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Special Report

RECYCLING OF WIND TURBINES

Prof. Dr.-Ing. Henning Albers, Dipl.-Ing. (FH) Saskia Greiner M.Sc.

Introduction

When new technologies are introduced, it is nowadays endeavored to consider the whole life cycle of installations from the very outset, namely at the development stage. It is clear, however, that key questions regarding recycling are still not being satisfactorily answered. Consider, for example, the recycling of end-of-life wind turbines. This concerns various types of materials:

- traditional bulk materials such as concrete and steel
- large quantities of modern materials such as glass fiber reinforced plastics from rotor blades
- smaller quantities of valuable materials such as heavy metals and rare earth metals

These materials have either to be disposed of as waste or processed into second-life products. Up until now there have been no efficient systems in place, either from technical and organizational standpoints, for all these materials and some systems have developed out of necessity or by accident. There is enormous uncertainty about responsibilities, handling procedures, and technical solutions, and particularly so regarding the options for recycling components and materials.

Boundary conditions and state of knowledge

Fundamental questions. It is often claimed that the materials used in these newer energy generation technologies should be recycled. The example of photovoltaic installations demonstrates that these ideas are becoming part of the European and national legislation processes but that there are still many unanswered questions. An overview has been given by Wambach (2013).

The setting up and operation of recycling processes and technologies requires the following questions to be answered to facilitate decision-making:

1. What objectives, tasks, and responsibilities have the individual participants in the process chain?
2. At the end of the life cycle, what waste materials arise from what components and in what quantities and qualities?
3. What recycling routes must be available for the various renewable energy technologies?
4. What markets and uses are there for the recyclates?

Responsibilities and organization. There are still major uncertainties regarding Question 1. Up until now, the legislator has not availed of the provision in the Waste Management and Recycling Act (Kreislaufwirtschaftsgesetz (KrWG)) to lay down responsibilities for products, in accordance with § 23, by statutory order [BUND 2012]. As wind farms are generally designed for a service life of at least 20 years, the waste problem is not yet topical. For the few wind farms that are nearing the end of their lives, discussions about recycling are ongoing between component manufacturers, WT manufacturers, and wind farm owners. There are in principle suitable existing recycling systems for many materials used in WTs. As far as the authors are aware, decisions have up until now been taken on a case by case basis. At present there is no established, optimized system. There is apparently deemed not be sufficient need at present given the small quantities of materials. Clear though, from the answer to Question 2, is that the need for action on Question 1 will increase.

Estimation of future material flows. The composition of WTs can be estimated using the data of Seiler/Henning (2013) as shown in Figure 1. To be remembered here is that onshore WTs have steel towers. The steel content of offshore WTs is much higher due to the submersed steel support structures.

The main materials are concrete and steel (including cast iron) in various qualities.

A more detailed breakdown based on the nominal power of WTs is also possible, but generally has to be derived from secondary data as data from manufacturers are often not available. Albers/Greiner (2013), for example, assumed 10 Mg rotor blade material per 1 MW nominal power.

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Material	Share [Masses-%]
Concrete	60 – 65
Steel	30 – 35
Fibre composite material	2 – 3
Electrical components	< 1
Copper	< 1
Aluminium	< 1
PVC	< 1
Liquids	< 1

Figure 1: Typical percentages of materials in onshore wind turbines [Seiler/Henning 2013]

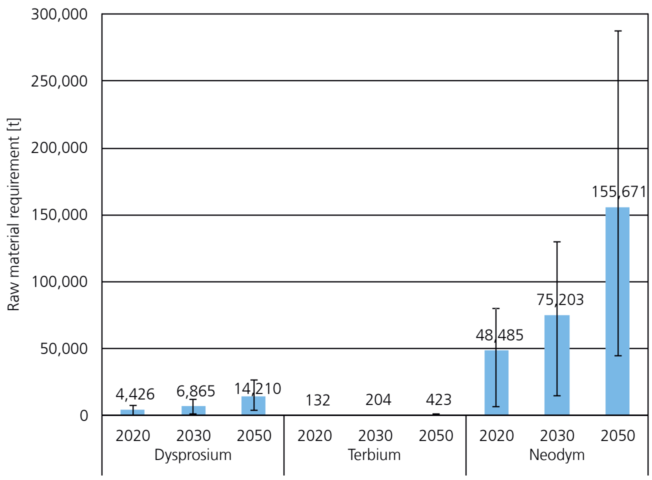

Figure 2: Forecast requirement for rare earth metals, showing scenario 2 and the range between scenarios 1 and 3 [Pehlken/Garcia Sanchez 2013]

This base data can be used for expansion scenarios, as shown in Figure 2. This compares worldwide expansion scenarios onshore and offshore, plus technology and market trends for permanent magnet generators.

