

*2 February 2009*

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# Evaluation of the vertical wind related activities at Uppsala University

**“The research related to vertical wind at Uppsala university is of a high standard and has shown results that are promising and could lead to the development of products with a potential to become successful on the market”**

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## o. Svensk sammanfattning

På uppdrag av Energimyndigheten har Faugert & Co Utvärdering tillsammans med experter från det holländska konsultföretaget Spin Consult och universitetet i Delft genomfört en utvärdering av det koncept med vertikalaxlade vindkraftverk som idag utvecklas vid Uppsala universitet. Sammanhållande för utvärderingen har Tommy Jansson, Faugert & Co Utvärdering varit, och Hans Warmenhoven, Spin Consult, har ansvarat för huvuddelen av rapporten. Charilaos Kotsarinis, University of Delft, Holland, har bidragit med kunskaper om vertikalvindtekniken, och professor Gerard van Bussel, University of Delft, Holland, har fungerat som sakkunnig och övergripande rådgivare.

Forskning kring detta vindkraftskoncept bedrivs vid Uppsala Universitet på Ångströmlaboratoriet, inom ramen för Centrum för förnybar elenergiomvandling (CFE) samt i enskilda projekt utanför centrubildningen, med Energimyndigheten som en viktig finansiär. Forskare inom gruppen vid Uppsala Universitet har startat företaget Vertical Wind AB för att utveckla och tillverka vindkraftverk utifrån den kunskap som tas fram genom forskningen.

Utvärderingen har tre övergripande syften:

1. Ge en statusrapport för tekniken där kunskapsläget i Sverige och internationellt redovisas
2. Göra en bedömning av de styrkor respektive svagheter i förhållande till konkurrerande tekniker som detta koncept av vertikal vindkraft besitter både tekniskt, ekonomiskt, miljö- och tillverkningsmässigt
3. Svara på om projektteamet vid Uppsala universitet innehar nödvändiga kunskaper i ämnet för att kunna slutföra konceptet till en alternativ förnybar elenergikälla.

Utvärderingen konstaterar att forskningen kring det koncept med vertikalaxlade vindkraftverk som utvecklas vid Uppsala universitet håller hög klass och uppvisar lovande resultat som skulle kunna leda till utvecklingen av produkter med en potential att bli framgångsrika på marknaden. Trots begränsade resurser har forskningsgruppen på kort tid intagit en respekterad position inom området vertikalaxlade vindkraftverk, och de val man gjort under utvecklingen av ett testsystem bedöms som välgrundade. Det faktum att två stora företag valt Vertical Wind AB som samarbetspartner i var sitt projekt i syfte att utveckla system för marknaden är en tydlig värdemätare av forskningsgruppens i Uppsala betydelse. Samtidigt som vi noterar den positiva utveckling som skett, finns det vissa områden som bör uppmärksammas.

Forskningsgruppen behöver ytterligare utveckla sitt kunnande inom aerodynamik och aeroelasticitet, två områden av stor vikt för vindkraftturbiner. För tillämpningar i tätbebyggda områden bör vidare mer uppmärksamhet ägnas problematiken kring buller och byggnadsinterferens. Utvärderingen noterar att en styrka med forskargruppen i Uppsala är det helhetsgrepp man anlägger, ett hehetsgrepp som samtidigt är av stor vikt och något som kräver större resurser än de som forskargruppen i dag förfogar över.

Gruppen bör vidare utveckla och tydliggöra en marknadsorienterad strategi som bas för forskningsaktiviteterna. För småskalig vertikalaxlad vindkraftteknik utgör tätbebyggda områden i dag en intressant marknad, och forskningsgruppen och företaget skulle kunna ägna denna marknad större uppmärksamhet. Man är fokuserade på att skala upp till stora vindkraftverk, vilket flera experter inom området är tveksamma till; svårigheterna ligger inte i de tekniska utmaningarna, utan i en osäkerhet om det kommer att finnas en tillräcklig marknad för storskaliga landbaserade vertikalaxlade vindkraftverk. Utvecklingen av dessa storskaliga system

beräknas ta minst fem år, och förutom de stora investeringskostnader som nämnts är frågan om den vertikalaxlade vindkraftteknologin har kapacitet att hämta in det försprång som konventionell vindkraftteknik har. Marknaden för stora turbiner domineras i dag av horisontella system; den samlade erfarenheten av dessa är stor, och stora forskningsresurser investeras i dem. Detta innebär dock sammantaget inte anledning nog att inte fortsätta utveckla vertikalaxlade vindkraftverk. Enkelheten i designen skulle kunna vara en fördel, i synnerhet för havsbaserade system. De resultat som gruppen i Uppsala visat upp är lovande, och det är försvarbart att de vill utveckla större system.

