of wind turbines
7th and 8th of March 2002

Tech-wise
energy. environment. knowledge

- Project financed by the Danish Energy Agency and by Vestas
- Budget of approx. 24 manmonths
- Meets ISO 14040 to 14043
- Based on EDIP (UMIP) method and tool

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7^{th} and 8^{th} of March 2002

Tech-wise
energy environment knowledge

The objectives of the LCA

- Compare the environmental profile for energy from onshore and offshore wind farms.
- For Vestas to have a tool for product development
- Development of environmental product declaration

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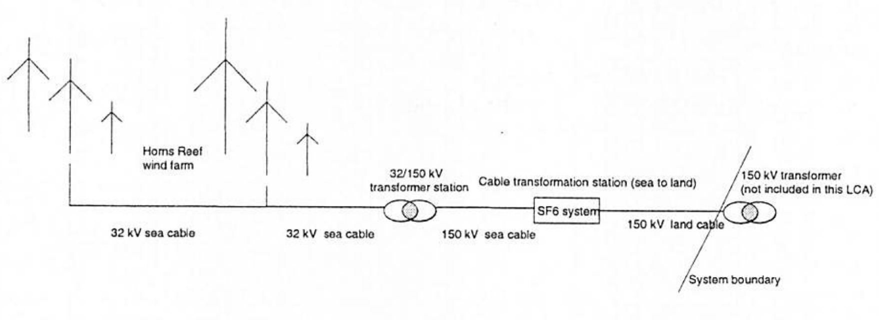
7^{th} and 8^{th} of March 2002

Tech-wise
energy environment knowledge



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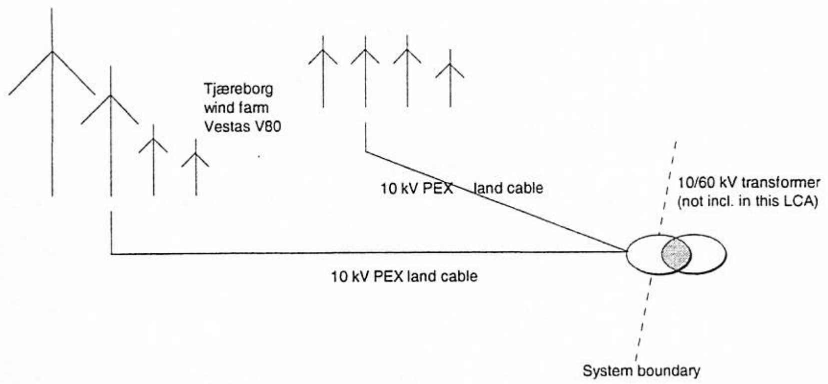
Tech-wise
energy. environment. knowledge



IEA Topical Expert Meeting
Material recycling and LCA of wind turbines
7th and 8th of March 2002

Tech-wise
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Data collection

- Vestas environmental management system
- Lists of components from Vestas
- Elsam/Tech-wise design of wind farms
- Eltra design of transmission
- Contact to suppliers
- Workshop on waste disposal

IEA Topical Expert Meeting
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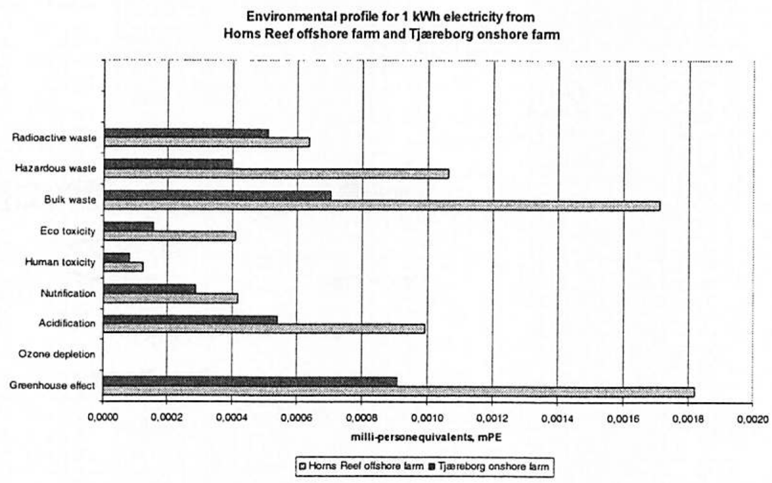

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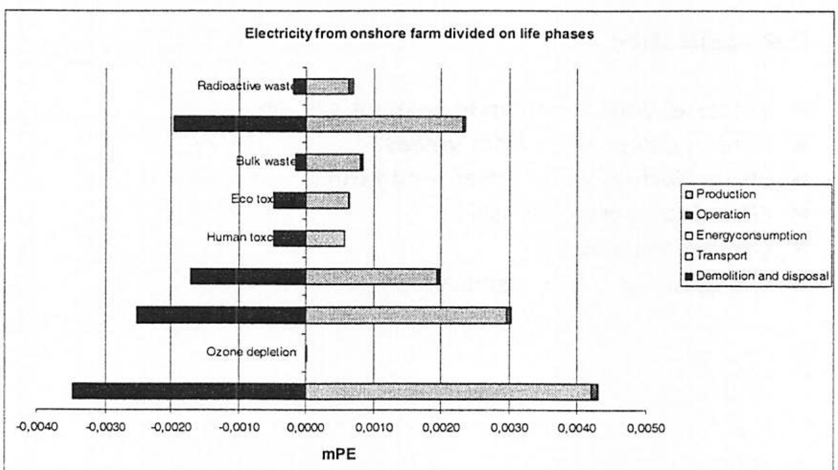

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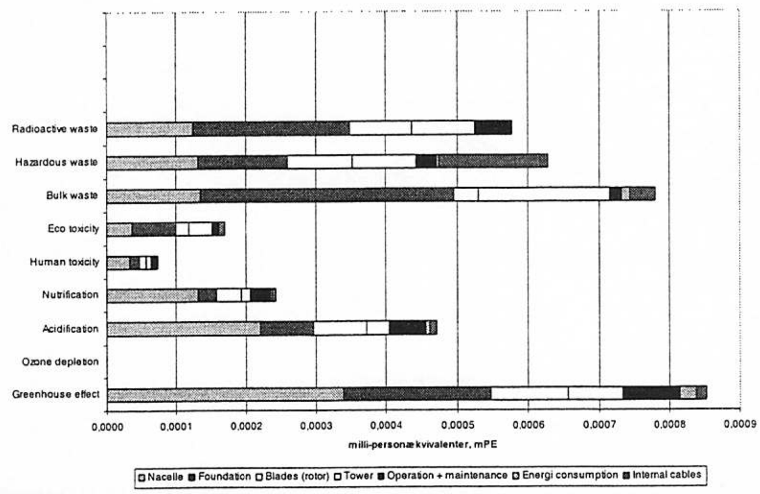
Environmental profile offshore farm divided to components