The raw material requirements for wind energy different expansion scenarios are shown using the examples of dysprosium, neodymium and terbium. Independent of the scenarios, the raw material requirements will at least double every ten years. Between the worst case and best case scenarios the requirement can vary by a factor of 12. The requirement is hence considerable. These materials will in principle be available for recycling at the end of life of a WT.

Besides this coupling to expansion scenarios and data for the number of WTs, estimates of the service life of WTs are needed in order to be able to answer Question 2. Additional boundary conditions must be included here:

- the dismantling of old WTs before expiry of the intended service life and their replacement by more powerful WTs, so-called repowering;
- the upgrading of old WTs and their use as second-life WTs in emerging and developing countries;
- further operation beyond the planned service life.

Although the latter point is already under discussion, but in the opinion of the authors is nigh impossible to estimate due to the lack of practical experience, fundamental trends are evident with regards to the two other boundary conditions. Specific and comprehensive data relating to these issues are however not yet available.

The REA amendment [BUND 2011] accelerated the dismantling of older WTs in 2012, largely due to the improved boundary conditions for repowering [Neddermann 2013]. Figure 3 shows there was a doubling of the repowered WTs within a year. Most of the WTs that were repowered were 10 to 15 years old. Up until now it is unknown what happened to the dismantled WTs: Were they upgraded and reused as second-life WTs? Were they stored whole or as components? Were the materials recycled or sent for disposal?

Taking account of the above-mentioned boundary conditions, scenarios were developed to roughly estimate the flows of waste materials. Figure 4 shows by way of example the potential waste for recycling in the current decade based on the following assumptions: Repowering after 10 to 15 years in service, recycling (and intermediate storage) about 90%. The results for GFRP were firstly compared to a "traditional approach" that considered a standard service life of 20 years and then disposal. The data in Figure 3 for the disassembled WTs were then linked to the specific values of Albers/Greiner (2013) for the mass of rotor blades. It could not be determined whether and to what extent this mass was actually recycled or sent for disposal.

Figure 4 clearly shows that the material flows will significantly increase by the end of the decade. Compared to other waste flows, however, the material flows here will be rather small.

Question 2 can hence only be answered with many assumptions and estimates, but orders of magnitude can be given. This means that preliminary conclusions about the required recycling capacities can be drawn.

Recycling technologies. Question 3 can at present also only be answered generally. For most components such as electronic parts and steel and concrete from the tower there are established return and recycling systems. There are therefore relatively high recycling quotas for WTs, estimated to be 80-90% by Seiler/Henning (2013) and more than 90% by Pehlken/Garcia Sanchez (2012). The question arises here whether there are any customized disassembly, dismantling, cutting and crushing technologies adapted for WTs which allow efficient recycling of type-pure materials. In the opinion of the authors, this matter is unresolved for the previously mentioned smaller quantities of valuable materials such as heavy metals and rare earth metals. Figure 5 shows the fundamental disposal options as outlined by the Waste Management and Recycling Act (Kreislaufwirtschaftsgesetz) [BUND 2012].

For the glass fiber reinforced plastics in the rotor blades and nacelle housing, namely the main waste flow in Figure 4, there

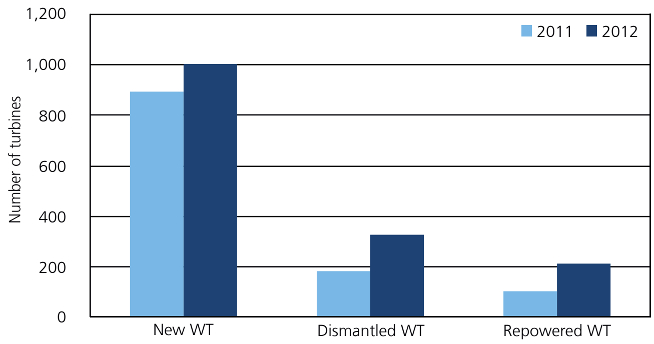

Figure 3: Overview of the newly constructed, dismantled, and repowered wind turbines in 2011 and 2012. Data sources: [Ender 2012 / Ender 2013]