## 1. Introduction

### 1.1 The organisation of the vertical wind activities in Uppsala

The organisation of the activities related to vertical wind covers three aspects:

- (Basic) scientific research is carried out at the Centre for renewable electric energy conversion (CFE). CFE was funded by VINNOVA and the Swedish Energy Agency from 2004 to 2008-06-30. The Centre has applied to the Swedish Energy Agency for the funding of CFE II.
- Within the University, research projects of a more applied nature related to vertical wind are carried out by the same research group. These projects have not been funded within CFE, but through individual research projects funded by the Swedish Energy Agency
- Commercial projects run by the company Vertical Wind AB. Here, systems are being developed in cooperation with commercial parties.

These three activities are interconnected. In effect, the resources dedicated to the research and development of vertical wind-related issues are small, and only one full time equivalent senior researcher and 2.5 PhD students have been working on the topic. The core personnel working with these issues within CFE and in the research projects outside of CFE are also the people behind Vertical Wind AB. In April 2008 the company expanded from ideas and patents to an operational development and production company with ten employees, and the majority of these are linked to CFE and/or the University.

### 1.2 The objective and the scope of the evaluation

This evaluation focuses on three main issues:

1. A state-of-the-art report on the technology, with a presentation of the knowledge levels in Sweden and internationally.
2. An assessment of strengths and weaknesses of this technology compared to competing and today conventional technologies - both technically and economically.
3. Provide an answer to what (possible) completing competences the project team at Uppsala University would need in order to bring this concept to an alternative renewable energy source.

As stated in the ToR, these evaluation issues are dealt with not only in relation to the vertical wind energy activities of CFE and other vertical wind related projects at Uppsala University financed by NEA, but also in relation to the activities of the company Vertical Wind AB.

### 1.3 The evaluation approach

The evaluation has been based on a desk study of available information of the developments at CFE and Vertical Wind AB, provided to us by CFE and the Swedish Energy Agency. In order to compare and value what is being done in Uppsala, a comparative study has been carried out in which we have identified the most relevant international developments in this field. This international comparison has focused on the technical development of vertical wind turbines, what the market for small scale vertical wind turbines is like and what the “competition” is doing. We have then carried out interviews with the research team in Uppsala, with programme managers at the Swedish Energy Agency and with spokespersons for the companies that Vertical Wind AB collaborates with.

This data collection resulted in a first analysis, with the building blocks of the evaluation report being:

- a SWOT analysis
- an economic potential analysis
- a risk analysis in relation to industrialization
- an assessment of the team

A draft of the report was sent to CFE and Vertical Wind for comments, and the report was completed after a presentation of the findings for the Swedish Energy Agency.

Hans Warmenhoven at Spin Consult, The Netherlands, has been the main responsible for writing the report. Charilaos Kotsarinis, Technical University of Delft, The Netherlands, has provided valuable knowledge concerning the vertical wind technology and the benchmarking of the Uppsala group. Professor Gerard van Bussel, Technical University of Delft, The Netherlands, has contributed valuable inputs at various stages of the work process. Tommy Jansson, Faugert & Co Utvärdering and Technopolis, has coordinated the evaluation.

The main finding of the evaluation can be summarized as follows:

**The research related to vertical wind at Uppsala University is of a high standard and has shown results that are promising and could lead to the development of products with a potential to become successful on the market.**

This conclusion is described in more detail in the following.

## 2. Within a short time span and with limited resources the group has managed to take up a serious position in the field of vertical wind

The overall conclusion of this chapter is that the vertical wind group in Uppsala has become a serious player in the field of vertical wind energy. This conclusion is based on the results they have realized in a very short time, as well as on the fact that they have been chosen by major companies as a partner to develop systems for the market. This conclusion is further elaborated in the following paragraphs.