IEA Topical Expert Meeting
Material recycling and LCA of wind turbines
7^{th} and 8^{th} of March 2002

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Conclusions

- Materials constitute the main effects
- At least 95% of the materials in turbine is included
- Degree of recycling crucial for the environmental profile
- Not possible without very close co-operation with Vestas
- Difficult to obtain data from suppliers
- Valid data for constructions

IEA Topical Expert Meeting
Material recycling and LCA of wind turbines
7th and 8th of March 2002

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Experience

- Data collection difficult to delimit
- Difficult to find reliable data for materials
- Important to make iterative data collection
- Close co-operation with producer is necessary

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Environmentally Sound Design and Recycling of Future Wind Power Systems

Per Dannemand Andersen
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Aims of the project

- Analysis of wind turbines' environmental impact during manufacturing and decommissioning in a long term perspective
  - manufacturing of turbines by 2020-30
  - decommissioning by 2040-50
- Societal recommendations concerning decommissioning, recycling and handling of waste for existing and future wind turbine concepts and components
- Development of methodologies for combining LCA (Life Cycle Assessment) and Technology Foresight/ Forecasting methodologies

Sponsored by the Danish Energy Research Programme (EFP)

Foresight methodologies

Conditions:
- Low uncertainty
- Short time range
- Incremental innovations
- Etc.

➡Trend analysis methodologies:
- Trend extrapolation
- S-curves
- Experience curves
- Etc.

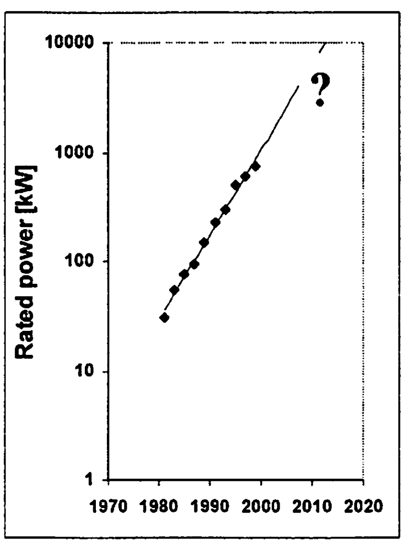
- Predict the future

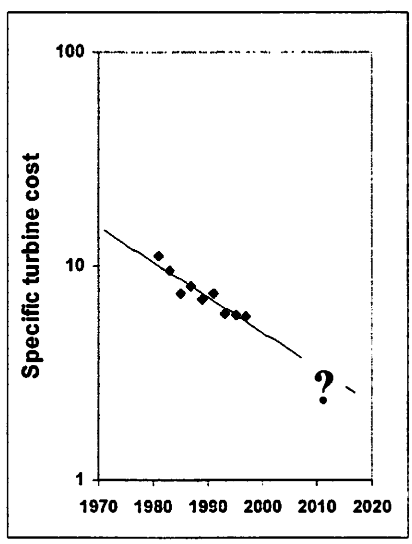
Conditions:
- High uncertainty
- Long time range
- Shifts in technology
- Etc.

➡Judgemental methodologies:
- Expert panels
- Delphi questionnaires
- Scenario building
- Etc.

- Discuss many futures

Extrapolation of trends





"Stiesdal's Law": Size - in rated power - doubles every four years

Trend analyses

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- Market volume
  - Existing plans + extrapolation (BTM's World Market Update)
- Cost of energy
  - Experience curves
- Size of machines
  - Extrapolation a decade or two
- Weight of main components
  - Experience curves + extrapolation a decade or two
- Etc.

Judgemental analyses

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- New concepts
- New materials
- New components
- New legislation and regulation

- Cannot be found through trends analyses - one need to ask for experts judgement

Project phases

- **LCA** at one state-of-the-art wind power system
- **Mapping current trends** of wind power technologies and concepts
- **Expert panel** brainstorm on future wind technology
- **Delphi survey** on future wind technology
- **Scenarios** of future wind power systems
- LCA scanning of future wind power systems
- Expert panel brainstorm on environmental aspects of decommissioning current and future wind technology
- Reporting

LCA state-of-the-art wind power system

- Two recent Danish projects
  - Project by TechWise and Vestas om Horns Rev
  - Project by SEAS and E2 on Rødsand
- Wind energy has very low environmental effects
- Largest contributions from
  - voluminous waste from tower and foundation (e.g. from steel production)
  - hazardous waste from nacelle (e.g. from steel alloys)
  - greenhouse effects (e.g. from steel production and surface treatment)

➡ Where to look for potential changes

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One day expert panel meeting

- 155 statements / factors were produced
- Ranked using
  - potential impact on wind power
  - uncertainty about realisation
- Factors were grouped
- The panel agreed on the most important groups of factors

- From each of the most important groups a number of factors was chosen to a Delphi questionnaire

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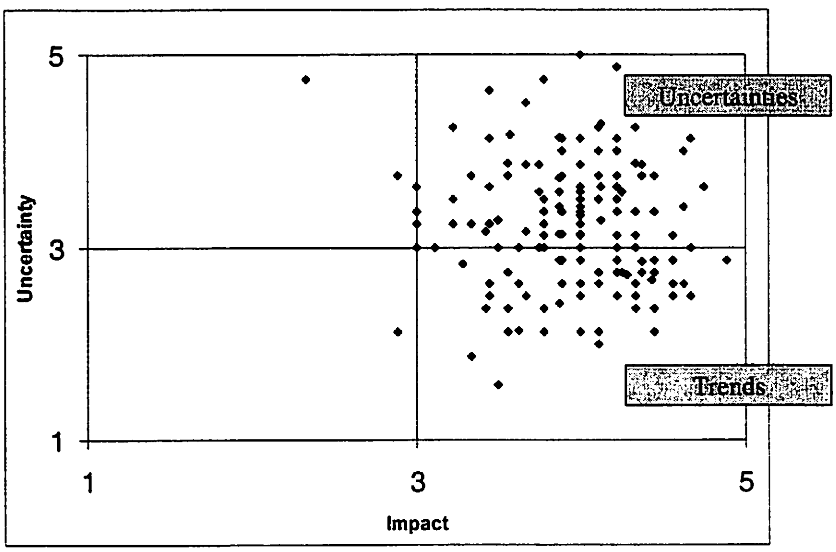
155 statements and factors