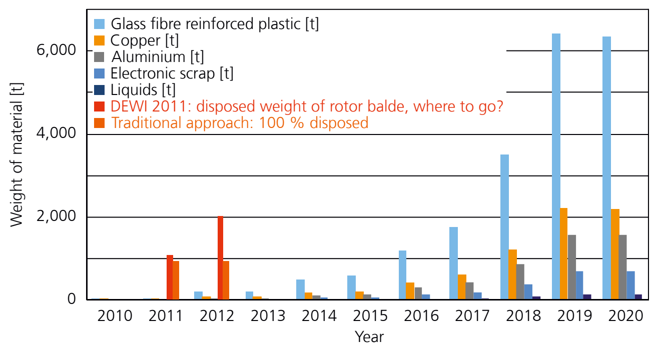

Figure 4: Estimated masses of materials from wind turbines [Albers et al. 2012]

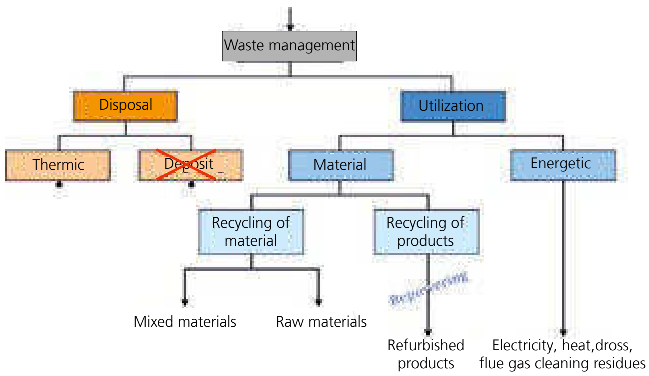

Figure 5: Disposal options for waste from wind turbines [Albers et al. 2009, amended]

are few recycling options thus far. Thermal treatment in incinerators is a common option for smaller material flows. Currently the most widely used and most established technical solution appears to be customized cutting/crushing and subsequent material recycling, combined with energy utilization, in cement factories of Zajons and Holcim [Hinrichs 2012]. Further options for material utilization, namely involving the "true" recycling of materials, have not yet become established. It is unclear whether this is due to the technical challenges or due to the lack of market opportunities. Technologies for separating composites and purifying the materials are currently being researched. Seiler/Henning (2013) show examples of technologies being used for GFRPs.

Markets and uses for recyclates. Question 4 can at present only be answered for the small number of large-scale recycling options that have been realized. Only after answering Questions 1 to 3 will qualified statements about Question 4 be possible.

Need for action

The wind energy industry provides "green" energy. It must reflect on how efficiently it uses materials and what recycling options it provides for products at the end of their service lives. In this regard, the four main questions raised here have up until now not been satisfactorily answered. As the sizes of the material flows will increase over the coming years, there is a need for action to develop and implement best-practice solutions, designed with both the environment and market in mind. This task is not only a technical environmental issue but also a resource management issue with a series of unanswered organizational matters. Particularly unclear is what decisions need to be made by what players and on what basis, in order to make optimum solutions available. The first results are available but these must be given more detail and consolidated.

Answering Question 2 about the waste materials (timing, mass flows, qualities) and Question 3 (treatment/purification technologies) appears to be the top priority at the moment because the results will provide the basis for answering Questions 1 and 4. For this, reliable data from the manufacturers about the material composition of WTs are required. Product passports and product data sheets can help here. In addition, the information about the assembly and disassembly of WTs must be supplemented with qualified statements about the recycling or disposal of components and the reutilization of components or whole WTs within the context of "second-life" activities.

The wind industry has up until now had little to say in relation to Question 1 concerning objectives, tasks, and responsibilities. The experience with other technologies such as solar energy is that the industry must either meet its responsibilities or be prepared for regulations to be laid down by the legislator.

Summary

At the end of the life cycle of a WT, the materials used in that WT can be either recycled or disposed of as waste. A further option is to upgrade the WT and use it as a second-life WT. Established and optimized systems for recycling all materials are not available at present. Some existing recycling systems are utilized.

The masses and qualities of materials for recycling and the moment of recycling have to be estimated, and often only secondary data are available. Material and WT specific technologies are only in their infancy. The potential markets and uses for some recyclates are unknown.

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