### 2.1 Only a limited number of people have worked on the topic

The group started working on vertical wind early in the 2000's, and the company Vertical Wind AB was set up in 2002. In April 2008 Vertical Wind expanded from ideas and patents to an operational company with about ten employees. In this period on average 1 full time equivalent senior staff has been active in the field. This senior staff capacity has consisted in a relatively large number of people, all with different backgrounds. In addition, an average of 2.5 PhD students have been active doing research related to vertical wind. Table 1 shows the members of the research group.

<b><u>Mats Leijon</u></b>	Professor and head of CFE. Research and supervision of graduate students in the areas of wave power and marine force and in some cases in the system
<b><u>Olov Ågren</u></b>	Professor. Research and supervision of graduate students in the basic theory of aerodynamics, fluid mechanics and electromagnetism
<b><u>Hans Bernhoff</u></b>	Associate professor. Research and supervision of graduate students in the area of wind power
<b><u>Sandra Eriksson</u></b>	Dissertation in the area of wind power, September 2008, now shares her time between Vertical Wind AB and Uppsala University, as senior researcher
<b><u>Paul Deglair</u></b>	Dissertation in the Wind in February 2009. He is now employed by Areva in Paris (France) as an expert in the area of turbines
<b><u>Katarina Yuen-Larsson</u></b>	PhD student, dissertation expected for late autumn 2010
<b><u>Mikael Bergquist</u></b>	Senior researcher. Research and supervision of graduate students in the area of wind power
<b><u>Arne Wolfbrandt</u></b>	Senior researcher. Research and responsible for fundamental linked estimates in all areas
<b><u>Marcus Berg</u></b>	Senior researcher. Research in wind power projects

Table 1: Composition of the vertical wind team in Uppsala.



## 2.2 They have published a large number of papers in reviewed magazines and presented their ideas at many congresses

The group has written a large number of articles and publication in the field of vertical wind, and two PhD students have written their theses about this subject. The research work carried out covers the different topics relevant for the development of vertical wind systems. Table 2 lists the main publications, subdivided by topics.

<b>General - Design</b>	
1.	<i>Evaluation of different turbine concepts for wind power</i> Eriksson , Bernhoff H., Leijon M. - Renewable & Sustainable Energy Reviews, 2008
2.	<i>Design of a 12kW VAWT equipped with a direct driven PM synchronous generator</i> Solum A., Deglaire P., Eriksson S., Stålberg M., Leijon M., Bernhoff H. - EWEC, 2006
<b>Aerodynamics</b>	
3.	<i>A time-dependent potential flow theory for the aerodynamics of VAWTs</i> Ågren O., Berg M., Leijon M.- Journal of Applied Physics, 2005
4.	<i>An analytical model for the performance of a VAWT,</i> Marstorp L. - Masters degree project, April 2003
5.	<i>Design oriented numerical model for the performance prediction of a VAWT,</i> Deglaire P. - Master' s degree project, 2004
6.	<i>Conformal mapping and efficient boundary element method without boundary elements for fast vortex particle simulations</i> Deglaire P., Ågren O., Bernhoff H., Leijon M. - European Journal of Mechanics B/Fluids, 2008
7.	<i>Conflicts between aerodynamics and the Betz factor for VAWTs,</i> Ågren O., Berg M., Leijon M. - Submitted to Journal of applied mechanics [2003?]
8.	<i>Analytical solutions for a single blade in vertical axis turbine motion in two-dimensions,</i> P.Deglaire, S. Engblom, O. Agren, H. Bernhoff, European Journal of Mechanics B/Fluids (2008)
<b>Structural Dynamics</b>	
9.	<i>Dimensioning and designing structure and foundation to a H-rotor type wind turbine</i> Brolin E. - Master' s degree project, May 2006
10.	<i>Generator-Damped Torsional Vibrations of a VAWT</i> Eriksson S., Bernhoff H. - Wind Engineering, 2005
<b>Electrics</b>	
11.	<i>Permanent magnet generator for direct drive wind turbines</i> Solum A. - Licentiate thesis, 2006
12.	<i>VAWTs with Direct Driven Generators</i> Eriksson S. - Licentiate thesis, 2006
13.	<i>Simulations and experiments on a 12 kW direct driven PM synchronous generator for wind power</i> Eriksson S., Solum A., Leijon M., Bernhoff H. - Renewable Energy, 2008
14.	<i>Experimental results from a 12 kW VAWT with a direct driven PM synchronous generator</i> Deglaire P., Eriksson S., Kjellin J., Bernhoff H. - EWEC, 2007
15.	<i>FEM simulations and experiments of different loading conditions for a 12 kW direct driven PM synchronous generator for wind power</i> Eriksson S., Bernhoff H., Leijon M. - International Journal of Emerging Electric Power Systems
16.	<i>Loss evaluation and design optimization for direct driven PM synchronous generators for wind power</i> Eriksson S., Bernhoff H. - IEEE Transactions on Energy Conversion, July 2008
17.	<i>Investigating the overload capacity of a direct-driven synchronous PM wind turbine generator designed using high-voltage cable technology</i> Solum A., Leijon M. - International Journal of Energy Research, January 2007
18.	<i>Direct Driven generators for VAWTs</i> Eriksson S. - Doctoral Thesis, 2008
19.	<i>Experimental verification of a 12 kW permanent magnet synchronous generator for direct-drive wind turbines</i> Solum A., Eriksson S., Bernhoff H., Leijon M. - Electric Power Systems Research, accepted for publication
<b>Control</b>	
20.	<i>Progress of control system and measurement techniques for a 12 kW VAWT</i> Kjellin J., Eriksson S., Deglaire P., Bülow F., Bernhoff H. - EWEC, 2008