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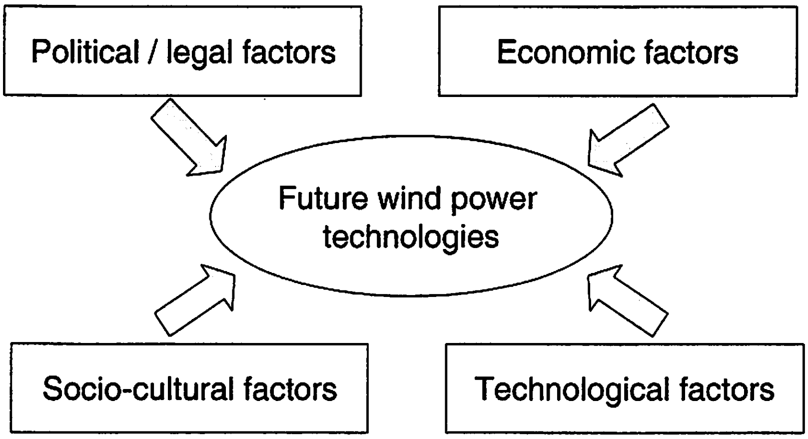
Driving Factors for Future Wind Power Systems



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Driving Factors for Future Wind Power Systems

63 statements/factors

Political / legal factors
- Implementation of Kyoto
- Energy sector deregulation
- Internalisation of externalities
- EU's energy dependency

Economic factors
- Increasing energy prices
- Public expenditures on R&D
- Competitive other RE sources

Socio-cultural factors
- Public acceptance
- Environmental awareness
- Increased energy consumption
- Rural electrification

95 statements/factors

Main groups of technological factors
- Energy storage technologies
- Installation concepts
- Control and regulation
- Scientific computing
- Components
- Grid and power transmission
- Blade materials
- Other materials
- New concepts and up-scaling
- Transport
- Towers

(in order for average impact in each group)

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Most important driving factors

- Factors affecting the future market volume (material masses)
  - Climate and energy policies (Kyoto,safety of supply, etc)
  - Conditions of future power markets (deregulation, decentralisation, etc)
  - R&D expenditures (public and industrial)
- Factors affecting future wind technology (material types)
  - New materials (replacement of steel, new composites, super conducting materials, etc.)
  - Concepts and main components (power electronics, control strategies, super conducting materials, etc.)
  - Grid conditions (grid structure, power quality, etc.)

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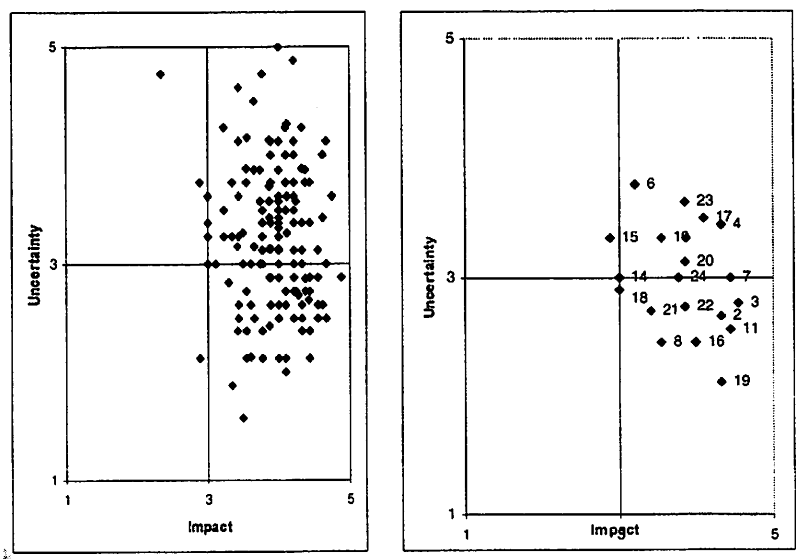
Statements / factors - 155 and 24 selected



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Delphi Survey
Who answered ?

Distribution by country

Belgium	1
Denmark	15
Germany	6
Greece	1
France	3
Japan	2
Netherlands	4
Portugal	1
Spain	8
Sweden	1
Switzerland	1
USA	2
Total	45

Distribution by affiliation

Industry	8
University or other research	18
Consultancy or self-employed	7
Public authority	2
Financial sector	4
Interest association, NGO, etc.	0
Power company (utility)	3
Developer	1
Other	2
Total	45

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Delphi statements

1. 10% of Europe's electricity from wind power
2. More than half of all new turbines in Europe are placed offshore
3. 40% cost reduction of wind produced electricity relative to 2001
4. Global implementation of Kyoto targets
5. 50% increase in EU and European national expenditure on wind power related research
6. Other renewable source of energy (other than hydro) becomes fully competitive with wind
7. Competitive concept for storage of wind energy (e.g. based on hydrogen)
8. Significant global market for small (<50 kW) turbines for stand-alone and hybrid systems
9. More than 75% of all wind turbines are of a two-bladed highly flexible design
10. More than 75% of all new turbines are without gear-boxes
11. More than 50% of all new offshore turbines are 10 MW or larger
12. Design life-time of 40 years for most new turbines
13. Commercially competitive hydraulic drive-train (e.g. based on synthetic oil or water)
14. More steel based than concrete based foundations for new offshore turbines
15. Steel is replaced by other materials for towers in more than 25% of all new turbines
16. Losses in power electronic equipment are reduced by a factor of 10 due to new materials (e.g. siliciumcarbide)
17. Commercial use of new environmentally neutral surface treatment for major steel parts (e.g. towers)
18. Widespread use of foam materials to prevent buckling in blades and towers
19. Plant (or cellulose) fibres are used instead of fibreglass in blades
20. Multipole generators with permanent magnets in half of all new turbines
21. Introduction of high voltage generators (20-60 kV)
22. High voltage frequency converters in more than half of all new turbines
23. Commercial use of super conducting cables for power transmission from wind farms
24. Noise emission from new turbines reduced by 50% compared to 2001 levels

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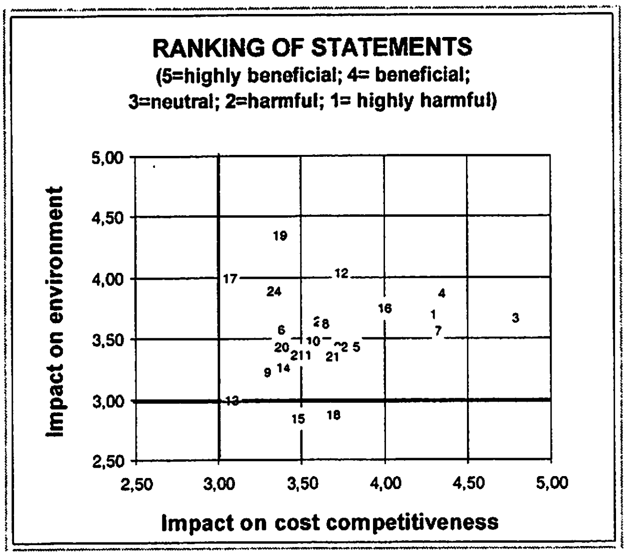
Result of Delphi survey



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Top four "market" statements
Political, economical, societal issues

	Own field	Know	No know	Cost competitiveness
40% cost reduction of wind produced electricity relatively to 2001	13	24	7	4,79
Global implementation of Kyoto targets	5	30	9	4,34
Competitive concept for storage of wind energy (i.e. based on hydrogen)	5	26	15	4,32
10% of Europe's electricity from wind power	14	28	2	4,29

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Top five technology statements

	Own field	Know	No know	Cost competitiveness
Losses in powerelectronic equipment are reduced by a factor 10 due to new materials (e.g.siliciumcarbide)		15	29	4,00
Design life-time of 40 years for most new turbines	9	24	10	3,74
High voltage frequency converters in more than half of all new turbines	2	18	23	3,73
Widespread use of foam materials to prevent buckling in blades and towers	4	15	26	3,69
Introduction of high voltage generators (20 – 60 kV)	3	19	22	3,69

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Conclusions I

- Respondents feel as less experts on technological statements than on political, economical and societal statements
- Political, economical and societal statements have larger impact on wind power's cost competitiveness than technological statements

Delphi Survey
Some indications on time horizons

- 10% of Europe's electricity from wind: between 2011 and 2020
- half of Europe's added wind to be offshore: between 2011 and 2020
- 40% cost reduction of wind power: between 2006 and 2020
- 50% steel based offshore foundations: before 2011
- 75% flexible two-bladed concepts: never
- Design of lifetime to 40 years never or less likely

- For the other 18 statements no indications can be drawn.

Key issues related to dismantling and recycling
Result of an expert meeting

1. Fundamenter:
a. Spild på stedet under fjernelsen
b. Fjernelse af hele fundamentet (også i havbunden)
c. Overgangsstykke og bådlandingsplatform
- Fugen af Dencit

2. Tårn:
a. Maling (på ståltårn)
b. Højstyrkebeton
c. Galvaniseringen

3. Nacelle-kabine:
a. PVC skum
b. Plasttyper
c. Glasfiber (polyester)

4. Generator og gear:
a. Special stållegeringer
b. Olier og fedt
c. Kobberstøv (generator)

5. Elektronik og kabler:
a. Kabler
Olie
Metaller
Andre kappematerialer (fiber mv.)
b. Offshore-transformator og nettilslutning
c. Styrings- og kommunikationselektronik
- metaller heri

6. Hydrauliksystemer mv.
a. Slanger, cylindre, rør mv.
b. Højstyrke stål

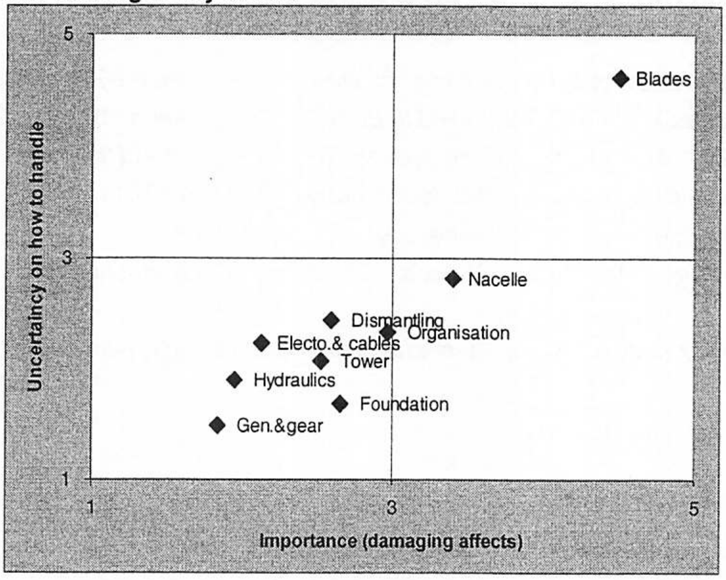
7. Vinger
a. Materiale (blanding af prepreg, epoxy-imprægnering etc.)
- produktionsaffald

8. Maskinel v. nedtagning og bortskaffelse
a. Specialredskaber og –udstyr
b. Specialskibe

9. Organiseringen og vidensopbygning
a. Inddragelse af erfaringerne fra offshoreindustrien
b. Institutioner, nye
c. Virksomhed specialiseret udelukkende i fjernelse og bortskaffelse af havvindmøller
d. Demontageanalyse, systematisk
e. Eksisterende genvindingsfirmaer inddrages
f. Samarbejde over lang tid mellem møllefabrikanter, genanvendelses-virksomheder mv.

Key issues related to dismantling and recycling

Experts' ranking of key issues



Future issues related to dismantling and recycling

Experts' brainstorm on key issues

- No significantly larger problems in the future compared with today
- Fibreglas might also be a large problem in the future
- Carbon fibres might give dismantling problems due to working environment
- Increased use of high strength steel – no problem
- Increased use of power electronics – no problem
- Superconducting materials, permanent magnets, siliciumcarbids ??
- Better contacts between wind turbines industry and waste management firms – maybe conflicting interests
- Dismantling and reuse considerations integrated in design

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Conclusions

- Future wind power technology can be analysed systematically in a long range perspective.
  - distribution and masses of materials
- Results can be applied in prospective LCA and EIA.

ERGEBNISSE VON TA-PROJEKTEN – NEUE TA-PROJEKTE

Prospective Life-Cycle Assessment on Wind Power Technology by 2020[1]

by Per Dannemand Andersen and Egon Bjerregaard, Systems Analysis Department and Wind Energy Department, Risø National Laboratory

This paper reports on a case study on prospective Life Cycle Assessments (LCA) combining LCA methodologies and technology foresight or forecast (TF) methodologies. The case analysed in the article is wind power technology as it might appear by 2020.

1 Introduction

There is an increased focus on technologies' adverse effects on the environment. In many countries this has led to legislation, regulation and standardisation. A number of standards and guidelines have been issued, such as the ISO 14040 on Life Cycle Assessments (LCA), a guide (no. 109) of the International Electrotechnical Commission (IEC) on Environmental Impact Assessment (EIA) and guidelines of the European Committee for Standardisation (CEN).