Table 2: Main publications by the vertical wind team in Uppsala.

### 2.3 The group has been chosen by major companies to develop vertical wind systems

In 2008 Vertical Wind AB signed a contract with Ericsson Telecom to develop a 12 kW vertical wind turbine that could be mounted on Ericsson's newly developed tower tube type radio masts. A prototype of this system has been built, see figure 1, and is currently being tested. The system is still in a research and development phase but could lead to market introduction within two years. The objective of the project is on the one hand to reduce the CO<sub>2</sub> emissions related to Ericsson's activities, but also to develop a system that does not require external energy sources. This is especially convenient in developing countries and on remote sites where no utility grid is available. For the group in Uppsala this development is important because it gives them the opportunity to further test and develop their knowledge in a commercial environment.



Figure 1: The vertical wind system on the Ericsson mast

E.ON and Falkenberg Energi AB have signed a contract with Vertical Wind AB to develop and build four 200 kW vertical wind turbines. E.ON has decided to do so because they want to test the technology that being developed in Uppsala on a relevant scale for the further up scaling of the technology to a multi MW level. The long term objective of this development is to produce large VAWT for the offshore market. The reasons Vertical Wind AB was chosen were among others the relation with the University, the patent situation and the technical achievements. Before E.ON signed the contract the development in Uppsala went through a technical due diligence performed by E.ON engineering in the UK. The due diligence report was in general very positive about the development in Uppsala, but also included some suggestions for the improvement of the basis design. These suggestions are being studied by Vertical Wind AB. E.ON did not agree with the initial time plan and were a bit sceptical about big machines in the MW sizes, considering their expected superiority when compared to the more mature horizontal machines. The E.ON contract gives the group in Uppsala the possibility to actually test their ideas on a much larger scale than they have up till now. Because of the close co-operation between Vertical Wind AB and the rest of the research group this contract should also ensure that research within the University will be aimed at solving problems related to the systems and their performance on the market.

### 3. The research team needs to expand their level of knowledge on some topics related to wind turbines

Based on this evaluation it is concluded that the Uppsala group already has a very good understanding of all issues related to building vertical wind system. However, up until now the group has developed a general system not aimed at a specific

application. Depending on which application they are working on, they need to expand their knowledge on some essential topics related to vertical wind.

This chapter first gives a general evaluation of the knowledge levels in Uppsala, and finishes with some paragraphs focussed on the subjects that could need some extra attention.

The issues that need to be considered for the development of vertical wind systems are shown in table 3. Their importance varies with the range of the systems. Together in the same table, the achievements of the CFE group are shown, based on available information.