Generally, the wind power industry welcomes this development. Wind energy is clean and safe and is generally recognised as one of the most environmentally sound technologies for producing electricity. Nevertheless, it is important to acknowledge that renewable energy technologies also are subject to assessments of their impact on the environment.

Wind power is the fastest growing energy industry with annual growth rates in the world market between 20 % - 40 %. If the expected future importance of wind power is going to be realised – resulting in two digit percentages of many countries' and regions' electricity supply – a lot of wind turbines are to be installed over the decades to come. This rapid growth in a long-term perspective is likely to affect the design of future wind turbines. The wind power technology installed 20 years from now might be radically different from the technology today. This change in technology is likely to happen not through radical changes but as a series of incremental changes (Dannemand Andersen and Hjuler Jensen 1998).

Looking 20 years ahead is not unknown in the energy sector. Several countries have carried out long-term energy planning for decades – especially since the oil embargo in the early 1970s. Furthermore, electricity-producing technologies have, traditionally, a long economic lifetime. Fossil based and nuclear power plants often have lifetimes of 20 to 30 years, and lots of hydro plants have been in operation even longer.

A challenge here is that most methodologies for assessing technology's environmental effects are based on historical data or on state-of-the-art of the technology. That is especially a challenge for technologies that are expected to change over a long planning period such as wind power technology (and PhotoVoltaics technology). Therefore, there is a need for developing LCA/EIA methodologies that include future changes in technology. This is the scope of the project reported in this article.

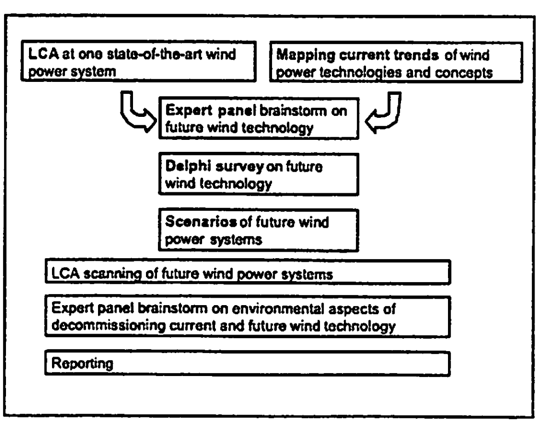
2 Aims and Approach of the Project

The project reported in this article has three aims. The first aim is to analyse the environmental effects of wind turbines during production and decommissioning of wind turbines in a long-term view. That is a time horizon of 2020-30 for the manufacturing of wind turbines and 2040-50 for dismantling. The second aim is to set up societal recommendations concerning decommissioning, recycling and handling of waste for existing and future wind turbine concepts and components. Finally, it is an aim of the project to contribute to the development of methodologies for using LCA as a tool for designation of experts and for making perspectives on a long-term.

The project is financed by the Danish Energy Agency and carried out in collaboration between Risø's Wind Energy Department and Systems Analysis Department.

The project is carried out in seven steps (cf. Fig. 1). Step 1 is an analysis of environmental effects of state-of-the-art wind turbines through a LCA with a focus on manufacturing and decommissioning. This project has not independently carried out LCA on state-of-the-art wind power systems but has relied on other studies on wind energy's environmental effects. The objective is to get an overview of the most important adverse effects on the environment from the manufacturing and decommissioning of wind power systems. Step 2 is a mapping of current trends of wind power technologies and concepts. The aim here is to get an overview of trends affecting how wind turbines will be designed in the future. Some trends can even be extrapolated for a longer period. Step 3 is an expert panel brainstorm on drivers for the development of wind turbine technology. The focus is set on factors that cannot easily be extrapolated. Step 4 is a Delphi survey on the future for wind energy technology with questions based on the first three phases. In step 5 a number of scenarios for future wind turbine technology (2020-2030) are drawn. In step 6 a LCA of future wind power systems is carried out as a desk study. Finally in step 7 a panel with experts on decommissioning, recycling, waste handling, etc. brainstorm on present and future (2050) environmental aspects after decommissioning the machines. This article reports on steps 1 to 4.

Fig. 1: Project phases



3 Methodological Consideration

This study is based on combining established methodological frameworks of Life Cycle Assessments (LCA) and Technology Foresight (TF). The coupling of TF and LCA is related to how to handle the time horizon in a life cycle assessment of a product where new procedures or new materials may be introduced in the future. So far, only a few articles have been published on this area (Weidema 1998; Pesonen et al. 2000; Borch and Rasmusssen 2000).

The technical framework for the LCA methodology as it is defined in ISO 14040 consists of four phases: Goal and scope definition, life-cycle inventory (LCI) analysis, impact assessment and interpretation. The phases are not necessarily followed sequentially. It is an iterative process, which can be followed in different rounds achieving increasing levels of detail (from screening LCA to full LCA), or which may lead to changes in the first phase because of the results of the last phase. Obviously, LCA is a decision support tool that can be used by industry already in the development and design phases of new products. Especially when considering LCA on a product system and not just a product, LCA seems to be a suitable tool in the mapping of the product system and its potential impact (Weidema 1998). However, it might be difficult to balance the importance of the LCA results with non-environmental related issues. Therefore, it is recommended to use LCA as early as possible in the product development chain (Brohammer 1999). A LCA screening may be carried out in the pre-study phase in order to find suitable environmental criteria and in the project execution phase LCA may be used in the environmental decision process in relation to materials used, procedures, etc.

Technology Foresight is often defined as *„the process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economical and social benefits*" (Martin 1995). The term Foresight is often affiliated with a societal process or dialog on priorisation of strategic, publicly financed research. Another related term is

Technology Forecasting. Technology Forecasting has been defined as *„an early recognition of technological developments and validation of their potential*", (Holtsmannspötter and Zweck 2001). Forecasting is often associated with monitoring of trends in technology and of break-throughs in natural sciences. Forecasting (or monitoring) is often carried out by governments for defence related reasons or by large enterprises for decision support or as strategic intelligence. Hence, dialogue between stakeholders is not a part of Technology Forecasting processes, but in both cases the same toolbox of methodologies can be utilised: expert panels, Delphi studies, scenarios, etc. In this project the focus is set mainly on technological issues. Prospective methodologies are used to get a broad base of knowledge to map wind energy's strategic environment with the aim of clarifying current or future practical problems in relation to the production and disposal of wind turbines. But the project is a little more than combining LCA with forecasts of the development of wind power technology. First, the project also contains a dialogue between central stakeholders. Representatives from the technology's main Danish stakeholders have been included in the process via an expert panel. Second, one of the objectives of the project is to give societal recommendations on recycling and disposal to the Danish Energy Agency.