	<i><b>Issue</b></i>	<i><b>Explanation</b></i>	<i><b>Work at CFE</b></i>
1	Wind Resource	For deriving the characteristics of the wind that are of interest for the determination of design loads.	Sophisticated models are necessary for full examination. There is cooperation with the Department of Earth Sciences, Meteorology section at Uppsala University.
2	Aerodynamics	For the analysis of rotor and blade aerodynamics and calculation of loads, power performance etc.	Considerable work and publications. Already in a good stage, but knowledge levels need to be expanded.
3	Structural dynamics	To describe the dynamic behavior of the system, including fatigue and ultimate loads, vibrations, excitation, torque ripple.	Sophisticated models have been used, with simulations and tests. The overall strength is based on the solid generator. This knowledge can still be expanded.
4	Aero elastics	To simulate the aerodynamic and dynamic interactions of the system.	Planned for next phases.
5	Electrics	To simulate the electrical aspects, including the generator and power quality issues.	A lot of work in modeling and testing generator systems. Advantage for CFE: the developed dedicated generator.
6	Control	To simulate control operation and optimize it for highest energy capture	The work on the optimization of control systems are still in initial phases of development.
7	Cost models	To assure that the selected design options drive to the lowest cost solution.	No information about cost issues was available.
8	Noise	To investigate the noise emissions of the system.	Work has taken place, but no specific information is available.
9	Safety	Considering blade throws, avian risk etc.	Results will come from full testing of the systems.
10	Grid interference	To simulate interactions with the electrical grid.	Work has been done for integration of big systems (power plants).
11	Electromagnetic interference	To simulate interactions with existing telecommunication systems.	

Table 3: The subjects of relevance for the development of vertical wind systems.

In order to evaluate the importance of these subjects for the development of vertical wind systems two risk maps have been constructed: one for small systems (about 10-15 kW), and one for large multi MW systems. The risk maps show to what extent uncertainties on different subjects can influence the overall performance of a system. The numbers in the risk maps correspond to the numbers of the different subjects in table 3. The risk maps are shown in figure 2. Based on the risk maps it can be concluded that for smaller systems it is essential to further develop the knowledge on aerodynamics and noise. For larger systems aerodynamics is also important, but it also becomes increasingly important to work on the subject of aero elastics.

#### Small systems (until 10-15 kW)

		CONSEQUENCE			
		Low			High
D E V E L O P M E N T  S T A G E		Negligible	Marginal	High	Critical
	Feasible in theory				
	Working laboratory model		4	1, 6, 7	2, 8
	Extrapolated on existing design			5, 11	3, 9, 10
	Proven design				

#### Bigger systems

		CONSEQUENCE			
		Low			High
D E V E L O P M E N T  S T A G E		Negligible	Marginal	High	Critical
	Feasible in theory				
	Working laboratory model			6, 7, 8	2, 4
	Extrapolated on existing design		11	1, 5, 9	3, 10
	Proven design				

Figure 2: Risk maps related to smaller and larger systems.

### 3.1 In the field of aerodynamics and aero elastics the team need to expand their level of knowledge

In general it is felt that the group could extend their work on aerodynamics. None of the senior staff really have a background in this field and it is an essential element in

the development of these systems. It would really be beneficial to the group if one of the senior staff had have a firm background in this field. In addition, the knowledge in this field could be expanded by starting structural co-operation with other institutes that do have a background in aerodynamics. It should be noted however that there is already some cooperation with other institutes (e.g. by exchanging students).

Especially when scaling up the technology to levels above 100 kW it is important to work on aero elastics as well. As the system becomes bigger, the dimensions and thus the flexibility of the various components increase. This requires a need to simulate the aerodynamic and structural interactions of the system in an integral fashion, including potential problems with vibration and fatigue. Hence it will be advantageous to attract expertise in this integrated knowledge field.

### 3.2 For the application of vertical wind systems in urban environments more attention should be given to noise and building interference

Currently vertical wind systems world wide are mainly being developed for urban areas as the concept is simple, robust and less sensitive to the constantly changing wind conditions in urban areas. Vertical systems have lower tip speeds resulting in lower avian risk and safer operation. However, the lower tip speeds, when compared to horizontal axis machines, do not necessarily result in lower noise emissions than horizontal turbines. More specifically, having two machines - one horizontal and one vertical - with the same tip speed, the vertical machine will be noisier due to periodic stall. If the group want to apply their systems in urban areas they will have to pay more attention to the noise issue and will also need to determine to what extent the yields of the system are influenced by the specific wind conditions in urban areas.

Up until now not much attention has been paid to these subjects, mainly because the group is not interested in this market.

### 3.3 The focus on further research to better understand how a vertical wind system works as a whole is important and would require more resources

The group is planning to work on several aspects that could be improved on the systems. The aero elastics is an important subject, the control and safety philosophy and other issues that have been pointed out in the previous paragraphs would need more attention. To be able to do this the group would need to expand, especially with some more senior staff.