As indicated above different sets of methodologies exist to introduce technological changes over time depending on the time horizon and the complexity of the studied system. For the short and medium term (1-5 years) and for forecasts for simple technologies and processes (low uncertainty and incremental changes), simple „econometric" methods can be used (e.g. extrapolation of trends and historical data, S-curves, experience curves, etc).

For the long term (5-25 years), for processes and systems characterised by high uncertainty, and more radical technological changes, it becomes increasingly relevant to use methodologies based on experts' judgements (e.g. expert panel, Delphi questionnaires, scenario building, etc.). This is often called judgemental methodologies.

For a discussion of combining methodologies of Technology Foresight (TF) and Technology Assessment (TA) see Loveridge (1996), Weidema (1998) and Holtmanspötter and Zweck (2001).

4 LCA on State-of-the-Art Wind Power Systems

Several projects have demonstrated that wind turbines are one of the most environmentally sound technologies for producing electricity. Wind energy has very low environmental effects. Other studies have carried out LCA on state-of-the-art offshore wind farms (Hassing and Varming 2001; Properzi, Hansen, Pedersen, Svensson 2001). These studies conclude that through the whole life cycle of state-of-the-art wind power technology the main adverse environmental effects are due to material utilisation and disposal from manufacturing processes and from decommissioning at the end of the lifetime of the wind turbines. During operation only negligible emissions will appear. However, through the whole life cycle of the technology there will be environmental effects due to material utilisation and disposal. The largest contributions come from three sources:

- Voluminous waste from tower and foundation (e.g. from steel production) even though 85 % of the steel is assumed recycled
- Hazardous waste from components in nacelle (e.g. from steel alloys)
- Greenhouse gas effects (e.g. from steel production and surface treatment).

The results indicate that further analysis should take into account changes in materials in tower and foundations and changes of nacelle components (changes of overall concept, gearless designs, use of power electronics, etc).

5 Expert Panel on Future Wind Power Technology

A lot of information on future wind power technology can be determined from analysing current trends in the wind industry. In this study a number of earlier studies and available international statistics have been revisited with the scope of this study in mind (Dannemand Andersen 1999; Aubrey 1999; Hansen and Dannemand Andersen 1999; Dannemand Andersen and Hjuler Jensen 1998). This has given a clear idea about future market volumes for wind turbines and trends for technical data such as masses of main components, sizes, cost of energy, etc.

An expert panel was established with 10 persons representing academic research, industry, power grid operators (utilities), wind farm operators, LCA-consultants, etc.

Usually literature recommends that expert panels meet several times over some month to arrive at robust conclusions and to secure a fruitful dialog. But in this study it was not realistic to hope for attendance of the experts for more than one day. A meeting was held with the objective to agree on the most important factors determining future wind power technology (wind turbines and farms) and their environmental effects. A total of 158 statements about technological, economic, cultural, and environmental factors influencing the future of wind power technology were first formulated by the panel members in several rounds. Emphasis (2/3 of the time) was allocated to technological factors and the rest (1/3 of the time) allocated to other factors.

Furthermore, the participants were asked to evaluate the impact as well as the uncertainty pertaining to the statements on the 1-5 scale. With a total of more than 150 statements, the interest was primarily directed to the statements, which embodied a high potential impact and at the same time exhibited a high uncertainty. Statements reflecting issues with a low potential impact on the future of wind power were of limited interest in this study. Statements reflecting trends and issues with low uncertainty were also excluded from further discussion in the panel as they where better analysed through trend extrapolation and other „econometric“ tools.

As many factors cover similar issues (in some cases even identical issues), the factors were grouped by the participants and placed under a number of headlines. Among these groups the participants were asked to identify those groups of the highest importance for the future development of wind power technology.

Important *political and legal factors* were identified such as implementation of the Kyoto protocol, energy sector deregulation, internalisation of externalities, and EU's increased dependency on imported energy.

Important *economic factors* were identified such as increasing energy prices, public expenditures on R&D, and the appearance of other competitive renewable energy technologies.

Important *socio-cultural factors* were identified such as public acceptance of wind turbines in the landscape, general environmental awareness, increased energy consumption and rural electrification in developing areas.

As mentioned emphasis was on *technological factors*. Here a total of 95 statements/factors were identified and grouped in 11 groups (in order of average impact score in each group): energy storage technologies, installation concepts, control and regulation, scientific computing, components, grid and power transmission, blade materials, other materials, new concepts and up-scaling, transport, and finally towers.

The panel was then asked to select the two most important factors (or groups of factors) influencing the appearance of future wind power systems. The idea was to construct four „scenarios“ on how wind turbines would be designed in 2020-2030. That showed to be impossible, either because of the time allowed during the meeting or because of the complexity of the technology. Instead the panel agreed on six important factors.

Three groups of factors were identified to affect the future market volume for wind turbines – and consequently the total amount of material utilised:

- National climate and energy policies (Kyoto, safety of supply, etc.)
- Conditions of future power markets (deregulation, decentralisation, etc.)
- R&D expenditures (public and industrial).

Also, three groups of factors were identified affecting the design of future wind technology – and consequently the types of material utilised:

- New materials (replacement of steel, new composites, super conducting materials, etc.)
- Concepts and main components (power electronics, control strategies, super conducting materials, etc.)
- Grid conditions (grid structure, power quality, etc.).

6 Delphi Study

On the basis of the results from the earlier phases in the project 24 statements were formulated in a questionnaire. The first 8 statements concerned market issues (political, economical and societal driving factors) and the remaining 16 statements were on technological issues (cf. Table 1).

The questionnaire was distributed to attendants at the European Wind Energy Conference, which took place on July 2-7, 2001 at Bella Centre, Copenhagen. In the questionnaire the respondents were asked for each statement to answer four questions: their level of expertise on the field of the statement; period in which the statement will have first occurred; impact on wind power's cost competitiveness; and environmental effects due to manufacturing and decommissioning. Often Delphi surveys are made in two rounds giving the respondents the results of the first round as inspiration in the second round. The intention is to create a larger consensus on the results. This study, however, only comprised one round due to the experimental nature of the project. Our primary interest was to demonstrate that a Delphi study could be useful and the focus of the project was on the expert panels and the scenario techniques.