### 3.4 The knowledge level of the Uppsala group is high compared to other groups working on vertical wind world wide

Table 4 gives an indication of the work carried out internationally at different institutions and universities in the past and in the present. This table, with “+” indicating the strength of each group in each area, is based on a quick scan of their activities rather than on an extensive review of the work carried out. It should therefore be used merely as an indication of the work that takes place worldwide. Moreover, it should be noted that research on isolated topics on vertical wind turbines can be found at other universities also. The column “other” refers to some special topics that have been studied by these groups. The first group in the table is not active any more. The other groups have worked recently on these machines and some others are still working on these.

	Wind	Aero	Structural	Electrics	Other	Notes
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	resource. (b.e.)	dynamics				
Sandia (US)	+	++	++	+	+	- Medium curved machines - In the 80's and 90's
Canada		+	++	+		- National Research Council - Ecole Polytec. of Montreal - McGill University - Medium & big machines
The Netherlands	+	++		++	+	- TUDelft - Mini straight curved mach.
Japan		+				- Tokai university
Australia	+	+	+		+	- Griffith University - University of Wollongong - Mini machines
New Zealand		+			+	- Mini machines
Sweden		+	+	++		- Uppsala University - Straight machines - close co-operation with commercial companies.
England	+	+			+	- Cambridge university - Mini machines

**Table 4:** Work on vertical technology at different research organizations and universities

Looking at the private sector, there is a number of companies constructing mainly mini and small vertical machines. Most of these are located in Europe, and some in other parts of the world. Most of them are shown in table 5, together with the ranges of their products. Concerning small systems in the range of some kW's, some of these companies already have produced a number of products, or are involved in commercial projects (e.g. XCO<sub>2</sub>, Turby, Ropatec). For bigger systems there is not much data available (e.g. for the Dermond). However, there are some activities taking place, e.g. Sustainable Energy Technologies has announced cooperation with Chinese organizations for further development and deployment their systems. Heidelberg Motor has built and tested prototypes, but it seems that there was no commercialization of their products.

Country	Company	Product	Range	Notes
The Netherlands	Venturi Wind	Venturi 110-500	0.5 kW	- diffuser surrounding the rotor
The Netherlands	Ecofys	Neoga	3kW	- Curved bladed
UK	XCO <sub>2</sub>	XCO <sub>2</sub>	6 kW	- Straight-twisted bladed
UK	Eurowind Small Turbines Ltd	Eurowind	1.3kW-30kW	- Straight bladed

The Netherlands	Turby BV	Turby	2.5kW	- Straight-twisted bladed
Italy	Ropatec	WRE	0.75kW-6kW	- Straight bladed
New Zealand	Soldwind	Wind Sail	30kW	- Straight rotor
Germany	Neuhauser		to 40 kW	
Canada	Dermond		100 kW	
Canada	Sustainable Energy Technologies	Chinook 2000	250 kW	
Germany	Heidelberg Motor		300 kW	- Straight rotor - Prototypes

**Table 5:** Vertical turbine products available on the market

Based on these tables, the conclusion is that the work being done in Uppsala is very well comparable to the work being done in other institutes. Based on table 5, the conclusion would be that the Uppsala group is top ranking in this field which is in line with the fact that they have been chosen as partners by major companies. Also, if you look at the vertical wind systems on the market the conclusion has to be that there are not really companies that have a great lead over the vertical wind group in Uppsala. These conclusions would probably be even stronger had we focused this scan on larger scale systems, since there are hardly any groups working in that field. Some groups are known to be thinking of up-scaling the vertical technology in MW-sized machines (like Aerogenerator in England), but they are still in the initial phases of development.

#### 4. The choices made when developing a test system are well founded but there is only limited information to be able to judge the performance of the system

##### 4.1 The choice to develop a vertical wind system is a good one for specific applications

When designing the system the group had a clear view of their objectives. They wanted to develop a simple system with low maintenance costs that was suitable for mass production. This approach, very important for both markets identified above, was taken in all elements of the development.