Approximately 200 questionnaires were distributed during the conference and 45 were filled in and returned. Respondents represented 12 countries, with the majority from Denmark, Spain and Germany. Respondents were asked about their organisational affiliation. Most respondents belonged to one of the following three groups: industry, university or other research organisation, and consultancy or self-employed. The profile of the respondents was by and large similar to the attendents of the conference, but the response rate was less than anticipated. Furthermore, in a number of cases the questionnaire was only partly answered. Almost all answered the statements related to market issues (economical, societal, and political factors) whereas the technological statements were only partly answered. Based on the respondents' comments, we have concluded that our technological statements might have been too specific for the audience.

Only results from people claiming to be knowledgeable or experts were chosen to ensure a satisfactory level of reliability. For some of the statements the number of respondents declaring „no knowledge“ on different statements was unfortunately quite high ranging from 5 % to 70 %. It is quite clear that no robust conclusions can be based on a limited sample size of say 12 respondents.

None of the statements have been perceived to have particular harmful effects on the environment. Only the statements on replacing steel in towers (#15) and using foam to prevent buckling in blades and towers (#18) have an average score a little more harmful than neutral.

The respondents by and large agreed that 10% of Europe's electricity will come from wind power at some point between 2011 and 2020, and that this will have a positive impact on wind power's competitiveness. Along with this a reduction of wind power's costs are expected approximately in the same time-frame.

As mentioned there are a few clear signals on the design of future wind turbines. The results indicated that the respondents expect replacement of steel in towers and that steel-based offshore foundations will be dominating. Also the results suggest that flexible two-bladed concepts will never have a radical break-through on the market place. Furthermore, a change of design of lifetime to 40 years seems less likely.

Together with the outcome of the expert panel meeting these observations can be used to construct a number of scenarios for wind power technology by 2020. These scenarios are technical scenarios: description of possible designs of wind turbines with lists of materials and their masses. Based on these scenarios an LCA scanning can reveal potential environmental advantages and adverse effects of the designs and, hopefully, give industry and public authorities advice on future developments.

Tab. 1: Results from Delphi questionnaire collected at the EWEC 2001 conference

		Your level of expertise on the field of the statement			*Period in which the statement will have first occurred*						*Impact on wind power's cost competitiveness*					*Environmental effects due to manufacturing and decommissioning of wind technology*				
Statement No.	*Statements about future wind power technology*	*Own field of work*	*Knowledgeable*	*No knowledge*	*Before 2005*	*2006–2010*	*2011–2015*	*2016–2020*	*After 2021*	*Never*	*Highly beneficial*	*Beneficial*	*Neutral*	*Harmful*	*Highly harmful*	*Highly beneficial*	*Beneficial*	*Neutral*	*Harmful*	*Highly harmful*
1	10 % of Europe's electricity from wind power	14	28	2		8	28	11	5		15	19	4			7	15	12	3	
2	More than half of all new turbines in Europe are placed offshore	11	29	4		6	10	10	8	6	5	17	8	7		4	11	15	5	
3	40 % cost reduction of wind produced electricity relative to 2001	13	24	7	1	10	7	12	3	4	26	5	1			7	9	11	4	
4	Global implementation of Kyoto targets	5	30	9	1	8	9	3	10	5	13	18	2			10	19	12	1	
5	50 % increase in EU and European national expenditure on wind power related research	13	21	12	7	8	9			11	7	17	6	3		6	13	9	5	1
6	Other renewable source of energy (other than hydro) becomes fully competitive with wind	7	20	8	1	7	8	9	10	2	3	11	11	6		4	10	15	1	
7	Competitive concept for storage of wind energy (e.g. based on hydrogen)	5	26	15		10	5	9	9		11	14	3			6	9	10	4	
8	Significant global market for small (<50 kW) turbines for stand-alone and hybrid systems	6	29	9	2	12	7	4	2	9	5	11	11		2	8	6	11	2	1
9	More than 75 % of all wind turbines are of a two-bladed highly flexible design	9	21	14			5	6	2	18	1	9	14	3		1	6	15	2	
10	More than 75 % of all new turbines are without gearboxes	10	19	15		8	5	7	2	7	2	11	11	1		2	9	13	1	
11	More than 50 % of all new offshore turbines are 10 MW or larger	9	28	7	1	3	11	1	9	12	3	19	8	3	1	3	15	9	6	
12	Design life-time of 40 years for most new turbines	9	24	10		6	5	6	3	15	7	14	2	7	1	9	14	6	2	
13	Commercially competitive hydraulic drive-train (e.g. based on synthetic oil or water)	2	11	31		3	6		1	6		4	7	2		1	2	8	2	
14	More steel based than concrete based foundations for new offshore turbines	3	20	21	8	8	4	1	1	2		10	9	2			8	11	3	
15	Steel is replaced by other materials for towers in more than 25 % of all new turbines	7	18	19	1	3	7	2	4	8		13	6	3		2	5	6	8	1
16	Losses in powerelectronic equipment are reduced by a factor of 10 due to new materials (e.g. siliciumcarbide)		15	29		4	6	4		1	4	8	2			2	5	7		
17	Commercial use of new environmentally neutral surface treatment for major steel parts (e.g. towers)	1	15	28	3	6	3	1	4	1		5	8	3		2	12	2		
18	Widespread use of foam materials to prevent buckling in blades and towers	4	15	26	7	4	5		3	1	2	8	6	1			4	7	6	
19	Plant (or cellulose) fibres are used instead of fibreglass in blades	2	23	19	3	4	5	5	4	5	1	7	11	3		9	12	2		
20	Multipole generators with permanent magnets in half of all new turbines	7	16	21	1	5	7	6	2	5	1	9	7	1	1		7	11	1	
21	Introduction of high voltage generators (20-60 kV)	3	19	22	4	6	7	4		2	1	14	4		1		9	11	1	
22	High voltage frequency converters in more than half of all new turbines	2	18	23		6	8	3	2	1	2	11	2	2			10	7	1	
23	Commercial use of super conducting cables for power transmission from wind farms	4	15	25		3	7	2	4	3	1	10	2	2		2	8	5	1	
24	Noise emission from new turbines reduced by 50 % compared to 2001 levels	7	23	13	2	3	7	8	2	9	2	7	18	2		8	8	13		

7 Conclusions

This study has demonstrated that judgemental technology foresight methodologies can be applied to estimate future technological characteristics to be used in prospective LCA studies. The study has also indicated, that extracting exact data and information from foresight studies and applying them in LCA studies is a very difficult and time consuming task. Judgemental methodologies depend entirely on external experts' willingness to participate – in expert panel meetings as well as in Delphi surveys. In this study we were not able to compensate these experts and this lowered the rate of participation and the value of especially the Delphi survey. A lot of further methodological investigations and theory building are needed on this subject in the future.