The choice to develop a straight bladed vertical wind turbine is based on an extensive comparative study of different systems. Based on this study, the Uppsala group concluded that vertical wind systems had an advantage over horizontal systems in their simplicity and low maintenance. Also Vertical systems have an advantage because they are better suited for severe wind climates in urban or mountain areas. The group chose the straight bladed system rather than the curved blades used in a Darrieus machine because of its strength and the possibility to keep the construction simple. The chosen concept could be especially advantageous when it is used in urban areas because of the complex wind conditions there, and offshore because of the importance of simplicity, low maintenance and strength on that market. It still, of course, remains to be proven that the system will be more effective in these markets than the horizontal axis systems that are now dominating the market (vertical systems are better than horizontal in urban areas, but this is not a fact for offshore applications).



The Uppsala group pointed out that another advantage of choosing a vertical system was that there is hardly any competition in that specific field. Hardly anyone is developing large vertical systems and therefore it is both an opportunity on the market and a scientific challenge.

Table 6 presents a SWOT analysis for the vertical wind system. The strength and weaknesses refer to the system itself, the threats and opportunities to external factors.

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>• Simplicity of design</li> <li>• No yaw system</li> <li>• The generator does not have to be lifted</li> <li>• Simple construction and manufacture</li> <li>• Originality/innovation</li> </ul>	<ul style="list-style-type: none"> <li>• Not really tested in practice</li> <li>• There is only a limited knowledge base for these systems</li> <li>• Not yet highly reliable technology (still in launch phase)</li> <li>• Not fully developed in practice (not tested for long periods of time)</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>• The increasing interest for small scale systems in urban areas</li> <li>• Skepticism whether horizontal systems can ever meet the requirements for offshore usage.</li> <li>• Potential for noise reduction</li> <li>• Hardly any competition for large scale systems</li> </ul>	<ul style="list-style-type: none"> <li>• Horizontal axis systems have a head start, millions of Euro's are being poured into this technique.</li> <li>• The companies involved in horizontal systems can not afford not to win and will therefore discredit the vertical system.</li> <li>• Public acceptance. Horizontal systems are not always accepted, and a new system could be more difficult.</li> </ul>

Table 6: SWOT analysis of the Uppsala group

Between 1980 and 2000 there were a number of companies that constructed and used medium and big vertical machines. These companies were located mainly in the United States and in Canada. These were the Flowind Corp. (US), which in the period from 1982 to 1997 built wind farms using 175kW and 250kW machines, Vawtpower (US), Indal Tehnologies Inc. (CAN), which built machines in the range of 50kW to 100kW, and Adecon Inc (CAN), which constructed machines about 150 kW. All these designs were with curved blades and the main problems they experienced were in the structural dynamics of the systems. The reason these machines failed in the long run was related to fatigue problems in the lower parts of the Darrieus blades and to noise issues. These problems, together with situations like poor wind energy market and lack of further funding, resulted in abandoning them. Specialists in the field believe vertical systems can potentially be successful in all ranges, but still work needs to be done on that.

#### 4.2 The design of the Uppsala system was based on up-to-date knowledge of all relevant aspects related to vertical wind systems.

Based on the review of the papers written by the Uppsala group, they have developed simulation methods and models to be able to develop the system by themselves. Their models are based on available knowledge from top institutes with proven knowledge in the different fields. The experimental results from the tests of the prototypes in general prove good agreement with the models developed by the CFE group. Based on this the conclusion is that the group has made well founded decisions based on top level knowledge. We should however also note that the system was developed in a relatively short time and that it should be improved based on further tests.



#### 4.3 Based on the experimental data that is available it is not possible to evaluate how the system performs in practice

The group has tested the 1 kW prototype and the 12 kW test system. As has been said the experimental results are in general in line with the model predictions, but the group has not yet fully evaluated the performance of the systems in practise. This kind of measurement requires a lot of time. The group is currently working on gathering the necessary data in order to evaluate it for further analysis to support design improvements.

### 5. There should be a more explicit relationship between the research activities and the market activities of Vertical Wind AB

#### 5.1 The team within CFE aims to better understand how vertical wind systems work to be able to develop large scale systems that can be successful on the market

Based on the information received from the group it is the objective of CFE and the University to do high level research. It is their objective to better understand how vertical wind systems work and how they can be improved. This research is not done for a specific market application but to gather the necessary knowledge to be able to develop successful systems for any application, with the main focus on big systems. Vertical Wind AB, on the other hand, has the objective to actually build systems for the market. Vertical Wind AB does not seem to have an explicit market strategy but is prepared to build the systems that their customers ask them to build. The group communicated that there is no real relationship between the two.