Note

1) The article is based on the conference presentation: Dannemand Andersen, P.; Bjerregaard, E.; Schleisner, S., 2001: Driving factors for environmental sound design and recycling of future wind power systems. 2001 European wind energy conference and exhibition, Copenhagen (DK), 2-6 July

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Summary of IEA Topical Expert Meeting on Material recycling and life cycle analysis (LCA) of wind turbines

Risø Wind Energy Department
Roskilde, Denmark 7th and 8th of March 2002
Egon T.D. Bjerregaard and Sven-Erik Thor

Background

Life cycle analysis is a systematic tool that can be used for analysing and assessing the environmental impact of a product throughout its entire lifecycle from cradle to grave. The methodology of LCA is used in different industries as a decision making tool in the design of new products. It is also used for bench marking of the environmental impact of alternative products and services, both when seen from the industry's and from the society's point of view.

Until now only a few LCA-studies involving wind energy have been carried out, but a growing awareness is emerging. Studies in Canada, USA, Austria, Holland, Germany and Denmark related to this item have been reported, and a couple of projects partly financed by the Danish Government are being carried out.

The symposium attracted 11 participants from utilities, manufacturers and research institutes giving 8 presentations covering different aspects of the theme of the symposium.

Current status

Denmark, Sweden, Finland and Holland have carried out LCA work that is directly related to the wind energy field. Activities are probably also ongoing in Germany, this can be seen on the internet.

Applications in other sectors were reported, examples are automotive industry, railway companies, aviation industry and utilities.

Summary of presentations

The presentations given by Bernhard Bulder (ECN), Tarja Turkulainen (VTT), Mikael Skrifvars (SICOMP) and Erik Grove Nielsen (Nordisk AeroForm ApS) dealt with the problems of large wind turbine blades made from composite materials. The broader scope of recycling, decomposition and LCA assessment of wind turbines as a whole were incorporated in the projects presented by Annika Andersson (Vattenfall Utveckling AB), Henriette Hassing (Tech-wise A/S) and Per Dannemand Andersen (Risø). In the latter presentation future technology scenarios were outlined in order to put the problem with disposal of the expected big number of wind turbines around year 2040 into perspective.

Concentrate on two phases

The meeting revealed a number of common observations and recognized problems that should be addressed in order to meet the challenges that the predicted deployment of wind energy will constitute. It was agreed that although wind energy is in general more "friendly" to the environment than energy production from fossil fuel when looked upon over the total production life time, it is important to try and reduce the adverse effects that are caused during the phases of the manufacturing of the wind turbine systems and the decommissioning of the wind turbines after end of service life. There is no need to look at the period of energy production of the wind turbines as the adverse effects connected with operation and maintenance are negligible.

Recycling materials

The large composite blades constitutes a big problem in the sense of LCA as only 20 % of recycled materials can be used successfully in other products. Methods of environmental friendly disposal of blades of composite materials are therefore being improved and new methods developed for more efficient burning or pyrolisis. Also research in new blade materials made from natural fibers (flax) and other new materials are carried out. It was mentioned though that the risk of germs and rot of natural materials might constitute a new problem when considering the functional criteria of such materials.

About 80 % of a wind turbine system incl. cabling can be recycled. Comparison between onshore and offshore sites shows that offshore is the most polluting due to the large amount of copper in the cabling.

The logistics is of big importance for the economy and therefore for the possible reuse of materials. Establishment of a common system for collection and reuse of materials has to be considered. Incentives on a national or regional basis may help in promoting recycling. Directives from EU similar to what is known from the waste directive, and systems already introduced in other industries like car, truck, tires and electronic equipment, where the manufacturers are responsible for the take back of worn-out products were mentioned.

Incentives and standards

The methods of LCA were discussed. The acronym is used both for "life cycle analysis" and "life cycle assesment". It was agreed that ideally LCA should be adopted in the design philosofy in the factories. However as the economy still is the main concern it may not be expected to be realistic in the first instance. Also it is a matter of attitude and knowledge of how to go by it. There are university courses in environmental issues that sometimes adresses the application LCA analysis.

There is at least one international journal and a conference related to the topic. But nothing exists which is specifically related to the wind energy sector.

It was mentioned that the annual production of glass fiber reinforced plastics amounts to 50 000 tons. Product liability imposed by current and future legislation will require a structured way of handling these quantities of material when their life-time has come to an end.

Although it is believed that application of LCA in the design process will lead to more expensive products in the beginning, it can be expected that the turbines can be cheaper in the long run due to more efficient dismantling. Not all participants agreed on that.

The effort done by the manufacturers to introduce more environmentally sound products and production processes are mainly driven by market demand. The buyers may require something like LCA. As an example it was mentioned that Vestas has expanded their scheme of certification to include the ISO 14001 standard covering the environmental aspects.

It was reported that some procurements require that a separate study of the environmental aspects is carried out for larger wind turbine projects. That mainly covers the visual impacts and the impacts on the natural habitat caused by the wind turbines during lifetime. Although only a few persons presently are working professionally with LCA related problems it is the feeling by the participants of the meeting that the manufacturers are getting more and more interested. Also big costumers like the utilities are now performing their own studies in the area.

One of the biggest problems on the operational side when doing LCA studies is to get data that can be used for comparison. The materials data are too few and too uncertain at present. There is a need for international databases that can be used with confidence. Bulder mentioned that ECO-scores has been turned out to be a useful tool in the study he presented at the meeting.

A practical way to introduce LCA in the companies might be to start with an environmental management system under ISO 14000, like Vestas did, and on top of that work with LCA.

Various standards have been developed or are under consideration to be applied as guidelines for LCA studies. The following were mentioned: ISO Guide 64, IEC Guide 109 and CEN Memorandum No. 4. CEN has also issued the following: Life Cycle Assessment, LCA (ISO 14040) and Environmental Impact Assessment, EIA (IEC Guide 109, annex B.

However there are different ways of interpretation of standards. Guidelines will be needed in order to facilitate the application and to normalise comparison.

Discussion/conclusion

At the finalising discussion there was a common interest to proceed with information exchange in this area in the future. A number of possible topics were touched upon.

There was also a discussion on the possibility to launch an EU-project, but no decision was taken.

As a result of the discussion it was decided to set up an Ad Hoc group in order to write a proposal for an Annex. The proposal will be prepared by Henriette Hassing, with assistance from the rest of the group.

Topics:

- Map status of the area
- What is needed for a guideline for LCA
- Establish the basis for developing guidelines

List of participants

IEA R&D Wind Annex XI Topical Expert Meeting

Material Recycling and Life Cycle Analysis (LCA) of Wind Turbines

March 7-8, 2002, Risoe Denmark

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