In practise it is to be expected that there is a relationship between the two because, to a large extent, the same people are responsible for both organisations. In fact this interrelationship is a very strong characteristic of the whole group. For companies that want to work with Vertical Wind AB it is interesting that they are linked to a University group because it gives them access to high level research results. For the government that is funding research it is very good to know that the research is also market driven and that the research results could help create new economic activity. Furthermore, for a lot of students it is probably interesting to do research in a more market driven environment.

#### 5.2 The team is now focussing on multi MW systems, but there are other interesting markets for vertical wind systems as well.

The group in Uppsala has no explicit market strategy but it is clear that the focus is on the development of large systems, in the MW-ranges. This is understandable if one wants to maximize the contribution of the research to the realization of a sustainable energy system. However, as will be explained in the following paragraph it is also uncertain if the objective will be realized. Therefore, if the objective was also to see to what extent the research results can contribute to the creation of economic activity it would be advisable to focus more on other potential markets as well. Two markets could be of interest:

- There is an increasing demand for small systems for the urban environment. There are already a lot of companies active in this field, but at this moment none of these seem to be very successful since also the specific market is in the initial phases of development. Especially a vertical wind system as the one developed by the group in Uppsala could be successful in this market. This would mean that more attention has to be given to noise and wind resource, but it could be an interesting market.

- Looking at the larger systems, all the manufacturers are developing large system of 3 MW and more. There is, however, also a market for 100-200 kW systems, especially in regions with weaker electricity grids. Weak electricity grids can be found in developing countries, but also in low-density populated developed countries, like Sweden. There is also a potential for rural areas with no grid at all. Some manufacturers are looking at this market. The low maintenance aspect of the system developed by the Uppsala group could also be very beneficial in this market.

It is not clear if these markets would really be interesting but it would be advisable to look into these other market opportunities and explicitly decide if they are interesting or not.

### 5.3 The development of a large system for offshore is promising but there are some risks related especially to the market

Together with E.ON and Falkenberg Energi AB, the Uppsala group has a clear view of how to develop large scale systems. First they will build four 200 kW systems to test and prove the technology. In parallel they will develop a 3 MW system for niche markets onshore. Eventually they hope to be able to launch an offshore system. There are other companies that are developing larger vertical wind systems up to a 100 kW. But for as far as we know this is the most concrete plan.

Most specialists agree that it is feasible to build successful vertical wind systems in the multi MW scale. The main risk in the development is related to the market. The market for large turbines is now dominated by horizontal systems, there is a lot of experience with these systems and a lot of research money is spent on these systems. It is clear that horizontal systems also have disadvantages - especially in the off shore market - but they definitely have a huge head start and are moving forward rapidly. To be successful in this market the vertical system would really have to be superior. Also the vertical system can not afford to run into any major failures during the market introduction process because that would reinforce the scepticism there will certainly be when the system is launched.

These market related risks are however not a reason not to take this route. Some of the design characteristics of vertical systems, such as its inherent simplicity of design, could be an advantage especially off shore. This development therefore could contribute to realizing a more sustainable energy system. The results of the Uppsala group have been promising so far and it is therefore justifiable that they want to develop larger systems.

According to specialists the development and introduction of a large, multimegawatt scale system will cost at least 50 million Euros and will take up to five years. E.ON is clearly willing to invest this amount of money in this development. This commitment in itself is already an important success factor for this development. It will certainly result in a rapid advancement of the knowledge in this field, and, possibly, also in the successful launch of large vertical wind systems.

# Appendix A

## List of people interviewed

Hans Bernhoff, Associate professor at CFE, Managing director of Vertical Wind AB

Mats Leijon, Professor of Electrical Energy generation and storage, head of CFE, chairman of the board of Vertical Wind AB

Mikael Bergqvist, Senior researcher at CFE and employed at Vertical Wind AB

Olov Åberg, Professor at CFE

Sandra Eriksson, Senior researcher at CFE and employed at Vertical Wind AB

Patrik Ström, Ericsson

Martin Lindholm, E.ON

Jörgen Svensson, E.ON

Maria Danestig, Swedish Energy Agency

Susanna Widstrand, Swedish Energy Agency

Sten Åfeldt, Swedish Energy Agency

